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Stability of the timing system during VSR2

L. Rolland, N. Letendre, A. Masserot, B. Mours

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VIRGO * A joint CNRS-INFN Project
Project office: Traversa H di via Macerata - I-56021 S. Stefano a Macerata, Cascina (PI)
Secretariat: Telephone (39) 50 752 521 – Fax (39) 50 752 550 – e-mail virgo@pisa.infn.it

Contents

1 Introduction

The Virgo timing system has been changed for the Virgo+ upgrade in 2008 [1]. The 1 PPS clock from the main GPS receiver is distributed to all the active elements of the four buildings of Virgo.

Channels recording the timing system behaviour are permanently acquired. In this note, the stability of the GPS receiver and of the timing distribution during the second Virgo science run (VSR2) are characterized. The run started on July 3rd, 2009 and ended in January 8th, 2010.

After a brief overview of the Virgo timing system, its overall stability is estimated comparing its 1 PPS clock to other clocks, from another GPS receiver and from an independent atomic clock. The stability of the timing distribution is then characterized and the timing jitter of the timing system is given.

Another important point for the calibration point of view is the absolute timing of the dark fringe readout, used for the $h(t)$ reconstruction [2]. The readout response has been characterized in the note [3]. Its stability over the full VSR2 is checked in the last section.

2 Overview of the Virgo timing system

The Virgo data acquisition system (DAQ) and timing system installed before VSR2 have been described in [1]. The timing system is based on a master timing system controlled by GPS. Its roles are to give the rythm of the control loops and to give the time stamps to the DAQ.

The GPS receiver delivers a 1 pulse-per-second (PPS) clock and the corresponding date encoded in the IRIG-B format [4]. This signal is distributed to all active elements (i.e. ADC, DAC) located in the four ITF buildings with the same propagation delay, measured [1] to $16.041\,\mu$s. The precision of the IRIG-B 1 PPS pulse is ± 100 ns with respect to the 1 PPS reference signal coming from the GPS system (the GPS receiver internal clock has a frequency of 10 MHz).

As shown figure 1 of note [1], the distribution of the IRIG-B signal is done through TDBoxes (Timing Distribution box, which do not contain digital electronics). Each ADC board contains a 100 MHz internal clock sychronized every second on the IRIG-B signal: the precision of the time stamps given by the ADC boards to the sampled data is thus of the order of 10 ns[1].

2.1 Monitoring of the timing system

The monitoring of the timing system is described figure 1.

As described in section 3.1, the IRIG-B signal from the main GPS receiver is compared to the 1 PPS clocks generated by an old GPS receiver and by an independent atomic clock.

[1] It was shown that the the 1PPS LEMO output of the TOLM has low frequency variations with respect to the 1 PPS input of the order $20-30$ ns (see p.10 of note [1]) due to the internal clock feed-back. The same clock and fee-back is used in the ADC boards.

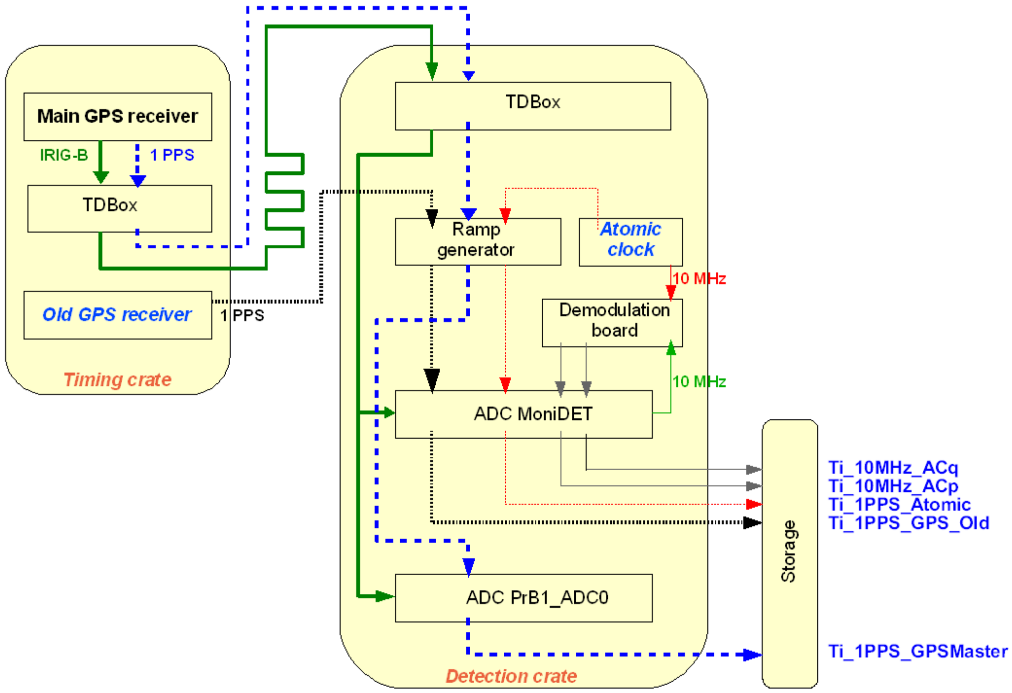


Figure 1: Overview of the monitoring of the timing system.

The jitter noise (section 3.3) is measured demodulating the 10 MHz clock generated by an ADC board by the 10 MHz clock generated by the atomic clock.

The stability of the delay introduced by the readout of the dark fringe channel is estimated comparing the IRIG-B signal to the 1 PPS from the main GPS receiver (section 4).

Note that the ADC board PrB1_ADC0 is used to sample the dark fringe channel at 20 kHz (Pr_B1_ACp), and the ADC board MoniDET is used to sample the dark fringe channel at 40 kHz (Pr_B1_ACp_40K).

3 Stability of the timing system

3.1 Comparison with auxiliary clocks

In this section, the IRIG-B 1 PPS clock from the main GPS receiver is compared to other clocks used as reference in order to estimate its stability at the 1 s level during VSR2 and to check the presence of glitches. Two clocks are used: the clock from an auxiliary GPS receiver[2] (100 ns precision), and an independent atomic clock (10 ps precision).

[2] the old GPS receiver used during VSR1.

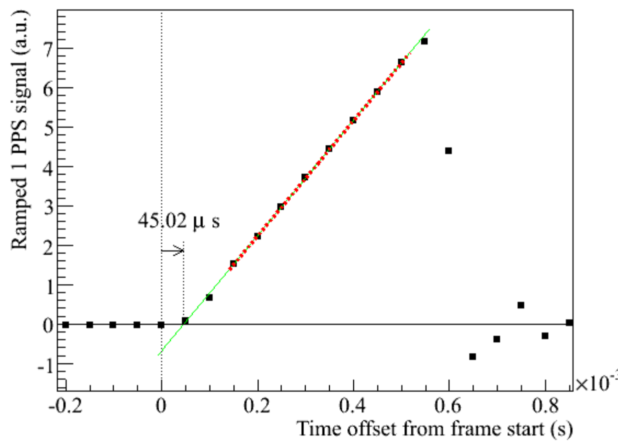


Figure 2: Ramped 1 PPS signal, sampled at 20 kHz. The red line shows the fitted ramp. The offset of its intersection with the off-ramp level gives the delay from the Virgo timing system and the 1 PPS clock. (signal Ti_1PPS_GPSMaster *at GPS 947000001).*

For a given reference clock, its 1 PPS square-shaped signal is integrated into a ramp [5] to better extract the starting time, and the ramp signal is sampled at 20 kHz through an ADC. An example of such a ramp signal is shown in figure 2. From the data, the delay between the start of the ramp and the start of the new second in the Virgo data is then measured. This measurement is computed online by TiMoni server. The evolution of the measured delays as function of time and their variations allow to characterize the timing system.

