An Out-of-Band Signal Jamming GNSS L1-Band in Observatoire de Paris

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Abstract*—LNE-SYRTE in Observatoire de Paris (OP), located in Paris (France), is operating for time transfer an ensemble of calibrated GNSS stations, which stayed over years close to each other in the ns range. In addition, the typical daily average offsets between GPS Common-View (CV) and Two-Way Satellite Time and Frequency Transfer (TWSTFT) were remaining largely below 2 ns on the links between UTC(OP) and a selection of remote UTC(k) after independent relative calibrations. But from November 2018 on, a large discrepancy either between the different OP GNSS stations or between GPS CV and TWSTFT, together with an irregular loss of GNSS data, could be observed. The cause was identified as being an out-of-band powerful signal transmitted from nearby OP jamming GNSS L1-Band. The French Agence Nationale des Fréquences (ANFR), which is among other missions in charge of the use of RF spectrum over French territory, helped to identify the source and to establish a limited power transmission not having a significant effect anymore on OP GNSS L1-Band collected data. We describe the GNSS station ensemble located in OP at the time. We provide an analysis of the jamming signal, together with the effect of the jamming signal on time transfer activities. After agreement on the power transmission, the noise of GNSS data collected in OP became normal again, as can be seen on Allan Time Deviation (TDEV) analysis. We show the monitoring we put in place for the spectrum survey around the GNSS L1 carrier, with an example on a resurgence of this jamming signal after some maintenance activities at the transmission site. We emphasize the filtering of the jamming signal by different GNSS antennas as we could see from equipment already available in OP.

***Keywords*—GNSS; Jamming; Time Transfer**

I INTRODUCTION

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 metrology 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 the French legal time. LNE-SYRTE is therefore operating among other equipment stations able to receive signals from Global Navigation Satellite Systems (GNSS) like the Global Positioning System (GPS) or Galileo, aiming at achieving accurate time transfer with other laboratories between remote clocks at a ns uncertainty level. LNE-SYRTE is also operating a ground terminal for Two-Way Satellite Time and Frequency Transfer (TWSTFT) remote clock comparisons at ns level uncertainty [3]. Both time transfer techniques are calibrated by independent means, allowing the typical average offsets between GPS Common-View (CV) and TWSTFT to remain largely below 2 ns on the links between UTC(OP) and a selection of remote UTC(k).

But at the end of November 2018, a large discrepancy either between the different OP GNSS stations or between GPS CV and TWSTFT, together with an irregular loss of GNSS data, could be observed. The cause was identified as being an out-of-band powerful signal transmitted from nearby OP jamming GNSS L1-Band [4]. The French Agence Nationale des Fréquence (ANFR), which is among other missions in charge of the use of RF spectrum over French territory, helped to identify the source and to establish a limited power transmission not having a significant effect anymore on OP GNSS L1-Band collected data from October 2019 on. Section 2 shows the GNSS stations implementation in OP at that time, and Section 3 describes the jamming signal. Section 4 shows the effect of this jamming signal on time transfer techniques and Section 5 provides the Allan Time Deviation (TDEV) noise analysis of GPS time transfer data collected in OP. Section 6 describes the spectrum monitoring survey put in place in LNE-SYRTE around GNSS L1-Band, with an example on a resurgence of the jamming signal after some maintenance activities at the tranmission site. We finally provide an analysis of the jamming filtering by different antenna types, before to conclude.

II GNSS STATION IMPLEMENTATION 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 is UTC(OP): a 10 MHz signal, potentially multiplied to generate a 20 MHz signal required by some older GPS-only 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, which is the GPS station OPMT00FRA included in the International GNSS Service (IGS) since 2004. 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. This ensemble is the multi-GNSS IGS station OP7100FRA agreed by IGS from August 2018 on. 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. The UTC(OP) signal is also distributed to a TWSTFT terminal, and to an Earth station of the European Geostationary Overlay Service (EGNOS), called Ranging and Integrity Monitoring Station (RIMS), aiming at relating EGNOS Network Time to UTC via UTC(OP) [5]. All station antennas are a few metres away from each other on the rooftop of one single building.

