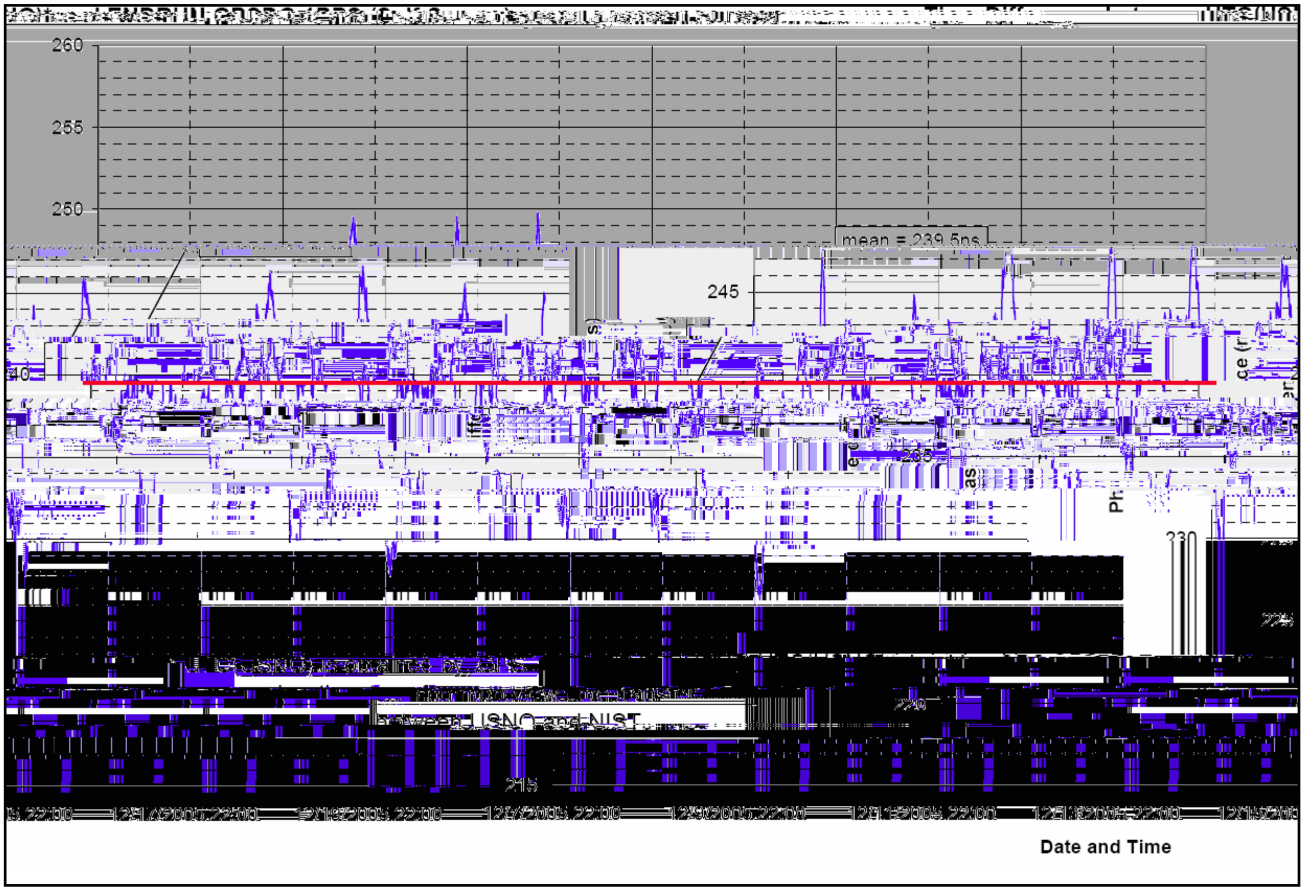
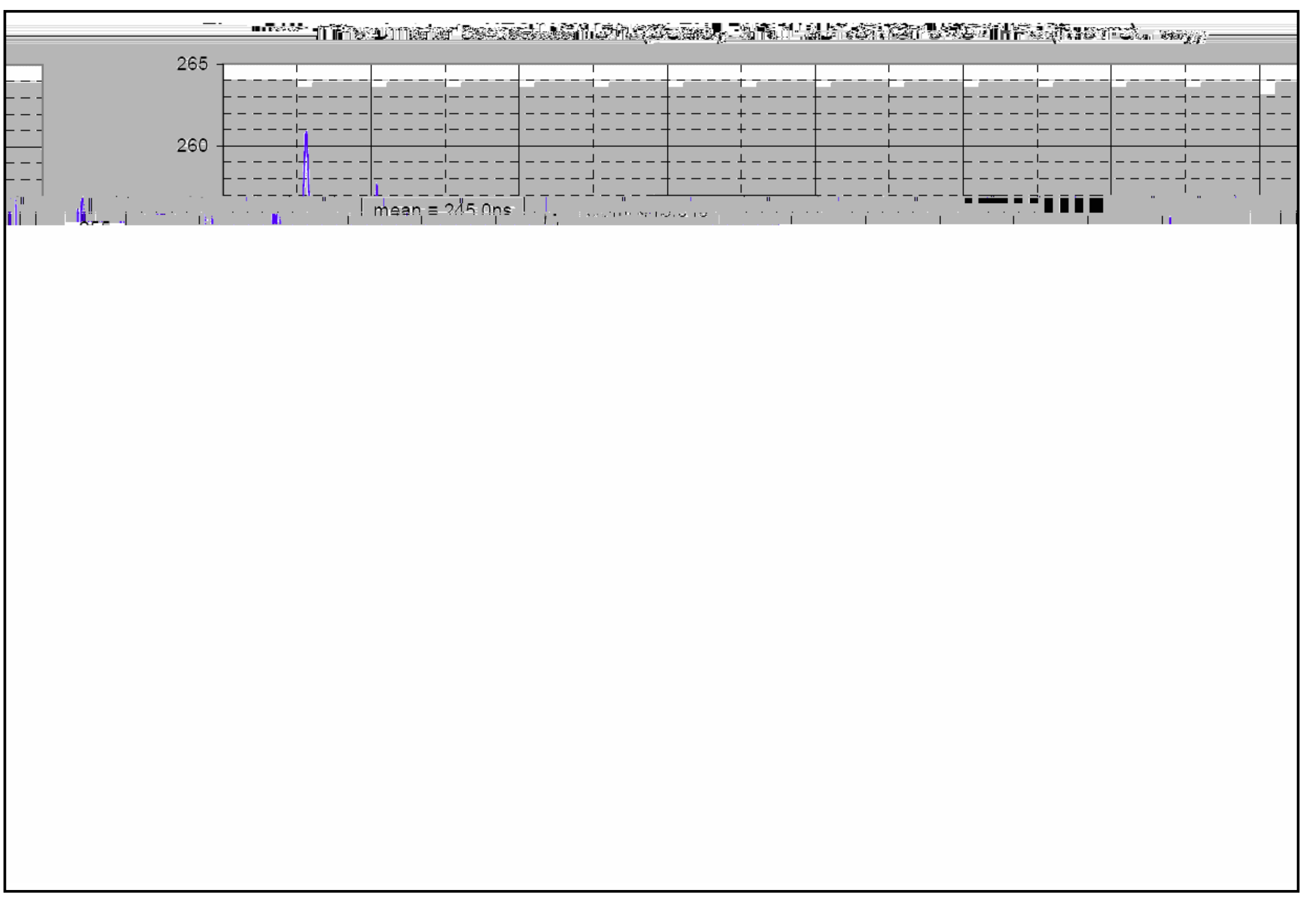
A Meridian was fitted with a high-stability Rubidium oscillator. The internal phase measurements of the Rubidium unit relative to the GPS engine, along with the steering control data and internal chassis temperature, were monitored for several weeks. The data were analyzed to verify that the system was operating normally and the stability of the system was as expected.

