C-AND Ku-BAND TWO-WAY SATELLITE TIME TRANSFER COMPARISON EXPERIMENT

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Abstract

In the development of a new time dissemination capability for the U.S. Air Force Eastern Missile Test Range, the satcom channels to be used became an issue in terms of performance over different links and available coverage. A primary advantage of C band is that satellite coverage is more widely available in remote areas where Ku coverage is limited or not available at all. To investigate the performance issue, a Two-Way Satellite Time Transfer (TWSTT) experiment was performed to obtain comparative data over both C and Ku band. Time transfers between two sites using atomic frequency standard clocks were performed over both links to compare results in a controlled experiment. The objective of the experiment was to determine the relative precision of TWSTT over the frequency bands.

Time transfers were performed between a station located at Rockledge, Florida and the NIST facility at Ft. Collins, Colorado for a period of approximately ten days. GPS receivers were used in common-view mode referenced to the same clocks as an independent comparative measure. Tests were conducted over a wide range of temperature variations and weather conditions. Observations were obtained during snow, heavy rain and sun with temperatures from 8 to 90 degrees Fahrenheit at the two stations. Analysis of the resultant data shows that time transfer over the two links performed equally, with residual RMS results of approximately 5 nanoseconds.

INTRODUCTION

The U. S. Air Force Eastern Missile Test Range has a requirement for precise time synchronization of their remote tracking stations which stretch along the Atlantic Ocean from Cape Canaveral, FL to Ascension Island, UK. The current technology of Two-Way Satellite Time Transfer (TWSTT) can provide the accuracy required for the remote station synchronization. Most TWSTT applications have used Ku-band satellite links because of the lower cost of the earth station equipment. However, the Ku-band satellite coverage is limited to spot beams focused on the major continents and does not provide coverage in the Atlantic Ocean over Ascension Island. The C-band communications satellites have a global beam which covers an area of a hemisphere that includes all of the Eastern Missile Test Range remote sites. The purpose of this experiment was to compare the performance of Ku-band TWSTT to that of C-band and to establish the link equipment requirements for C-band.

TWO-WAY SATELLITE TIME TRANSFER (TWSTT)

TWSTT is a method for determining the precise time difference between two separated timing systems. The method uses Very Small Aperture Terminals (VSATs) and computer-controlled spread-spectrum modems to perform synchronization measurements via a geostationary satcom. The satcom contains a transponder with sufficient bandwidth to accommodate the 4 MHz two-way time transfer signal. Measurements are performed in sessions of five-minute measurement periods and each session takes 30 minutes or less to perform.

A basic TWSTT link is shown in Figure 1. The signal is transmitted between a Master and a Target site through the satcom satellite. The transmission between the two sites occurs simultaneously, which allows canceling of timing signal path delays when the measurements made at each site are differenced. The high accuracy of this technique is dependent upon these reciprocal delays canceling out in the comparison process. Operation as a Master or Target site is under software control, and an individual site may operate in either mode depending upon operator selection.

TWSTT ACCURACY AND ERRORS

The accuracy of the TWSTTs lepends on several factors. These include the ionosphere, satellite movement, transponder delays, antenna hardware, cabling, and the quality of the clock source.

The ionosphere can cause delays in the signal path to and from the satellite. Since the uplink and downlink frequencies are separated by 2 GHz, the delays in the uplink and downlink can differ. The differential delays on C-band, which is at 6 GHz and 4 GHz, will vary more than at Ku band, which is at 14 Ghz and 12 GHz. As the frequency increases, the effect from the ionosphere decreases. The errors are introduced when the ionosphere varies for each leg of the satcom link, leaving the two-way delay non-reciprocal.

Satellite movement may also affect the time transfer accuracy. If the satellite is not station kept, the path lengths can vary during the transfer operation and cause non-reciprocal errors. Depending on how much the satellite moves, a tracking antenna may also be required.

The properties of the satellite transponder can have a serious effect on the accuracy of the time transfer. The principal source of accuracy with this technique is common or reciprocal error that will cancel in a simultaneous two-way transmission. If the transponder uses the identical equipment in translation and retransmission of the signal, then the signal delays are identical and will cancel in the process. If,however, the equipment in changing frequencies between up and down links should also change antennas in the spacecraft, then the signals may not follow the same path and delays are not identical. Observed delays in some TWSTT applications have experienced large errors due to this effect.

Delays in the earth station antenna hardware may vary since it is exposed to the environment. Temperature variation will have the largest influence. Since the hardware used is sufficiently wide bandwidth, the hardware delay variations are less than two nanoseconds. Cables exposed to the environment, especially in long lengths, can have delay variations of multiple nanoseconds.

SATELLITE COVERAGE

The Ku-band continental spot beam coverage typical of satcoms is shown as the S2 footprint in Figure 2. This coverage is not adequate for the Eastern Missile Test Range application,which extends below the Equator into the South Atlantic Ocean. The C-band satcom coverage is represented by the outer concentric rings which include a hemisphere of the earth and all the remote sites of the test range. In fact, the area of interest in this application is located generally in the center of the C-band global beam coverage.