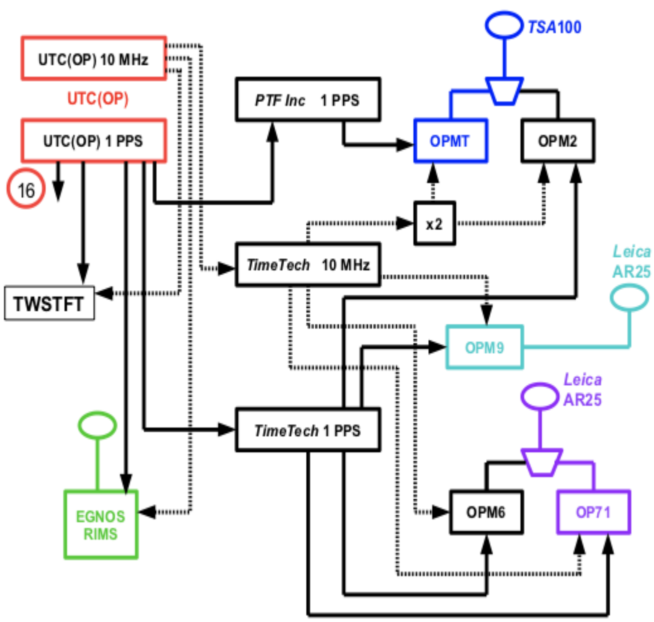


Fig.1. GNSS stations implementation in OP, where the source signal is UTC(OP). OPMT is the main unit of GPS-only IGS station OPMT00FRA, and OP71 is the main unit of multi-GNSS IGS station OP7100FRA.

III The Out-of-Band Jamming Signal

At the end of November 2018, a large discrepancy either between the different OP GNSS stations or between GPS P3 CV [6,7] and TWSTFT, together with an irregular loss of GNSS data, was observed. With a spectrum analyzer connected to one of the GNSS antennas implemented in OP, the cause was identified as being an out-of-band powerful signal transmitted from nearby OP [4]. Fig. 2 shows the observed spectrum around GNSS L1-Band in January 2019. One can see the jamming signal more than 35 dB above the spectrum analyzer noise, in a frequency band which is normally reserved for downlink satellite telecommunications by International Telecommunication Union (ITU). LNE-SYRTE raised a formal complaint to ANFR. The public institution source of the signal was quickly identified. Its intention was to jam all telecommunications, not only in this band especially, in order to prevent unauthorized telecommunications around its site. We eventually obtained the spectrum of the detected signal at transmitter level thanks to ANFR. As can be seen on Fig. 3, it was clearly the signal we observed on Fig. 2.

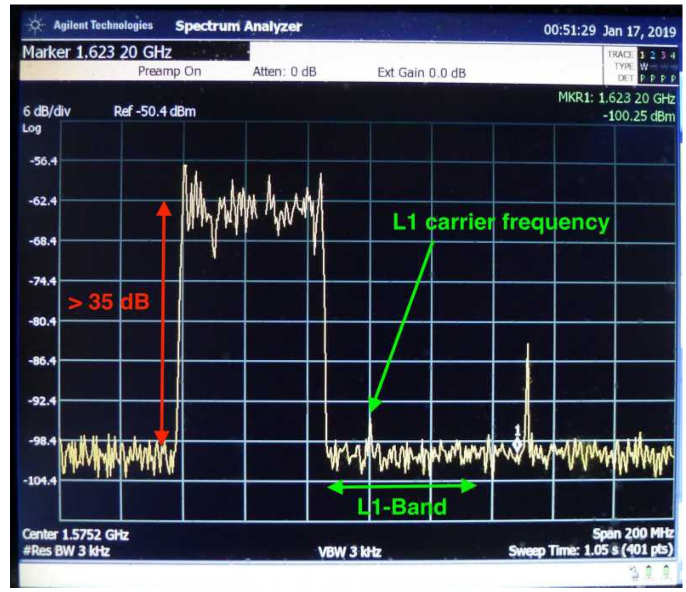


Fig. 2. Frequency spectrum observed on 16 January 2019 on the screen of a spectrum analyzer connected to a GNSS antenna. The center frequency is 1575.2 MHz, the span is 200 MHz, the Y-axis scale is 6 dB/div. The jamming signal is visible in the band 1515-1560 MHz [4].

