Notes on Arecibo 1 PPS-GPS clock offsets and the December 30-31, 2018 maser event
Version 1.0
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1. Summary

The Arecibo maser failed on December 30-31, 2018, and was replaced by a rubidium frequency standard (appended, in §A). The signals provided by these frequency standards are used in several ways by our observing system. One way to check the integrity of these signals is to compare the observatory 1PPS (one pulse per second) signal with a 1PPS signal slaved to the GPS system. Comparisons before and after the event are shown in §3 using the Princeton TAC system as the GPS 1PPS reference. The behavior is similar before and after the maser failure event. This suggests that the system is sufficiently stable for high-precision pulsar timing. (Data from the days of the event itself, December 30-31, should not be used.)

2. Overview

The maser used to drive reference frequency signals at Arecibo failed on December 30-31, 2018, and was replaced for the near-term with a rubidium frequency source. Details provided by the observatory are in §A.

The reference frequency signal is used in our observations in three ways:

- It controls the observed radio frequency (via the IF/LO system).
- It controls the PUPPI data sampling rate.
- It controls the observatory 1PPS (one pulse per second) signal that is used as a short-term absolute time reference by PUPPI. In essence, the 1PPS signal is generated by counting cycles of a high-frequency reference signal.

The measurements in §3 use the 1PPS signal to test the reference frequency stability and hence our ability to do absolute pulsar timing at Arecibo. As a practical matter, as long as the 1 PPS drift rate is no more than a few nanoseconds per day, then we can easily measure and correct for it. Normally its drift is much less than this. The measurements below show that the drift continues to be much less than this, which is good news.

I have not done any tests on short-term stability of the frequency standard. If there were short-term issues, especially red noise manifested as drifts in frequency, I would expect them to integrate up and appear as long-term drifts in the observatory 1 PPS signal relative to GPS.

It would be good to test the clock by analyzing actual pulsar data from before and after the December 30-31 incident. This has not yet been done.

3. Clock Measurements

Arecibo clock offsets used for pulsar timing are measured via the "Princeton TAC" system, which measures the difference between the observatory station 1 PPS and a GPS signal. Normally these observations are boxcar-smoothed with a 2-day time constant. However, raw data files from the system have 10-minute resolutions. For this work, I analyzed raw data collected over the past year.

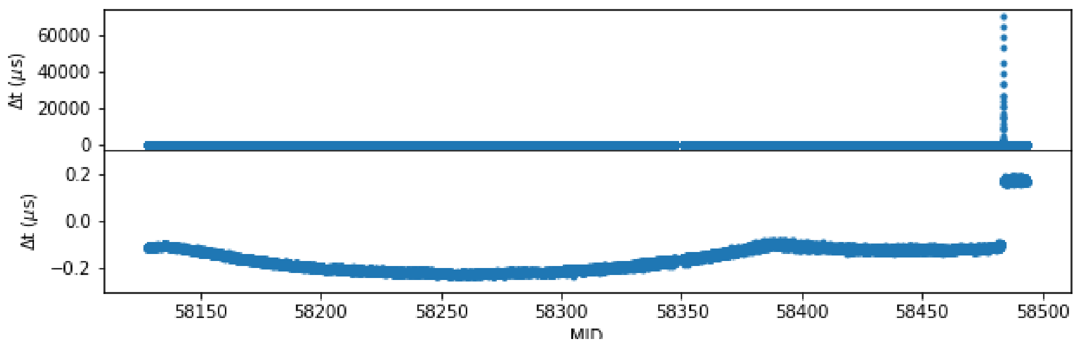
3.1. Measurements over the past year

The plots below show time offsets over the past year on two different scales. The upper plot shows the full vertical scale; the lower plot shows a closeup around 0 ± 0.3 μs.

The maser event is clearly visible as a series of large time offsets followed by a permanent step at MJD 58482−58483.

The small kink in the signal around MJD 58388 implies a small frequency change in the maser. Such tweaks are implemented by engineers from time to time to keep the maser close to its target frequency. This is normal and is unrelated to the maser event.

