August 6, 2010

All,

As many of you are aware SVN62 was switched to operating one of the new Block IIF rubidium clocks on July 12. It had been operating on a cesium prior to July 12. A short analysis of the on-orbit performance of this new rubidium clock is given here. For this analysis, geodetic clock estimates for SVN62 from the IGS CODE analysis center were used, referenced to UTC(NRL) via the NRL1 station. UTC(NRL) is realized from a very stable Hydrogen Maser reference clock. Also included for comparison were 5-minute clock data collected from the NRL BIIF Lifetest (BIIF units SN#05 and SN#25), also referenced to UTC(NRL). Estimates from the IGS CODE analysis center were chosen since SVN62 is currently not well sampled in the IGS Combined Products. It is also noted that while the IGS CODE analysis center provides 5-second clock data for the GPS satellite clocks---including SVN62---a single high quality reference clock was not available at 5-second sampling over the full analysis period. Therefore, 5-minute data were mostly used, though a short segment of 5-second data was also included for the determination of short-term frequency stability. Because of the latency of these Final IGS CODE products and because of several delta-V and clock adjustments being made to SVN62 only 10 days of data were available for this analysis, July 17 through July 26. During this period only one day was the satellite in eclipse (17 July) and we are not aware of any delta-V adjusts or any other clock adjustments that were performed on the satellite during this period.

Figure 1 below shows the residual phase error of SVN62 relative to UTC(NRL) after an integrated logarithmic model has been removed. This log model generally fits the initial transient drift behavior of the IIF Rb clock quite well and has been removed for the purpose of isolating this very large initial transient drift from the data. Distinct 12-hr and 6-hr harmonics are clearly shown in the residuals, as is also evidenced in the accompanying amplitude spectrum (Figure 2) and Hadamard deviation (Figure 3) plots below. Four-hour (6 cycles-per-day) harmonics are also evident in the spectral density plot. Because of the short dataset length and only 5-minute sampling, the spectral resolution (Fourier frequency) is still too coarse to determine exactly the period of the harmonics (e.g., sidereal versus sun repeat period). The exact cause of the harmonics has not yet been identified, though at these amplitudes the effects are not likely orbit modeling errors alone. A small part of the 6-hr amplitude is expected to be unmodeled relativistic effects such as the 6-hr harmonic expected from Earth oblateness, which has about an amplitude of ~0.07 nanoseconds for GPS orbits (Kouba '04, Improved relativistic transformations in GPS). However, not all of the 6-hr amplitude observed can be relativistic. Some possible additional causes for the harmonics include thermal or other satellite-local effects as seen in older satellites (Senior, Ray, & Beard, GPS Solutions '08) where 12-, 6-, 4-, and 3-hr harmonics were all observed. It is perhaps not coincidental that Montenbruck et al. (GPS World, 2010) have found a oscillating variation in the phase of the SVN62 L5 signal having predominant periods near 12 and 6 hr, and with an amplitude of roughly 10 cm (or 0.3 ns). This could suggest some common environmental (thermal) influence on both the clock and L5 phase signals. But note that the IGS clocks rely on the L1 and L2 phases, not on L5.

