TimeMachines Time Server Accuracy
TM1000A and TM2000A/B and TM2500B

revision D, January 2024

1 Introduction

The purpose of this paper is to discuss and demonstrate the accuracy testing methods for the TimeMachines GPS time server products, specifically the TM1000A, TM2000B, and TM2500C. Using data collected by a hardware time-stamping Linux based system, the accuracy of the time servers can be graphically represented in both NTP and PTP modes. Also discussed in this document are the effects of network jitter on timing accuracy of both models, and the holdover accuracy of the TM2000/2500.

The TM2000B was released in early July of 2020 as a followup product to the TM2000A. It had additional hardware to support a more accurate measurement and correction of the OCXO frequency for the purposes of PTP and NTP time generation. The TM2500C was subsequently released which added 1PPS and 10MHz reference frequency outputs. For purposes of PTP, the TM2000B and TM2500C are identical.

2 Test Methodology

The method of evaluation is to use a “known accurate” timing source as a reference to the time provided by the TimeMachines TM1000A and TM2000A. In this case, a Microsemi TimeProvider 2700 with GPS input, a NIST certified time source, was used as the reference for all measurements. It was also confirmed against Orolia SecureSync Server (traces not shown).

The software used to grab time from multiple sources simultaneously is TimeKeeper by FSMLabs. The graphics shown in this document come directly from that application. This is a highly recommended piece of software for PTP work. It is an excellent client and works very well in Linux and Windows. It is also one of the easiest PTP clients to setup.

In all graphs, the TimeProvider 2700 will be shown as Source 0 using PTP protocol as the point of comparison. The clock of the computer is compared to Source 0 and all incoming time packets, both PTP and NTP, are hardware time-stamped and compared against the computer clock to determine their offset from the reference time provided by Source 0. Sample rates of the NTP points are greater than 1 sample per second. Long data sets have been recorded to confirm that the plots used in this analysis are representative of the product's accuracy, but the reduced time sets will be used here to make the details of the graphs clear.

The TM1000A was running version 3.3 firmware. The TM2000/2500 used for these plots was revision D hardware and 0.6.4 firmware.

3 Basic Accuracy

3.1 Illustrations 1 & 2 – Raw Accuracy

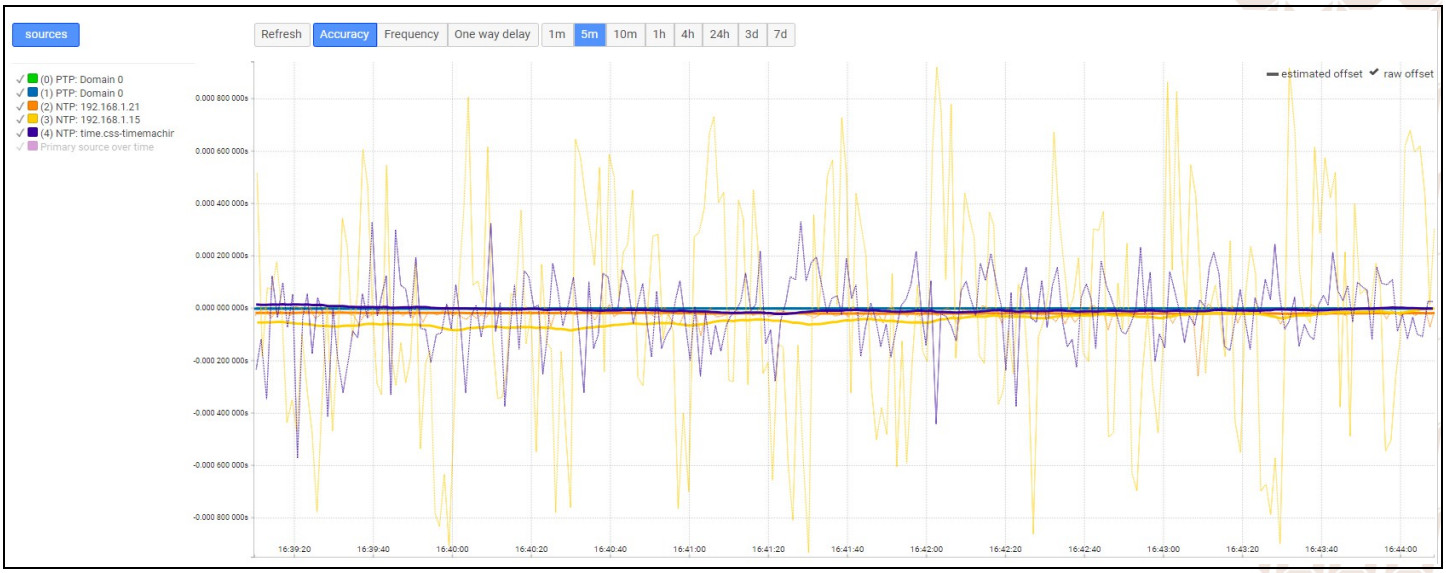

Illustration 1: All Sources - 5 Minute Span - Raw Data Points

Illustrations 1-4 show all of the input sources in use. Those sources are:

- Source 0: Microsemi TimeProvider 2700, PTP mode, Reference Source
- Source 1: TimeMachines TM2000B, PTP mode
- Source 2: TimeMachines TM2000B, NTP mode
- Source 3: TimeMachines TM1000A, NTP mode, local network connected
- Source 4: TimeMachines TM1000A, NTP mode, connected offsite via Internet through port forward. Round trip delay is approximately 4ms between the test location and the remote TM1000A.

The dark lines show the smoothed (averaged) version of each source. It should be noted that the averaged data of all sources exist well within 0.0005 second accuracy. The data displayed by the fine lines is raw data, which are the actual samples from each sources. The TM1000A on the local network, Source 3, has all of its data within +/- 0.001 seconds of the reference, which is consistent with the internal timekeeping parameters of the TM1000A. The TM1000A that is being monitored through the Internet connection, Source 4, shows a wider variation of accuracy with most points falling within the +/- 0.0015 range, but at least 1 point greater than 0.002 seconds offset from the reference. This is simply due to the additional network jitter introduced by transporting time over the Internet.

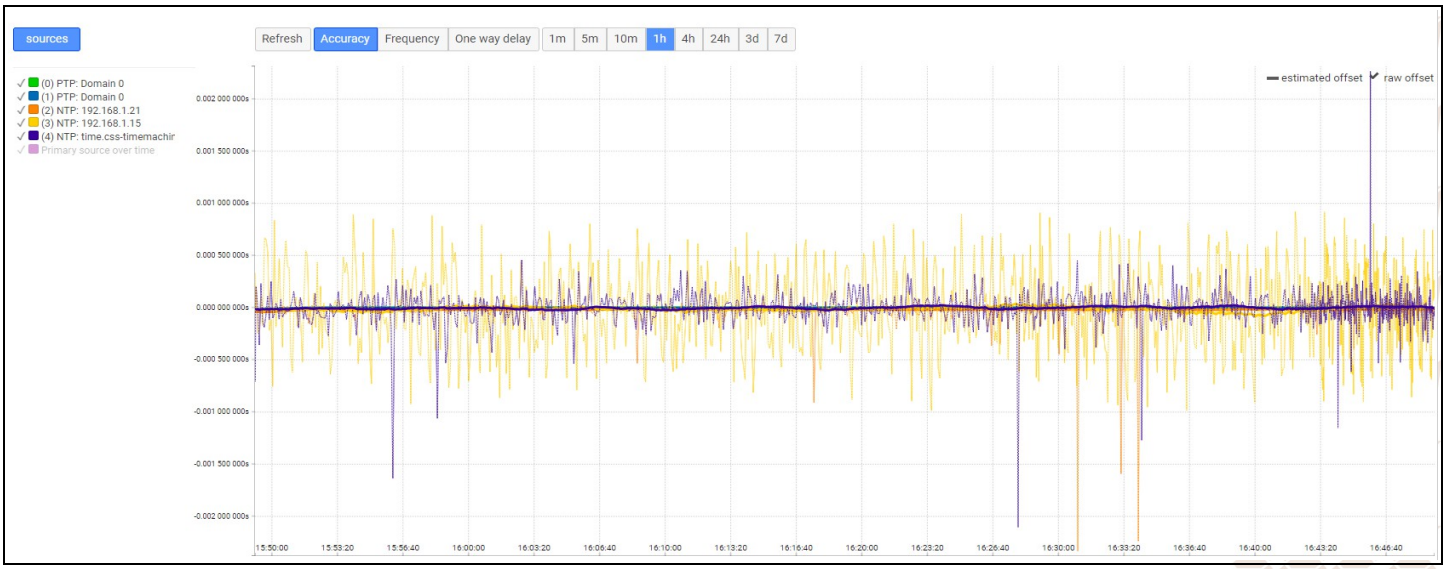

Illustration 2: All Sources - 1 HR Span - Raw Data Points

Illustration 2 shows essentially the same data as Illustration 1, except that the span of time is 1 hour rather than 10 minutes. It shows the same accuracy and increased jitter introduced by the Internet connected TM1000A.

