Fuzzy Time

GPS-Based Synchronizers in the Presence of Interference

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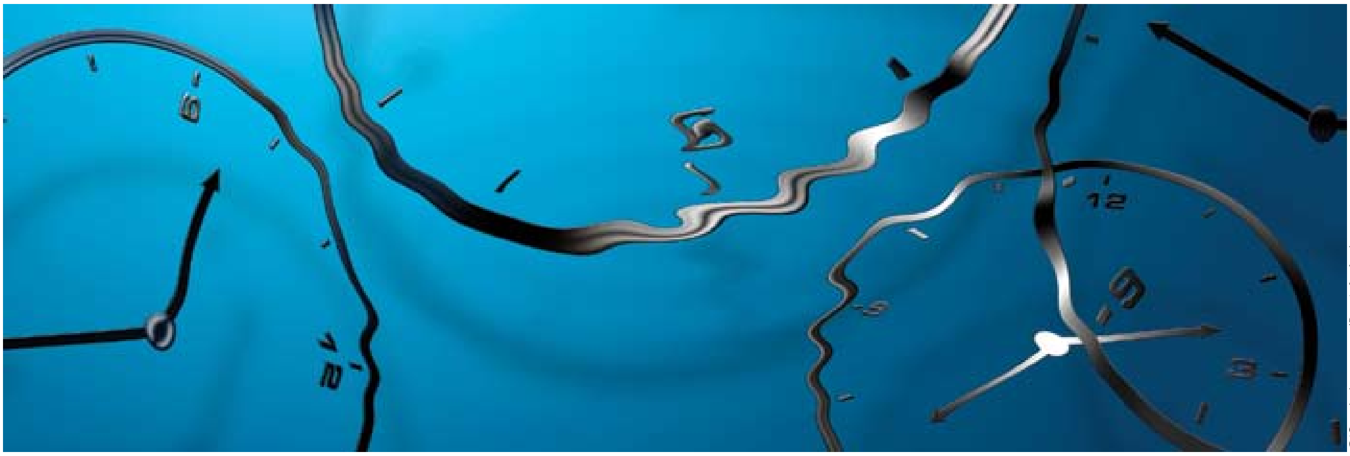

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The effects of RF interference on GNSS signal acquisition, tracking, and positioning accuracy have been studied extensively. In the United States, a national program is under way to identify and mitigate interference and jamming of GPS. However, the practical significance of interference for precise timing and synchronization is less well understood. This article describes the results of laboratory testing that reveals how two kinds of interference affect GPS signal reception and timing.

Synchronization serves as a pacemaker for current and next-generation digital telecommunications networks, particularly cellular networks such as the CDMA2000 1xEV-DO system.

These networks with their large coverage areas, increased complexity, and high data rates call for precise and accurate time alignment of operations. For instance, according to IS-95/IS-2000 standard established by the Third Generation Partner Project 2 Technical Specification Group, CDMA network operators expect an accuracy of three microseconds per day from synchronization sources.

Also, the European Telecommunications Standards Institute (ETSI) GSM 05.10 standard specifies a synchronization accuracy of 0.05 parts per million (ppm). Failing to achieve these requirements can result in dropped calls, spectrum violations, and corrupted data transmissions.

Due to their precision, GPS-based synchronizers (GBSes) have long been relied upon by such telecommunications systems for fulfilling their timing/frequency requirements and improving throughput and quality of service as a result. Key performance indicators of these communication systems depend upon their inter-network and intra-network synchronization, which is derived from these GPS-based synchronizers.

Other synchronization sources such as LORAN-C or atomic standards can also be used for timing/frequency requirements of high-speed communications networks. But, GBSes outperform such synchronization sources on the basis of better short-term and long-term stability, accuracy and precision in following Coordinated Universal Time (UTC), ease of deployment, availability of service, and, most importantly, cost. All these non-GPS-based synchronization sources are associated with such drawbacks as high installation, operations, and maintenance costs.

Given this growing dependence upon GPS-based timing capabilities, a corresponding increase has arisen in the need to understand the environmental and operational factors that can negatively affect the operation of GBSes. One such factor is radio frequency interference (RFI).