COMPARISON EXPERIMENT

A time transfer experiment was performed between a facility at COMLINK, Inc., Rockledge, FL and NIST, Fort Collins, CO. Each site had Ku-band and C-band earth station equipment with an NRL-designed TWSTT modem. The same modem was used for both Ku-band and C-band measurements. Each site used an HP 5061 cesium standard as a clock reference source. In addition, STEL 5401C GPS Time Transfer Receivers were used to perform independent common-view time transfer (CVTT) measurements during the experiment. Time transfer measurements were obtained over a period of six days during April, 1997. A comparison was made between the Ku-band and C-band TWSTT data to determine the difference in precision of the two measurement systems. The GPS CVTT datawerealso compared as an independent check of the time transfer results.

TWSTT RESULTS

The phase offset results from the Ku-band TWSTT are shown in Figure 3. The data show a phase offset of about 7.5 microseconds and a frequency offset of about 4 pp10^{13}. There are 31 sets of observations, and each observation represents five minutes of TWSTT measurements taken in groups of three about every twelve hours. Each five-minute measurement point is the result of averaging 300 one-second time interval measurements. The RMS ranges from 250 to 300 picoseconds. A plot of the residuals to a linear fit of the Ku-band data is shown in Figure 4. The scale is expanded in order to look at any signature in the data. The RMS of the residuals is eight nanoseconds. No particular interest was given to the variations in the data although some may be attributed to the behavior of the cesium reference at the Florida site due to a large temperature rise when the facility lost air conditioning. The objective was to determine how well C-band measurements would compare with those of Ku-band.

The C-band phase offset measurements are shown in Figure 5. There are 94 sets of observations shown here. Three or four sets of C-band measurements were taken before and after each Ku-band measurement session. The data show about the same phase offset and frequency difference as that of the Ku-band measurements. The residuals to a linear fit are shown in Figure 6. The RMS of the residuals is nine nanoseconds,which is comparable to the eight nanosecond RMS of the residuals of the Ku-band measurements.

GPS COMMON-VIEW TIME TRANSFER RESULTS

GPS common-view time transfer measurements were taken during the period of the TWSTT test as an independent comparison. Position of the receiver is a key parameter required for GPS time transfer and exact surveyed positions were not available. The STEL 5401C GPS receivers were used in a self-survey mode for about three days to determine positions of the two sites. The receivers were also operated in the GPS Standard Positioning Service (SPS) mode which results in noisy solutions and data due to the affects of GPS Selective Availability (SA). The GPS CVTT phase offset measurements are shown in Figure 7. The noise due to the effects of GPS SA are apparent in the spread with peak deviations of several hundred nanoseconds. The residuals of a linear fit are shown in Figure 8. The RMS of the residuals is 27 nanoseconds. It should be noted that an attempt was not made to achieve the best performance available from GPS,but rather to obtain an independent measurement for comparison to the TWSTT measurements.

COMPARISON RESULTS

A comparison of all the methods is summarized in Figure 9. The phase offset results of the Ku-band and C-band measurements are plotted on the same graph. The GPS CVTT measurements are also plotted for comparison. The TWSTT measurements track very closely and the GPS CVTT measurements show the same data trends with a bias. Since the interest was primarily in determining the difference in the Ku-band and C-band measurement systems, little attention was given to the absolute calibration of any of the time transfer measurement systems. For implementation in an actual time transfer application, significant efforts are required to insure that each measurement system is calibrated and maintained in calibration.

CONCLUSIONS

The difference between the Ku-band and C-band results are shown in Figure 10. The RMS of the difference is 0.84 nanoseconds,which demonstrates comparable performance of the C-band TWSTT measurement system to that of Ku-band. The bias of 24 nanoseconds should be removed when both TWSTT measurement systems are calibrated. The C-band measurement system earth station requirements to achieve these results included a 5.5-meter antenna in Rockledge, FL and a 4.6-meter antenna in Ft. Collins, CO. The transmitted power was set at six to seven watts.

The results of this experimental comparison show that C-band TWSTT may be used in this application with comparable performance to Ku-band, and an adequate C-band earth station, would include approximately a five-meter antenna with a ten-watt RF transmitter.

REFERENCES

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5. I. J. Galysh and G. P. Landis, "Two-way Time Transfer Results at NRL and USNO," Twenty-fourth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, December 1 - December 3, 1992, pp. 231-242.

