1 Introduction

The purpose of this paper is to discuss and demonstrate the accuracy of the TimeMachines GPS time server products, specifically the TM1000A and TM2000A. 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 analyzed in this report are the effects of network jitter on timing accuracy of both models, and the holdover accuracy of the TM2000A.

The TM2000B was released in early July of 2020. 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, as well as the 10MHz reference frequency output for the TM2500B.

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.

The software used to grab time from multiple sources simultaneously is the TimeKeeper Active Client by FSMTIME. The graphics shown in this document come directly from that application.

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.
3 Basic Accuracy

3.1 Illustrations 1 & 2 – Raw Accuracy

Illustration 1 shows all of the input sources in use. Those sources are:

- Source 0: Microsemi TimeProvider 2700, PTP mode, Reference Source
- Source 1: TimeMachines TM2000A, PTP mode
- Source 2: TimeMachines TM2000A, 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, in this view, are the actual samples from Sources 3 and 4. 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 the Internet connection.
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 - Averaged Time Data

Illustration 3 shows all sources plotted over a 10 minute 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. Source 0 is the reference source and its plot is show as the zero line of the chart. Source 1, TM2000A PTP mode, is tracking Source 0 very closely within about -3.5uS. Source 2, TM2000A NTP mode, tracks the reference at a little greater than -0.00005 seconds, 50uS, of accuracy. The TM2000A 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. With the raw data being averaged, as is common in many NTP devices, Source 3 maintains an averaged accuracy sub 50uS although with significantly more variability than Source 2. Source 4 accuracy, because of the internet induced jitter, is a bit worse at around 150uS.
3.3 Illustration 4 – PTP Accuracy

The TM2000A PTP accuracy can be viewed best in Illustration 4. Its accuracy is maintained in the -3.5uS range through the displayed 4 hour plot. Notice that the irregularities in the plots are reflected in both the reference plot and the Source 1 plot. Because these irregularities are reflected in each plot, it is assumed this is the base level jitter of the hardware clock in the test platform, and not a result of some inaccuracy of the time sources.

3.4 Illustration 5 – TM2000A NTP Jitter

Illustration 5 is included to show the actual data of the TM2000A NTP data. It was previously noted that the average offset of the TM2000A in NTP mode, plotted in Illustration 3, is consistent in the -50uS range. The TM2000A NTP accuracy and stability exceeds that of the TM1000A noticeably. NTP clients would generally average out those outlying points and, given the normal sample rate of NTP, would rarely be seen.
TM2000A Holdover Performance

The TM2000A contains a 20ppb Oven Controlled Oscillator (OCXO) that allows it to maintain its internal clock in the absence of a GPS signal for a period of time. This clock source is then used to serve time during GPS signal loss. The TM1000A does not have an OCXO internal clock and thus does not continue to serve time if its GPS lock is lost.

4.1 Illustration 6 – 4 HR PTP Holdover Performance

Illustration 6 shows the holdover performance of the TM2000A for PTP timing with smoothed data, however the timing sources have been changed from the previous section of this document. Timing Source 0 in this Illustration is a TM2000A whose GPS antenna is not disconnected during the test. Source 2 and Source 4 are are the PTP timing of two other TM2000As that have effectively lost the GPS signal input.

The internal frequency accuracy of the OCXO of each of the TM2000As under test are slightly different. This can be seen in that Source 2 is actually running slightly slower than nominal and over 4 hours it ends up approximately 225µS behind the reference source. Source 4 on the other hand is running a little bit faster than nominal and after 4 hours is almost 400µS ahead of the reference source.