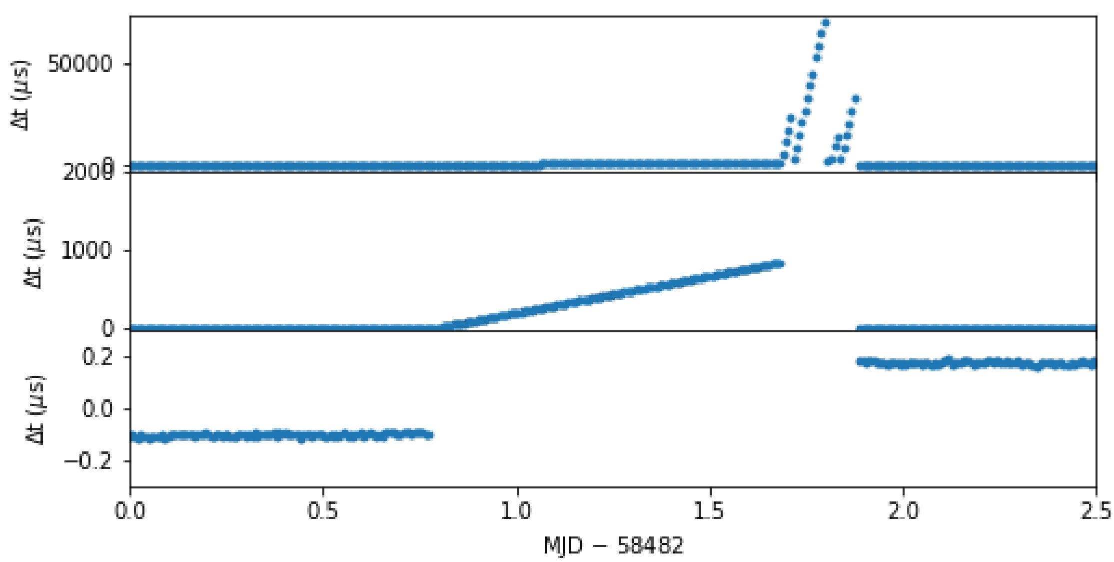
Clock offsets over one year (low and high resolution)



3.2. Measurements near the event

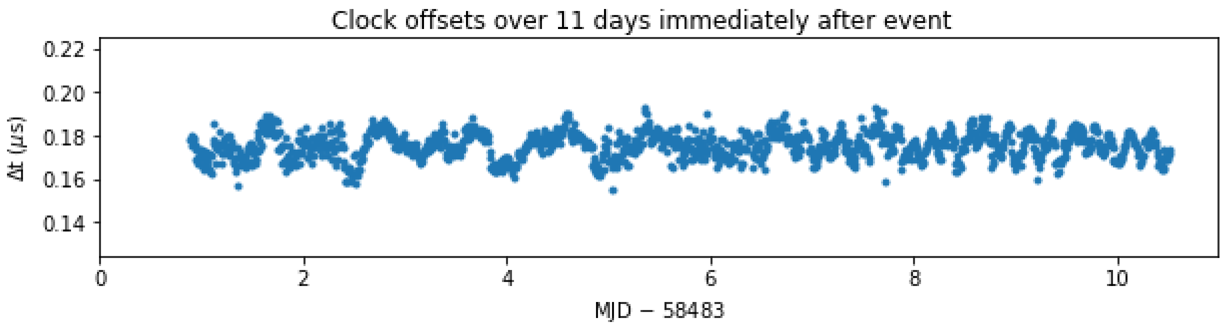
The plots below show time offsets around the time of the event on three different scales. They show that the clock started drifting around MJD 58482.75 (December 30, 18:00 UT), was disconnected about a day later (December 31, 18:00 UT), and was replaced by a new standard shortly after that. (The Arecibo report in §A reports potentially erratic behavior beginning a few hours before it can be detected in this data series.)