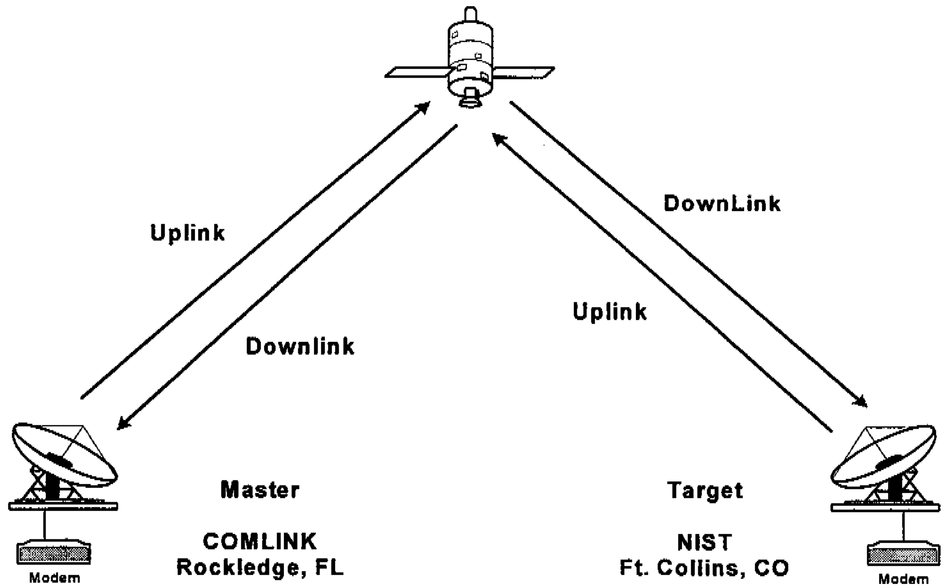

Figure 1. Basic Two-Way Satellite Time Transfer Link

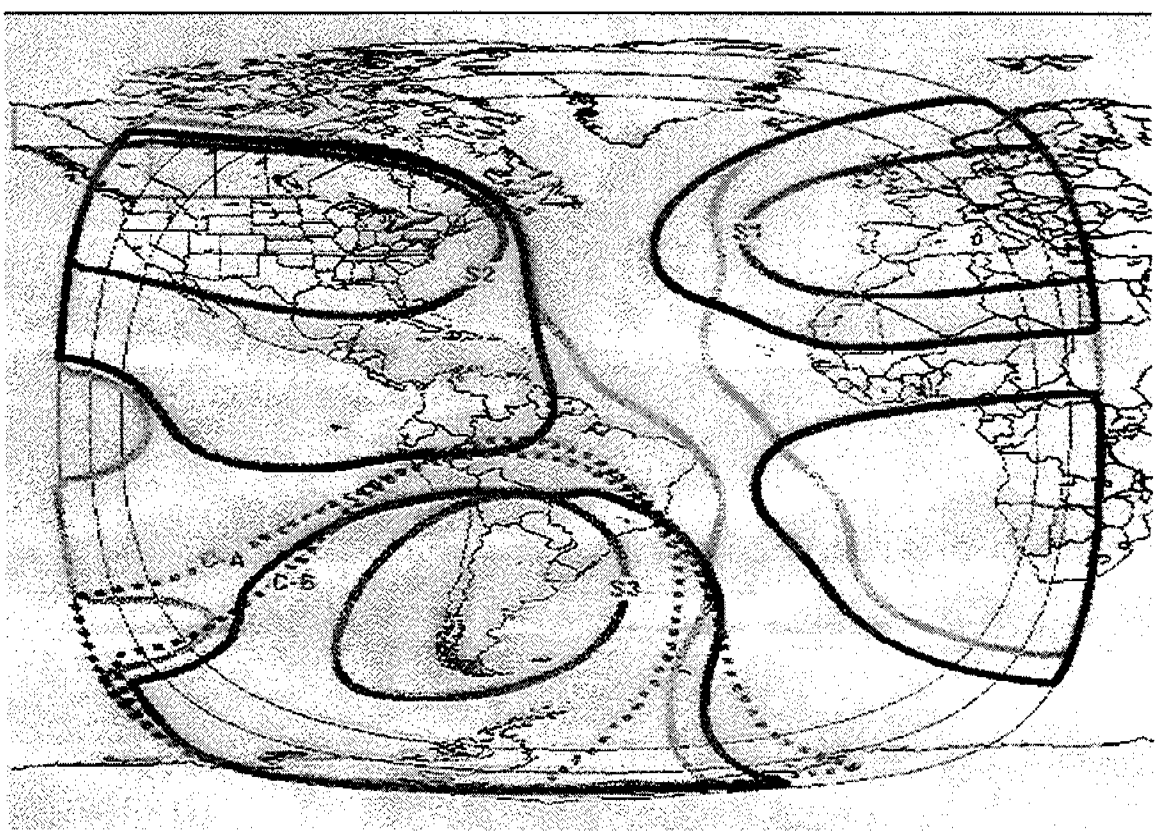

Figure 2. Satellite Footprint

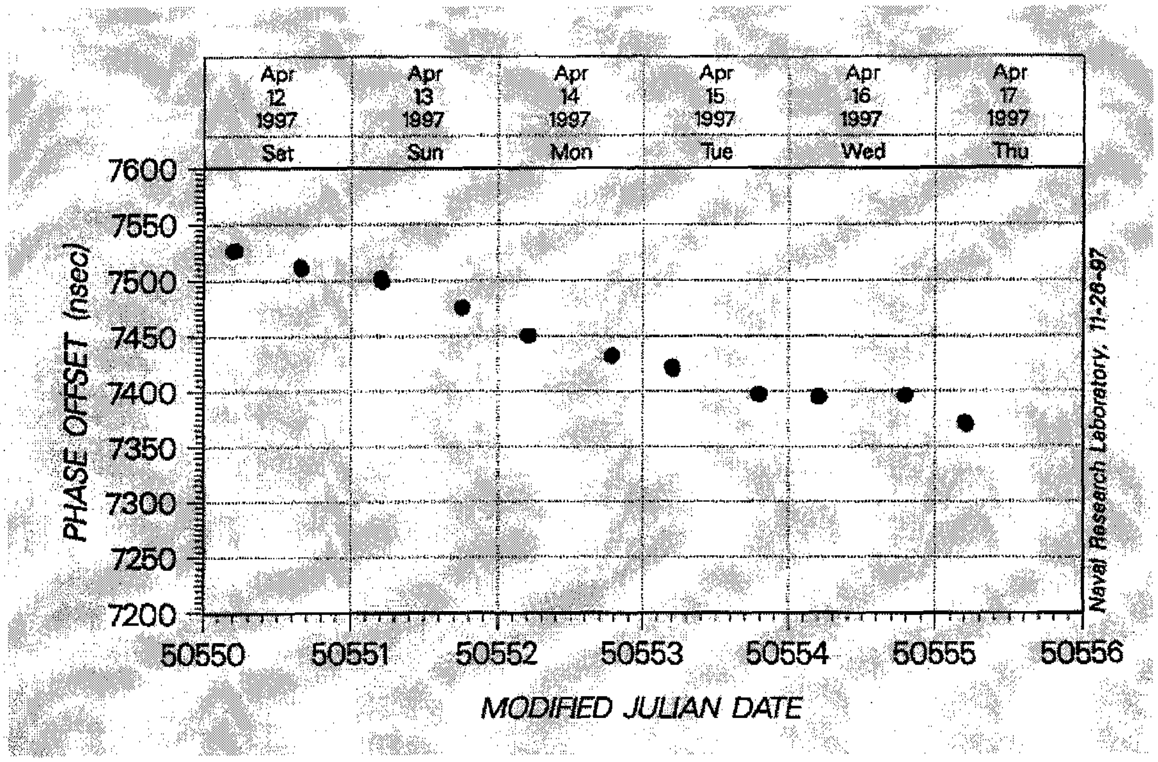