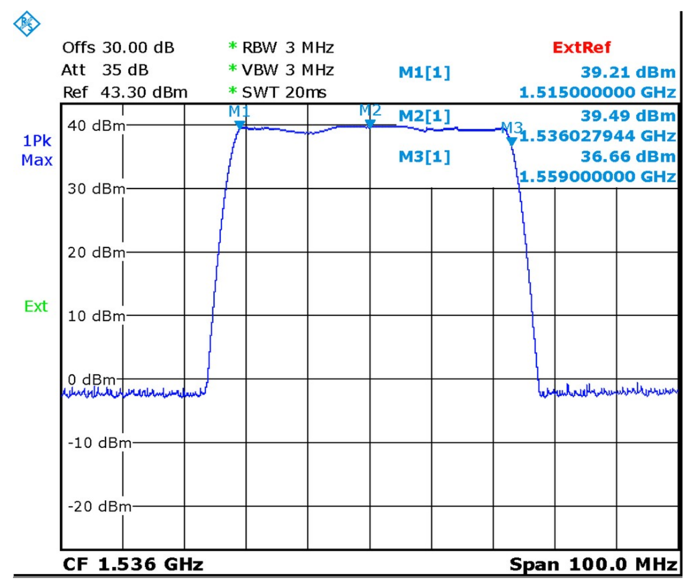


Fig. 3. Spectrum of the transmitted signal, obtained from the company in charge of this transmission thanks to ANFR. The jamming signal is more than 40 dB above the noise ground between 1515 and 1559 MHz.

IV Effect of Jamming Signal on GPS Time Transfer

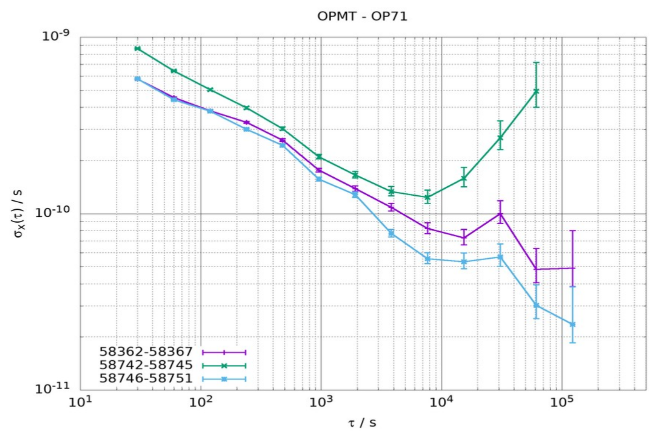
The power of the jamming signal was fluctuating over time, and even off during some periods, preventing a correlation analysis between out-of-band power and GNSS signal reception. We are having only scarce information from the manufacturers about the built-in filters in the signal conditioning stage of the different GNSS receivers in operation in OP, and more especially about the bandwidth of such filters [8]. 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 else [9,10]. We have nevertheless shown elsewhere that three generations of receivers from a given manufacturer were not reacting the same way to a few hours limited full power jamming, indicating a significant difference in filtering and/or correlator capabilities [4]. We have also shown that the GPS-only station was not affected as badly as multi-GNSS stations, but we were able to relate that to the antennas transmission and reflection loss (see Section VII) [4].

Fig. 4 illustrates the effect on time transfer between OP and two other European NMIs, PTB (Germany) and ROA (Spain), when comparing GPS P3 CV based on OP71 station to TWSTFT measured between the same local UTC(k) reference points. During the period of time before the irruption of jamming signal, the average daily offsets between both techniques were only partly above 1 ns, perfectly in line with the claimed combined uncertainties for both independent techniques. From the end of November 2018 on, the offsets were largely fluctuating, reaching more than 6 ns later in 2019. There were also complete interruption of GPS data collection at some points. Tests were made during summertime with the company in charge of the signal transmission, leading at the end of September 2019 to an agreement limiting the transmitted power under a given level. One can see in Fig. 4 that the average daily offsets between both techniques was back to typical limits afterwards.

