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A Novel Study on Timing Performance of NavIC-enabled SWaP-C GNSS Receivers

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Abstract

In addition to the four global constellations of GNSS, two more regional services NavIC from India and QZSS from Japan are in operation. Parallelly there is tremendous progress and advancement in types and categories of GNSS receivers coping with the ever increasing and ever varying user demands. In these developments of receivers, the advent of Size, Weight, Power and Cost efficient (SWaP-C) GNSS receivers has remarkably broadened the ranges of applications. In addition to the PNT applications, atmosphere probing etc. are emerging prominently. But the provision of hardware 1PPS output of such receivers has added a new dimension to the timing applications. Still not much intensified effort has been seen to justify its utility for this application. This paper attempts to address this gap. The paper details the outcome of the extensive experiments focusing on the timing application of NavIC-enabled SWaP-C receivers. The detailed analysis of the experimental observations that have been included to confirm the capability of this type of receivers for the users who demanding precise time.

1. Introduction

Global Navigation Satellite System (GNSS) comprises of four global constellations- GPS, GLONASS, Galileo and Beidou offering precise Positioning, Navigation and Timing (PNT) services. In course of time two more regional constellations- NavIC and QZSS are operational to augment regional services around India and Japan respectively.

To facilitate GNSS-based applications, various types of receivers are commercially available providing the users with a variety of application specific choices. Most common GNSS receivers are commercial, geodetic professional-grade receivers that cost anywhere between \$5,000 and \$30,000. But most of them have commonality in their operational aspects and output features. Some of them differ in channel capacity, functioning features like single or dual frequency, availability of data format like RINEX, NMEA etc.

In the meantime, due to the mass-market demand, small, compact (<100 gm), affordable (<1000 US\$), low-power consuming (< 1W) GNSS receivers were introduced in the market in the early 2010s. They are also known as Size, Weight, Power and Cost efficient (SWaP-C) GNSS modules. Thus, a different class of receivers known as 'low-cost GNSS receiver or SWaP-C' has emerged [1, 2].

Initially single frequency low-cost receivers were introduced; subsequently, the dual-frequency SwaP-C receivers were introduced in the market [3]. Introduction of the dual frequency SWaP-C modules took care of many limitations of such receivers in comparison with the professional grade geodetic GNSS receivers [4]. As a result, the user community now has access to GNSS hardware which are compact in size, are of small weight, consumes low power, can use all available GNSS signals in multiple frequencies and most importantly, are of low cost. Naturally, such SWaP-C modules generated ample interest among the users for GNSS-based PNT and non-PNT applications. The SWaP-C GNSS modules were proved to offer excellent positioning performances in Single Point Positioning (SPP) [3], Real Time Kinematic (RTK) [4, 5] and Precise Point Positioning (PPP) [6] and many GNSS-based applications using such receivers were witnessed globally [7-12]. Apart from the PNT applications, some interesting works to use this receiver for ionospheric probing like TEC and amplitude scintillation monitoring have been reported [13 - 15]. SWaP-C receivers with enhanced and attractive features are evolving caused by the immense interest for and increasing use of them. In recent years there has been significant progress in this field through the increasing availability of low-cost receivers. With these advancements now low-cost receivers may be considered a mature complement to high-grade receivers in emerging applications.

An important application of GNSS is timing. Successful use of the SWaP-C GNSS receivers in other application areas naturally called for studies on the performance of these SWaP-C receivers for GNSS-based timing applications. Most of these SWaP-C GNSS System on Chip (SoC) modules are equipped with a hardware 1 pulse per second (1PPS) output and therefore, have the possibility of using these receivers for timing applications. Although many manufacturers have claimed the applicability of their SWaP-C modules GNSS evaluation Kits (EVK) for precise timing applications (e.g., uBlox M8T), not much serious attention has yet been given to explore the usefulness of the low-cost version for timing performance and not many reports on the performance of the SWaP-C modules for timing are found. A preliminary study on the timing capabilities of such SWaP-C modules has been presented in [16]. Considering the advantages of the SWaP-C modules, more studies on the topic are essential.

