Chapter 6. Temperature Effects

6.1 Introduction

This chapter documents the investigation into temperature drifts that can cause a receiver clock bias even when a stable reference is used. The first step was a zero baseline test with Ashtech Z-12 receivers. A zero baseline test consists of hooking up two (or more) receivers to the same antenna and observing the differences between the measurements made by the two receivers, which would ideally be zero. In the case of the Z-12 receivers, a common external reference was used during all but one of the zero baseline tests. The phase lock loops that track the external reference can drift due to temperature changes, as will be shown. These effects were encountered during an experiment which was designed to show the effect of antenna rotation on the received carrier phase. This chapter deals with the characterization of the temperature drifts using a series of zero baseline tests, including two in which ice baths were used to stabilize the temperature of the receivers.

6.2 Zero Baseline Test using Ashtech Z-12 Receivers

A zero baseline test was conducted by connecting two receivers to the same antenna and also running them from the same clock. The setup is shown in Fig. 6.1. A DC Block was used in one of the antenna lines to make sure only one receiver fed the preamplifier. A splitter was used to connect a 10 MHz rubidium oscillator to the external reference inputs of the two Z-12 receivers. The Z-12 receivers still used internal oscillators, but were phase-locked to the
Figure 6.1 Setup for Ashtech Z-12 Zero Baseline Test
incoming 10 MHz reference signal. Data were collected once every five seconds over a period of
two hours, and the results are shown in Fig. 6.2.

The single differences are shown with the initial ambiguity terms subtracted to allow
comparison of all the measurements on the same scale. Recall from Chapter 3 that the single
difference contains the clock offset between the two receivers while eliminating clock biases at
the satellite. With a common clock and a common antenna, this allows for a direct evaluation of
the external reference tracking loops.

The single differences exhibit a drift that is common to all channels. This is symptomatic
of a clock error. There appears to be a jump in the clock a little before the 1.5 hr mark. This
could be a problem with the external reference tracking of one receiver. It is not likely that the
oscillator itself jumped because this would be seen by both receivers and would not appear in the
single difference.

Two of the single differences disappear shortly after the 0.5 hr mark. This occasional
"flatline" is not uncommon with the Ashtech Z-12 receivers. Because the drift is large and levels
off over time, it was assumed to be a hardware drift caused by temperature variations. The
operation of phase lock loops (PLLs) can vary with temperature, and the 10 MHz clock has a
wavelength of about 30 meters.
Figure 6.2  
L1 Carrier Phase Single Differences from Zero Baseline Test with Z-12 Receivers (2 Hours) — Multiple Lines Correspond to Different Satellites
To further investigate this phenomenon, a second zero baseline test with the same setup shown in Fig. 6.1 was conducted. Data were collected once every 20 seconds over a period of four hours. The single differences are shown in Fig. 6.3. Here again the initial ambiguity terms have been subtracted from each single difference in order to directly compare the measurements. Cycle slips have been removed as well. There is a drift of about 20 meters which seems to level off sometime during the third hour of data collection. This confirms the hypothesis that temperature variations cause the clock drift. As the receivers heat up and reach thermal equilibrium, the phase lock loops do not wander relative to one another. Because the Z-12s use an internal oscillator slaved to the external reference, it was determined that another zero baseline test should be conducted with two receivers truly running off the same clock.
Figure 6.3  L1 Carrier Phase Single Differences from Zero Baseline Test with Z-12 Receivers (4 Hours) — Multiple Lines Correspond to Different Satellites
6.3 Zero Baseline Test using Novatel Receivers

The MITRE Corporation in McLean, VA has two Novatel GPSCard receivers which have been modified to run from a common 10.23 MHz reference which is synthesized from a 20.473 MHz source. The cards fit into full size slots in a Compaq computer, while the oven controlled crystal oscillator (OCXO) fits into another slot. The setup for this zero baseline test is shown in Fig. 6.4. Data were collected for about 68 minutes at an interval of once per second. The results are plotted in Fig. 6.5.

The single differences do not show the temperature drift seen in the Ashtech Z-12 data. This could be due to the fact that the GPSCard receivers are housed in the same PC, and are hardwired for the 10.23 MHz frequency. The Ashtech Z-12 receivers have frequency synthesizers and other hardware to allow tracking of external references in the range 1-21 MHz. The single differences from the Novatel receivers exhibit large variations on the order of 10 meters. The large spike in the data is coincident with the acquisition of SV 19. Clearly there is a large clock error induced when a satellite is acquired. The receivers do not acquire and lose signals in an identical fashion even though they use the same antenna. The cause of the spikes is related to hardware differences between the two receivers. The OCXO is not a likely origin of such spikes in the single differences, particularly because the oscillator output is delivered to both receivers. To see the clock variations during normal operation, a plot of the single difference for SV 22 during the first 25 minutes of data collection is shown in Fig. 6.6. The single difference is very noisy compared to what was seen in the Z-12 data. The clock exhibits variations of ±0.3 meters which is ±1-2 L₁ wavelengths. For accurate positioning during clock
Figure 6.4 Setup for Novatel GPSCard Zero Baseline Test
Figure 6.5  L1 Carrier Phase Single Differences During Zero Baseline Test Using Modified Novatel GPSCard Receivers
Figure 6.6  L1 Carrier Phase Single Difference for SV 22 During the First 25 Minutes of a Zero Baseline Test Using Modified Novatel GPSCard Receivers
coasting, variations of this magnitude are not desirable. Therefore, the next step was to address the problem of temperature drifts in the less noisy Z-12 carrier phase measurements.