Although the effects of RFI on GNSS signal acquisition, tracking, and positioning accuracy have been studied extensively, its practical significance for precise timing and synchronization is less well understood. This article will examine how two forms of RFI — continuous wave and frequency modulation — affect the timing function in GPS receivers.

Is GBS OK?

GBS can serve as timing/frequency reference delivering very high levels of accuracy. Commercially available products now offer better than 50 nanoseconds RMS and 0.001 parts per billion (ppb) accuracy.

As with most other technologies, however, GPS timing receivers used in these synchronizers are not fail-safe. GPS depends on information transfer over the air interface between satellites and receiver. This wireless nature of GPS communications links and the weak power levels of GPS signals make them vulnerable to RF interference. A loss of synchronization can occur at anytime due to corruption of incoming GPS signals by RFI.

In spite of filtering and interference rejection techniques employed in GNSS receiver designs, interference from in-band and/or adjacent band signals may still leak through. Such interfering signals can affect the reception of GPS signals, reducing the carrier-to-noise (C/N_0) ratio and causing tracking loop measurement errors.

Algorithms like TRAIM (Time – Receiver Autonomous Integrity Monitoring) can be used to monitor the solution integrity, detecting and removing satellites that are contributing to faulty solutions. However, a reduction in number of satellites used for producing timing solution may still decrease timing accuracy.

An intensive RFI signal can even cause these GPS timing receivers to lose lock completely on all incoming GPS signals. Once this happens, network synchronization would be at the mercy of the local oscillator in the GPS timing receiver, which will drift relatively rapidly away from GPS/UTC time.

GPS Performance in Presence of RFI

We propose a hypothesis regarding the effects of interference on GPS timing receiver, based on theoretical grounds. According to this hypothesis, the effects of RF interference on GBS can be divided into three stages or levels of receiver behavior (see **Figure 1**):

Level 1 — This can be defined as the stage in which the received interference remains within manageable limits. Solution degradation here should be negligible.

Level 2 — In this stage, the effects of interference become noticeable. Although the receiver may not lose lock, its performance would be degraded.

Level 3 — This would be the stage during which the interference increases to such an extent that it forces a receiver to lose lock with incoming GPS signals. This would prevent timing being locked to the UTC(USNO) time on which GPS system time is based.

We tested our hypothesis experimentally in a laboratory by subjecting a test GPS timing receiver to interference signals, using a GPS signal simulator. Effects were studied using both narrowband, continuous wave (CW) and wider band frequency modulation (FM) interfering signals. A 12-channel, L1 C/A-code timing receiver considered to be an industry standard was used as the test receiver.

Although an atomic clock serves as the most suitable reference, useful information can be gathered by using a stable timing receiver isolated from the test RFI as the timing reference. We used a set of 12-channel, L1 C/A-code receiver from a different manufacturer as the reference receiver.

Simulated signals were used for the experiment to ensure that the signals under test were consistent. This was done within laboratory and the interference signals were injected directly in the signal path to by-pass any effects of antenna on incoming RF interference.

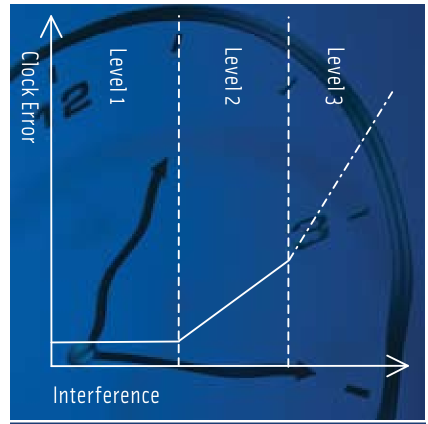

FIGURE 1 Proposed hypothesis: The clock error is the difference between the receiver's time and UTC or GPS time

We observed the phase difference (PD) of the timing solution (pulse per second – PPS) from the test and reference receivers, initially without any interference being introduced to the test receiver's signal path. This served as reference for further observations. Then, interference was introduced at -136 dBm and gradually increased until the test receiver lost lock with all the incoming satellite signals.