Navigation with Indian Constellation (NavIC) is India's own regional satellite-based navigation system. Many SWaP-C modules now support reception and use of NavIC signals, but no report on the use of NavIC-enabled SWaP-C GNSS modules for timing applications is currently available in public domain.

This paper, therefore, presents an exhaustive and novel study on the timing performance of selected NavIC-enabled SWaP-C GNSS modules through detailed analytical study.

The manuscript is organized in the following manner- after the Introduction section, the experimental arrangement is described followed by the results and discussion and finally, the conclusions are included.

2. Experimental Details

Although most of the SWaP-C SoC modules have the provision for hardware 1 PPS output, only a few SWaP-C evaluation kits (EVK) have provision for directly obtaining 1 PPS output from the unit. Therefore, three EVKs – namely uBLOX ZED-F9T, TELIT SL869T3-I and NTLab 104 v3 were selected for the study. All these SWaP-C GNSS modules provide 1PPS output from the EVK over SMA connector and all the modules provide NavIC timing signal together with GPS time. A brief description of the EVKs is shown in Table 1.

Table 1. Comparative specifications of the NavIC-enabled SWaP-C GNSS receivers used in this work

Receiver Type	Constellations supported	Power requirement	Cost (US $)
uBloX F9T	GNSS, NavIC L5	5V DC, USB	300
NTL 104 v3	GNSS, NavIC L5, S	5V DC, USB	850
TELIT SL869T3-I	GNSS NavIC L5	5V DC, USB	350

The experiments were conducted at CSIR-National Physical Laboratory (NPLI), New Delhi where the standard timing reference traceable to UTC (UTC(NPLI)) is available. The experiments were carried out during March 2022 and January 2024, when the probability of ionospheric scintillations is low as the ionospheric scintillations affect the actual performance of the GNSS module.

The experimental setup is shown in Fig. 1. The time offset of the 1PPS of a receiver under test is compared with the UTC(NPLI) through a high-resolution time interval counter (TIC). The corresponding time interval values for every second are recorded in a computer with time tagging using an in-house developed software GLB-UniLog [17]. The SWaP-C receivers were operated in "NavIC-only" mode. For each of the set-up, measurements were taken for sufficiently long duration at the sample rate of 1Hz so that the statistical average smooth out the effect of many short-term noises. The collected data was post-processed for studying the timing performances.

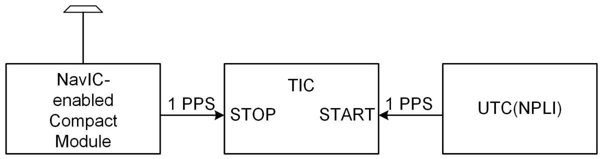

Figure 1. Experimental arrangement for assessing timing capability of NavIC-enabled SWAP-C receivers.

3. Data Analysis

As discussed earlier, three SWaP-C enabled GNSS receivers with 1PPS output are compared for their timing performances w.r.t UTC(NPLI) in NavIC-only mode. Representative results for two individual modules are shown in Figs 2 and 3.

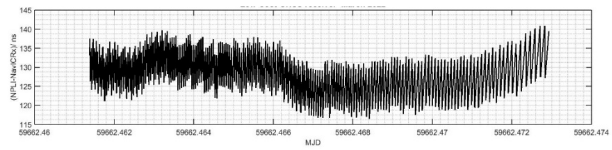

Figure 2. NavIC 1PPS offset fluctuations of TELIT SL869T3-I SWaP-C receiver w.r.t UTC(NPLI), March 2022

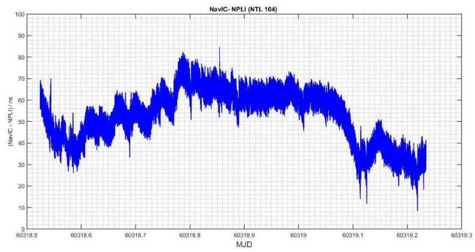

Figure 3. NavIC 1PPS offset fluctuations of NTL104 v3 SWaP-C receiver w.r.t UTC(NPLI), January 2024

Now the data for all three receivers are analyzed and the results are shown in Table 2. For the sake of comparison, GPS-UTC(NPLI) for the TELIT SL869T3-I module is also shown in Table 2.