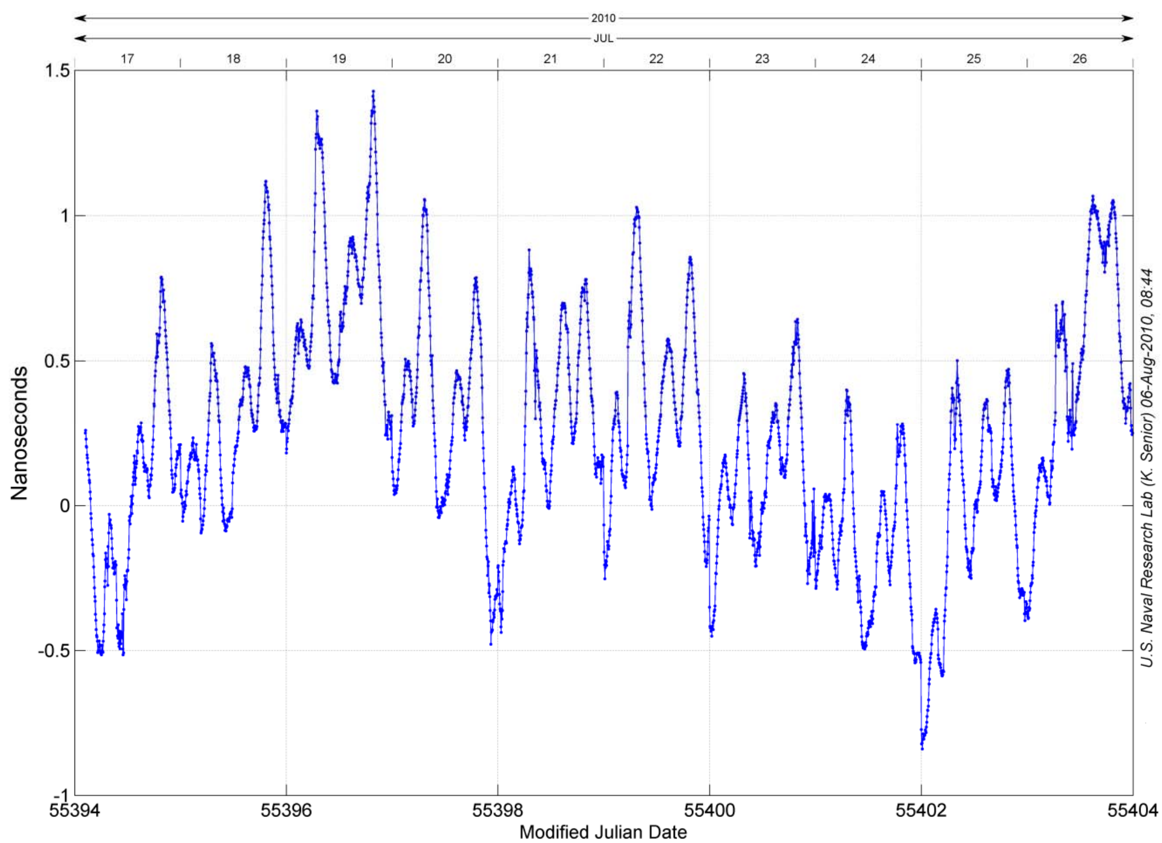

Figure 1 Phase (time) error residuals of SVN62 (PRN25) with respect to UTC(NRL) for the period 17 July through 26 July after an integrated logarithmic frequency model ($y = a\ln(bt+1)+c$) has been removed.

