# STABILITY AND ACCURACY OF THE REALIZATION OF TIME SCALE IN SINGAPORE

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*Abstract*

***Singapore Productivity and Standards Board (PSB) maintains the national time scale in Singapore. The time scale has been linked to Coordinated Universal Time (UTC) since October 1997. This paper reports the analysis on the stability and accuracy of the time scale. Time dissemination through GPS is also discussed.***

## INTRODUCTION

The National Measurement Center (NMC) of PSB is the national metrology institute in Singapore. There are three high performance cesium clocks: Clock I (HP5071A), Clock II (HP5071A), and Clock III (FTS4065). The generation of the UTC(PSB) is based on Clock I selected from the clock ensemble. Clock II is used as backup. Since October 1997, Clock I and Clock II have been linked to UTC through a AUSTRON 2200A GPS receiver, which follows BIPM common-view schedule. It is aligned to UTC within 100 nanosecond.

The dissemination of time scale to users is also very important. GPS common view is a useful method because its high accuracy. A common-view experiment has been done with AUSTRON 2200A and AOA TTR-4P GPS receivers to verify the method.

The aim of this paper is to introduce the setup of the time scale of PSB and the time dissemination through GPS. The first part of the paper mainly introduces maintenance of the time scale. The second part presents the common-view experiment results in PSB.

## TIME SCALE OF SINGAPORE

### SETUP OF THE TIME SCALE

The setup of the time scale is shown in Figure 4. Clock I is selected from three cesium atomic clocks to realize the national time scale UTC(PSB). AUSTRON 2200A GPS receiver is a single channel NBS type receiver. Its software version is D.32 B.00. The receiver delay is 142 ns. The computer-controlled time interval counter is used to measure the time difference between Clock I and Clock II. The control software is compiled in LabVIEW.

BIPM and other time laboratories have similar setups. These atomic clocks can be compared with each other using the GPS time as reference. These laboratories send data to BIPM every week. The time differences between UTC(PSB) and UTC are computed through the coordination by BIPM. Hence, UTC(PSB) is traceable to UTC. The UTC(PSB) is then aligned to UTC using a microphase stepper adjusted continuously or by step to maintain a long-term agreement.

## STABILITY ANALYSIS

Figure 1 (a) shows the difference of UTC and UTC(PSB) from MJD 50674 to MJD 50884 published in BIPM Circular T. Figure 1 (b) shows the difference of UTC and UTC(PSB) from MJD 50899 to MJD 51084. The Allan deviation of UTC(PSB) compared with UTC were computed for different measuring times in Figure 2. For Clock II, its deviation and stability related to UTC(PSB) were also evaluated and analyzed starting with one hour.

The curve in Figure 1 (a) is smoother than the curve in Figure 1 (b). It can be illustrated by calculated Allan deviation. The curve in Figure 2 (b) is not smooth because there are not enough points. But the Allan deviation can be compared for 5 and 10 days. From the figures, the Allan deviation in Figure 2 (a) is $1.23 \times 10^{-14}$ for five days and the Allan deviation in Figure 2 (b) is $3.11 \times 10^{-14}$ for five days. The value in first period is better than the value in second period. It implies the stability in the first period is better than that in the second period.

Time difference between Clock I and Clock II was measured at one hour intervals. Then the difference between UTC and Clock II was calculated. The similar curves like Figure 1 was obtained. Allan deviation was also calculated. The Allan deviation for five days in the first period is also smaller than the Allan deviation for five days in the second period. The factors influencing stability are mainly ambient conditions and lifetime of the cesium clocks.

## ACCURACY ANALYSIS

The time difference between the reference clock and GPS time also includes the delays in the antenna, cable, and receiver. It also includes propagation time from satellites to antenna and time offset of the reference. Delays in the GPS receiver, antenna, cable between antenna and receiver, as well as cables between receiver and counter, are calibrated or measured. The uncertainty of calibration of GPS receiver is about 8 nanoseconds. The delay of cable can be measured with 2 ns uncertainty. The effect of ionosphere can be compensated. The propagation time from satellites to antenna can be calculated and compensated. There is no significant effect on the common view results if coordinates of antennas can be determined accurately to within centimeters. The coordinates of GPS antennas were determined by precise geodetic survey in our laboratory, with accuracy better than 1 meter. It is estimated the total effect is not more than 20 nanoseconds.