Frequency	Deviation
200 KHz	400 Hz
400 KHz	400 Hz
200 KHz	1 KHz

TABLE 1. Modulating Signal Specifications

Test Results

A sinusoid at 1575.42MHz was used as the CW interference signal. For FM interference, a sine wave carrier at 1575.42 MHz, modulated by the signals given in **Table 1**, was used. **Figures 2 and 3** show the standard deviation of the phase difference in the presence of, respectively, CW and FM interference.

Experiments were repeated thrice for each interference signal. As shown in the figures, up to certain power levels (-87dBm in case of CW interference and -96dBm in case of FM interference), the PD remains below 20 nanoseconds. During this period, the test receiver was able to track satellites, and the solution did not deviate considerably. This situation can be correlated to the Level 1 of the hypothesis in Figure 1.

As the interference increased further, the test receiver's solution started degrading, and eventually the receiver lost lock with all incoming GPS signals. During this period, a gradual increase in the phase difference can be observed in Figures 2 and 3. This situation can be correlated to the Level-2 of the hypothesis.

We also plotted the Allan deviation of the phase difference to analyze the stability of the solution at discrete interference levels. **Figures 4 and 5** show Allan deviation plots for PD in presence of CW and FM interference, respectively.

Again, two distinct regions can be detected here. The Allan deviation at -136 dBm can be considered as reference, as the PD deviations in this situation were nearly in agreement with those in absence of interference. In the figures, we can see that for interfering signal power levels up to -87 dBm (CW) and -96 dBm (FM), the Allan deviation remains in close agreement with reference. However, for increased levels of interference, drift can be observed from these Allan deviation lines. Again this behavior correlates to Level 1 and Level 2 of the proposed hypothesis (see Figure 1).

Once all satellites are lost, the GPS timing receiver outputs PPS on the basis of its local oscillator. **Figure 6** shows the Allan deviation of PD in this situation. A drift can be observed here which is typical of crystal oscillators and can be correlated to Level 3 of the proposed hypothesis.

Some important observations can be made from these test results. Firstly, the boundaries for the different levels of performance differ between CW and FM interference. In case of FM interference, Levels 2 and 3 start at much lower interference power levels than in case of CW interference. Secondly, in the case of FM interference, the receiver loses lock before much degradation occurs in the timing solution.

GPS C/A-code consists of code spectral lines spread across 20 MHz of bandwidth. Narrowband CW interference only affects one of these lines — the one with which the incoming interference

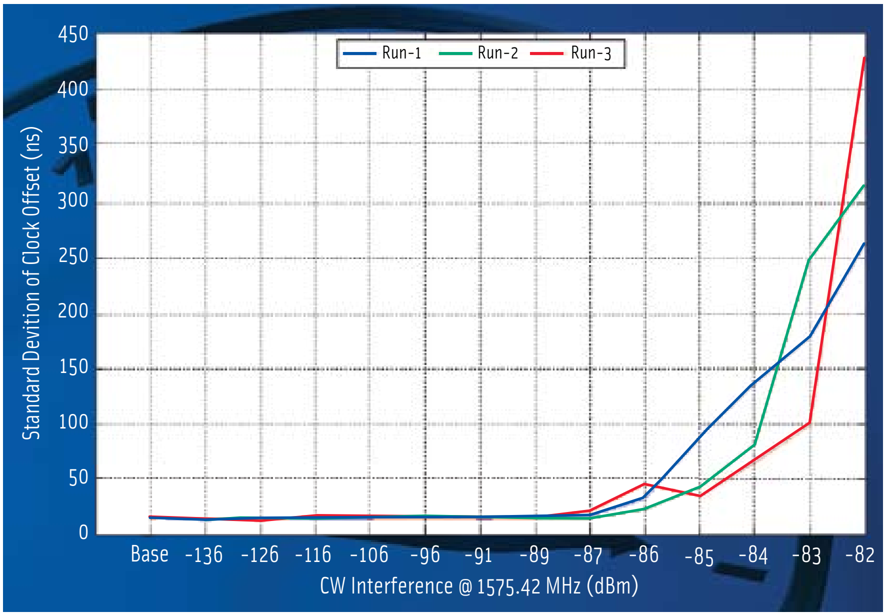

FIGURE 2 **Standard deviation of phase difference between the test and reference receivers' PPS outputs, due to CW interference**