3.1.1 Data selection

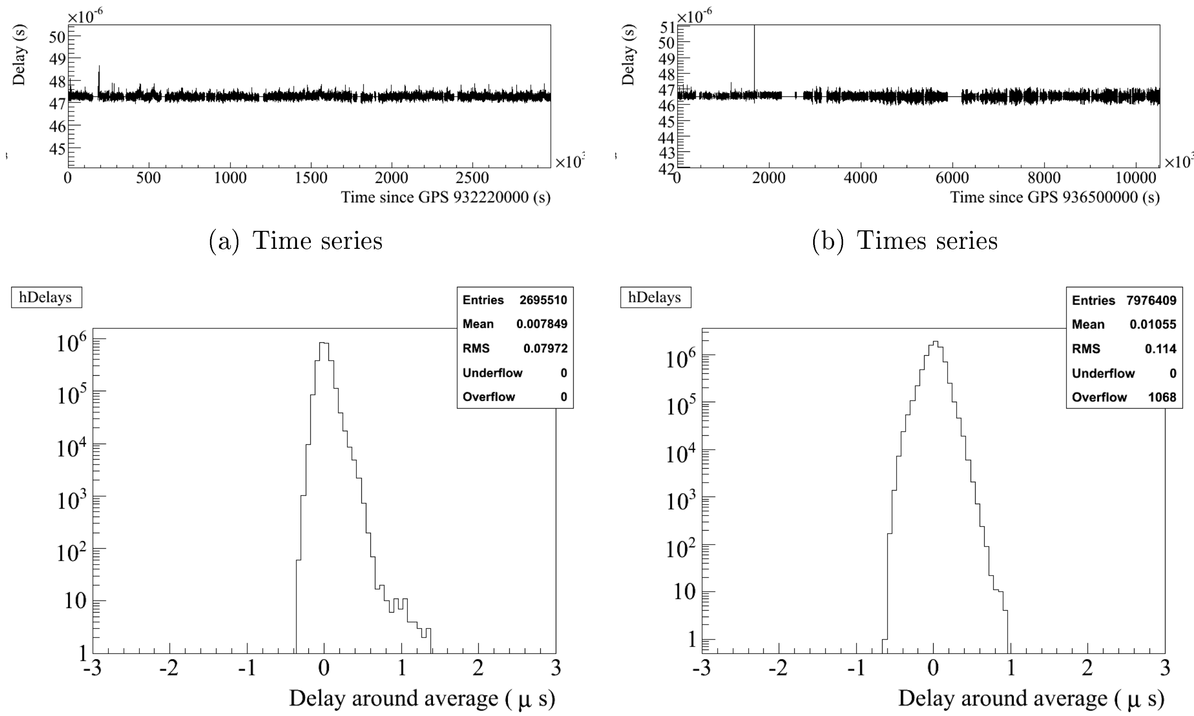
In order to be independent of possible interventions on the DAQ or on the TiMoni server only the data in *science mode* were included in the analysis[3]. The total duration of data in *science mode* is 12870197 s (149 days) out of 15987600 s (185 days) of VSR2 (from GPS 931035615 to 947023214). The total duration of data not in *science mode* is 3117402 s (36.1 days).

Since the monitoring channels have been installed in July 21st 2009 (GPS 932220000), only the data after this date are used.

Periods with missing data were excluded. A criteria for missing data is defined for each analysis:

- Auxiliary GPS receiver analysis: TiMoni_Ti_1PPS_GPS_Old_t0 is 0,
- Atomic clock analysis: TiMoni_Ti_1PPS_Atomic_t0 is 0.

[3] Channel Qc_DQmoni_ITF_SCIENCEMODE_flag = 1 when ITF in *science mode.*



(a) Time series

(b) Times series

(c) Delay distribution

(d) Delay distribution

Figure 3: Monitoring of the timing system using an auxiliary GPS receiver. The first column shows the data from July 21st to August 25th 2009 while the second column shows the data from Sep 9th 2009 to January 8th 2010. First line: time series of the monitored delays. Second line: distribution of the monitored delays. Only data during science mode segments of VSR2 have been selected.

In the *science mode* segments, the same periods of missing data are found for the two channels, which confirms that they are periods of missing data due to the DAQ. The total duration of skipped data due to missing data is 341 s: they represent only 0.0023% of the *science mode* data (their list is given in appendix A.1).

Periods with measured delays larger than 1 s were excluded since they indicate some troubles in the TiMoni server [4]. It never happened during *science mode* data.

3.1.2 Comparison with auxiliary GPS receiver

The delay computed by the TiMoni server related to the auxiliary (old) GPS receiver is stored in the channel TiMoni_Ti_1PPS_GPSOld_t0 (1 Hz). The 1 PPS clock of the auxiliary GPS receiver has a precision of 100 ns (internal clock of 10 MHz). This monitoring would highlight timing glitchs from the GPS receiver and the timing distribution path from the GPS receiver

[4] for example when the ramped channel was sampled at 800 kHz during few minutes.

to the ADC sampling the ramped signal. It would not see glitchs related to the GPS system itself which is the master of both GPS receivers. The 1 PPS signal from the auxiliary GPS receiver is sent to the *ramping* electronics through 3 km of cable in order to introduce a similar delay as the one of the IRIG-B signal propagation. Thus, the absolute value of the measured delays should be close to 0.

No drift is expected between both clocks, enslaved on the GPS signal. Since the ADC channel used to read the ramped signal has been changed in August 25th 2009 (logbook entry 24413)[5], two periods have been analysed (the average delay is sligthly different between both periods due to the use of different anti-alias filters in the ADC board mezzanines). The channel TiMoni_Ti_1PPS_GPSOld_t0 contains bad data from this change up to September 9th 2009, when the TiMoni server has been restarted. This period has been excluded from the analysis.

The time series and distribution of the delays monitored during the full VSR2 is shown in figure 3. 1068 delays are outside the distribution. They all happened on September 28th 2009 (Monday), between 13h04m34s and 13h37m28s LT, with delays around 0.39 s (see appendix A.2). It was a period when the auxiliary GPS receiver was not properly locked[6]: they do not indicate any trouble in the main timing system.

Not taking into account this outsider events, the RMS of the distribution is ~ 100 ns and no tails are observed outside ± 1.5 μs. The RMS is in agreement with the precision of the GPS receiver clocks. The tails are also of the same order of magnitude as the clock precisions.

