GPS clock calibration using an atomic clock

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Abstract

Time difference of GPS at SK and KEK was measured by making reference to an atomic clock. Following value was obtained:

\[ T_{GPS@SK} - T_{GPS@KEK} = 0.115 \mu \text{sec}. \]

1 motivation

- measure time difference of GPS at SK and KEK
- check if there are any unknown delay?

2 setup

What we have done:

1. measured time difference of GPS and atomic clock at MIZUSAWA (1999 Oct 19th),
2. measured time difference of GPS and atomic clock at KEK (1999 Oct 20th-21rd),
3. measured time difference of GPS and atomic clock at SK (1999 Oct 23rd-24th),
4. measured time difference of GPS and atomic clock at MIZUSAWA again (1999 Oct 26th).

The atomic clock was borrowed from Mizusawa Astrogpaeodyamics Observatory, National Astronomical Observatory.

2.1 setup at KEK

The GPS system at North Counter Hall was triggered by 1pps from the atomic clock instead of −1.1msec spill trigger. Spill number and GPS time were recorded by GPS DAQ software.
The atomic clock time was read out via RS-232C by polling 1pps from the atomic clock. The schematic view of the setup is shown in fig.1, and atomic clock time data.

Time difference of atomic clock 1pps and GPS 1pps directly was also measured, by feeding 1pps from the atomic clock into the GPS receiver at north counter hall.

2.2 setup at SK

The time difference at SK was measured in two way: feeding 1pps from the atomic clock into the HITSUM fan in/out, and triggering the laser system with atomic clock 1pps.

1. HITSUM run:
Atomic clock 1pps was fed into the HITSUM (fig.2). HV of the PMT was turned off to veto events in SK. Event number and GPS time are recorded with OD DAQ software. The atomic clock time was read out via RS-232C.

2. laser run:
Atomic clock 1pps was fed into the laser system to flash the laser difuser ball in SK(fig.3). Event number and GPS time are recorded with OD DAQ software. The atomic clock time was read out via RS-232C.

3 results

3.1 mizusawa (1999 Oct 19th,26th)

The time difference of the atomic clock and GPS at mizusawa was measured twice: before borrowing the atomic clock (1999 Oct 19th) and after returned it (1999 Oct 26th). $\Delta T$ of atomic clock and Mizusawa Standard Time was measured, and $\Delta T$ of GPS and Mizusawa Standard Time, thus the time difference of the atomic clock and GPS was obtained.

\[
\Delta T = T_{GPS} - T_{ATOMCLK} = 3.055 \pm 0.300 \mu \text{sec} \ (1999 \text{Oct 19th})
\]
\[
\Delta T = T_{GPS} - T_{ATOMCLK} = 3.180 \pm 0.300 \mu \text{sec} \ (1999 \text{Oct 26th})
\]

To synchronize SK and KEK using GPS, what is important is the time difference between SK and KEK ($T_{GPSSK} - T_{GPSKEK}$), not absolute value of the $\Delta T$ at Mizusawa, SK and KEK.

There are 2 GPS clocks in mizusawa which differ about 300nsec. Those GPS time changed about 200nsec when the satellite which the receivers were tracking had changed. So we will quote $\pm 0.300 \mu \text{sec}$ for GPS error in mizusawa.
Drift of the atomic clock was also measured, making reference to Mizusawa Standard Time. The drift during 7 days—transportation of the atomic clock was 85nsec, i.e. 12ns/day. It is consistent with drift of fixed location at Mizusawa (~ 10nsec/day). No drift due to transporting the atomic clock was observed.

3.2 kek (1999 Oct 20th-21st)

1. 1pps trigger run

Figure 5 shows the distribution of $\Delta T$, which is calculated as following:

$$\Delta T = T_{GPS} - T_{ATOMCLK} - (83\text{nsec} + 980.21\mu\text{sec} + 50\text{nsec} + 113.04\mu\text{sec})$$

83nsec and 980.21$\mu$sec are delays shown in fig.5, which was measured by an oscilloscope. 50nsec is delay in LTC module to latch GPS time. 113.04$\mu$sec is a delay made in GPS DAQ software.

The mean value of $\Delta T$ is 2.366$\mu$sec. We will quote $\pm 0.150\mu$sec error for accuracy of GPS receiver and $\pm 0.012\mu$sec for atomic clock drift.

2. direct comparison of atomic clock 1pps and GPS 1pps at KEK

Figure 6 shows the distribution of $\Delta T$.

The mean value of $\Delta T$ is 2.480$\mu$sec. We will quote $\pm 0.150\mu$sec error additionally due to accuracy of GPS receiver and $\pm 0.012\mu$sec for atomic clock drift.