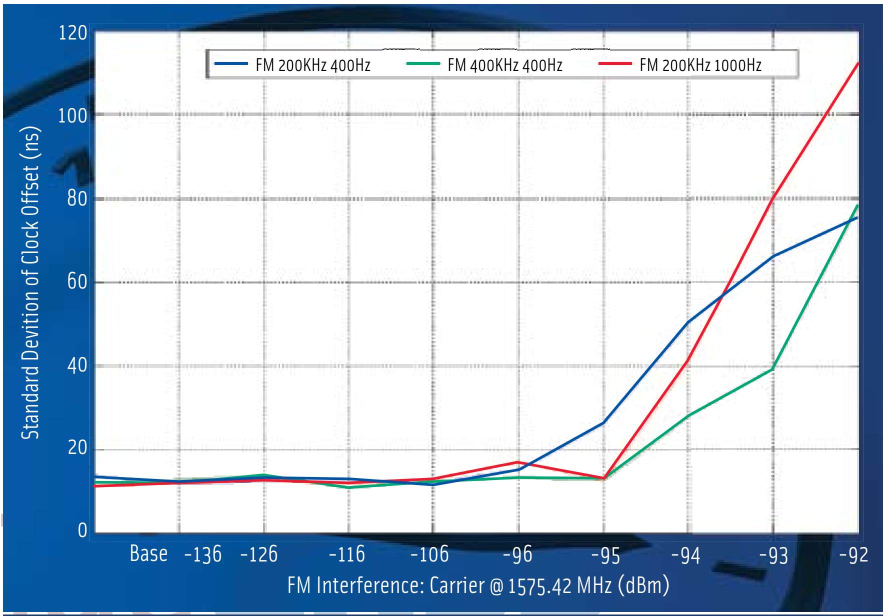

FIGURE 3 **Standard deviation of phase difference between the test and reference receivers' PPS outputs due to FM interference**

signal overlaps. However, in the case of FM interference, which has wider bandwidth, many more lines from various satellites would be affected simultaneously. This characteristic of FM interference degrades the C/N_0 of the GPS signals to which these lines belong, introducing errors in their timing solution. This simultaneous degradation of C/N_0 for multiple satellites hastens the rate of timing solution degradation.

The positions of level boundaries in the hypothesis may also depend upon receiver design parameters such as a) interference rejection at the GPS antenna, b) behavior of the front end of the receiver in presence of interference, c) interference filtering and mitigation techniques employed during signal processing, and also the observation time. (The observation time, here, refers to both the time-of-the-day and the dura-

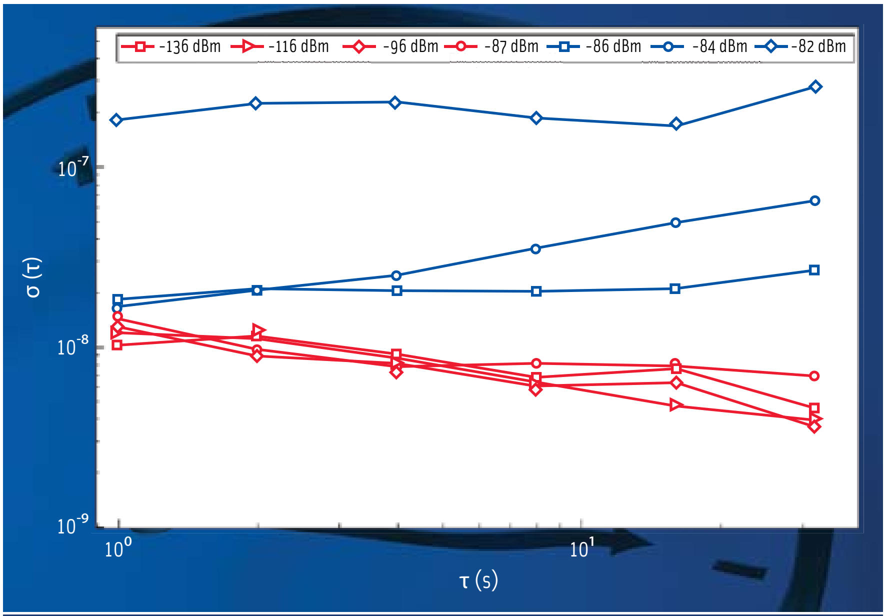

FIGURE 4 Allan deviation of the Phase Difference due to CW interference (refer to legend in Figure 5)