Further long-term monitoring was performed on the unit and after several months, the Meridian with GPS antenna and downlead cable were shipped to Dr. Tom Parker at NIST in Boulder, CO for characterization. The goals were to determine the absolute timing offset of the unit relative to UTC as maintained at USNO and to determine the stability of the outputs relative to the NIST frequency standards. With these data, it would be possible to form a strategy for using the NIST-characterized unit to calibrate production units at the EndRun Technologies factory in California. These data are also the basis for the stability specifications of the Meridian and Tycho GPS family of products. The stability numbers measured at NIST [1] support the goal of providing traceability at the 10 nanosecond level with a reasonable test cost.

Figures 1 and 2 show the NIST time interval measurements of the 1PPS output of the Meridian relative to UTC(USNO)--first while operating for about 12 days with its own self-surveyed position (a 24-hour averaged position) and second while operating for about 15 days with the NIST geodetic surveyed position. The two positions differ by about 2.4 meters, mostly in the height coordinate. A laboratory temperature environment was maintained to the +/-1.5ºC level during the testing, and all measurement setup and cable delays are accounted for in these two graphs. The NIST-stated uncertainty to UTC(USNO) in both of these measurement sets is +/- 6 nanoseconds.

The UTC(USNO) reference time starts the time interval, and the Meridian 1PPS stops it, so positive numbers less than one-half second mean that the Meridian 1PPS is late relative to UTC(USNO). The data presented here can be thought of as the offset to UTC(USNO) at the 1PPS BNC connector on the rear of the Meridian, operating with the GPS antenna and downlead cable that were shipped with it to NIST. No calibration correction for the downlead cable delay was input to the Meridian, so the NIST-measured delay does include this cable delay.