The absolute value of the measured delay is ~ 47 μs. As described in note [3], p.$6-7$ (for channel Ti_1PPS_GPSMaster), the expected delay between the start of the frame and the 1 PPS clock from the auxiliary GPS receiver is 50 ± 2 μs[7]. It was also shown that the estimation of the delay fitting the ramp by a straight line introduces systematic errors of ± 4 μs on the absolute value (depending on the number of samples used in the fit for example)[8]. The measured delay is thus finally 47 ± 4 μs and the expected delay 50 ± 2 μs. To conlude, the 1 PPS signals from the two GPS receivers are coincident within systematic errors.

3.1.3 Comparison with an independant atomic clock

Another way to monitor the stability of the timing system at the 1 s level, is based on the 1 PPS signal delivered by an independent Rubidium atomic clock [5]. The 1 PPS output of the atomic clock has a jitter of 10 ps RMS. As previously, the signal is integrated into a ramp and sampled at 20 kHz through an ADC. The delay between the start of the ramp and the start of the new second in the Virgo data is then measured: channel TiMoni_Ti_1PPS_Atomic_t0 (1 Hz).

[5] signal Ti_1PPS_GPSOld acquired on channel 09 before and on channel 13 after.

[6] It was found in the log file where all the issues of the auxiliary GPS VME board are stored: /virgoLog/TiM/TiServer/GPS_status.txt

[7] here we neglect the slight difference of delay introduced by the ADC analog mezzanine wrt the note [3].

[8] the online fit uses 11 samples for Ti_1PPS_GPSMaster and 13 samples for Ti_1PPS_GPSMaster

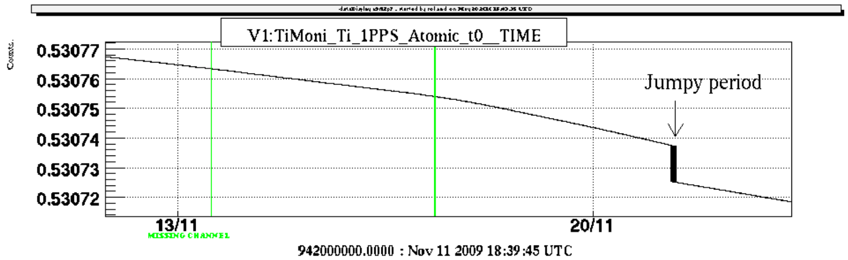


Figure 4: Measured delay between the atomic clock and the GPS receiver 1 PPS clocks during ~ 12 *days.*

This comparison would highlight timing glitchs from the GPS system, the GPS receiver and the timing distribution path from the GPS receiver to the ADC sampling the ramped signal. It is thus more important than the comparison with the auxiliary GPS receiver.

The monitoring atomic clock being independent of the Virgo timing system, its clock slowly drifts from the GPS reference. The drift is estimated assuming it is linear over periods of one day. In the following, the time series is corrected for the estimated drift. In order to properly correct for the drift, all VSR2 data were included in this analysis, not only the *science mode* segments.

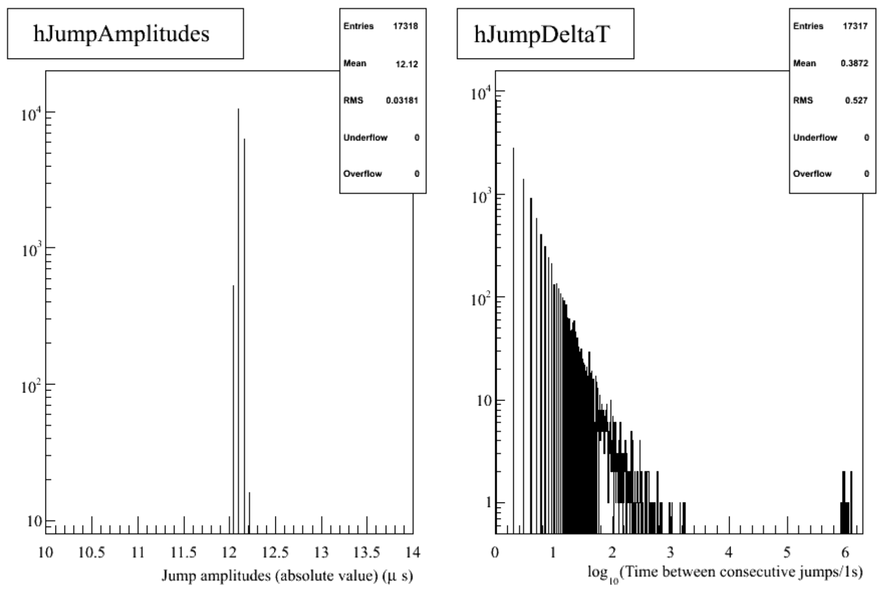
Due to the drift, the ramp samples that are used in the fit are also slowly drifting as shown figure 4. Every time the clock has drifted by 50 μs, a new sample at the start of the ramp is included in the fit of the ramp[9]. This introduces a bias in the delay estimation, seen as a *jump* in the delay measurement. Such jumps appear about every 12 days ($\sim 10^6$ s) with estimated amplitudes of 12.12 ± 0.032 μs (see figure 5(a)). Due to the presence of noise in the signals, the new sample used in the fit is included/excluded randomly when it is close to the fit selection threshold. Such a jumpy period lasts about 15 minutes ($\sim 10^3$ s). In order not to remove these periods from the analysis, 12.12 μs are added or subtracted to the channel TiMoni_Ti_1PPS_Atomic_t0 each time such a jump is detected. In practice, a jump is defined when these two conditions are fulfilled:

- the difference between the current delay $t0_i$ and the delay measured the previous second $t0_{i-1}$ is between 11 μs and 13 μs.
- and the difference between the identities of the first sample used in the current fit and in the previous fit varies by ± 1.

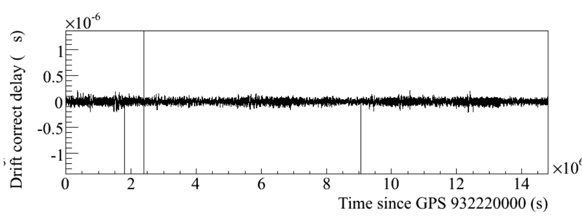
The ADC channel used to read the ramped signal has been changed in August 25th 2009 (logbook entry 24413)[10]. The value of TiMoni_Ti_1PPS_Atomic_t0 changed by ~ 0.3 μs since a different mezzanine is used in the two periods. The estimation of the drifts has been

[9] Since the ramp is not perfectly linear.