3.2 Illustration 3 – PTP Only Data

The PTP only data is displayed in Illustration 3. It is essentially not visible in the previous illustrations as the quality of the data is significantly better.

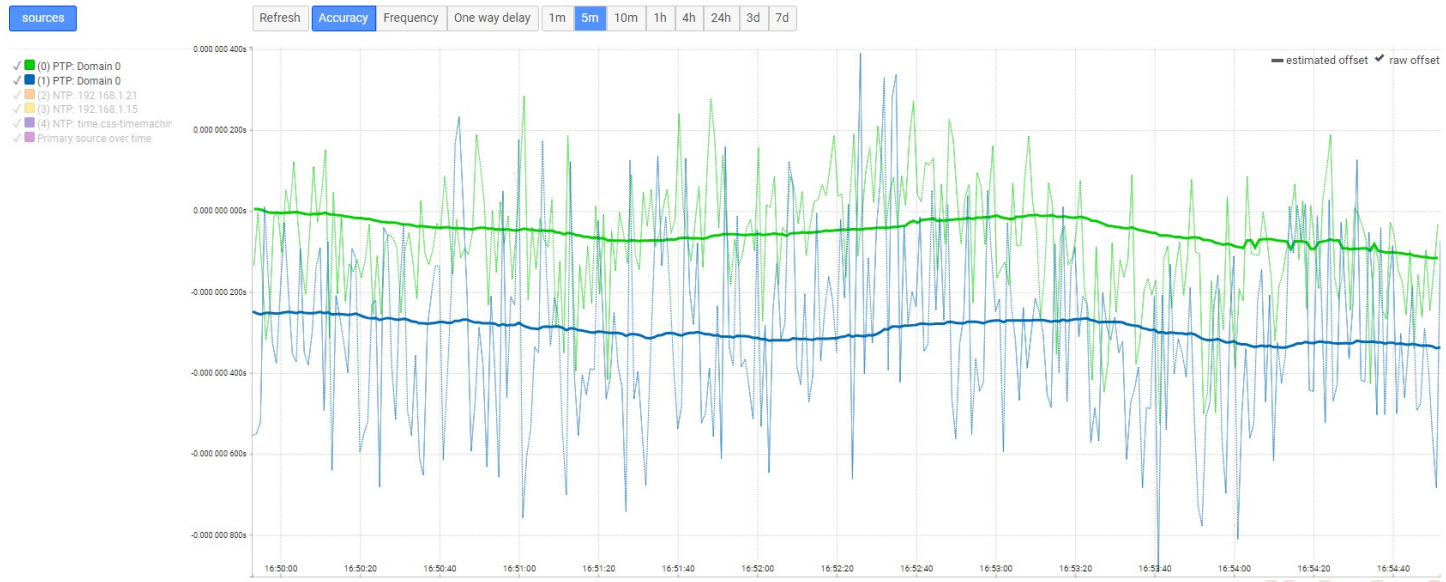

Illustration 3: PTP Sources - 5 min Span - Raw Data Points

The blue trace from the TM2000/2500 is running within about 200 nano-seconds of the reference server. Jitter for these PTP sources runs on the order of +/- 500 nano-seconds.