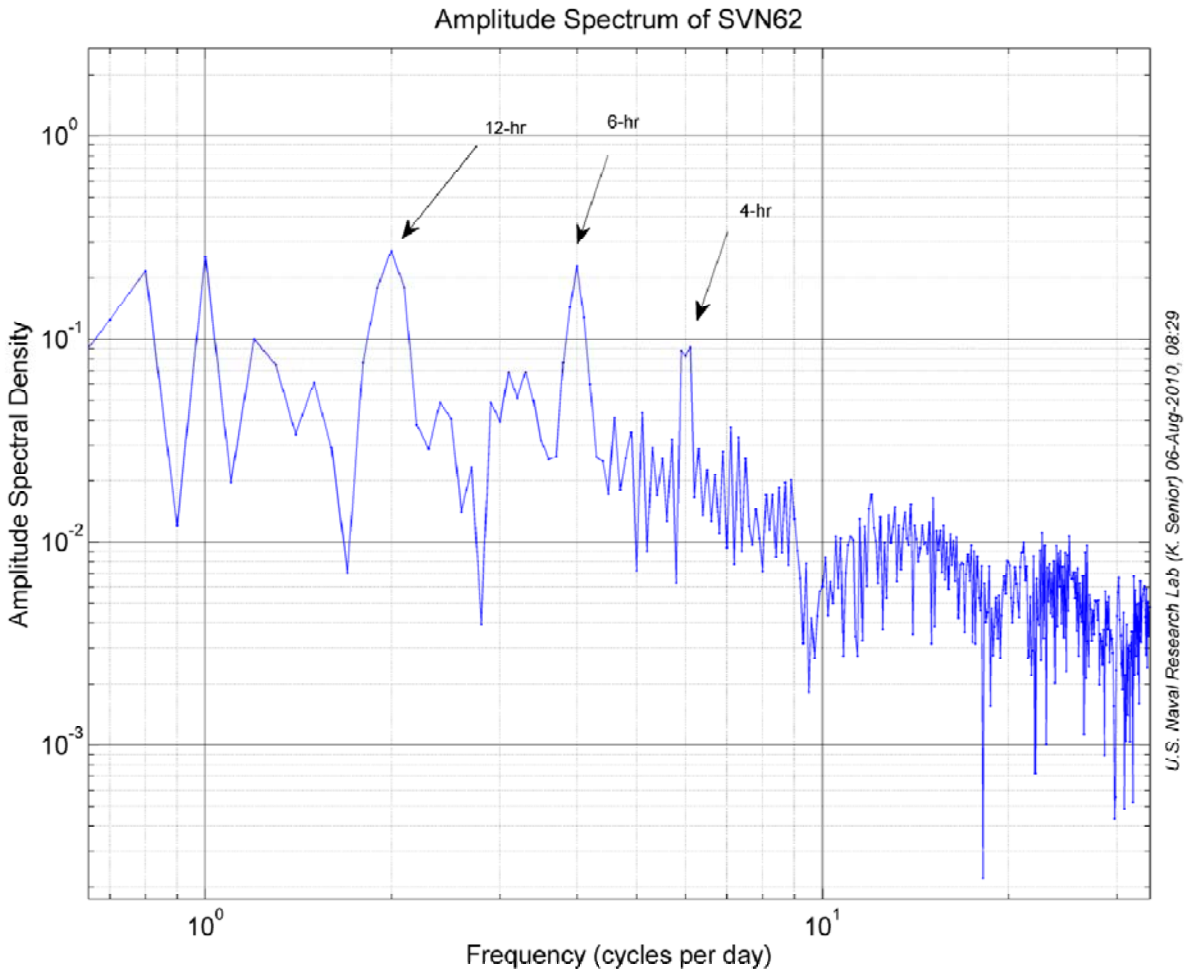

Figure 2 Amplitude spectrum for SVN62 calculated over 17 July through 26 July.

For comparison, data from the NRL Block IIF Lifetest was also included in the generation of the frequency stability plot (Figure 3) below. The on-orbit performance of SVN62 in the short-term is near that of the two BIIF Rb clocks under test, though still about a factor of 3 worse. Note that the ground performance of the BIIF Rb clocks is almost as good as a Hydrogen Maser. The large hump-like features in the Hadamard deviation plot of SVN62 are clearly a byproduct of the harmonics mentioned above. A short IGS CODE dataset using 5-second data was also included in order to calculate the frequency stability of SVN62 in the very short-run (light blue series).

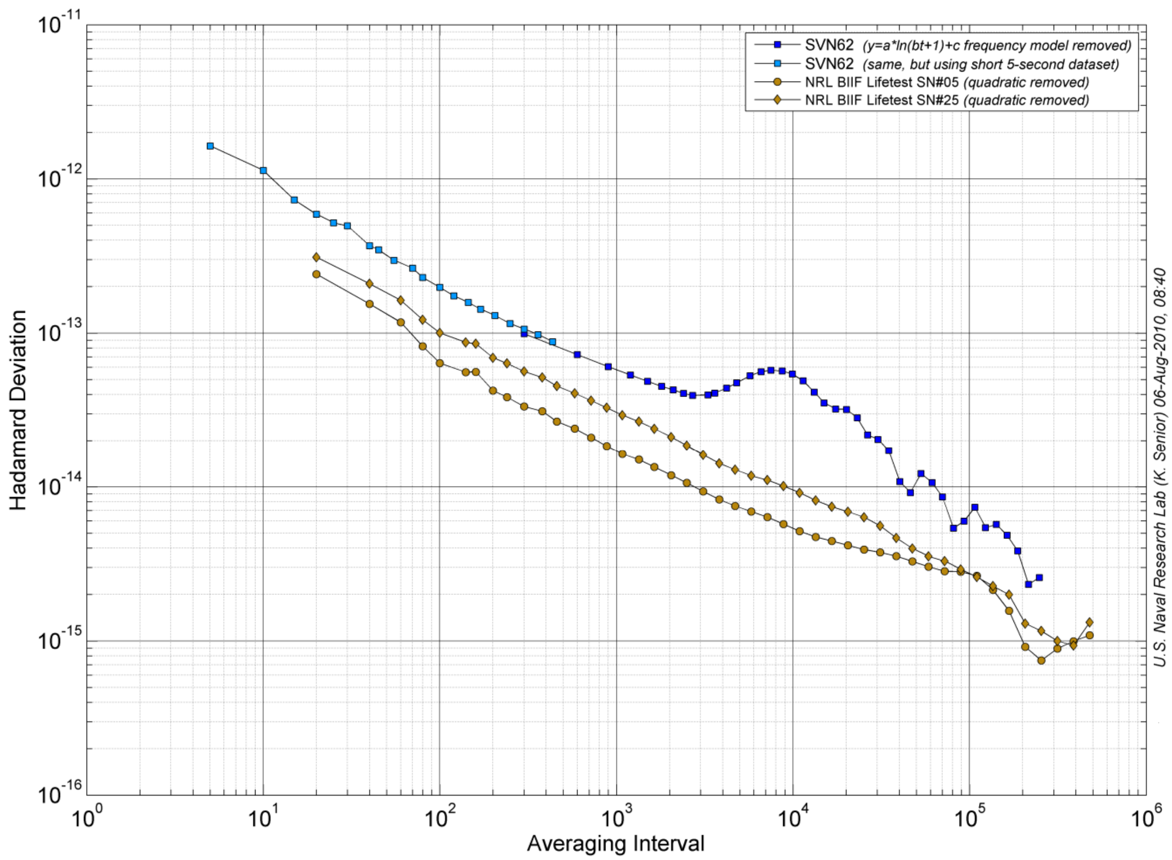

Figure 3 Frequency stability (Hadamard Deviation) of SVN62 as well as two BIIF Rb clocks currently under lifetest at NRL.