From the figures, the drift of UTC(PSB) is about 6 ns/day. The UTC(PSB) is then aligned to UTC using a microphase stepper. When the drift is large it can be adjusted continuously. When the drift is small it can be adjusted by step. Through this method the time scale can be maintained for a long-term agreement with UTC within 100 nanoseconds.

## TIME DISSEMINATION THROUGH GPS

### EXPERIMENT SETUP

A common-view experiment has been performed for two months and measurement setup is shown in Figure 4. At one site, AUSTRON 2200A GPS receiver was used and Clock I (HP5071A) is used as reference. At the other site, TTR-4P GPS receiver was used and Clock III (FTS4065) was used as reference. The same time interval measurement between Clock I or Clock III and GPS time was performed.

The TTR-4P GPS receiver was upgraded from firmware version 2.8.2.0 to firmware version 3.0.34.4 in February 1998. Though it is a multichannel receiver, it can be used to follow BIPM schedule as AUSTRON receiver. The difference is that it tracks several satellites at the same time. So it is necessary to choose tracking data according to BIPM schedule. One problem is the tracked satellites according to BIPM schedule may be in different channels. Different channels may have different delays. It will result in some errors. Another problem is that the tracking time is always in 16-minute intervals. It is not the same as the BIPM schedule. The start time of tracking had to be changed daily to track more satellites. The third problem is a software problem. When TTR-4P tracked SV 15, there is an extraordinary offset of several hundred nanoseconds. When SV 15 is enabled and even SV 15 is not tracked, there are also some offset for other satellites in comparing the condition when SV 15 is disabled. Moreover, the offset varied with time. So TTR-4P had to work with SV 15 disabled.

### MEASURED SYSTEM DELAYS

The experiment was performed in the same laboratory. In order to determine the relative delay of the TTR-4P GPS receiver to the AUSTRON receiver, Clock I was also used as the reference of the TTR-4P receiver at the beginning. Then comparison was performed about half month. The average relative delay is -49 ns. The standard deviation is 19 ns. The comparison results were scattered. This noise comes mainly from the receiver. Temperature and humidity conditions and multichannel errors also have some effects.

### EXPERIMENTAL RESULTS

Next Clock III was used as the reference of the TTR-4P GPS receiver. A common-view experiment was performed from MJD51106 to MJD51127. The common-view results are compared with direct measurement results. The average value was estimated. From Figure 3, the mean results of the common view are agreed well with the direct measurement results. Though noise is high, the effect of noise can be averaged and removed for long term experiment. The difference between average common-view results and direct measurement results is less than 20 ns. It verifies the effectiveness of the method. It is also noted that the drift of Clock III was about 67 ns per day. Through this method, Clock III is also traceable to UTC(PSB). This method allows time standards in various parts of Singapore to be calibrated remotely and accurately.

## CONCLUSION

The coordinates of the antenna and time delay shall be measured more accurately. The noise of GPS receiver needs to be reduced to increase common-view accuracy. More time dissemination methods also need to be studied. In order to improve the long-term stability and reliability of UTC(PSB), an ensemble of atomic clocks, including a hydrogen maser, will be used.