3.3 Illustration 4 - Averaged Time Data

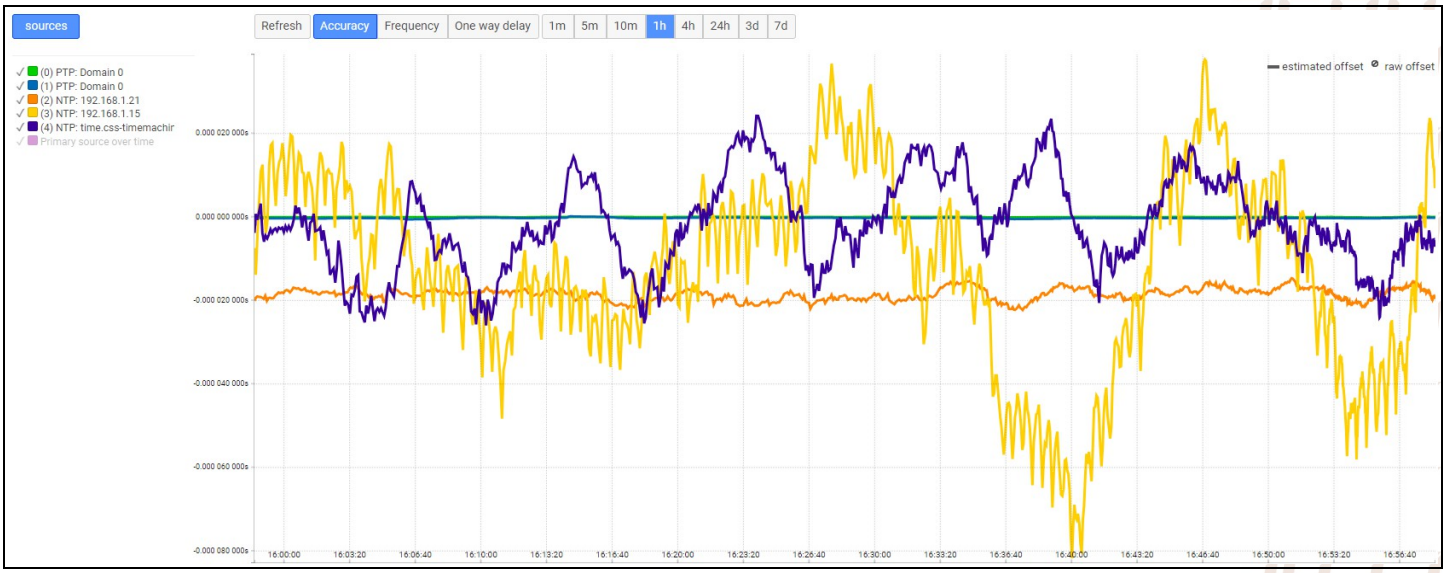

Illustration 4: All Sources - 10 Minute Span - Averaged Data

Illustration 4 shows all sources plotted over a 1 hour span, however the raw data points are removed and only the smoothed/averaged times are displayed. From this plot, a more refined accuracy can be seen for each device. NTP and PTP clients will typically be performing the same type of averaging as shown above. Source 0 is the reference source and its plot is shown as the zero line of the chart. Source 1, the TM2000/2500 PTP mode, is tracking Source 0 very closely within about 200nS. With these scales, it is difficult to see a difference between Source 0 and Source 1. Source 2, the TM2000B in NTP mode, tracks the reference at a little better than -20uS seconds. The TM2000/2500 has to maintain a very accurate internal time to maintain its PTP accuracy, and this shows up in significantly improved NTP performance compared to the TM1000A. Source 3, the local TM1000A, maintains an averaged accuracy sub 80uS although with significantly more variability than Source 2. In this plot, Source 4, the Internet connected TM1000A, accuracy is actually showing up a bit better than Source 3, but this is not typical. Typically, NTP would never claim much better than millisecond accuracy.

4 TM2000B/TM2500C Release and Accuracy Improvements

The TM2000A underwent a hardware and software update in the spring of 2020. The result was two new models of time server, the TM2000B and TM2500C. The TM2000B was updated to improve the timing accuracy, particularly in PTP mode, both under GPS signal control and during holdover. The TM2500C had the same accuracy improvements, as it is the same hardware platform, and added a 1PPS and 10MHz frequency reference output on the back panel. The following information shows just how much the accuracy of the TM2000/2500 family was improved.