Finally, a frequency stability plot showing SVN62 along with the other GPS constellation clocks (colored by block), five ground clocks, as well as various NRL Lifetest data is given below in Figure 4. Note that the constellation clocks are plotted over a different period than for SVN62 using IGS combined clock products. As the plot shows the current on-orbit performance of SVN62 is clearly better in the short term than any existing GPS clock, but because of the harmonics performs only as an average BIIR Rb clock for intervals of about 5E3 s < tau < 3E4 s. The stability of SVN 62 at intervals > 3E4 s appear also better than any GPS clock, though the relatively small SVN62 dataset presents a bit of statistical uncertainty at these intervals.

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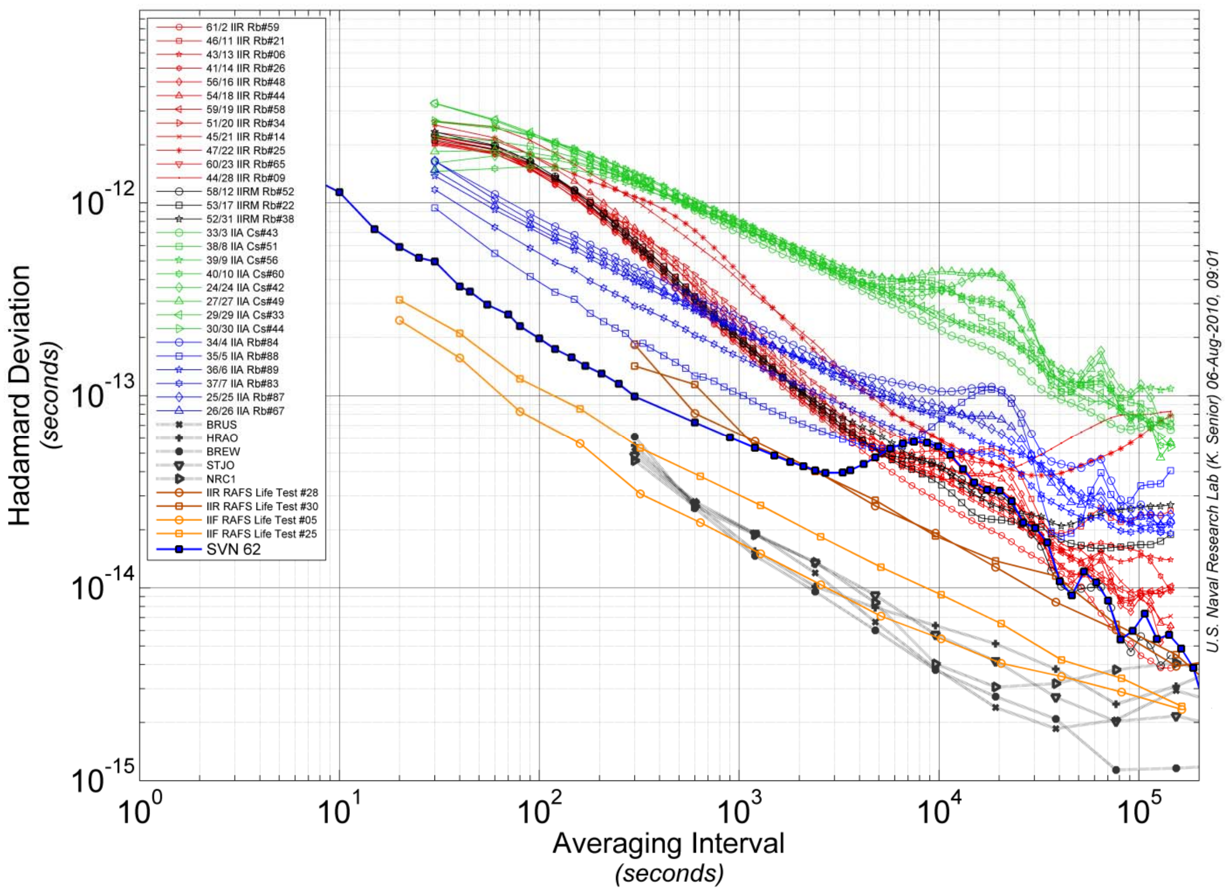

Figure 4 Frequency stability of SVN 62 along with the GPS constellation clocks using IGS CODE data and IGS combined products, respectively. Also included are several ground clocks and data for several other BIIR and BIIF Rb clocks from the NRL Lifetest. Note that the constellation frequency stability was calculated over a different time period as were the various Lifetest data but are shown here together to indicate relative performance.