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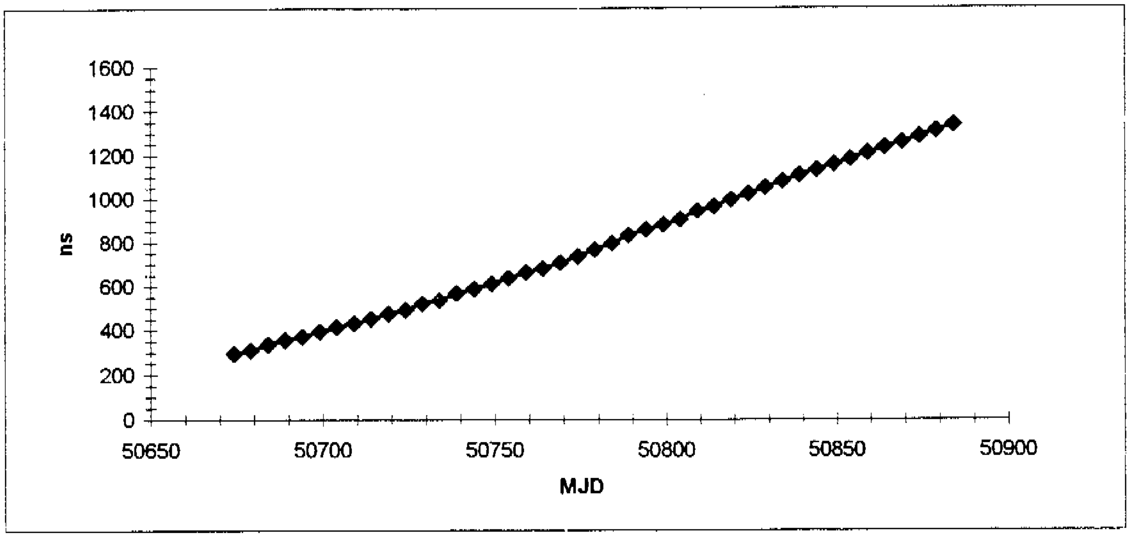
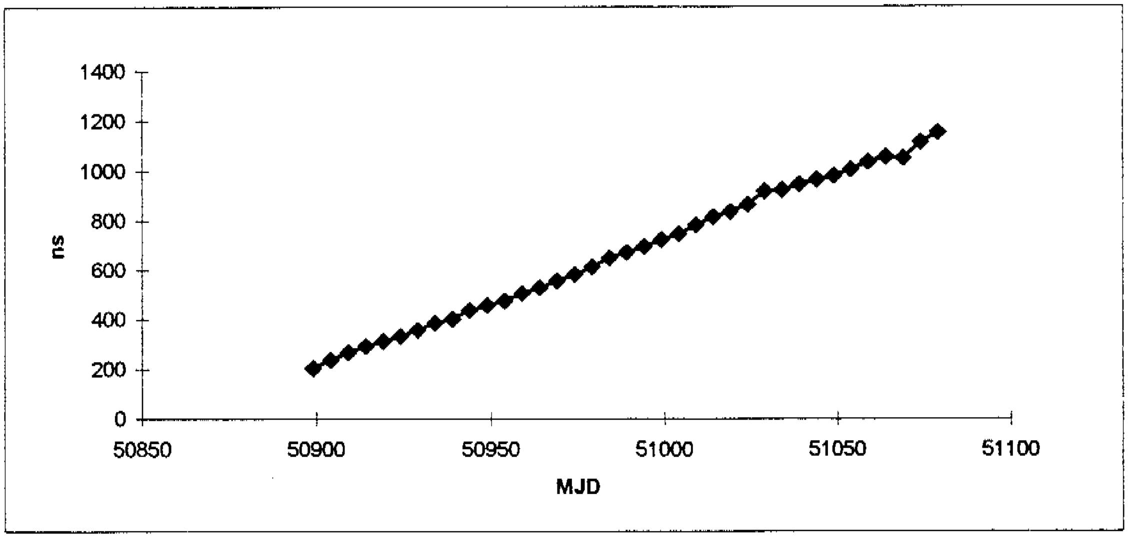
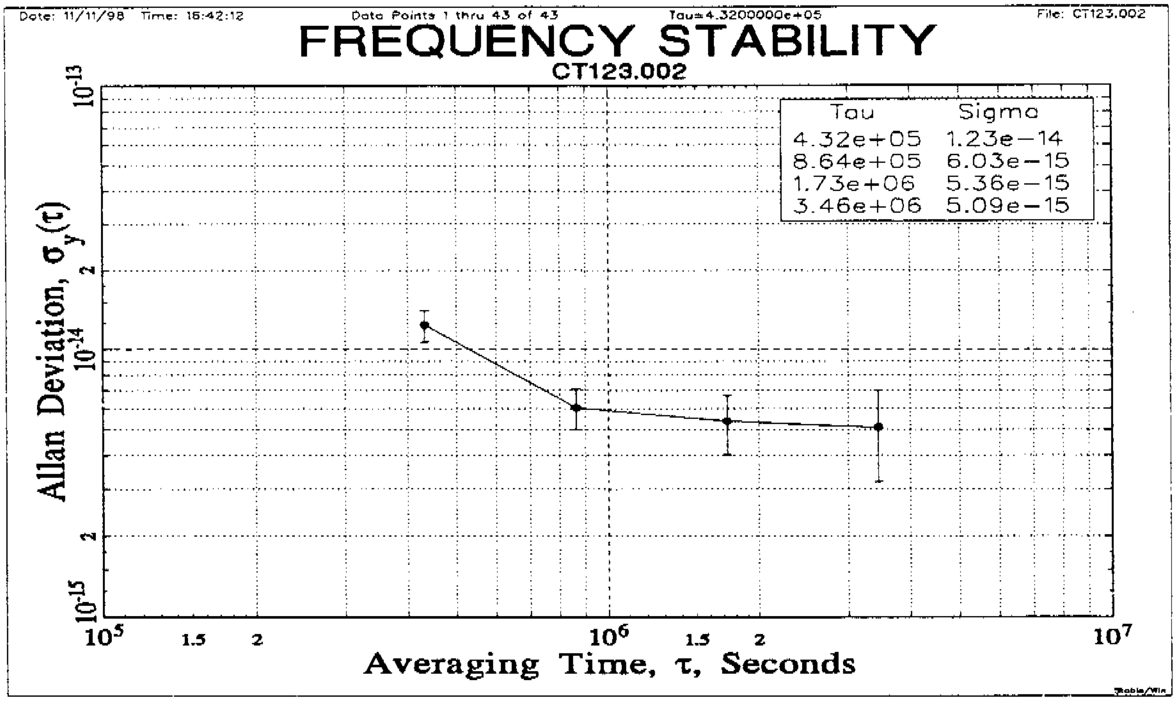