4.1 PTP Accuracy and Holdover performance after 1 hour

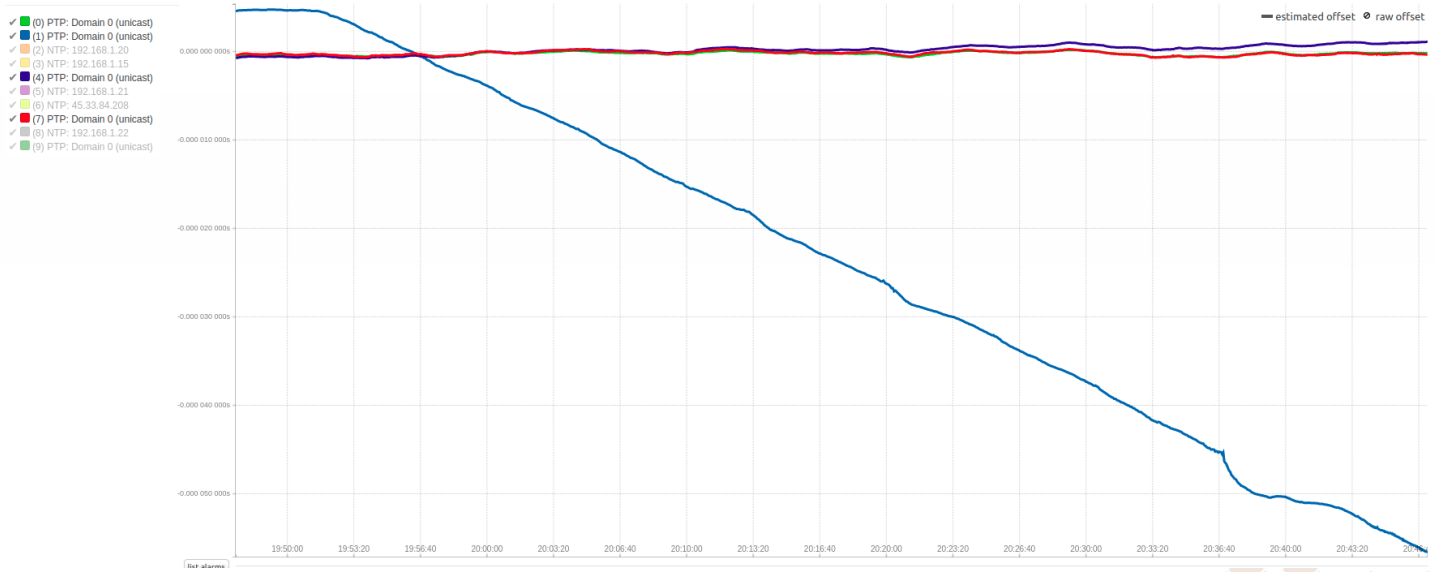

Illustration 5: PTP 1 Hour performance

Illustration 5 shows several time servers in its plot. The Green is the reference source, the Microsemi TP-2700. The purple and red traces are both TM2000B servers. The bright blue is a TM2000A server. Before the GPS signal is removed from all three TM2000X servers, the TM2000B servers are fractions of a microsecond different from the reference source, where the original TM2000A is off of the reference server by about +4.7uS. This is one improvement in the B series time servers. After about an hour, the TM2000A is -61uS off the reference clock. The TM2000B servers are almost indiscernible from the reference trace. The purple trace does show a slight offset of about 1.2uS.

