Monitoring of GPS signals at NPL, New Delhi, for precise time comparison

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The Global Positioning Satellite System (GPS) signals are being extensively used for worldwide time comparison. The National Physical Laboratory (NPL), New Delhi, has also been utilizing GPS signals for comparison of time for a long time and has been contributing to the Coordinated Universal Time (UTC) maintained at BIPM, Paris. This paper explains the experimental set-up of the network of international time link via GPS. The detailed analysis of data has been presented. It highlights a quantitative estimate of the deterioration of time accuracy as a result of introduction of selective availability in the GPS system.

1 Introduction

The Global Positioning Satellite System (GPS) is a satellite-based radio positioning, navigation and time-transfer system. The constellation of GPS consists of 24 satellites each of which has one atomic clock on board. Each satellite transmits two L-band frequencies (L1 = 1575.42 MHz and L2 = 1227.6 MHz). The L1 signal carries coarse acquisition (C/A) and precision (P) codes. Superimposed on these signals are navigation data including satellite ephemeris, atmospheric, propagation data and satellite clock bias information.

At present, the configuration of GPS consists of Block I and Block II satellites. In Block II satellites two methods have been introduced for denying the full use of the system to civilian users. The first method is selective availability (SA) on the C/A code and the second one is anti-spoofing (A-S) on the P-code. While A-S is of no interest in this paper, SA has significant effects on the time accuracy. To get more accurate GPS time one would prefer to track only Block I satellites to avoid the SA effect. However, only 4 Block I satellites (e.g. satellite Pseudo Random Noise, code No. PRN #3, 11, 12 and 13) are still operational and this number is likely to decrease.

National Physical Laboratory (NPL), New Delhi, has been using GPS signals for timing application and has been contributing to the formation of Coordinated Universal Time (UTC). This paper describes the experimental concept of monitoring of GPS time and includes the detailed analysis of the data vis-a-vis the effect of SA.

2 Concept of time link

2.1 Single channel system

To use the GPS time-dissemination service, one must track 4 GPS satellites simultaneously to get the solution for four unknown parameters (three coordinates of the location and time offset of the local clock). But if the location coordinates are known, tracking of one satellite would suffice. So, for all timing laboratories, location of the GPS receiver being known, a single channel GPS receiver will serve the purpose.

Very common configuration of a single channel GPS receiver that is available in the market has been shown in Fig. 1. In addition to the actual receiving unit, this type of receiver has also one time interval counter (TIC) and some programmable controlling system built into it. It provides hardware output of the second pulse locked to GPS time. Time interval counter compares the GPS time with respect to local second pulse and the controlling system generates a complete set of data including satellite PRN No., elevation, azimuth, tracking time, ionospheric corrections, etc. in a standard format through RS232C port.

![Fig. 1—Configuration of single channel GPS receiver](image-url)
These functions are in addition to its other functions of automatic tracking according to the pre-programmed schedule, making use of raw data, generating other information.

In timing receiver, initially the receiver may be put to a sequential navigation mode to determine the precise location of the antenna. The precise position coordinates thus determined are fed to the receiver. The receiver uses these coordinates to find out time from the pseudo range of a single satellite.

2.2 International network

In a coordinated common-view time transfer method as illustrated in Fig. 2, a pair of stations simultaneously observes one common satellite. The local clock time is compared with respect to the time disseminated by GPS with the help of TIC of timing receiver. The difference between these readings is quite accurately the difference between the times of station clocks. This common-view method is actually employed to achieve the international time linking and generation of international time scale.

The International Atomic Time (TAI) and UTC, maintained at Bureau International des Poids et Mesures (BIPM), Paris, are obtained from a combination of data from atomic clocks kept by 60 laboratories spread over the world. The network of time links mainly relies on the observations of GPS satellites in the common-view mode. These centres equipped with GPS receivers follow the international tracking schedule published and updated regularly by BIPM. The GPS data are regularly reported to the BIPM by 45 timing centres maintaining a local UTC. The GPS receiver used at NPL is a single channel receiver of M/s Hewlett Packard (Model TTR 5).

In a rigorous computation to generate the international time scale. The status of clocks of respective centres with respect to UTC is also fed back regularly to the timing centres through BIPM circular T. The epoch maintained through a bank of commercial cesium clocks (HP 5071 and HP 5061 of M/s Hewlett Packard) at NPL, New Delhi, has been designated as NPL. The GPS receiver used at NPL is a single channel receiver of M/s Allen Osborne Associate (Model TTR 5).

