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EFFECTS OF ANTENNA CABLES ON GPS TIMING RECEIVERS*

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ABSTRACT

We report efforts to minimize the effect of reflected signals in GPS antenna cables on the delay instability of GPS common-view time transfer receivers. The delay instability of interest is at long term time intervals out to about one year. Our measurements of various cables indicate a range of power for multi-path signals from the cables arriving at the receiver. For NBS-type receivers with traditional cables we find significant variations of the reflected power with frequency changes around the 75 MHz IF. The levels range from -16 dBc to -27 dBc. For a commercial receiver with the signal transmitted from the antenna to the receiver at the L-band frequency, the best result is for a special cable system we have built with a reflection loss of -30 dBc. With new cabling systems, any effects due to reflected signals in the cables for either the NBS-type or the commercial receivers should be below 1 ns. We include several weeks of data from receivers using these cables. A full evaluation of the results will require many months, and perhaps years, of data.

1. INTRODUCTION

This paper describes an effort to eliminate sources of instability in the total time delay through GPS receivers, particularly through the use of cabling systems that provide phase stability in the cable and good 50 Ω termination at both the receiver and antenna. We have also studied other sources of instabilities, with a goal of controlling all significant effects at the 1 ns level for averaging times of 1 d and longer.

Common-view GPS time transfer still remains the primary method of comparison of the local version of Coordinated Universal Time (UTC) of labs throughout the world for the generation of International Atomic Time (TAI). TAI is relied on primarily for its long term stability, at time periods of months and years [1]. Any uncalibrated changes in the time or phase delay through GPS receivers used for the generation of TAI contribute noise to TAI. Receivers can be calibrated against each other by moving a traveling receiver from one lab to another, and performing common-clock common-view comparisons. Closure is achieved by re-calibrating the first lab at the end of the trip [2]. This needs to be done periodically through the network of receivers which contributes to TAI. At best this can be achieved annually. Hence, the instability of the delay of receivers out to at least one year is a contributor to the noise of TAI. Our goal is to attain a receiver stability of better than 1 ns out to one year.

We, along with several other researchers, have studied the temperature effects on a particular commercial GPS receiver [3]. Even without temperature stabilization the antennas do not contribute to instabilities greater than 500 ps. The receiver unit of this commercial system requires stabilization of both temperature and power supply voltage. For the worst case we found a variation of delay with temperature of 250 ps/°C. We have stabilized the temperature of our receivers to a peak-to-peak variation of 2 °C, implying a variation of no more than 500 ps. We have found a worst case variation of delay with voltage of 20 ps/mV. We have built power supplies which should vary no more than 5 mV over a year.

Using a network analyzer we measured the impedance of several cables typically used for GPS antenna cables. We also measured the impedance of several GPS receivers and antennas. Of particular interest for this work is the signal power reflected back from the receiver to the antenna, and then back again at the antenna to the receiver. After making several such measurements we designed a new cable system for our commercial system. This system uses an amplifier and attenuators to provide 50 Ω terminations at each end of a cable with increased phase stability with temperature.

In the next section, we discuss the theory of how cables can affect the delay through common-view receivers. In section 3 we report on work done on NBS-type receivers. NBS-type receivers are those either built by or based upon receivers built at the National Bureau of Standards in the early 1980's [4]. In section 4 we discuss cable systems for our commercial receivers. We present data for these receivers in section 5.

2. THEORY

As discussed by Ascarrunz in a related paper in this same symposium, a pseudo-random noise (PRN) signal, such as a GPS signal, can exhibit large variations in the code-lock point due to small variations in the carrier

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phase of delayed coherent interference [5]. Such interference can occur due to reflections in an antenna cable.

The code in a GPS signal is bi-phase modulated on the carrier. A receiver locks onto the code by correlating the received signal with a locally generated replica. A delayed copy of the signal added to the direct signal can pull the lock point if the delay is within the PRN chip length. Because the phase of the carrier determines the phase of the code chip, the relative phase of the reflected signal strongly affects the way the lock point is pulled. A change in the reflected carrier phase of half a cycle produces a maximum change in the lock point due to that multipath signal. For a GPS receiver with the L1 frequency coming down through the antenna cable, this requires a change in the reflected phase of about 330 ps. The NBS-type receiver brings the signal down through the antenna cable at the intermediate frequency (IF) of 75 MHz.

