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EVALUATION OF TIMING PERFORMANCE OF A JAVAD LEGACY RECEIVER

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SUMMARY

We have evaluated a Javad Legacy receiver compared with two other GPS receivers, all deployed at USNO using H-maser frequency standards. The Javad system, which was equipped with a JPS Regant single-depth antenna, appears to have been subject to a high level of multipath variation at low elevation angles, particularly below about 20 degrees. There is no way to establish whether this is intrinsic to the Javad system itself or caused by the particular siting of its antenna. While this would be expected to degrade troposphere and station height estimates, the observed clock performance, based on data analysis for the week 21-27 March 1999, was nonetheless outstanding.

DATA COLLECTION

The Geosciences Research Division at NOAA/NGS was loaned a Javad Legacy receiver for testing and evaluation during Spring, 1999. During a portion of the loan period, the receiver was deployed at USNO to test the system connected to a H-maser external frequency standard. Also running at USNO during the same period was an AOA TurboRogue SNR-12 receiver and an Ashtech Z-XII3 receiver (modified for time transfer applications), both connected to H-maser frequency standards. Deployment information for all three receivers is tabulated below.

Table 1. Receivers evaluated during 18 March - 02 April 1999

name	receiver	antenna	freq. std.	location at USNO
USNJ	JPS Legacy	REGANT_SD_E	MC3 H-maser	Bldg 52 roof, W end
USNO	AOA TR SNR-12	AOAD/M_T	MC3 H-maser	Bldg 52 roof, E end
USNB	Ashtech Z-XII3	ASH D/M	MC2 H-maser	Bldg 78 roof

The USNO receiver is a permanent installation which reports data to the IGS. AOA TurboRogues use a P1-P2 cross-correlation technique to measure the pseudorange at the L2 frequency and they report C/A pseudorange for the L1 frequency.

The USNJ receiver was equipped with a single-depth antenna. It was also deployed for a period using a Javad dual-depth antenna but unfortunately no useful data were collected during that time.

The USNB receiver is a transportable GeTT system developed by the CODE-OFMET group for time transfer applications (F. Overney, L. Prost, G. Dudle, Th. Schildknecht, G. Beutler, J. Davis, J. Furlong, and P. Hetzel, Proc. 12th European Frequency and Time Forum, 94-99, 1998). It is deployed at USNO for an extended demonstration period.

Both the Javad and Ashtech receivers employ a non-cross-correlation, Y-codeless method for tracking the pseudoranges at both the L1 and L2 frequencies, which is distinct from TurboRogues. The non-cross-correlation method gives P2 observables with higher SNR values, especially at lower elevation angles. (See IGS Mail No. 2320, which is available at ftp://igscb.jpl.nasa.gov/igscb/mail/igsmail/igsmess.2320.)

The two master clocks, MC2 and MC3, are both steered Sigma Tau H-masers operating in separate environments in different buildings. MC3 is tightly steered to MC2 as a back-up clock. The differences between these two clocks are continuously monitored and are avaiable at ftp://tycho.usno.navy.mil/pub/usnodc-amc.gpscp/.

In most respects, USNJ and USNO shared more common elements than USNB, particularly the frequency standards and local antenna conditions. The Bldg 78 rooftop is much more cluttered with other antennas and equipment than Bldg 52, and greater problems with multipath might be expected.

The comparison test was not ideal in that each receiver used a separate antenna each at a different location. This was done for expediency and to minimize disruption of the operational systems. As we will see, this limitation was not serious in establishing the basic performance of the Javad receiver for timing purposes. For a detailed comparison of the relative merits of each receiver type, a common antenna would be required. Such a test would not necessarily be representative of actual user experience, however, since each receiver would normally use an antenna from the same vendor.

The table below compares several measures of data quantity and quality for GPS week 1002, 21-27 March 1999, as reported by the UNAVCO utility "teqc." Of the possible observations above 10 degrees elevation, the Javad and AOA receivers recorded "complete" usable data similar fractions of the time, 92% and 94% respectively. The Ashtech was more successful at 99%. Using teqc's estimates of pseudorange multipath variation at L1 (MP1) and at L2 (MP2), the differences among the receivers are much more striking. The overall multipath variation (for all observations above 10 degrees) is similar for the AOA and Ashtech receivers at L1 but distinctly better for the Ashtech at L2. This is probably a direct consequence of the different code tracking techniques used, which favors better P2 data for the Ashtech, especially at lower elevation angles. Overall, the multipath variations seen by the Javad are much larger than for either of the other receivers. However, examining the elevation dependence it is seen that this is caused by observations at low elevations, below 40 degrees and most dramatically below about 20 degrees. At high elevation angles, the Javad actually shows the smallest multipath effects.