3.3 SK (1999 Oct 23rd-24th)

1. HITSUM run

Figure 7 shows the distribution of $\Delta T$ calculated as following:

$$\Delta T = T_{GPS} - T_{ATOMCLK} - (0.63\mu\text{sec} + 50\text{nsec})$$

The 0.63$\mu$sec cable delay, shown in fig.2, was measured using an oscilloscope. 50nsec delay is delay in LTC.

The mean value of $\Delta T$ is 2.396$\mu$sec. We will quote $\pm 0.15\mu$sec error for accuracy of GPS receiver and $\pm 0.048\mu$sec for atomic clock drift.

2. laser run

Figure 8 shows the distribution of $\Delta T$, which is calculated as following:

$$\Delta T = T_{GPS} - T_{ATOMCLK} - (2.65\mu\text{sec} + 50\text{nsec})$$
2.65\mu\text{sec} is total delay of atomic clock 1pps to OD trigger as shown in fig. 4 and 50nsec is delay in LTC module.

The mean value of $\Delta T$ is 2.481\mu\text{sec}, and we will quote $\pm 0.15\mu\text{sec}$ error additionally for accuracy of GPS receiver, $\pm 0.048\mu\text{sec}$ for atomic clock drift and $\pm 0.1\mu\text{sec}$ for time jitter of laser system.

The total delay of atomic clock 1pps to OD trigger was also confirmed using oscilloscope and obtained 2.73\mu\text{sec}. It was consistent within 100nsec error.

Results of HISTSUM run and laser run are consistent within $\pm 0.150\mu\text{sec}$ error.

3. direct comparison of atomic clock 1pps and GPS 1pps at SK

Time difference of atomic clock 1pps and GPS 1pps was measured at radon hut and central hut, which are connected with 2km optical-fiber, using an oscilloscope. Following values were obtained.

\[
\Delta T_{\text{radon hut}} = T_{\text{GPS}} - T_{\text{ATOMCLK}} = 2.30\mu\text{sec},
\]

\[
\Delta T_{\text{central hut}} = T_{\text{GPS}} - T_{\text{ATOMCLK}} = -7.66\mu\text{sec}.
\]

From above values, time delay from radon hut to central hut is

\[
\Delta T_{\text{radon hut} \rightarrow \text{central hut}} = 9.96 \pm 0.30\mu\text{sec},
\]

which is consistent with measurement by Hans G. Berns, 10.008\pm 0.002\mu\text{sec} within error of GPS receiver.

4 summary

1. $\Delta T$ in KEK

$\Delta T$s in KEK, which were obtained in 2 different setup, were consistent within $\pm 150\text{nsec}$ error of GPS receiver.

2. $\Delta T$ in SK

$\Delta T$ in SK, which obtained by HISTSUM run and laser run, were consistent within $\pm 150\text{nsec}$ error of GPS receiver.

3. drift of atomic clock

Drift of the atomic clock was measured by making reference to Mizusawa Standard Time. The drift during our 7 days-transportation of the atomic clock was 85nsec, and it is consistent with drift of fixed location at Mizusawa ($\sim 10\text{nsec/day}$). No drift due to transporting the atomic clock was observed.

4. $\Delta T$ at SK and KEK

Figure 9 shows $\Delta T$ at KEK and SK. Time difference of GPS at
SK and KEK was consistent within error:

\[ T_{GPS_{SK}} - T_{GPS_{KEK}} = 0.115 \pm 0.237 \mu \text{sec}. \]

The 0.237\( \mu \)sec error are quadratic sum of accuracy of GPS receivers in KEK and SK (both 150nsec), accuracy of laser system (100nsec) and drift of atomic clock (12nsec/day \times 3\text{days}).

To synchronize SK and KEK using GPS, what is important is the time difference between SK and KEK\( (T_{GPS_{SK}} - T_{GPS_{KEK}}) \), not absolute value of the \( \Delta T \) at SK and KEK them selves.

5. **\( \Delta T \) at Mizusawa and KEK (or SK)**

\( \Delta T \) at Mizusawa and KEK (or SK) differ systematically. Because SK GPS time and KEK GPS time are average of times from all satellites in the star-view. On the other hand, Mizusawa GPS time is from one satellite.
Figure 1: setup at kek
Figure 2: setup at SK: HITSUM run
Figure 3: setup at SK: laser run

Figure 4: delays at SK

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Figure 5: $\Delta T$ of KEK 1pps trigger run
Figure 6: $\Delta T$ of direct comparison at KEK
Figure 7: $\Delta T$ of SK HITSUM run
Figure 8: $\Delta T$ of SK laser run
Figure 9: $\Delta T$ at MIsusawa, KEK and SK