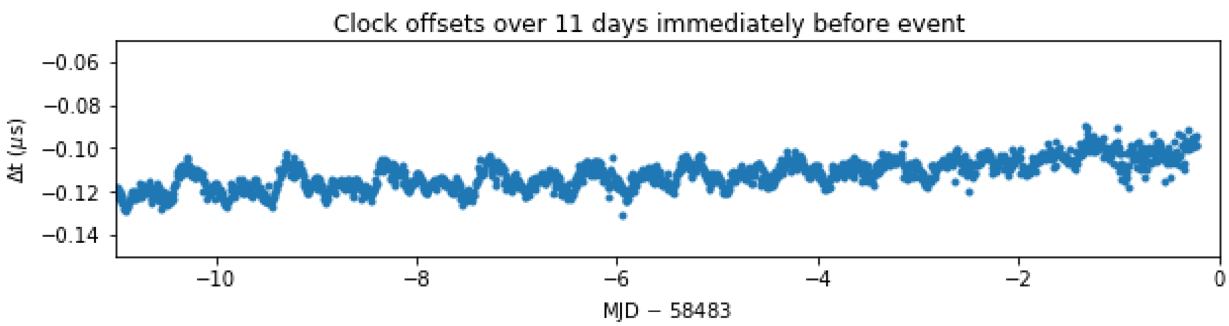
Clock offsets around the maser event (low, medium, high resolution)

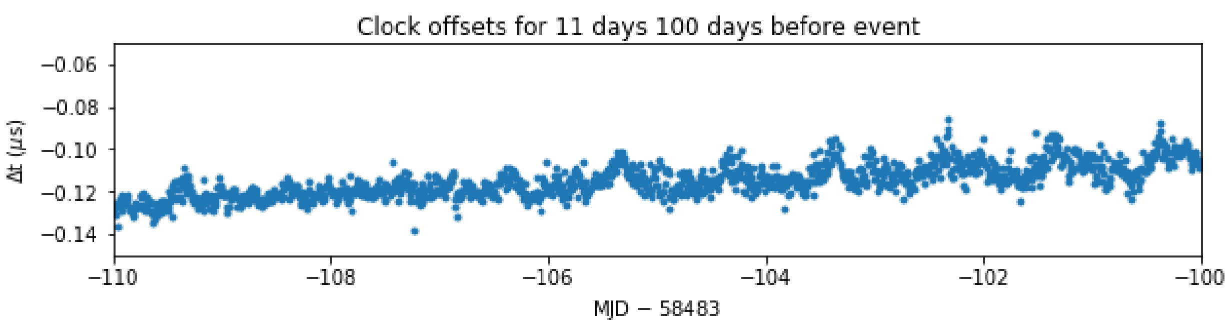


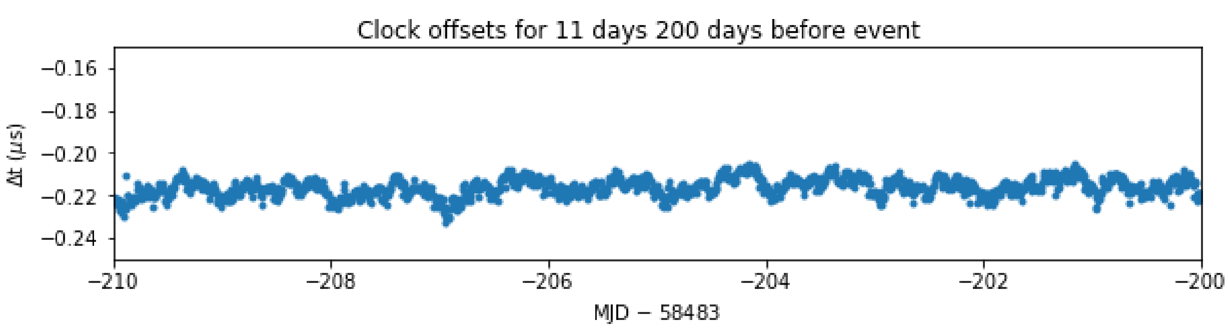
3.3. Measurements before and after the event

The plots below show time offsets measured in the 11 days after the event (top plot), the 11 days before the event (second plot), and 11-day periods 100 and 200 days before the event (third and fourth plots). The overall behavior seems grossly similar in all the plots. Thus we conclude that this test indicates the post-event timing system is effective for pulsar timing, at least from the perspective of the 1PPS signal.