4.2 NTP Holdover performance

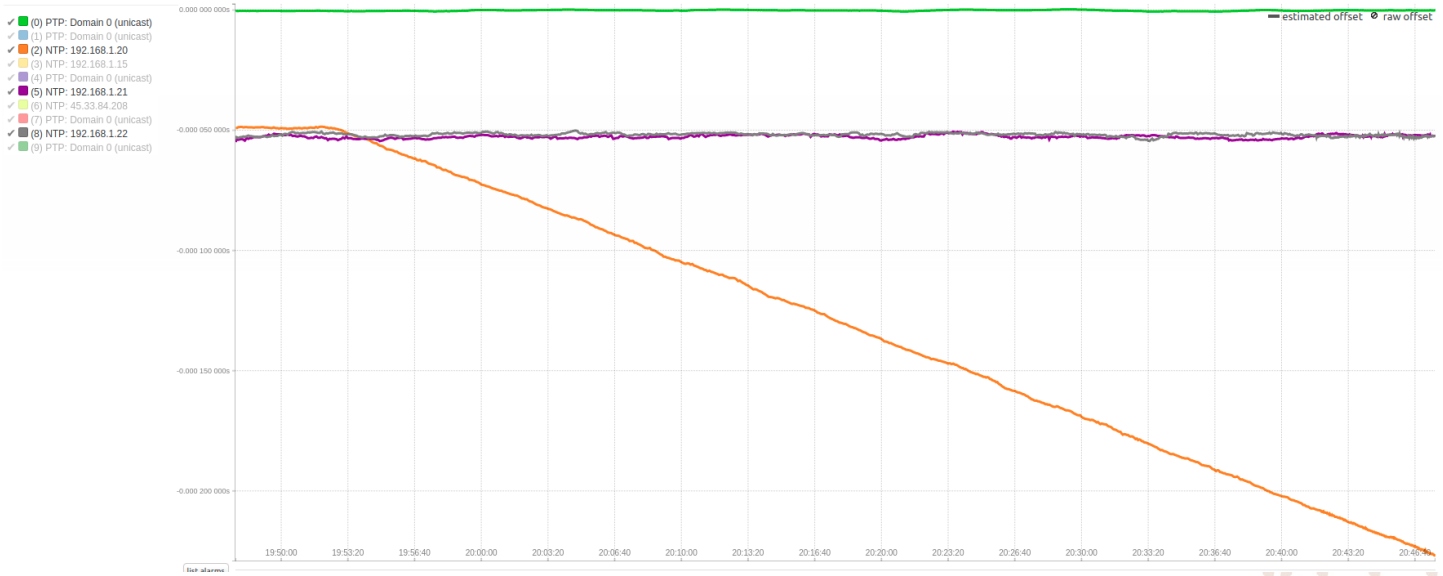

Illustration 6: NTP 1 Hour performance

Illustration 6 shows the reference green trace PTP source from the TP-2700. In addition the orange trace is a TM2000A NTP trace in holdover. The gray and purple traces are NTP plots from TM2000B servers. Over a 1 hour period, the TM2000A has drifted from its initial value of -49uS to -233uS. The TM2000B servers are essentially unchanged. Note: NTP accuracy to reference was improved in subsequent TM2000/2500 firmware from -49uS to around -20uS.

4.3 Long Term PTP/NTP Performance

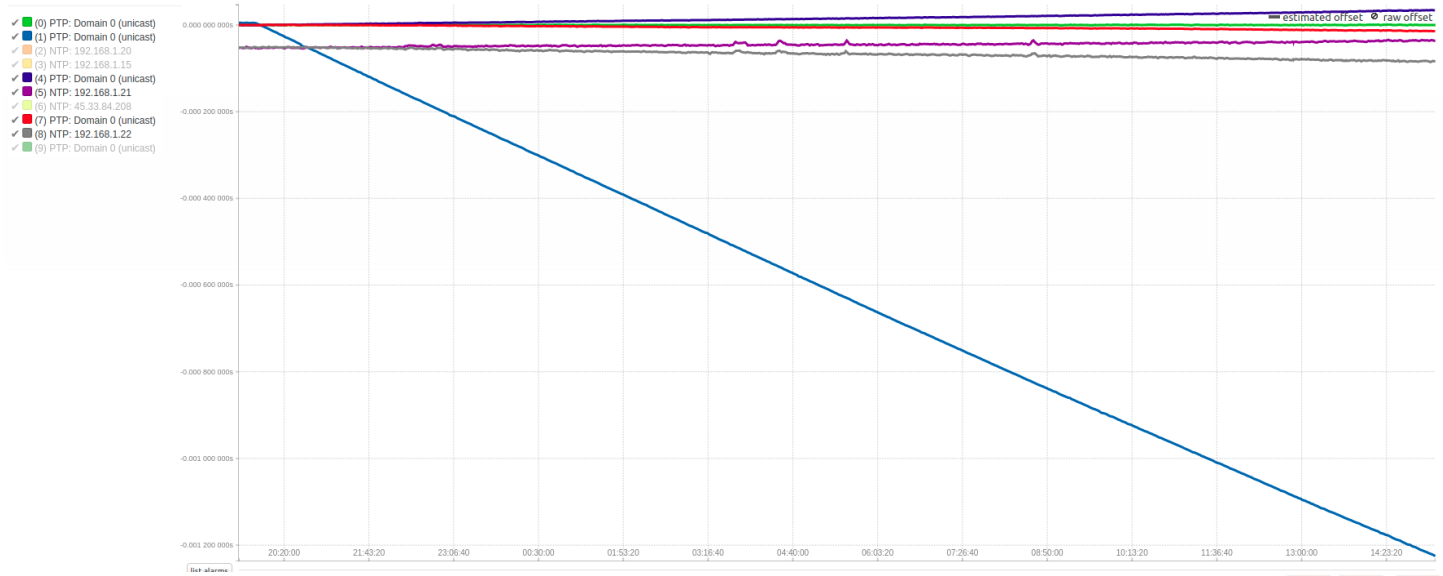

Illustration 7: 19 Hour Performance

Illustration 7 shows all the traces, except TM2000A NTP to avoid making the scale un-readable, after about 19 hours. The reference and TM2000/2500 units have maintained a fairly linear separation.