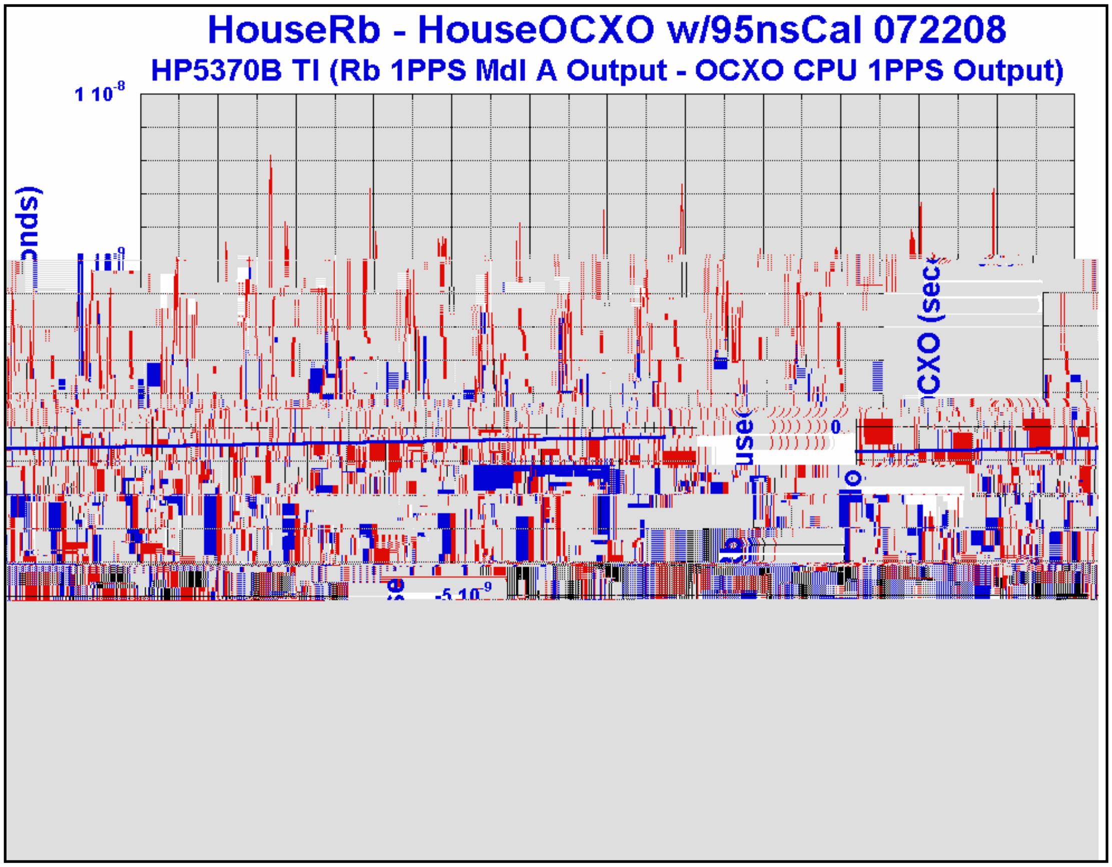

260
255
250
mean = 239.5ns
245
Date and Time


265
260
mean = 245.0ns

A study of the TDEV statistic will clearly indicate how long a production unit would need to be measured relative to the NIST-characterized unit, to achieve a certain level of precision. The peak value of TDEV versus tau indicates the uncertainty for all measurements averaged less than or equal to the tau at which the TDEV peak occurs. As tau is increased beyond this, the uncertainty is reduced, until the flicker phase modulation (PM) noise floor is reached. At this point, no further benefit to longer averaging times can be realized.

Using the self-surveyed NIST-measured data, the statistics indicate a peak in TDEV of about 2.5 nanoseconds at a tau of 20,000 seconds and TDEV then falls to about 1.5 nanoseconds at a tau of 100,000 seconds. The flicker PM noise floor appears to be reached between 100,000 and 200,000 seconds. From this, a calibration interval of one day is attractive, as it is both near the flicker PM noise floor and optimal for minimizing diurnal effects.

Figures 5 and 6 show the time interval data and the computed


HouseRb - HouseOCXO w/95nsCal 072208
HP5370B TI (Rb 1PPS Mdl A Output - OCXO CPU 1PPS Output)
1 10-8
0
-5 10-9


HouseRb - HouseOCXO w/95nsCal_072208
HP5370B TI, Rb 1PPS Mdl A Output vs OCXO CPU 1PPS Output
TDEV

tau of about 1/2 day, and has a deep null at a tau of 1 day. The TDEV at a tau of 1 day is a very manageable 300 picoseconds. It is clear that the stability of these two Meridian systems while operating in ZBCV mode is sufficient to achieve sub-nanosecond precision for 24-hour averaged time interval measurements.

The following discussion concerns variations in antenna and cable delay. In a manufacturing environment, it is impractical to mount the actual antenna and cable that will be shipped with a Meridian or Tycho GPS unit on the roof of the facility in order to perform the calibration versus the NIST-characterized Meridian. It would be much better to characterize the delays of the production antennas in a lab, over the bandwidth of the GPS C/A code signal, relative to the NIST-characterized antenna. Then the statistics can be evaluated to assess the accuracy degradation by not individually characterizing antennas and cables. To do this, some issues must be understood:

1. How does the angle of incidence of the GPS signal affect the measured delay, both in azimuth and elevation?
2. How does the delay vary versus frequency across the GPS signal bandwidth?

A test jig was fabricated to allow the repeatable mounting of a passive GPS patch antenna, used as the radiator, and an antenna under test, the AUT, at a fixed separation distance and orientation. To characterize the change in delay versus angle of incidence of the radiated signal, the jig also allows varying the orientation of the AUT with respect to the radiator. A vector network analyzer (VNA) is used to drive the radiator while measuring S21, the transmission s-parameter of the cascaded passive radiator and the AUT. These measurements can show the relative gain and group delay between various antennas as a function of frequency, azimuth and elevation. The intent is not to perform a rigorous absolute calibration of either the antenna pattern or group delay, but to determine the differences in these values between multiple antennas.

The VNA was calibrated to place the reference planes at the ends of the cables that connect to the radiator and the AUT.

Condition 1 made it possible to assess the flatness of the delay of the various AUTs. The radiator used does not have a narrow band, the radiator ... cation ... hbbe ... steep-skirted SAW filters and its input reflection coefficient was verified to be smooth over the bandwidth of the GP ... are ... mo ... t- ... ex ... Condition

[redacted]

In the production calibration environment, only the receiver input reflection coefficient is a variable. The electrical length of the cable is held constant, since the same cable is used to calibrate all units. Likewise, the antenna output reflection coefficient is held constant, because the same antenna is used to calibrate all units. So errors in the unit calibration will be due to differences in the reflection coefficient of the receiver under re ant

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