3. Morphology of data

Analysis of data covers the measurement period of 21 June 1993 (49159 MJD) to 27 Jan. 1994 (49379 MJD). During this period the satellites were monitored according to common-view tracking schedule No. 21 as issued by BIPM. Three Block I satellites that were still available (PRN 3, 12 and 13) were included in the schedule. Out of them only PRN 3 and PRN 12 were selected in the schedule for NPL, India. The Block II satellites which were chosen in the schedule for India were PRN 1, 2, 14, 15, 16, 17, 19, 21, 23, 24, 25, 26, 27, 28, 29 (total 15 satellites of Block II). Monitored data have been sorted into two categories—one for Block I satellites as shown in Fig. 4 and other one for Block II satellites as illustrated in Fig. 5, so that the effect of SA could be observed separately.

It is observed from Fig. 5 that there is an absence of data for quite several days at a stretch. This is very surprising since 15 Block II satellites were in the schedule. In contrast there is no such discontinuity of data in Fig. 4, where only two satellites were scheduled to be tracked. The causes of the absence of data for Block II satellites are not known. A project to study this aspect has already been undertaken by NPL.

The feedback data related to status of NPL through BIPM circular T have been plotted in Fig. 6. Reg-
Fig. 4—Monitoring of GPS time with Block I satellites without SA (Broken line is the fitted curve; Jitter: 0.0573 μs)

Fig. 5—Monitoring of GPS time with Block II satellites with SA (Broken line is the fitted curve; Jitter: 0.1104 μs)
ression analysis has been performed on all the three sets of data. Broken lines in Figs 4-6 represent the regression-fit and the results of the analysis have been tabulated in Table 1. Jitter in the Table 1 indicates the jitter of the residuals of the regression-fit. The $R$-squared values, conventionally, represent the degree of agreement of the regression-fit to the actual data. It may be noted from the Table 1 that less the value of jitter, more the $R$-squared value approaches unity.

Jitter in the case of Block II satellites has been found to be significantly higher. This confirms the appreciable deterioration of timing accuracy due to the introduction of selective availability. Jitter for Block I satellites are comparable to the jitter of BIPM feedback data. Although the BIPM data, being small in number, are not useful for the estimation of jitter they are much smoother. This is also supported by the maximum value of $R$-squared parameter. In fact, the BIPM data reflect the inherent stability of the cesium clock of NPL.

The frequency offset of the NPL clock has been found to be almost of the order of $10^{-13}$ and is of the same order in all the three sets. This has been estimated from the mean slope of data of the measurements carried out over a period of seven months. The frequency offset also dictates the accuracy of the maintenance of the epoch of NPLI. Though SA does not have much impact on the value of frequency offset the data shown in Fig. 5 amply demonstrate that the significant deterioration due to SA is almost unavoidable for on-line time comparison.

### Table 1—Regression analysis of three sets of data

<table>
<thead>
<tr>
<th>Sets</th>
<th>No. of samples</th>
<th>Freq. offset ($\Delta f/f$)</th>
<th>Jitter (ns)</th>
<th>$R$-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block I</td>
<td>631</td>
<td>$9.32 \times 10^{-13}$</td>
<td>57</td>
<td>0.989127</td>
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<tr>
<td>Block II</td>
<td>1247</td>
<td>$9.38 \times 10^{-13}$</td>
<td>110</td>
<td>0.963136</td>
</tr>
<tr>
<td>UTC-NPLI</td>
<td>21</td>
<td>$1.046 \times 10^{-13}$</td>
<td>65</td>
<td>0.993678</td>
</tr>
<tr>
<td>BIPM Circular T</td>
<td></td>
<td></td>
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</tbody>
</table>

4 Conclusions

The monitoring of GPS time in a coordinated common-view mode has been proved to be a convenient and very precise time link. In this way the behaviour of NPLI could be traced to UTC and also to the time scales of all other time keeping laboratories. The effect of SA has been observed to deteriorate the time accuracy quite appreciably. It can be estimated fully or partially through averaging over a long time or in a common-view mode. But SA poses a major threat to the on-line time accuracy.

Its impact on the accuracy has been strongly felt by different users of GPS signals. Some works have...
been initiated to study the problem of SA. But, since Block I satellites are being phased out, more serious efforts should be made to evolve measures to eliminate or reduce the effect of degrading accuracy by SA.

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References