(a)

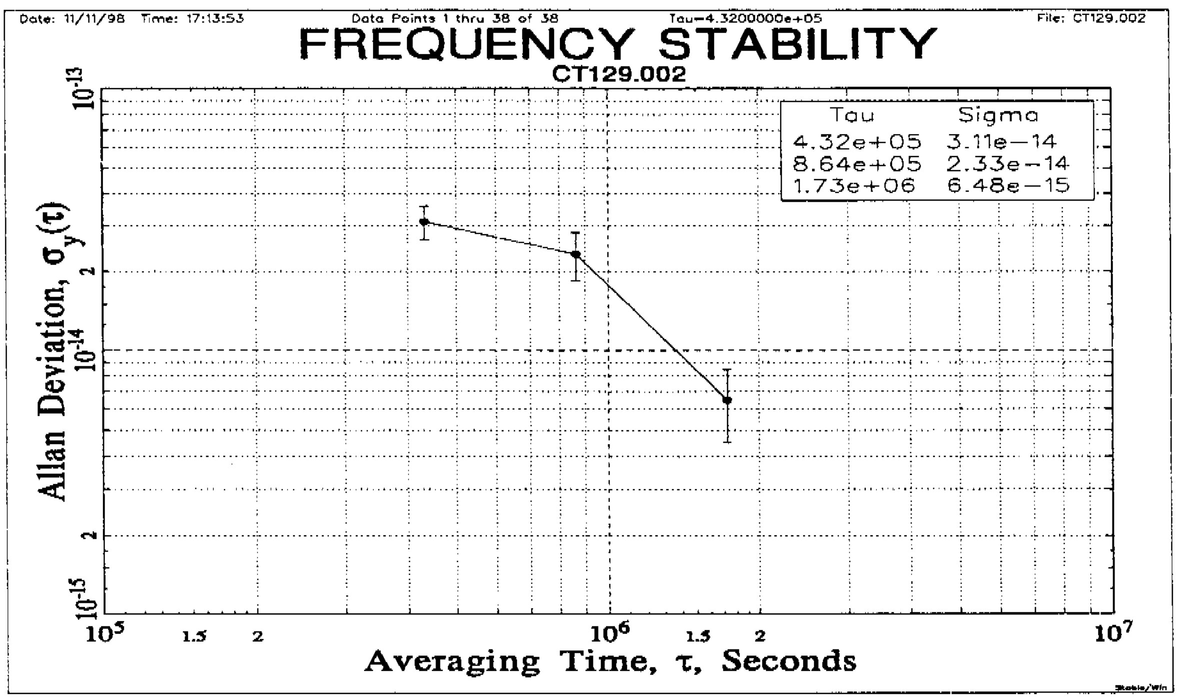



(b)

Figure 1: Difference Between UTC and UTC(PSB). (a) From MJD50674 to MJD 50894. (b) From MJD50899 to MJD51084




(a)




(b)

Figure 2: Allan Deviation of the Time Difference Between UTC and UTC(PSB)
(a) From MJD50674 to MJD50894. (b) From MJD50899 to MJD51084