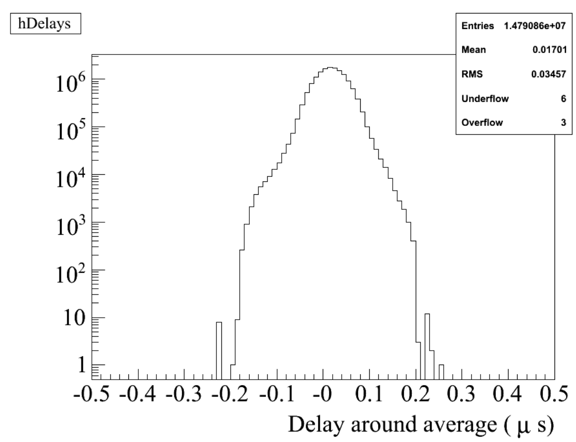
[10] signal Ti_1PPS_Atomic acquired on channel 08 before and on channel 12 after. GPS 935222496.



(a) Checks of removed jumps



(b) Time series



(c) Delay distribution

Figure 5: Monitoring of the timing system using an independent atomic clock. (a) left: amplitude of the jumps that have been rejected. right: distribution of the time between two consecutive jumps. (b) The time series of the monitored delays (corrected for the clock drift) are shown, from July 21st 2009 to January 8th 2010. (c) Distribution of the monitored delays. No selection on the science mode status was applied.

forced to be done before and after this time independently.
An anormal behaviour was found on August 11th 2009 at 8h38m UTC (GPS 934015111 to 934015113) that spoiled the drift estimation for this day. They happened during a maintenance period and is thus related to non-standard activities. These 3 s of data have been rejected from the analysis.
The data that have been rejected (due to missing data during DAQ maintenance) between July 21st 2009 and January 8th 2010 represents 12350 s (0.083% of the data).

The distribution of the delays around the average drift monitored during the full VSR2 is shown in figure 5. 9 events have delays that are outside the distribution range. They all happened during maintenance periods:

- August 11th 2009, 8h38 UTC, with DAQ maintenance (logbook entry 24188),
- August 18th 2009, between 7h30 and 7h54 UTC, with DAQ maintenance (logbook entry 24294),
- August 25th 2009, 8h01 UTC, with DAQ maintenance and a swap of channels to read the ramped 1 PPS signals (logbook entry 24413),
- November 3rd 2009, 8h33 UTC, with DAQ maintenance (logbook entry 25482).

As a consequence, they do not indicate glitches in the Virgo timing system in normal condition.
The RMS of the distribution is 34 ns and no tails are observed outside ± 0.3 μs. The RMS is in agreement with the expected fluctuations of the ADC internal clock used to timestamped the data (the jitter from the atomic clock being negligible). The tails have the same order of magnitude as the precision of the IRIG-B signal from the main GPS receiver used to control the ADC.

3.2 Monitoring the ADC clock control signals

Each ADC board contains a 100 MHz clock used to give the rythm of the sampling. These clocks are enslaved on the IRIG-B signal coming from the main GPS receiver through different TDBoxes (see figure 1 of note [1]). The corrections generated every second by the ADC boards to re-synchronize their clock to the IRIG-B signal are permanently saved in the data. They are expected to monitor glitches from the main clock, in the timing distribution system or from the ADC board clock itself.

The distributions of the errors received by ADC boards at different locations in the timing distribution are given figure 6, using *science mode* segments of VSR2. The measured RMS is ~ 4 ns. It is lower than the $\sim$10 ns from ADC clock synchronisation since the fluctuations are at low frequency: most corrections are around 0, which induces a lower RMS. Some tails are visible but the error signals are all lower than ± 0.3 μs, which is compatible with the precision

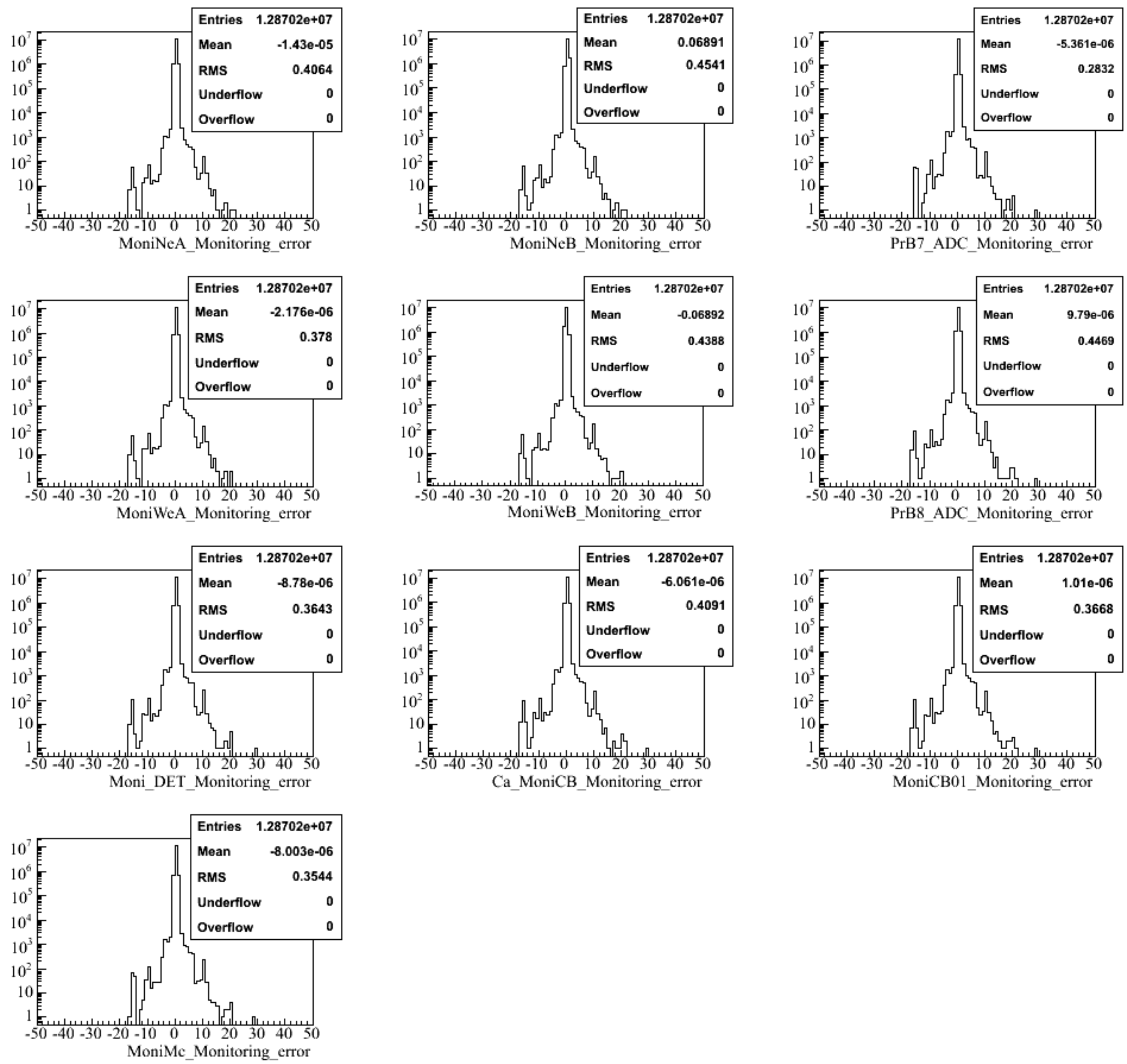


Figure 6: Distribution of the error signals used to control 10 different ADC boards clocks during VSR2. In x-axis, 1 count represents 10 ns. Only science mode segments have been analysed.