Figure 3. Rockledge, FL vs. Ft. Collins, CO Ku-band TWSTT

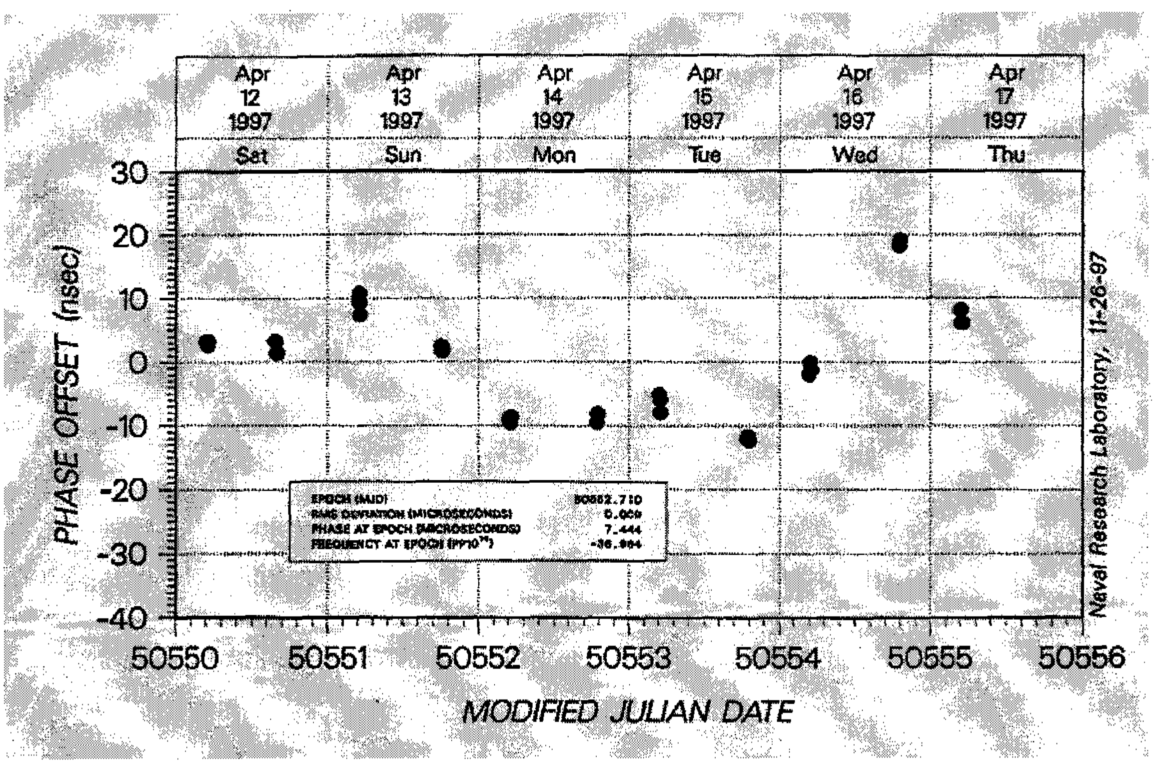

Figure 4. Rockledge, FL vs. Ft. Collins, CO Ku band TWSTT linear residuals

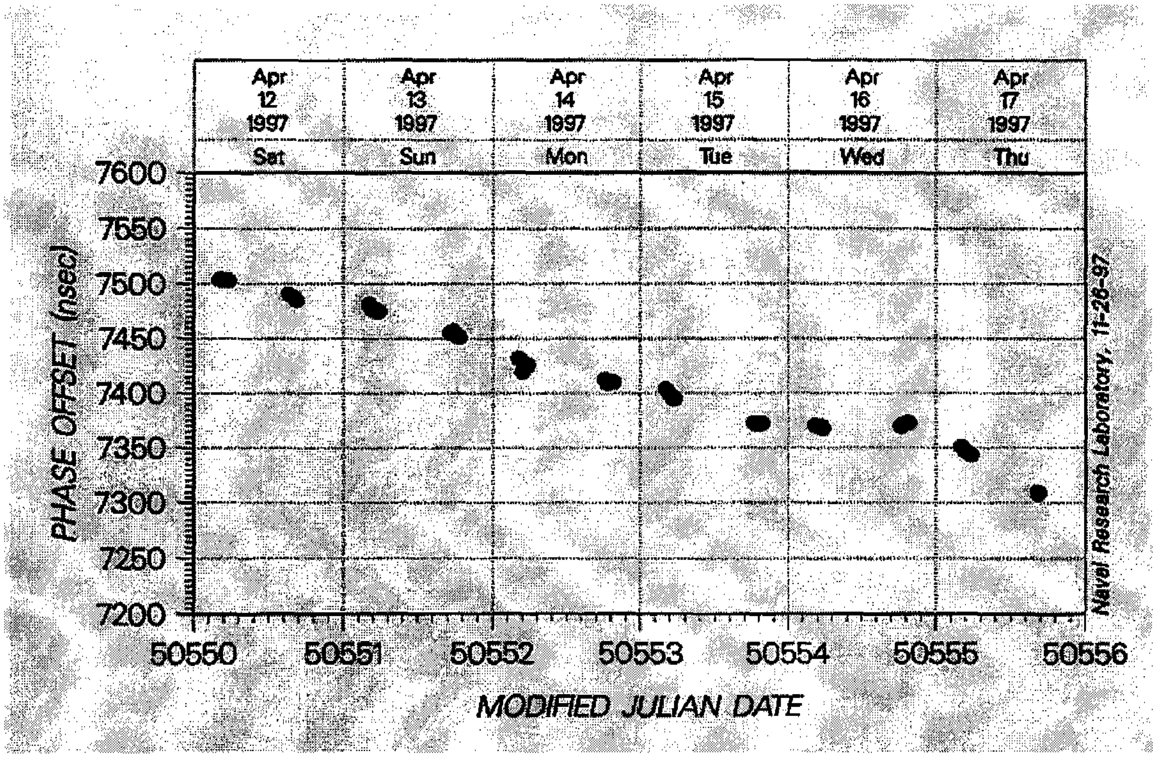