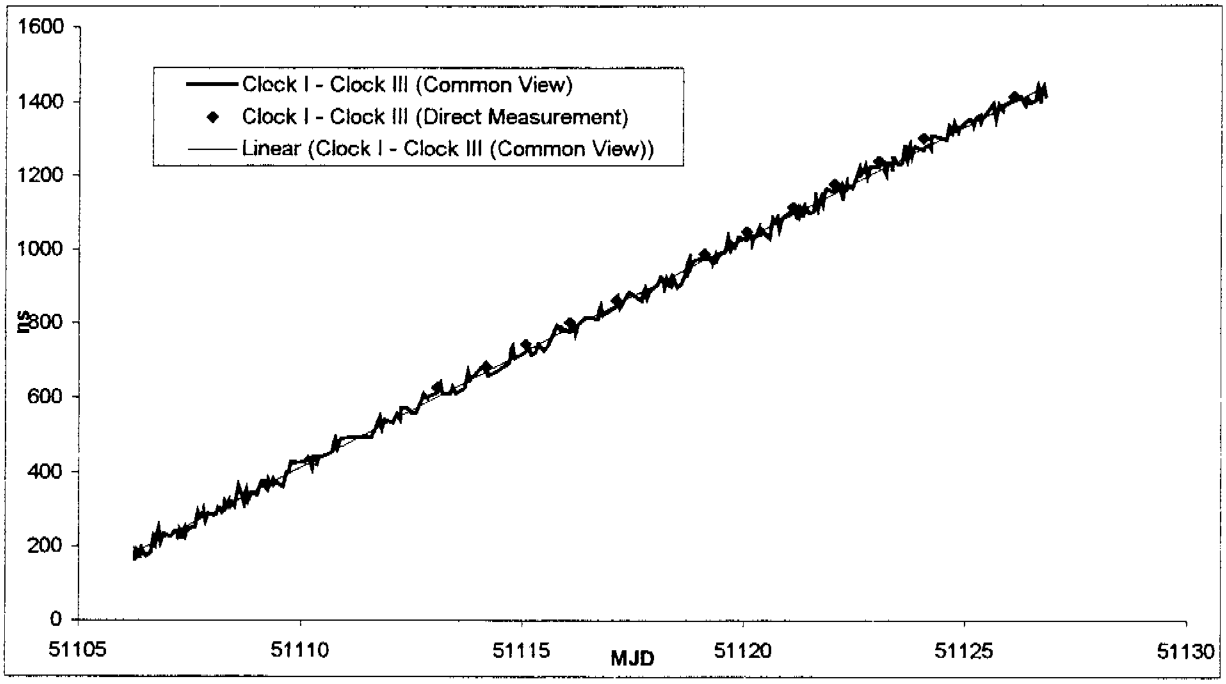



Figure 3: Comparison Between Common-View Results and Direct Measurement

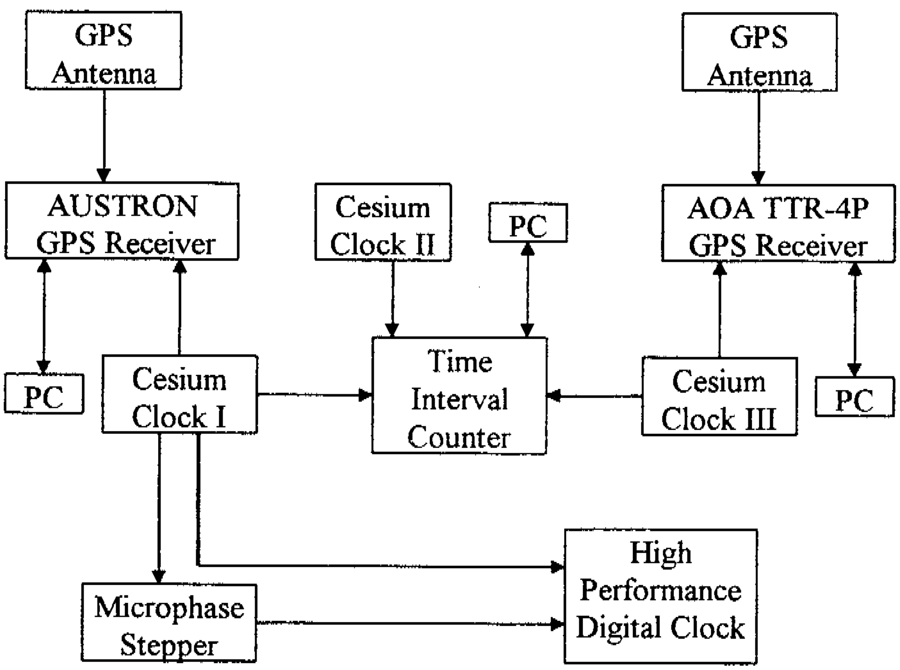



Figure 4: Setup of the Time Scale and Experiment at PSB of Singapore