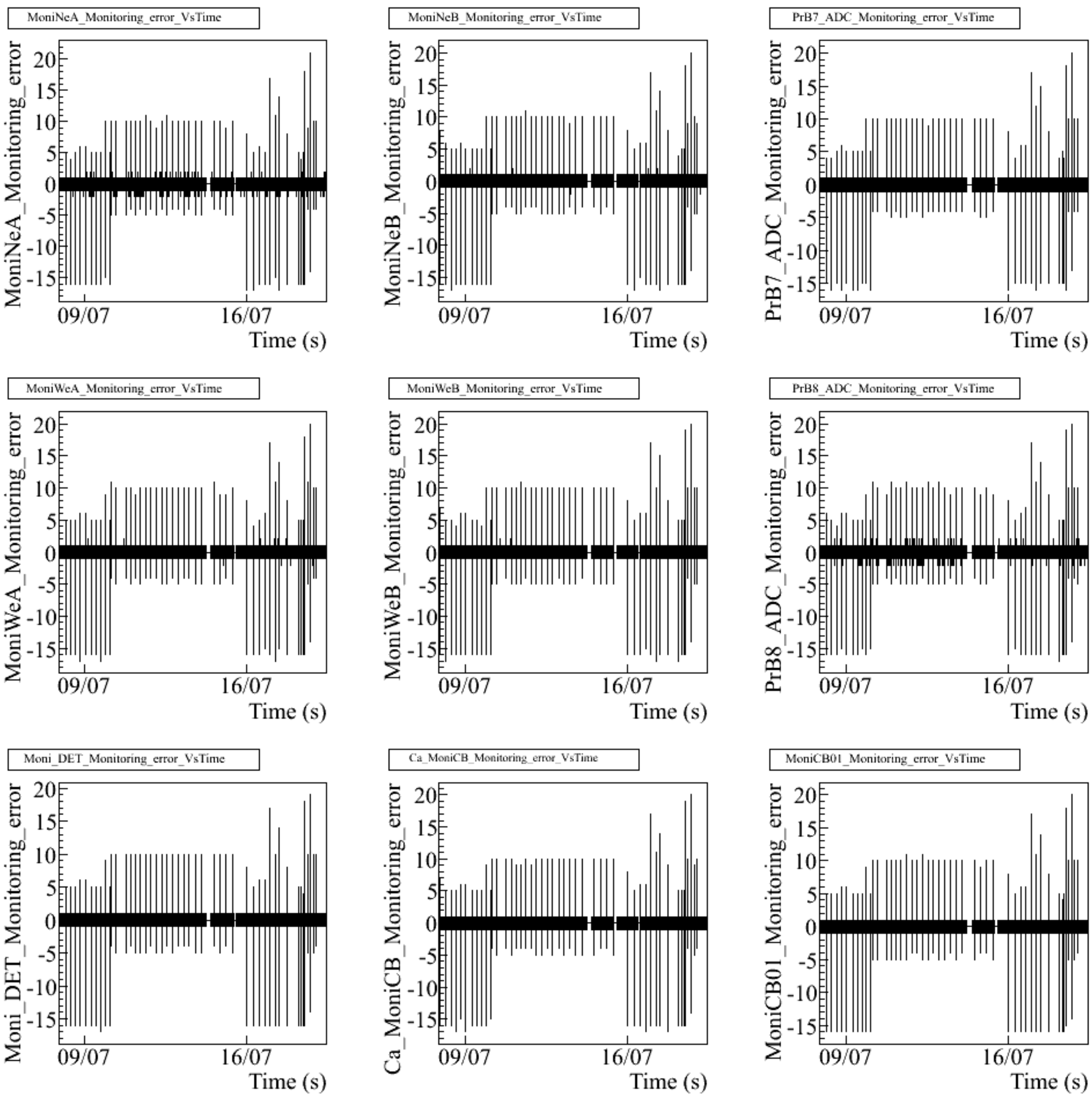


Figure 7: Time series of the error signals used to control 10 different ADC boards clocks, in July 2009. In y-axis, 1 count represents 10 ns. Errors are artificially set to 0 when the ITF is not in science mode.