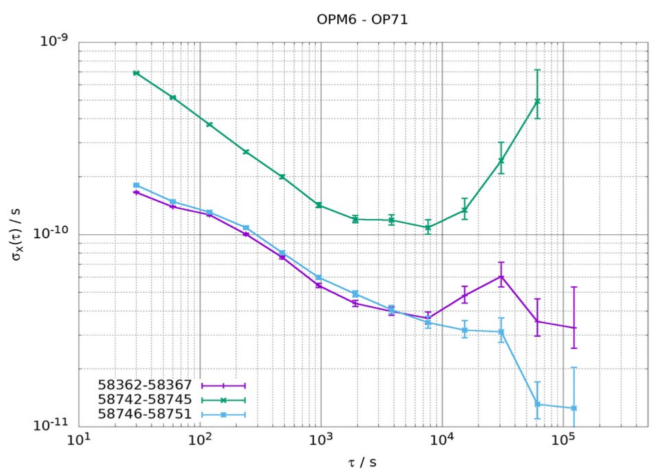
Fig. 4. Average daily offset between GPS P3 CV and TWSTFT from 1st January 2018 to 20th January 2020. The jamming signal appeared on 26th November 2018. Its effects were a severe loss of GPS satellite tracks and an increase in reception noise. Its power was fluctuating during months until 20th September 2019 where a limited transmission power was agreed thanks to ANFR after a final series of tests. Before and after that period of time, the peak to peak offset between both techniques stays significantly below 2.5 ns centered on 0, in line with the claimed uncertainties of both techniques.

V NOISE ANALYSIS OF GPS COLLECTED DATA

LNE-SYRTE computed GPS CV between pairs of local stations in common-clock set-up, based on 30 s sampled geodetic RINEX files. Fig. 5 is showing a noise analysis of such GPS CV as TDEV plots, either between two receivers connected to two antennas or between a pair of receivers connected to one single antenna, for three different periods of time: either before the irruption of the jamming signal in September 2018; or during a period where the jamming signal was on at about mid-power with respect to Fig. 2, that is about + 20 dB above the GNSS pseudo-noise; or after agreement of a limited transmission power at the end of September 2019. We can see that the TDEV is appearing very similar during periods where the jamming signal was there, hence not related to the antenna set-up. The white phase noise goes down to more than 100 ps up to an averaging period of about 10^4 s, before increasing again as flicker frequency noise up to almost 1 ns at an averaging period of 1 d. The common part of both green plots being OP71, the noise level exhibited here seems limited by the jamming effect on GPS data collected by this station.



(a)



(b)

Fig. 5. TDEV of GPS RINEX CV between pairs of OP stations in common-clock set-up: (a) two receivers, OPMT and OP71, and two antennas, (b) two receivers, OPM6 and OP71, and one single antenna. The green plot is computed during a period where the jamming signal was on at about mid-power. The purple plot is computed from data before the irruption of the Jamming signal in September 2018. The cyan plot is computed from data collected after the limited transmission power agreement in September 2019.

On the other hand, the white phase noise is appearing very similar between before and after the jamming period for small averaging periods below 10^4 s. There is however a large improvement for periods above 10^4 s for the latest data set. But this is fully explained by the comprehensive update of the temperature control system in the OP operational room having taken place in-between, lowering significantly the diurnal. Note the noise level difference between both set-ups, showing an effect of about a factor 3 of two different antennas on GPS data noise. The limited transmission power of the jamming signal is having a remaining effect on the resulting TDEV of less than 40 ps for two antennas and below 20 ps for a single antenna set-up at an averaging period of 1 d.

VI Spectrum Monitoring Around GNSS L1 Carrier

In order not only to monitor this out-of-band jamming signal but also to implement some kind of survey of the RF spectrum around the GNSS L1 carrier, LNE-SYRTE developed a daily mapping of the power received by a local GNSS antenna inside a frequency band between 1.50 GHz and 1.65 GHz. Fig. 6 provides an example of this mapping function, related to a resurgence of the jamming signal having taken place on 24th February 2020 (MJD 58903). In the frequency band between 1515 and 1559 MHz, one can see the typical jamming power received in OP since the power limitation agreement. This transmission is stopped before 14:00 UTC that day, allowing for about two hours to see the satellite telecommunication signals active in this band. The jamming signal is then back around 16:00 UTC at a power largely above the agreed limit, about + 20 dB with respect to the former transmission. This resulted in an offset of about 2.5 ns between the GPS-only station OPMT and the multi-GNSS station OP71, which were not affected the same way by the jamming signal, as can be seen on Fig. 7 directly taken from the continuous operational monitoring of LNE-SYRTE. This abnormal high power transmission was stopped after about twelve hours, and the situation went back to typical afterwards.