Figure 5. Rockledge, FL vs. Ft. Collins, CO C-band TWSTT

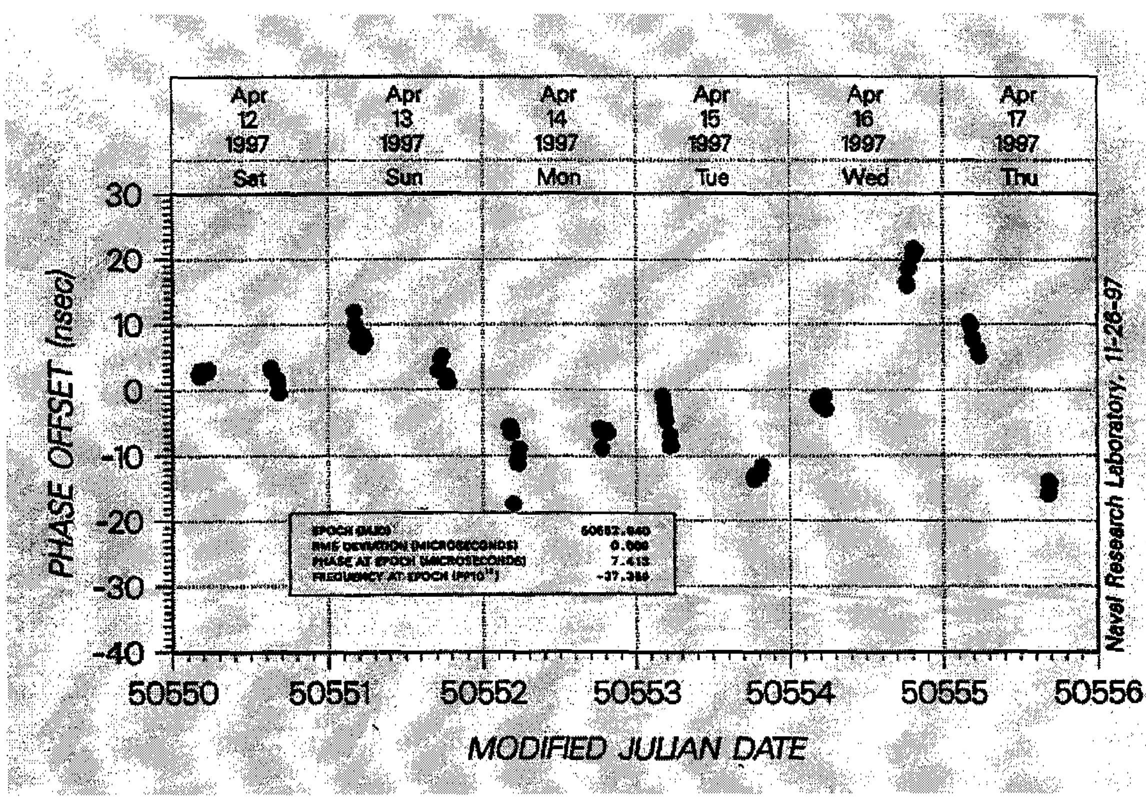

Figure 6. Rockledge, FL vs. Ft. Collins, CO C-band TWSTT linear residuals

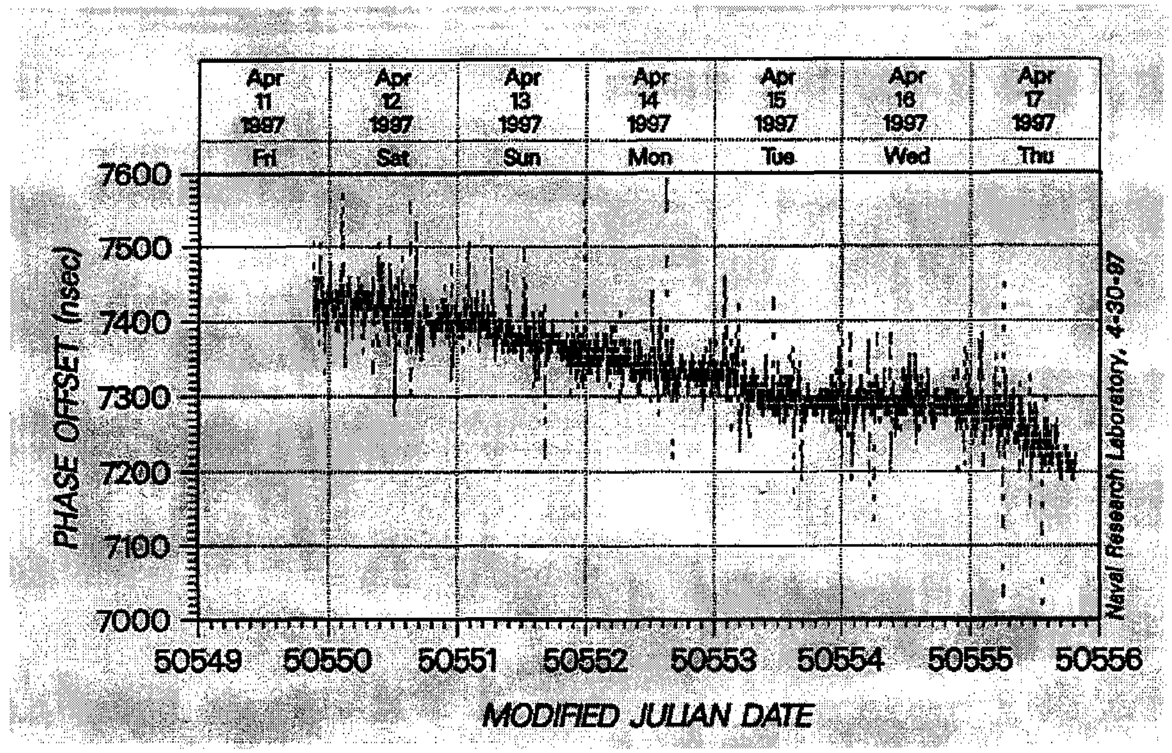