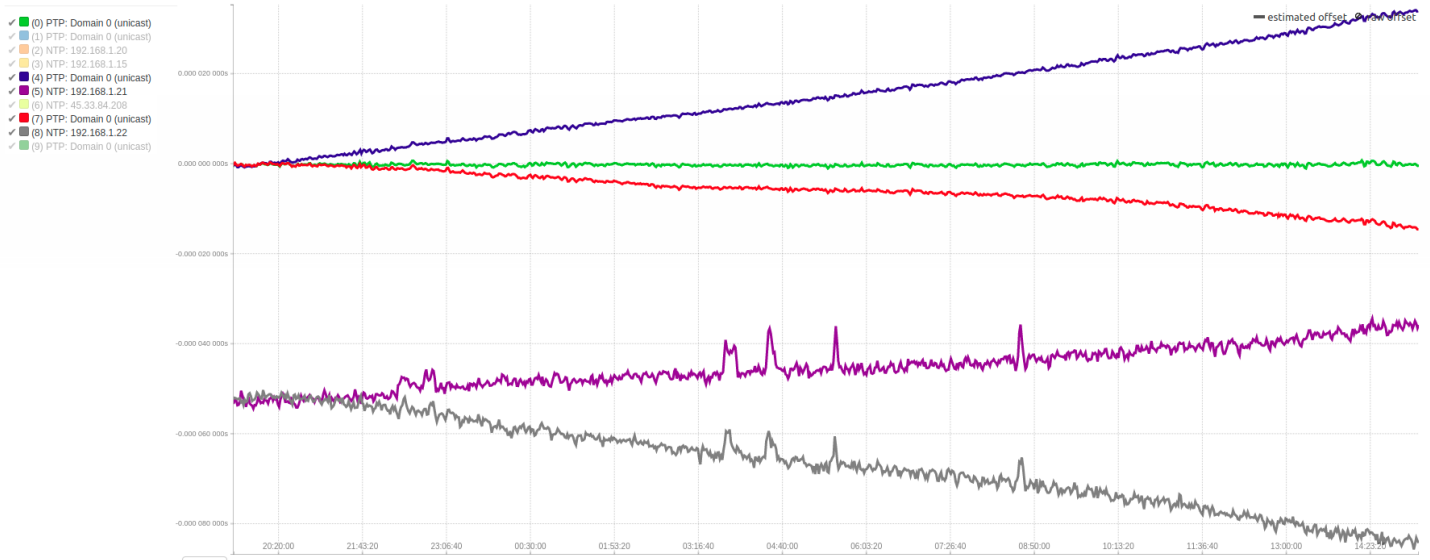

Illustration 8: 19 Hour Performance without TM2000A

Illustration 8 shows the same 19 hour plot without the TM2000A to tighten up the zoom. After approximately 19 hours, the The TM2000B PTP drift is about 34uS on the blue trace and -14uS on the red trace. The NTP drift is -34uS (from starting value of -52uS, which has improved in subsequent software to sub -20uS) on the purple and -84uS (from starting value of -51uS) on the gray. The difference in the NTP tracks very closely with the differences in the PTP readings over the same period of time.

These 19 hour performance values can be extrapolated to approximate day and yearly drifts:

	19 Hrs	24 Hrs	30 Days	1 year
Time Drift:	34uS	43uS	1.3mS	0.016 Seconds

This will vary depending on the correction quality at the moment GPS is lost.

4.4 TM2000/2500 Other Observations

One of the interesting phenomenon that sometimes appears after longer periods of time in holdover, is that while the TM2000A will essentially stay on a linear degradation drift path, the TM2000B, because of its much tighter control of the internal clocking, can actually wander up and down, albeit much more tightly and at lower slopes than the TM2000A, but still varying from positive changes to negative changes in offset from reference time. This is due to the ever changing OCXO output over time and the lack of GPS signal to correct for it.

It is also possible, depending on the accuracy of the correction at the time of GPS signal loss, that the TM2000/2500 may sometimes lose accuracy in a positive or negative direction. If the correction is slightly off in a positive direction then the offset from from reference time will become greater over time, while conversely if the correction is off in a slightly negative direction, the offset from reference time will lag over time. The magnitude of these offsets are significantly smaller than any offset generated by the former TM2000A over similar periods of time as can be seen from the previous illustrations.

4.5 TM2000/2500 in Software PTP mode

Starting in version 0.6.4, the TM2000/2500 products support PTP server function without having GPS as the time source. This results in a significant degradation in performance, compared to GPS sourced time, both with respect to the reference time, but also in nearly 10X worse jitter because hardware time stamping is no longer in use because the GPS signals are used to initialize time stamping hardware.