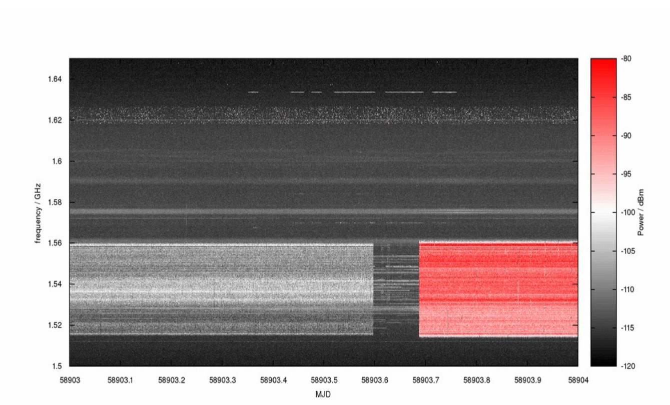


Fig. 6. Daily monitoring of the spectrum around GNSS L1 carrier inside a frequency band between 1.50 GHz and 1.65 GHz, recorded on MJD 58903 (24th February 2020). The horizontal line in the middle of the plot shows the L1 carrier at 1575.42 MHz. The frequency band between 1515 MHz and 1559 MHz is where the jamming signal is recorded. The vertical scale on the right allows to read the color code of the received power level at the GNSS antenna connected to a spectrum analyzer.

VII Jamming Filtering by Different Antenna Types

We observed that the transmission loss of different GNSS antennas does not cover the same frequency band. Fig.8 reminds the antennas transmission loss we had measured back in 2011 with a Vector Network Analyzer (VNA), showing how a GPS-only antenna is exhibiting a sharp trend around each of the GPS carriers L1 = 1575.42 MHz and L2 = 1227.6 MHz when compared to the large bandwidths of multi-GNSS antennas [4]. This explains why OPMT, which is a GPS-only station, is less affected by the jamming issue than others multi-GNSS ones: the jammed frequency band is much better filtered out.

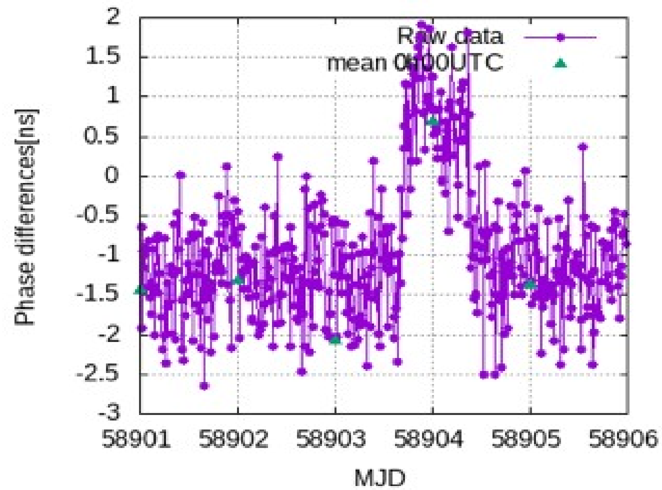


Fig. 7. GPS CV between OPMT and OP71 stations in OP. On MJD 58903, one sees clearly at about 16:00 UTC a sudden offset of about 2.5 ns synchronous with the start of the high power transmission shown in Fig. 6. The GPS CV between both stations went back to typical after about twelve hours.