Figure 7. Rockledge, FL vs.Ft. Collins, CO GPS Common-View Time Transfer

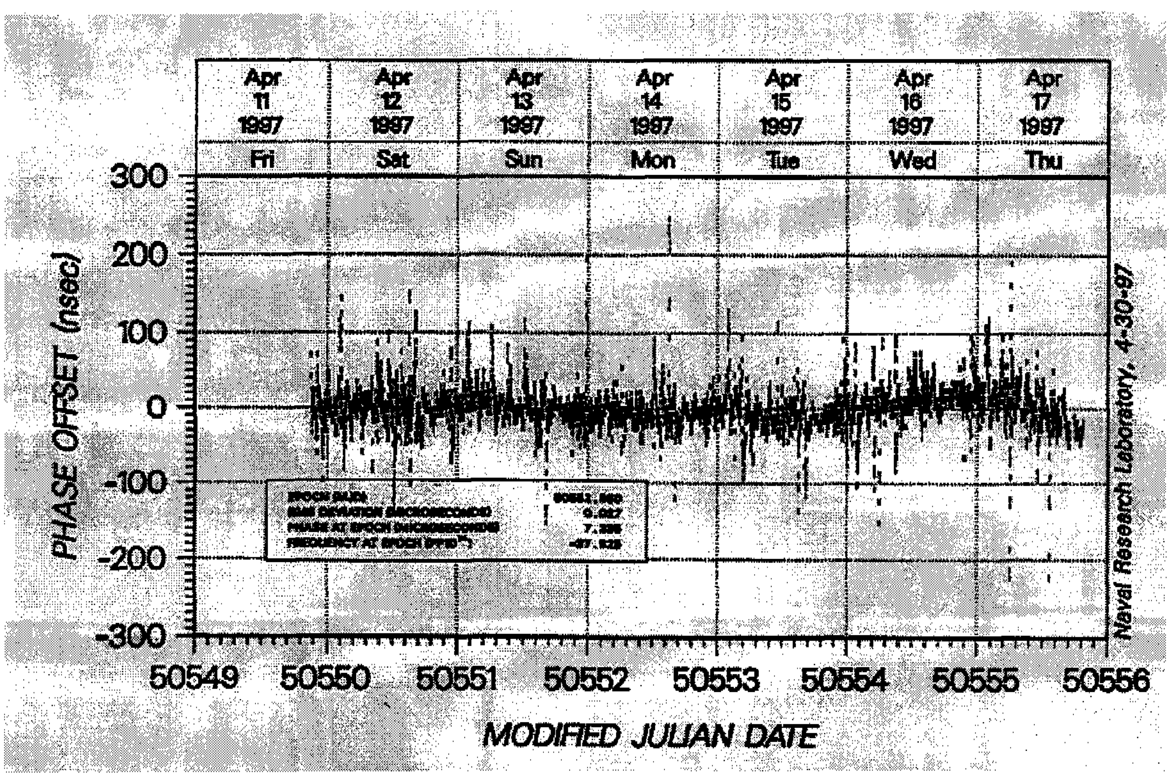

Figure 8. Rockledge, FL vs.Ft. Collins, CO GPS CVTT linear residuals

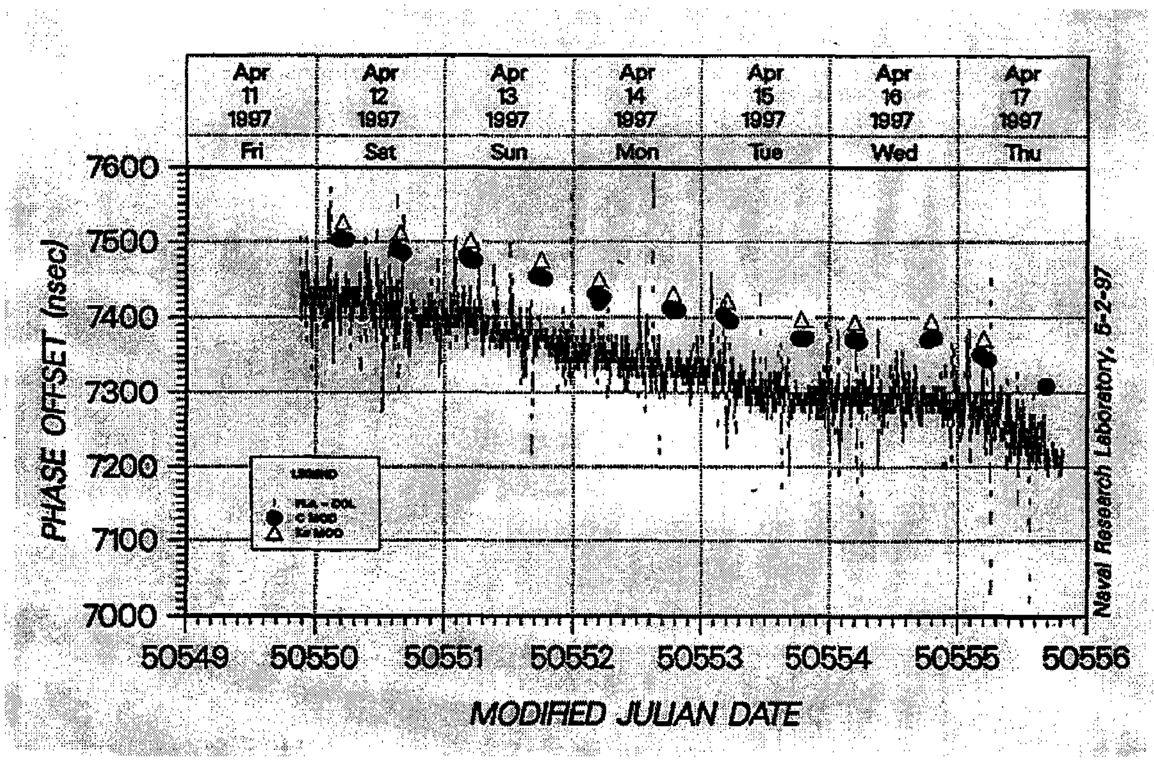