This plot shows the relative variability of the TM2000A based on the accuracy of the OCXO. When tested prior to this plot, the reference TM2000A was running slower than nominal, but was much closer to the published frequency of the OCXO and as such its holdover accuracy was about 100µS behind reference after 4 hours.
4.2 Illustration 7 – 12 Hour Holdover Performance for PTP and NTP

Illustration 7 is the same configuration of comparisons as in Illustration 6 where Source 0 is a TM2000A with GPS signal intact, but it also includes the NTP performance of the other two TM2000A units. Thus, in this Illustration, Source 3 is the NTP performance of Source 2, and Source 5 is the NTP performance of Source 4. The plot shows the performance of the TM2000A after 12 hours with no GPS signal for both PTP and NTP holdover. Accuracy of each source over time is displayed in the table below:

<table>
<thead>
<tr>
<th>Source</th>
<th>0 Hr</th>
<th>1 hr</th>
<th>4 hrs</th>
<th>12 hrs</th>
<th>Offset / HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source 2 - PTP</td>
<td>0</td>
<td>-55uS</td>
<td>-220uS</td>
<td>-670uS</td>
<td>-55uS</td>
</tr>
<tr>
<td>Source 3 - NTP</td>
<td>-50uS</td>
<td>-225uS</td>
<td>-775uS</td>
<td>-2.2mS</td>
<td>-180uS</td>
</tr>
<tr>
<td>Source 4 - PTP</td>
<td>0</td>
<td>+90uS</td>
<td>+375uS</td>
<td>+1.1mS</td>
<td>92uS</td>
</tr>
<tr>
<td>Source 5 - NTP</td>
<td>-50uS</td>
<td>+240uS</td>
<td>+1.1mS</td>
<td>+3.5mS</td>
<td>+295uS</td>
</tr>
</tbody>
</table>

4.3 Overall Holdover Performance

Holdover performance is based almost entirely on the accuracy of the clock source in the TM2000A and its stability. Even with a highly stable and accurate time source, there is variability from one device to the next. Based on a sample set of TM2000A tested, NTP accuracy is expected to degrade approximately 200-300uS per hour and PTP accuracy approximately 50 to 100uS per hour. Based on needed accuracy for any application, GPS lock must be maintained to ensure timing accuracy is not lost over time.

5 TM2000B/TM2500B 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 TM2500B. The TM2000B was updated to improve the timing accuracy, particularly in PTP mode, both under GPS signal control and during holdover. The TM2500B had the same accuracy improvements and added a 1PPS or 10MHz frequency reference output on the back panel. The following information shows just how much the accuracy of the TM2000 family was improved.
5.1 PTP Accuracy and Holdover performance after 1 hour

Illustration 8 shows several time servers in its plot. The Green is the reference source, the Microsemi TP-2700. The dark blue 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 red trace does show a slight offset of about 1.2uS.

5.2 NTP Holdover performance

Illustration 9 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.
5.3 **PTP 2.5 Hour Performance**

The same plot as Illustration 8 is shown in Illustration 10. TM2000A PTP performance continues on its linear separation from the reference time. A more visible divergence of the TM2000B can be seen in this plot of a couple microseconds from their active GPS values.

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5.4 **NTP 2.5 Hour Performance**

The same plot as Illustration 9 out to 2.5 hours. TM2000A NTP continues its linear divergence. The TM2000B is starting to show a small change from its original value at the time the GPS signal was disconnected, but again, the NTP holdover performance is still quite good with an offset of a 2-5 uS.
5.5 Long Term PTP/NTP Performance

Illustration 12 shows all the traces, except TM2000A NTP to avoid making the scale un-readable, after about 19 hours. The reference and TM2000B units have maintained a fairly linear separation than can now be observer.

Illustration 13 shows the same 19 hour plot without the TM2000A to tighten up the zoom. After approximately 19 hours, 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) 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.

5.6 TM2000B 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 path, the TM2000B, because of its much tighter control of the internal clocking, will 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, the TM2000B/TM2500B 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 simply lag over time. The magnitude of these offsets are significantly smaller than any offset generated by the TM2000A over similar periods of time as can be seen from the previous illustrations.

6 Conclusions

The TimeMachines TM1000A and TM2000A, and now the TM2000B/TM2500B 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 this development!