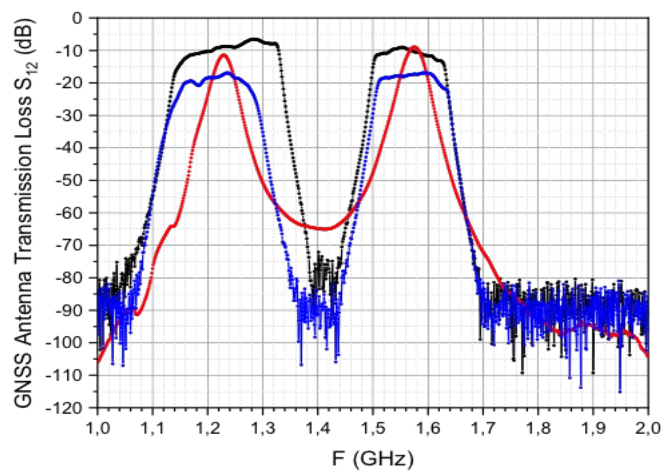


Fig. 8. GNSS antenna transmission loss measured with a VNA around the GPS carriers L1 = 1575.42 MHz and L2 = 1227,6 MHz. In red, a GPS-only antenna which filters sharply outside a small bandwidth. In black and blue, two different multi-GNSS antennas which are exhibiting a large bandwidth around the GNSS carriers [4].

On the other hand, LNE-SYRTE also had the opportunity to test different multi-GNSS antennas from different manufacturers, all implemented in the same rooftop area nearby operational systems. Each antenna was sequentially powered by the same GNSS receiver, and connected to a spectrum analyzer during a few hours. Fig. 9 is showing the related spectrum, which includes the relative power reception of each antenna (no offset added). During the periods of tests, the jamming signal was transmitting at a typical low power. Therefore, the GNSS L1-band was not affected, and one can detect in the center of all plots the typical small bump corresponding to the L1 carrier. It can be noticed that one of the four antennas has a lower power gain compared to the three others, but also that the actual transmission loss around L1 can be clearly different from one antenna to the other. The rejection slope on both sides of the GNSS band varies from none to relatively sharp. In addition, one of the antennas seems to filter the out-of-band signal much more efficiently when looking at the power level in the satellite telecommunication band 1515-1559 MHz.

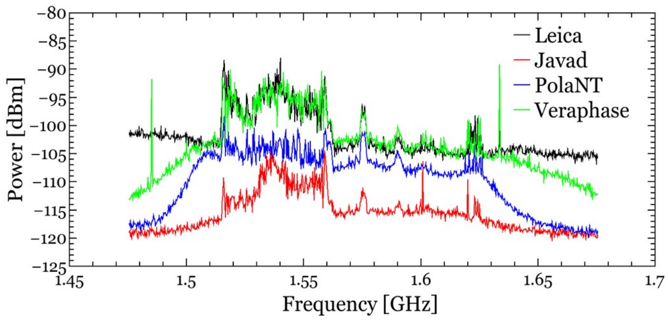


Fig. 9. Reception power measured by a spectrum analyzer from different multi-GNSS antennas around the GNSS L1 carrier at 1575.42 MHz in the band 1475-1675 MHz, no offset introduced, each antenna having its own power gain: In black a Leica AR25, in green a Veraphase 6000, in blue a Septentrio PolaNT B3/E6 and in red a Javad GrAnt.

VIII Conclusion

From November 2018 to September 2019, GNSS L1 data collection in LNE-SYRTE in OP was hampered by an out-of-band powerful signal transmitted from the ground in a satellite downlink telecommunication band below 1560 MHz. Another public institution was the source, aiming at jamming all kinds of telecommunications around its site. We identified the source, described accurately the jamming signal and, with the help of ANFR, we obtained a limited transmission power, which effect on GNSS data collection in OP turned insignificant to a noise level below 20-40 ps at an averaging period of 1 d.

LNE-SYRTE developed a monitoring of the frequency spectrum around the GNSS L1 carrier, allowing for survey of such unexpected signals. It appeared that the antenna is a major element in this kind of issue, in terms of either GNSS bandwidth, or transmission loss, or filtering, or potential saturation of the signal transmitted to the GNSS station main unit. In particular, one geodetic antenna seems to exhibit the ability to properly filter out the jamming signal when transmitted at its current typical power. We had also already noted that the correlation techniques implemented in different receiver types could handle more or less efficiently the signal saturation at input of the main unit [4].

With the development of GNSS signals and uses, it can be foreseen that this kind of issues might grow in the near future, preventing some sites from proper GNSS signal reception, with consequences for the time and frequency metrology community in terms of time transfer between remote time scales.

Acknowledgment

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Disclaimer

Product names and model numbers of the equipment are included for reference only. No endorsement or criticism is implied.

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