For this section, the Peer NTP time server option was used. Three NTP servers are setup for best accuracy, the GPS antenna is left disconnected, and PTP is set to Software Time Stamping.

The other thing that is done when running in this mode is to allow the unit to operate with a 3D GPS lock for a period of time, days if possible, then save the OCXO correction on the Status page. This will allow the last known correction to be applied on startup without GPS, which will improve the drift performance in particular, if using manual time set rather than Peer.

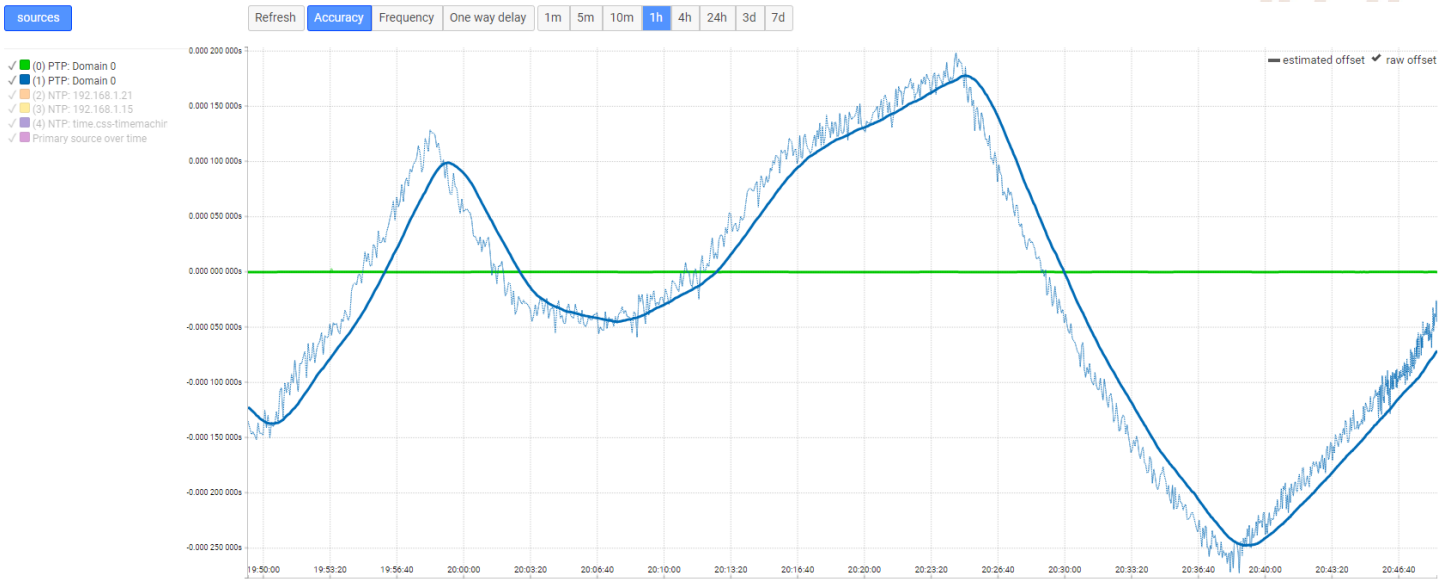

Illustration 9: No GPS - Software Timestamping - NTP Peer Sourced Time

In this mode, one of the obvious drawbacks of NTP is visible. At best, NTP is able to set the time of the TM2000/2500 +/- 200uS compared to the reference, so that is the best PTP will be able to generate, but if no GPS is available and PTP with +/-200uS is functional, then this can be a good option. The above graph also shows the raw sample data. The jitter level on the blue software time stamped PTP trace is visible. The jitter on the green reference source is significantly less due to hardware time stamping, and isn't visible on this scale.

One thing to observe is that the wandering nature of the NTP Peer sourced time can be eliminated at the expense of not correcting the time. If the manually set time is used instead of NTP Peer setting, or NTP Peer is used and then the unit disconnected from those peers by separating the network, the wandering will mostly disappear because the only thing that will be affecting the internal time will be oscillator drift, rather than being updated continuously by external sources. It really depends on the project needs and options available.

5 Conclusions

The TimeMachines TM1000A and TM2000A, and now the TM2000B and TM2500C represent breakthrough performance for their price points. Work will continue on these and other new products to improve their accuracy and to bring new features. As always, we appreciate our customers support and constructive feedback to continue and enhance these products!