Figure 9. Rockledge, FL vs.Ft. Collins, CO Ku and C-band TWSTT, and GPS CVTT

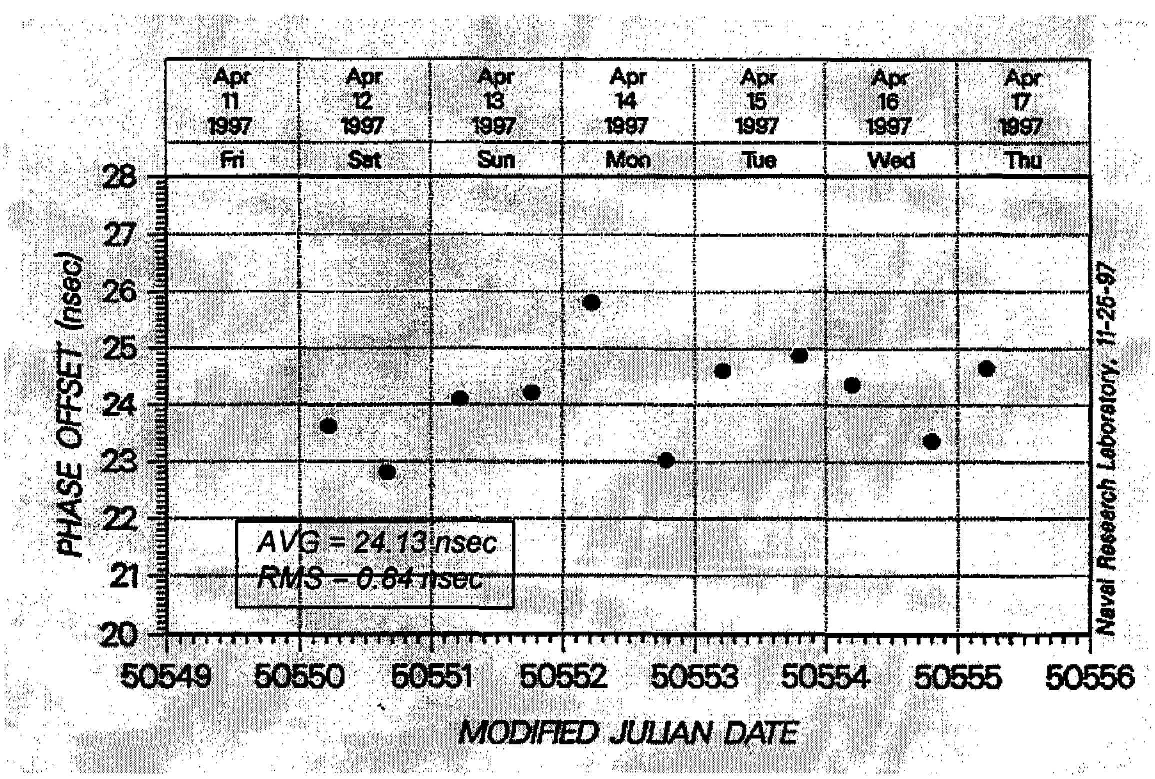

Figure 10. Ku-band and C-band TWSTT Difference

Questions and Answers

BOB WEAVER (UNIVERSITY OF SOUTHERN CALIFORNIA): What size C-band antenna did you use? You said you used 10 watts.

ORVILLE OAKS (NRL): The antenna was a five-and-a-half-meter antenna at the Florida site. NIST was 5.6, something like that.