The average time offset values being compared with respect to UTC(NPLI) may be regarded as calibration values which are specific to the setup including the SWaP-C receiver, its antenna and cable used during the study. These values may not have any significance if the receiver operates with a different antenna and/or connecting cable.

The standard deviation shows the confidence level in timing accuracy, once the respective receiver is calibrated. It may be noted that the values of 1σ in all cases are of the same order and within reasonable limits of 12 ns or less. This observation well confirms that these receivers very well serve the purpose of semi-precise timing users with the traceability to UTC(NPLI).

Table 2. Summary of data analysis (in ns)

Model	Measurement	Average	Std. Dev (1-σ)
uBlox EVK F9T	NavIC - NPLI	-95.0	6.22
NTLab 104 v3	NavIC - NPLI	52.49	12.66
TELIT SL869T3-I	NavIC - NPLI	129.156	5.58
TELIT SL869T3-I	GPS – NPLI	41.6	5.43

From the recorded data, the frequency stabilities of the timing outputs of the respective receivers with respect to UTC(NPLI) are also calculated and illustrated in Fig. 4. A geodetic-grade NavIC receiver data is also presented in the figure for comparison using the red dashed line.

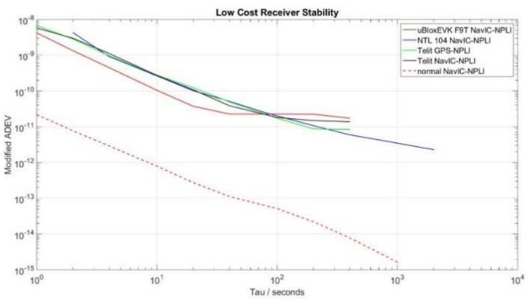

Figure 4. Frequency stability represented by modified Allan Deviation (ADEV) for the SWaP-C NavIC-enabled GNSS receivers.

From Fig. 4, the encouraging observation is the frequency stability of timing outputs of the SWaP-C GNSS modules. These are comparable to a good stable oscillator like OCXO and cannot have any drift as long as the frequency remains locked to the received GNSS/ NavIC signal. The base oscillator of the receiver would remain disciplined by the incoming GNSS signals. This behaviour will be irrespective of the poor stability of the internal oscillator of the receiver, if any. It is also to be noted that the frequency stability of the TELIT SWaP-C module in GPS-only operation is comparable to that of the NavIC-only operations. However, a geodetic NavIC receiver shows better frequency stability as seen by the red dashed line.

Overall conclusions based on these studies may be drawn that the compact, low-cost GNSS receivers, apart from their SWaP-C advantages, offer timing accuracy better than the specified timing accuracy that NavIC/GPS signals are supposed to assure to be within 50 ns or so. These values based on our experimental findings are found to be always less than 15 ns.

4. Conclusions

The timing performances of the NavIC-enabled SWaP-C modules have been studied in this work for the first time and this novel work shows the NavIC timing performance of the SWaP-C modules are encouraging. The average values of the offsets with respect to UTC(NPLI) have been found to vary widely as the initial values of calibration. These values are valid for the same set of configurations and should be used as reference values for further use of the receiver for the same applications. The corresponding standard deviations are indicative of the degree of confidence and reliability of the measurement carried out. The standard deviations are of the same order as found for the professional grade geodetic receiver. Further the frequency stability of the timing output does not vary much for different types and make of the SWaP-C category. These observations lead us to conclude that the timing capability of low-cost receiver is almost of the same order of 10 ns.

Future work in this regard would be detailed study of a greater number of such SWaP-C modules and extension of the study for other GNSS signals (e.g., GPS, GLONASS, Galileo) and intercomparison during the same time period. With the new class of NavIC satellites transmitting L1-band signals, in future, efforts are needed to study the timing performance of NavIC L1-enabled SWaP-C modules.

5. Acknowledgements

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