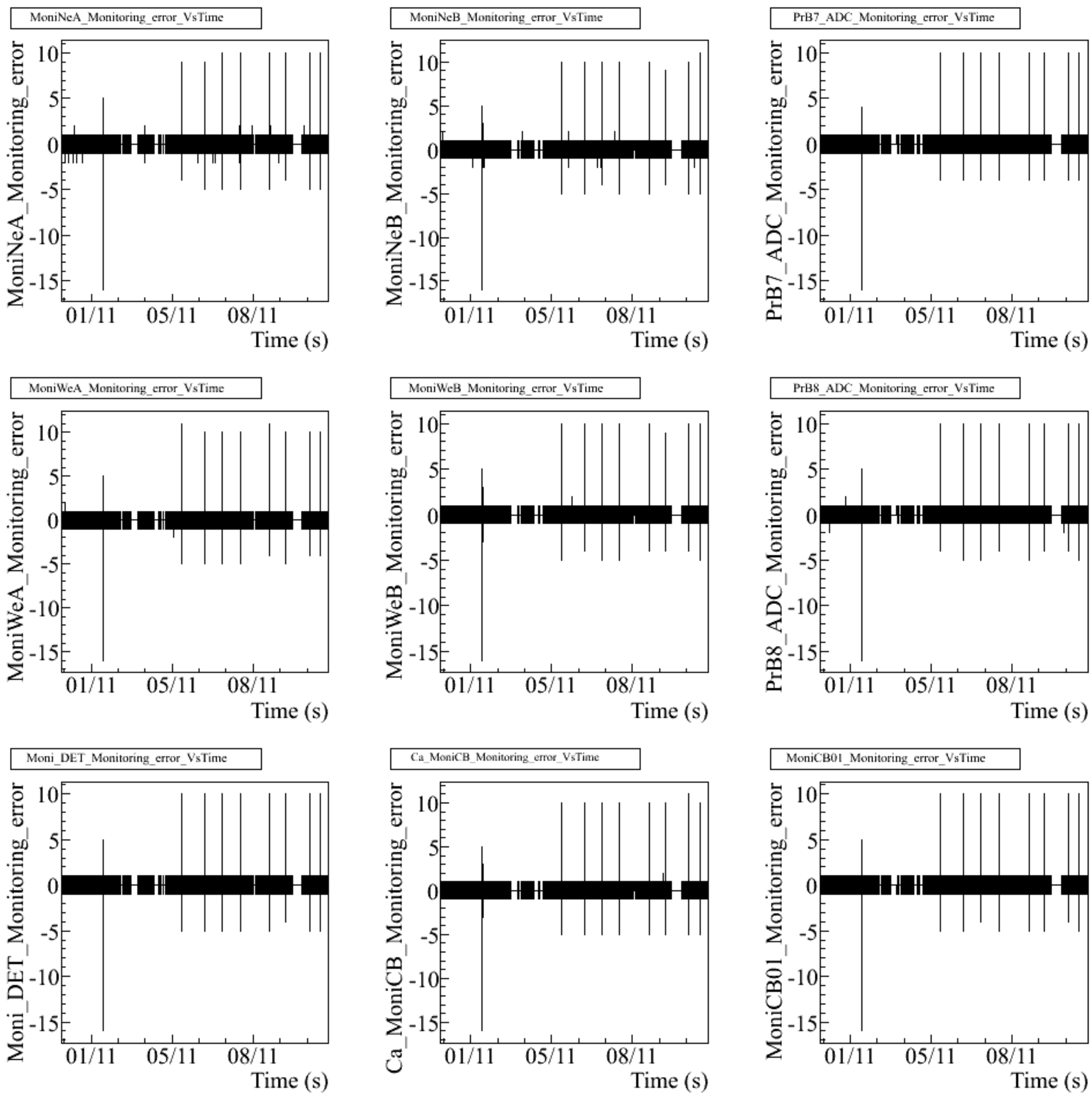


Figure 8: Time series of the error signals used to control 10 different ADC boards clocks, in November 2009 In y-axis, 1 count represents 10 ns. Errors are artificially set to 0 when the ITF is not in science mode.

of the IRIG-B signal of the main GPS receiver used to synchronize the ADCs.

The time series of the error signals are given figures 7 and 8 during two short periods[11]. Most of the glitchs are seen by all ADC boards at the same time and with the same amplitude[12], which indicates that they come from the GPS system, the GPS receiver or the first TDBox which is common to the all the timing distribution. The second hypothesis is unlikely since no glitch is observed from the other TDBoxes, which anyway do not contain any digital logic.

3.3 Timing jitter

The timing jitter of the timing system below 1 s has also been measured. The method are result are given in the note [3][13]. It permits to monitor the phase noise of the 10 MHz clock generated by the ADC and used to sample the data.

The 10 MHz clock generated by the ADC MoniDET is used as local oscillator to demodulate the 10 MHz clock generated by the independent atomic clock. The phase between the two clocks is extracted as function of time from the demodulated signals Ti_10MHz_ACp, ACq sampled at 20 kHz.

As shown figure 9, the timing jitter was found to be below $0.1\,\mathrm{ns}/\sqrt{\mathrm{Hz}}$ above 1 Hz.

3.4 Summary

Different ways to monitor the Virgo timing system has been studied. The different results are summarized and combined in order to conclude about the Virgo timing stability during VSR2.

The comparison of the 1 PPS clock of the main GPS receiver of the timing system with the clock of an independent atomic clock is the most powerfull test to search for instabilities in the timing system. It has shown that the timing (GPS system, GPS receiver and timing distribution) has been stable within 0.3 μs during VSR2. However, this monitoring was installed only in July 21st 2009: the first 18 days of VSR2 were not checked with this method.

Similar, but less stringent, comparison using the clock of an auxiliary GPS receiver as reference did not show any issue. Additionnal information extracted from this comparison is that the 1 PPS arrival times from both GPS receivers agree within 4 μs(the uncertainty coming from the systematic errors of the ramp linear fit).

[11] Note that the channels MoniNeA, MoniNeB, MoniWeA and MoniWeB did not work from November 17th 2009. It is probably an issue with the frame builder.

[12] Note that the glitches seen in the ADC boards used for locking (i.e. B1, B7, B8, with $PAGE\_DELAY = -50$ μs) are seen 1 s before the glitches seen in the monitoring ADC boards ($PAGE\_DELAY = 0$). This is under investigation but is probably related to the time offset added in the DAQ ($PAGE\_DELAY$).

[13] The ADC7674 SN30 whose 10 MHz clock is used to demodulate the atomic 10 MHz clock is not the ADC used to read the dark fringe at 20 kHz. It is the ADC used to read the dark fringe at 40 kHz.

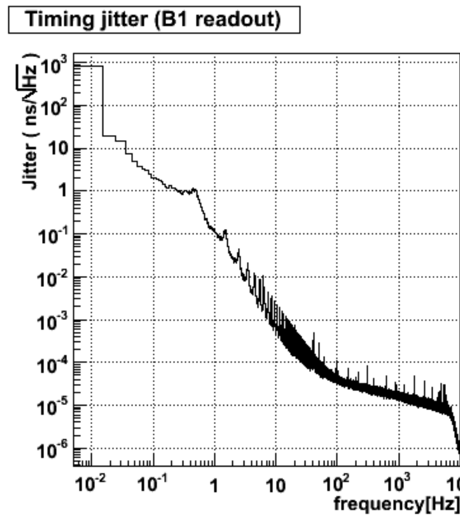
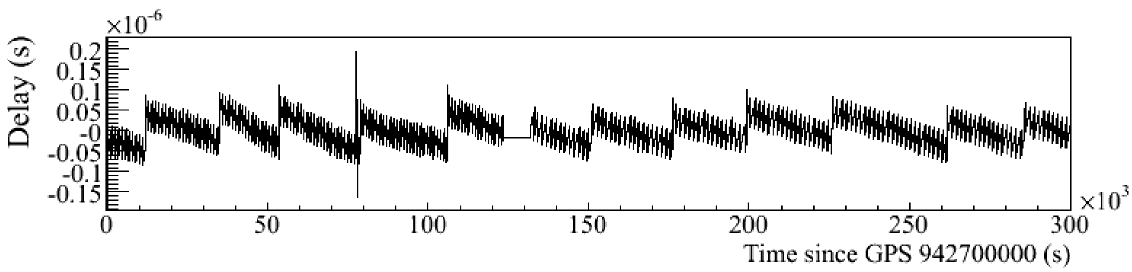
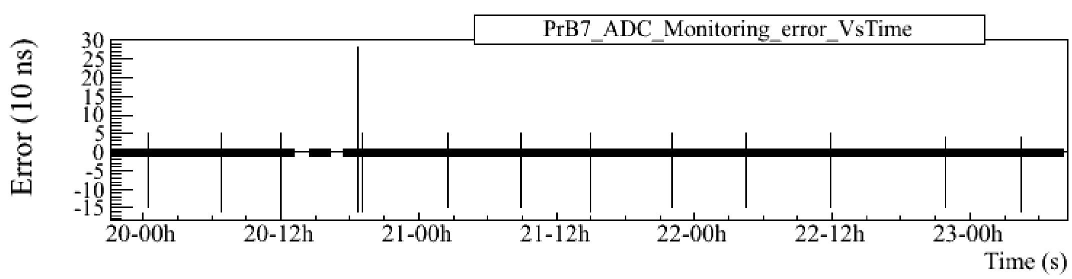


Figure 9: Timing jitter measurement. Data from GPS 933001200, for 1.7 hours.