Table 2. Data comparisons for GPS week 1002 (21-27 March 1999)

statistical measure	Javad/USNJ	AOA TR/USNO	Ashtech/USNB
% total observations complete (> 10 deg)	92%	94%	99%

total MP1 RMS (> 10 deg)	1.02 m	0.57 m	0.55 m
MP1 RMS, 85-90 deg	0.11 m	0.15 m	0.18 m
MP1 RMS, 15-20 deg	1.76 m	0.93 m	0.81 m
total MP2 RMS (> 10 deg)	1.14 m	0.80 m	0.56 m
MP1 RMS, 85-90 deg	0.11 m	0.15 m	0.16 m
MP1 RMS, 15-20 deg	2.12 m	1.34 m	0.78 m

With the data available, it is not possible to determine whether the high low-elevation multipath variation experienced by the Javad receiver (USNJ) is due to the intrinsic performance of the receiver, the instrinsic performance of its single-depth antenna, the particular siting of its antenna, or other effects. Test data using the dual-depth antenna might have been helpful in this regard, but those test data were not successful.

CLOCK ANALYSIS

To evaluate the timing performances of the receivers, the Javad USNJ data were added to the USNO "Final" clock solutions for GPS week 1002. Results are posted at http://maia.usno.navy.mil/gpsclocks/index.html in the sub-directory "1002" for all solution clocks relative to USNO. The basic analysis procedures are described at the web site. Only observations above 15 degrees elevation are used. Differences in the pseudorange observables due to cross correlation versus non-cross correlation receiver types was compensated for (see IGS Mail No. 2320). Antenna phase pattern corrections were applied based on results by Gerry Mader (see http://www.grdl.noaa.gov/GRD/GPS/Projects/ANTCAL/).

Over the entire week, most of the clock differences observed were due to discontinuities at day boundaries. This can be seen in the two following tables, which show clock differences first within individual days, then over the full week. For the comparisons involving USNB, which used a separate frequency standard (MC2) from the other two receivers (MC3), the MC2-MC3 H-maser differences can be significant. However, on 23-25 March, the clock differences involving USNB were much larger than the differences in H-masers. These could possibly reflect slight differences in temperature sensitivity within the Ashtech system, particularly in its antenna and RF cable. On the other hand, the USNJ (Javad) and USNO (AOA TR) clocks behaved very similarly within each one-day period.

Table 3. RMS clock differences within observation days, GPS week 1002

WRMS clock diff.	USNJ - USNO	USNB - USNO	USNB - USNJ	MC2 - MC3
21 March 1999	49 ps	58 ps	92 ps	47 ps
22 March 1999	24 ps	30 ps	29 ps	34 ps
23 March 1999	25 ps	127 ps	129 ps	32 ps
24 March 1999	20 ps	112 ps	109 ps	26 ps
25 March 1999	26 ps	107 ps	115 ps	55 ps
26 March 1999	32 ps	85 ps	68 ps	28 ps
27 March 1999	22 ps	27 ps	29 ps	54 ps

Table 4. RMS clock differences for full GPS week 1002

	USNJ - USNO	USNB - USNO	USNB - USNJ	MC2 - MC3
WRMS clock diff.	666 ps	857 ps	619 ps	89 ps

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  adjusted WRMS *       666 ps         852 ps         613 ps
  ===========================================================================
  * after quadratic subtraction of MC2-MC3 variation for differences
    involving USNB
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All the clock differences are much larger when considered over the full seven-day span due to day-boundary discontinuities. With three pairs of clock differences, we can infer the RMS magnitudes of the clock differences due to individual receiver systems assuming that their variations are independent (after correcting the USNB differences caused by MC2-MC3 variations). The results are given in the following table.

Table 5. Inferred RMS day-boundary clock variations attributable to individual receivers

USNJ (Javad)	216 ps
USNO (AOA TR)	630 ps
USNB (Ashtech)	574 ps

DISCUSSION

The Javad receiver is inferred to produce the smallest clock discontinuities at day boundaries, at least over the one week analyzed. Its variation is only slightly larger than expected based on the formal errors of the clock estimates. The day-boundary discontinuities of the other two receivers are considerably larger. This result is suprising in view of the larger multipath variation of the Javad data (Table 2) and could be interpretted as excluding multipath as a cause of day-boundary clock discontinuities. Such an interpretation would probably be simplistic, however, partly because of the small sample size of just 6 day boundaries. Moreover, it should be noted that low-elevation data contribute geodetic information primarily for tropospheric and station position (especially height) parameters, whereas high-elevation data are more important for clock estimates. So the Javad's large multipath variation at low elevation angles may not be controlling. In this view, the very low multipath of the Javad at high elevation angles would be more important. More data will be needed to test this hypothesis.

Even if the Javad low-elevation multipath does not degrade the clock estimates, it is expected to be undesirable for high-quality tropospheric and height determinations. As noted previously, we cannot isolate the cause of the USNJ high multipath variation as being internal to the Javad system or related to the environment of the antenna.

Regardless of the uncertainties of the multipath cause and its possible relationship to day-boundary clock discontinuities, this test does demonstrate that the Javad Legacy receiver can provide excellent timing performance.