4. Additional notes

The plots above show intra-day variation in 1PPS observatory clock minus GPS clock at the $\lesssim 0.10\ \mu\mathrm{s}$ level. Sometimes this is diurnal or semi-diurnal. The origin of these variations is not clear: it could be the observatory clock, or the TAC 1PPS reference, or the Princeton comparison system. In any case, we have traditionally smoothed these time offsets with a 2-day time constant; it might be worthwhile to maintain these offsets with higher time resolution. We should also switch from the Princeton TAC system to NIST common-view system for our GPS reference, for reasons of system integrity (the Princeton system runs on a PC that is now over 20 years old) and tractability.

The lore in the pulsar timing has been that the frequency stability requirements for VLBI are more stringent than the requirements for pulsar timing, so that radio observatory clock systems are often "over-engineered" for pulsar timing purposes. I don't know of any quantitative analysis of this, however.

A. Report from Arecibo

The following was written by Felix Fernandez Rodriquez on January 2, 2019, and forwarded by Hector Hernandez on the same day.

What happened?
Upon our weekly Monday inspection on 2018-12-31 we found out that the MASER's VCO was not locking properly. It would intermittently loose lock. Further inspection of the MASER's parameters it was clear that the IF amplitude had gone below the systems specs. The lost of the IF amplitude implies that the MASER will not provide an accurate frequency reference for AO. Whether or not this implies we need to purchase a new MASER is still not clear. We already contacted Microsemi (the maker of our MASER) tech team and we are still debugging the event as to learn what happened and if there is something we can "repair."

How long was AO without proper timing/frequency ?
Based on our NIST common view GPS service data, our MASER started showing signs of erratic behavior on 2108-12-30 at around 14:30 UTC and was completely out of lock at around 18:20 UTC. We were able to complete our back-up set-up at 19:05 UTC. Any observations made within this time period should be notified that their data might not be usable.

What is our current state? After deciding that the MASER was unavailable we implemented our back-up plan. Currently we are driving our timing system from a Rubidium (Rb) frequency standard, namely an FS725 from SRS Research. This frequency standard is being paced/disciplined by a GPS clock, currently a CNS Clock II from CNS systems. The frequency stability and phase noise specs for each reference are as follows:

	Stability	
Allan Deviation	MHM 2010 (MASER)	FS725 (Rb Standard)
1s	8.0e-14	2e-11
10s	1.5e-14	1e-11
100s	4.0e-15	2e-12

	Phase Noise (5MHz output)	
Bandwidth	MHM 2010 (MASER)	FS725 (Rb Standard)
10Hz	¡-135dBc	¡-130dBc
100Hz	¡-148dBc	¡-140dBc
1kHz	¡-155dBc	¡-150dBc
10kHz	¡-155dBc	¡-155dBc

Lastly, based on our NIST data our system is currently running somewhere between 286 to 366 ns behind UTC.

What are the next steps?

First, scientist need to decide whether or not they want to observe with a Rb standard as our reference. (...) We need to let them know where we stand and allow them to make a decision if the decide to carry on their projects with our current state.

Second, we need to decide if our MASER is "dead." It will take a couple of days to figure this out. Worst case scenario, we will need to purchase a new MASER as soon as possible. I have no time-frame for this repair/purchase. Hopefully by the end of this week we will have a clear picture.

(...)

Please, remember that timming characterization are based on long term data sets so we might need a couple of more days to have better accuracy on our current system's status. If you have any other questions, please let me know and I'll reply ASAP.