(a) Drift corrected delay from atomic clock



(b) Error signal of an ADC board

Figure 10: Correspondance of the times series of the drift corrected delay estimated from the atomic clock and of the error signal of an ADC board during the same period (GPS 942700000, for 300000 s).

The monitoring of the errors signals that control the different ADC boards clocks has also shown that the timing distribution is stable within 0.3 μs and during the full VSR2. The observed glitches are detected on all the error signals, which indicates that the source of the glitches is close to the main timing board. No hint for glitches introduced by the timing signal propagation were found. As shown figure 10, these glitches are also seen in the monitoring using the atomic clock and are therefore already included in the timing precision estimated above.

To conclude, the precision of the timing system during VSR2 has been of 0.3 μs. The observed glitches could come from the GPS system or the main GPS receiver. The glitches being compatible with the precision of the GPS receiver internal clock, we conclude that the GPS receiver is the source of most of them.

3.5 Search for corresponding glitches in h(t)

In this section, it is checked if the glitches observed in the timing distribution have an impact on the $h(t)$ channel. The mbta online analysis for CBC search has been used for this check.

For every glitches seen in the detection ADC board (channel PrB1_ADC0_Monitoring_error, glitches with more than 10 ADC counts, i.e. 100 ns), the number of mbta events in a window of 1 s around the glitch has been measured[14]. The number of mbta events in 1 s windows translated by ± 20 s around the glitch have also been measured to estimate the background. The number of mbta events as function of the window position is thus obtained for each timing glitch. The sum of these distribution over the 418 timing glitches is shown figure 11. No excess of events is seen around 0, when the window is in coincidence with the timing glitches. It is an indication that the timing glitches have no impact on the data analysis.

4 Stability of the dark fringe readout (Pr_B1_ACp)

The absolute timing calibration, used in particular for $h(t)$ reconstruction, is based on the dark fringe readout timing calibration. As described in the note [3] (section 2), the delay introduced by the dark fringe readout is monitored from the ramped 1 PPS signal from the main GPS receiver, sampled at 20 kHz. The precision of the 1 PPS output signal of the main GPS receiver is ± 10 ns. The delay is measured online and stored in the channel TiMoni_Ti_1PPS_GPSMaster_t0 (1 Hz).

The times series of the delay measured during the *science mode* segments of VSR2 is shown figure 12(a). As expected, no drift is observed. The distribution of the delays around the average value is shown figure 12(b). Its RMS is 38 ns and all tails are lower than 0.3 μs. This distribution is similar to the timing system fluctuations monitored with the atomic clock (see figure 5(c)). This is expected since,as for the atomic clock, the precision of the 1 PPS clock of

[14] All mbta events are used, no selection on SNR has been applied.

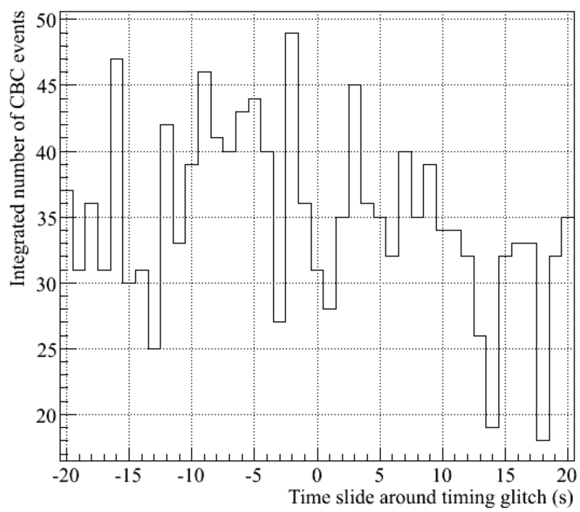
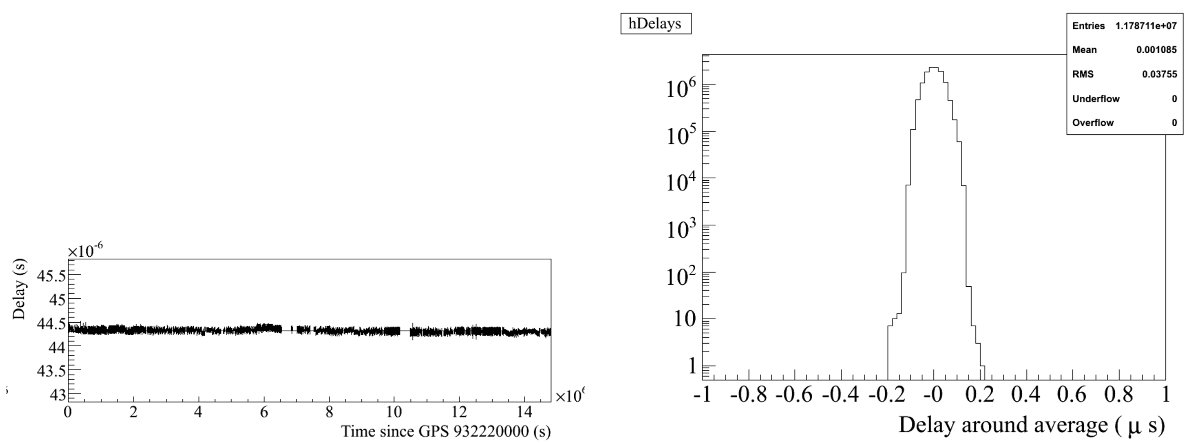


Figure 11: Number of mbta events in 1 s time windows located from -20 s to +20 s around the time of the timing glitches.



(a) Time series (b) Delay distribution

Figure 12: Monitoring of the B1 readout timing stability. (a) The time series of the monitored delays are shown, from July 21st 2009 to January 8th 2010. (b) Distribution of the monitored delays. Only science mode data were used.

the main GPS receiver is better than the fluctuations of the ADC internal clock.

To conclude, no hint for variations of the delay introduces by the readout of the dark fringe channel during VSR2 has been found: its possible variations are well below 0.3 μs.

5 Conclusion

The stability of the Virgo timing system during the VSR2 *science mode* segments has been checked with different monitoring methods. All methods are in agreement within their respective precision. At the 1 s level, the precision of the timing signal generation and its distribution has been estimated to 0.3 μs. On shorter time scales, the timing jitter is lower than $0.1\,\mathrm{ns}/\sqrt{\mathrm{Hz}}$ ($f > 1$ Hz).

Extending the results from note [3], it has been shown that the delay introduced by the readout of the dark fringe channel has been stable within better than 0.3 μs during VSR2.

Concerning the precision of the reconstructed $h(t)$ channel, these results indicate that the timing of the different channels used in the reconstruction has been stable and did not introduce any systematic errors. The calibration of the dark fringe readout response is the base of the $h(t)$ absolute timing. Due to its stability, the error on the absolute timing of $h(t)$ coming from the dark fringe readout variations is well below 0.3 μs.

It was also checked that the 1 PPS signals from the main and from the auxiliary GPS receivers are coincident, as expected, within systematic errors of the measurement method estimated to 4 μs.

References

[1] N. Letendre, A. Masserot, B. Mours, *Virgo+ timing deployement* (2009) VIR-073B-08.