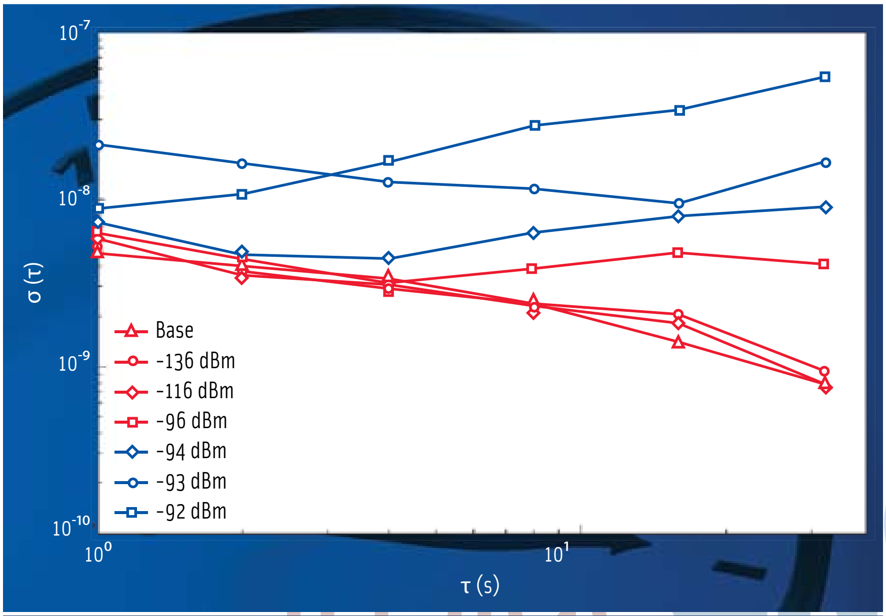

FIGURE 5 Allan deviation of the phase difference due to FM interference

tion of the observation. However, the effects of the time of observation will have relatively more effects than the duration of observation period.)

Conclusions

Repeated tests in the presence of both narrow and wider band interference confirmed our hypothesis and increased the reliability of results. As proposed in the hypothesis, lower levels of interference exist that do not affect timing accuracies. Intermediate levels of interference degrade performance without forcing the receiver to lose lock. Finally, higher levels of RFI have been identified that prevented timing being locked to the UTC timing standard.

The boundaries of these levels varies, depending on whether narrow band CW or wider band FM interference is experienced, with FM RFI interrupting timing

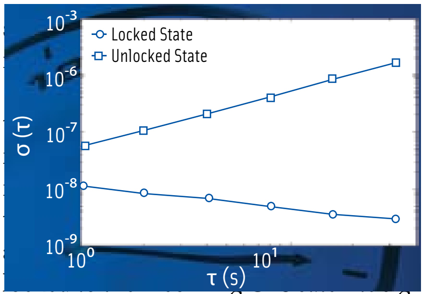

FIGURE 6 Allan Deviation of the test receiver, before and after loss of lock on GPS satellite signals

nals, it still may not provide stable timing solution. This places a question mark on the performance of GBS in presence of RF interference and calls for further and more rigorous investigations.

Manufacturers

A set of *multiNAV* MG5001 timing receivers from **SigNav Pty Ltd.**, Fyshwick, ACT, Australia, was used as the reference receiver. A legacy M12 receiver from **Motorola** served as the test receiver. A GSS6560 GPS simulator from **Spirent Communications**, Paignton, England, was used to generate the GPS signals and inject the interfering signals into the GPS signal path.

Author

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