The timing offset in the GPS code lock due to a multipath reflection will depend on both the delay in the reflected signal and its signal power. If there is a reflected signal 25 dB below the direct signal, the code lock point can be pulled as much as 0.03 of a chip (see Figure 1). For the 1.023 MHz chip rate of GPS this implies an offset of almost 30 ns. For a signal at -35 dBc the maximum is closer to 10 ns, as shown in Figure 2. This maximum corresponds to an envelope which grows linearly with the delay of the reflected signal out to about 435 ns. Thus, a cable with a delay of 217 ns could produce the worst effect. If the relative phase of the carrier for the reflected signal moves by half a cycle, the resultant code lock point will change by twice the envelope as shown in Figures 1 and 2. Thus, with a 435 ns delayed signal at -25 dBc, a change in the reflected phase of 330 ps would produce a change in the apparent received signal of almost 60 ns. Figure 2 illustrates how a change in the phase of the reflected carrier can cause variations in the code-lock point.

The phase of the received GPS signal must remain stable to achieve good the time stability. If there are cable reflections and they never change, then the system can be calibrated and will remain stable. Multipath reflections outside of the antenna also pull the code lock, but the amount of pulling tends to vary with the geometry of the relationships among the antenna, the satellite, and the reflectors. Since the satellites have repeating ground tracks each day, the effects of multipath outside of the antenna can average down somewhat over a day. For receivers contributing to TAI, the worst problem occurs when the lock point is slowly pulled over weeks or months..

3. NBS-TYPE RECEIVERS

NBS-type receivers employ a mixer in the antenna package which heterodynes the GPS signal down to 75 MHz from the L1 frequency. Typically at least three such receivers are operated at NIST, and until recently these receivers have all used RG-58 cables to connect the antenna to the receiver. The cables ranged in length from 160 ns to 234 ns. Measurements on the receiver, cable, and antenna systems indicate that the levels of delayed coherent interference (the signal resulting from reflection at the receiver, followed by reflection at the antenna, and including propagation loss for two passes along the cable) range from 40 to 50 dB below the direct 75 MHz signal at the receiver. With a 40 dB return loss and a 234 ns cable, a half cycle change in the carrier phase of the reflected signal would change the code lock by 4.6 ns.

However, the low IF frequency works to our advantage here. A half cycle change of the carrier phase at 75 MHz is 6.7 ns. RG-58 cable has a temperature coefficient of phase delay of 70 ppm/°C [7]. If the 234 ns cable were subjected to a temperature change of 40 °C over its entire length it would cause a change in the carrier phase of the delayed signal of only 1.3 ns (1/10 of a wavelength). In

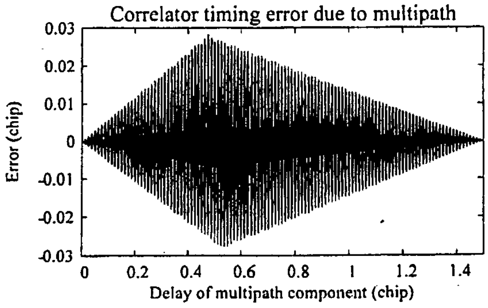

Figure 1 GPS correlator timing error due to a multipath signal 25 dB below the direct signal as a function of the delay.

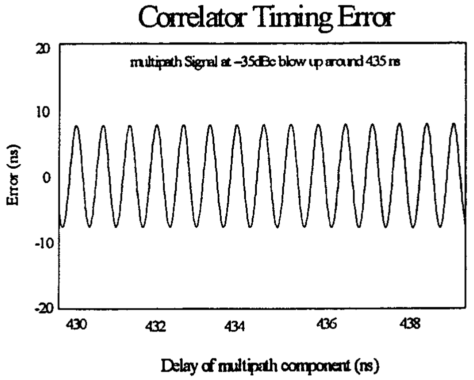

Figure 2 GPS L1 correlator timing error due to a multipath signal 35 dB below the direct signal. The window shows the interval of maximum variation.

the worst case, a 40 dB return loss in a 234 ns cable, this would result in a change in the code lock of 1.4 ns. The direct signal could shift by about half that due to the actual physical change in delay caused by the temperature. These effects could add or subtract depending on the relative phase. Thus temperature sensitivity in RG-58 cable could cause no more than a 2 ns shift in apparent group delay. However, one must be careful when changing cables since the apparent cable delay may not be consistent with measurements made on the cable itself with, for example, a network analyzer.

High phase stability cables exist that have a 10 times lower temperature sensitivity. The RG-58 cables has been replaced with the better cable and we hope to see whether any improvement has been achieved. With these cables any shift in apparent receiver delay due to temperature changes and coherent interference should be below 1 ns.

4. A COMMERCIAL GPS RECEIVER

We also made measurements with a commercial GPS receiver and its associated cables. In this case the signal comes down from the antenna at the L1 frequency. We estimate that for this receiver and the cables we had been using that the delayed coherent interference due to reflections in the cable is about 30 dB below the direct signal.