[2] B. Mours & L. Rolland $h(t)$ *reconstruction for VSR2 ; Versions 2 and 3* (2010) VIR-0340A-10.

[3] L. Rolland *Calibration status in September 2009* (2009) VIR-0576A-09.

[4] http://irigb.com

[5] S. Vilalte *Circuit Design of a Pulse Generator* (2003) VIR-0572A-09.

A Rejected data for timing stability studies

This appendix gives the list of the *science mode* data that have been rejected during the analysis of the 1 PPS ramped signals, along with the reasons for non-selection.

A.1 Missing data

The monitoring channels were not installed before July 21st 2009 (GPS 932220000).

From then, the total duration of skipped data due to missing data is 341 s:

```
from GPS 932968282 during 1 s
from GPS 934135642 during 1 s
from GPS 934230625 during 1 s
from GPS 934385915 during 1 s
from GPS 934828590 during 10 s
from GPS 934828602 during 23 s
from GPS 934828784 during 1 s
from GPS 934836162 during 1 s
from GPS 934838022 during 1 s
from GPS 934842249 during 1 s
from GPS 934842252 during 28 s
from GPS 934842282 during 2 s
from GPS 934842443 during 1 s
from GPS 934842564 during 1 s
from GPS 934842626 during 1 s
from GPS 934842688 during 1 s
from GPS 934842874 during 1 s
from GPS 934842936 during 1 s
from GPS 934842998 during 1 s
from GPS 934843184 during 1 s
from GPS 934843246 during 1 s
from GPS 934843308 during 1 s
from GPS 934843494 during 1 s
from GPS 934843556 during 1 s
from GPS 934843618 during 1 s
from GPS 934843680 during 1 s
from GPS 934894825 during 1 s
from GPS 934896386 during 1 s
from GPS 936355637 during 7 s
from GPS 938053777 during 3 s
from GPS 938117951 during 1 s
from GPS 938117959 during 1 s
```

```
from GPS 938117963 during 21 s
from GPS 938118553 during 1 s
from GPS 938118559 during 1 s
from GPS 938118563 during 19 s
from GPS 938119159 during 1 s
from GPS 938119163 during 26 s
from GPS 938119759 during 30 s
from GPS 938120359 during 31 s
from GPS 938120961 during 6 s
from GPS 938120974 during 18 s
from GPS 938121563 during 4 s
from GPS 938121574 during 15 s
from GPS 938122165 during 2 s
from GPS 938122174 during 18 s
from GPS 938122767 during 1 s
from GPS 938122774 during 25 s
from GPS 940236591 during 1 s
from GPS 940236593 during 1 s
from GPS 940236597 during 3 s
from GPS 940236603 during 1 s
from GPS 940236605 during 1 s
from GPS 940236607 during 9 s
from GPS 940236617 during 1 s
from GPS 940236619 during 1 s
from GPS 940237203 during 1 s
from GPS 940237205 during 1 s
from GPS 940237207 during 1 s
from GPS 940237591 during 1 s
from GPS 940238889 during 1 s
from GPS 941542460 during 1 s
from GPS 941542462 during 1 s
from GPS 941542464 during 5 s
from GPS 941542470 during 2 s
from GPS 941542474 during 1 s
from GPS 941542476 during 1 s
from GPS 941542478 during 1 s
from GPS 941542481 during 4 s
from GPS 941542488 during 1 s
from GPS 941542494 during 2 s
from GPS 941542498 during 1 s
from GPS 941542506 during 1 s
```

```
from GPS 941542510 during 1 s
from GPS 941542512 during 4 s
from GPS 941542520 during 1 s
from GPS 941542522 during 3 s
from GPS 941542528 during 1 s
from GPS 941542530 during 5 s
from GPS 941542538 during 1 s
from GPS 941542543 during 2 s
from GPS 941542546 during 1 s
from GPS 941542548 during 1 s
from GPS 941542550 during 1 s
from GPS 941542552 during 3 s
from GPS 941542562 during 1 s
from GPS 941542566 during 1 s
from GPS 941542568 during 1 s
from GPS 941542570 during 1 s
from GPS 941542572 during 3 s
from GPS 941542576 during 1 s
from GPS 941542578 during 1 s
from GPS 941542586 during 3 s
from GPS 941542592 during 3 s
from GPS 941542598 during 1 s
from GPS 941542602 during 5 s
from GPS 941542608 during 1 s
from GPS 941542612 during 3 s
from GPS 941542617 during 2 s
from GPS 941542823 during 1 s
from GPS 946980949 during 1 s
from GPS 946980953 during 1 s
from GPS 946980960 during 1 s
from GPS 946980962 during 3 s
from GPS 946980966 during 3 s
from GPS 946980970 during 5 s
from GPS 946980976 during 1 s
```

A.2 GPS Old

All the delays were found within ± 1.5 μs around 0, except for 1068 values estimated around 0.39 s. All the values happened on September 28th 2009, between 13h04m34s and 13h37m28s LT. It was a period when the old GPS receiver was not properly locked. They are summarized in the following table:

GPS start	GPS end	duration (s)	min delay (s)	max delay (s)	mean delay (s)
938171089	938171128	39	0.386000127	0.386000336	0.3860002
938171143	938171219	76	0.385999382	0.386000634	0.386000036
938171269	938171308	39	0.386000395	0.386001349	0.386000885
938171329	938171368	39	0.386000813	0.386000872	0.386000839
938171395	938171488	93	0.386999012	0.387000681	0.386999845
938171521	938171555	34	0.387000025	0.387000979	0.387000488
938171581	938171612	31	0.387000651	0.387001247	0.387000943
938171641	938171674	33	0.387001068	0.387001664	0.38700136
938171701	938171735	34	0.386999429	0.387000561	0.386999987
938171761	938171794	33	0.387001008	0.387001306	0.387001152
938172073	938172119	46	0.38800025	0.388000787	0.388000521
938172133	938172182	49	0.387998671	0.388000608	0.387999609
938172199	938172238	39	0.388999582	0.389000625	0.389000091
938172259	938172299	40	0.388999671	0.389000536	0.389000065
938172319	938172360	41	0.38899842	0.389000476	0.388999416
938172385	938172478	93	0.388999344	0.389000625	0.388999911
938172505	938172538	33	0.389000238	0.389000774	0.389000508
938172571	938172602	31	0.389000983	0.3890014	0.389001197
938172631	938172665	34	0.389001012	0.389001668	0.389001339
938172691	938172726	35	0.389000208	0.389001072	0.389000626
938172751	938172786	35	0.389000387	0.389002592	0.389001518
938172823	938172878	55	0.389000655	0.38900137	0.389001035
938173003	938173058	55	0.39000097	0.390001387	0.390001229
938173063	938173094	31	0.38999942	0.390000642	0.390000017

A.3 Atomic

3 s of data with glitches during a maintenance period were ”manually” rejected since they were spoiling the estimation of the drift: August 11th 2009 at 8h38m UTC (GPS 934015111 to 934015113).

A.4 GPS Master

No other periods were rejected.