6.4 Zero Baseline Test with Z-12 Receivers in Ice Bath

On the suggestion of Sergei Gourevitch, Chief Scientist at Ashtech, it was decided that placing the receivers in an ice bath would help reduce the temperature variations. The setup for this experiment is shown in Fig. 6.7. The receivers were placed in thick-ply contractor trash bags, with antenna and battery cables kept dry. Two large Coleman coolers were used, one for each receiver. The idea was to maintain a steady temperature of 32° F. As an additional precaution the two receivers were given instructions to track only a certain set of satellites. This kept the number of active processors constant and kept the heat generated by each receiver about the same. The results are shown in Figs. 6.8-6.9. During the initial data collection (Fig. 6.8), the single differences drifted by about 8 meters. This large effect is due to the fact that the receivers had been at a relatively warm ambient temperature prior to being immersed in the ice bath. Also, there was a shortage of ice during this first data collection, leading to less than optimal temperature control.

The results for a later session (Fig. 6.9) were improved. More ice was added to improve the temperature control, as well as to offset the melting which had occurred during the first hour. Prior to being immersed in the ice bath, the receivers were removed to download the data for the previous collection. The temperature drift was reduced to about 2 meters and the single
Figure 6.7  Setup for Ashtech Z-12 Zero Baseline Test Using Ice Bath and Common Clock
differences leveled off to within a few centimeters after about half an hour. This shows that by keeping the temperature constant the drift can be eliminated. The sensitivity is apparent at the tail end of Fig. 6.9, where one receiver was removed from the ice bath before the termination of the data collection. In the short time it took to remove one receiver and close the data file, the single difference drifted off by 17 cm.
Figure 6.8  L1 Carrier Phase Single Differences from Zero Baseline Test Using Ashtech Z-12 Receivers in an Ice Bath — Data from Five Satellites Shown
Figure 6.9  L1 Carrier Phase Single Differences from Zero Baseline Test Using Ashtech Z-12 Receivers in an Ice Bath — Data from Four Satellites Shown
6.5 Zero Baseline Test using Z-12 Receivers and Separate Clocks

The ultimate goal is to be able to rely on clock coasting during differential GPS operation. Thus, a common clock zero baseline test is not realistic and another zero baseline test was conducted (Fig. 6.10) in which separate clocks were used. It was expected that the single differences would show a combined drift based on the relative drift rate between the rubidium oscillators. This is shown to be about 1.3 cm/s in Fig. 6.11, which shows the L1 carrier phase single difference for SV 23. Data were collected once per second for 5 hours. The data were stored on portable laptop computers via serial cables so that the receivers could remain in the ice bath. Ice was added and water drained periodically in order to maintain temperature control.

At the beginning of the experiment, the temperature drift is somewhat apparent in Fig. 6.11. To better illustrate this effect, a first order fit to the data in Fig. 6.11 was used as a reference for all the single difference measurements. The result (Fig. 6.12) is that the initial temperature drift is highly visible. After about a half an hour the temperature drift stabilizes but variations of ±1 m are apparent over the remaining four and a half hours. This could be related to the performance of the phase-lock loops at different frequencies — one oscillator is at 10 MHz and the other is at 5 MHz. It could also be variations between the oscillators, i.e. the relative drift between the oscillators may not be precisely linear.
Figure 6.10 Setup for Ashtech Z-12 Zero Baseline Test Using Ice Bath and Separate Clocks
Figure 6.11  L1 Carrier Phase Single Difference for SV 23 from Zero Baseline Test Using Ashtech Z-12 Receivers in an Ice Bath — Separate Rubidium Oscillators
Figure 6.12 L1 Carrier Phase Single Differences Minus First Order Fit from Zero Baseline Test Using Ashtech Z-12 Receivers in an Ice Bath — Separate Rubidium Oscillators
6.6 Conclusions From Zero Baseline Tests

The experiments in this chapter have shown that achieving the benefits of clock aiding is not a simple proposition. Hardware variations on the order of 10 meters were seen to be common, with extensive temperature control needed to reduce the effect. This of course drives up the cost of clock aiding because a receiver would have to be designed with expensive components that do not experience significant clock drifts with temperature changes. This could be accomplished by including temperature sensors and modeling the performance of the phase lock loops as a function of temperature. Another option would be to thermostatically control the receiver temperature. Either way, the problem of temperature drifts makes clock aiding less applicable as temperature control would drive up the cost of a GPS receiver.

Figure 6.12 shows that even with controlled temperature, the receivers cannot be assumed to be precisely synchronized with GPS system time. Thus, it may be necessary to incorporate a clock model, or in this case a hardware model, that can be used to predict the temperature effects based on previous measurements. The temperature effects seen during the zero baseline tests are slow changing errors that could be modeled by a polynomial fit. That approach is covered extensively in Chapter 8, which discusses the implementation of clock aiding in DGPS when the ground and airborne receivers are not synchronized.