At -30 dB, a reflecting multipath signal would pull the signal about half of what we see in Figure 1. The existing low-loss cables had delays of 60, 82, and 100 ns, implying potential reflected signals with 120, 164, and 200 ns delays. These lie on the envelope of Figure 1 where the potential change in code lock would be 15, 22, and 26 ns, respectively. That is, a reversal in phase of the reflected signal would change the lock point by the preceding amounts. A reversal of phase of the carrier would occur with a 330 ps change in the total delay of the reflected signal through the cable. This would occur if the cable delay changed by half of that, 165 ps, or the electrical length changed by about 5 cm. Over months, the cables could experience an average change of 20° C in temperature. For a 30 m length of cable, and an average temperature variation of 20° C over the cable, we would need a temperature coefficient of 83 ppm/°C to see an effect of this magnitude. Ascarrunz measured temperature coefficients of 70 ppm/°C for RG-58 cables, and 7 ppm/°C for the new cables with improved phase stability [7].

To improve this situation we chose to do three things: 1) use cables with an impedance closer to 50 Ω, 2) use cables with a lower temperature coefficient, and 3) create a termination closer to 50 Ω for the cables at both the antenna and the receiver. We chose to improve terminations by adding attenuators at both ends of the cable. This added two complications. First, we needed more signal strength from the antenna in order to overcome the loss of the attenuation. Second, since the cable carried 5 V DC, we needed to pass the DC current around the attenuators. Figure 3 illustrates the resultant configuration. We used bias tees to bypass the DC power around the attenuators. This system yielded a delayed signal approximately 40 dB below the direct signal, an improvement of about 10 dB. In addition, there is little variation in this reflected power with frequency over the C/A code bandwidth.

The delays through the new cables are 103, 107, and 120 ns, suggesting potential delays for the reflected signals at 206, 214, and 240 ns. At -40 dB the envelope for maximum loss at a delay of 435 ns would be under 3 ns, implying a potential 6 ns change in code lock with a reversal of reflected phase. For the delays in these cables we could see a maximum change of 2.8, 3.0, and 3.4 ns, respectively, due to a complete phase reversal of the reflected carrier. With the new cables having increased temperature stability, any coherent interference effect due to reflections in the cable should be below 1 ns.

5. DATA

Our goal with these improved cable systems is to improve long term stabilities out to periods of a year or more. We have only a few weeks of data, so our results are preliminary.

We replaced the RG-58 cables of two NBS-type receivers with more phase-stable cables. In addition, since the new cables had less loss, we were able to place 1 and 3 dB attenuators at the ends of the cables in order to improve the match to 50 Ω. Thus far we have seen little difference in the data. The standard deviation of the differential delay between the two over 1 d has remained just under 2.0 ns. In the past, we have seen an annual

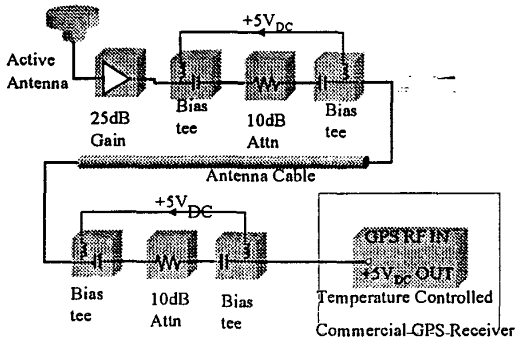

Figure 3 Antenna cable system for commercial receiver designed to minimize reflections.

variation between these two receivers on the order of a few ns. We will look for any changes.

For the commercial receiver there is also little change in the short-term, steady-state stability, though there is indication of increased stability during snow. Figure 4 shows the Time Deviation for 14 days of data taken every 15 s. We see white phase modulation (PM) starting at about 1 ns out to 1 min. The stability is consistent with a flicker PM floor at about 300 ps, out to 1 d. At 1 d the level drops to about 100 ps. The confidence is poor beyond 1 d.

6. REFERENCES

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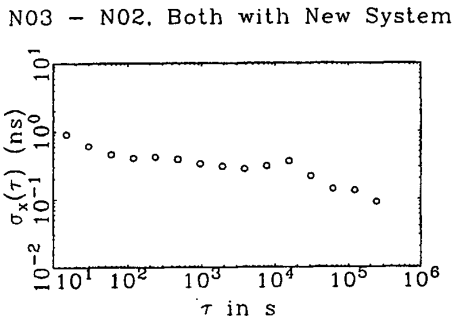

Figure 4 Time Deviation of the differential delay between two commercial GPS receivers using new antenna cabling systems. The data are from MJD 51261 to 51275.

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