29-04

GPS MOVING VEHICLE EXPERIMENT

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Abstract

The Naval Research Laboratory (NRL), in the development of timing systems for remote locations, had a technical requirement for a Y code (SA/AS) GPS precise time transfer receiver (TTR) which could be used both in a stationary mode or mobile mode. A contract was awarded to the Stanford Telecommunication Corporation (STEL) to build such a device. The Eastern Range (ER) also had a requirement for such a receiver and entered into the contract with NRL for the procurement of additional receivers. The Moving Vehicle Experiment (MVE) described in this paper is the first in situ *test of the STEL Model 5401C Time Transfer System in both stationary and mobile operation.*

The primary objective of the MVE was to test the timing accuracy of the newly developed GPS TTR aboard a moving vessel. To accomplish this objective, a joint experiment was performed with personnel from NRL and the ER at the Atlantic Undersea Test and Evaluation Center (AUTEC) Test Range at Andros Island. This range is under the direction of the Naval Undersea Warfare Center (NUWC), Newport, Rhode Island. The test was conducted through the West Palm Beach (WPB) Detachment of the NUWC.

Results and discussion of the test are presented in this paper.

BACKGROUND

The U.S. Naval Research Laboratory (NRL), in the development of timing systems for remote locations, had a technical requirement for a Y code (SA/AS) GPS precise time transfer receiver (TTR) which could be used both in a stationary mode or mobile mode. A contract was awarded to the Stanford Telecommunication Corporation (STEL) to build such a device. The Eastern Range (ER) also had a requirement for such a receiver and entered into the contract with NRL for the procurement of additional receivers. The Moving Vehicle Experiment (MVE) described in this paper is the first *in situ* test of the STEL Model 5401C Time Transfer System in both stationary and mobile operation.

OBJECTIVE

The primary objective of the MVE was to test the timing accuracy of the newly developed GPS TTR aboard a moving vessel. To accomplish this objective, a joint experiment was performed with personnel from NRL and the ER at the Atlantic Undersea Test and Evaluation Center (AUTEC) Test Range at Andros Island. This range is under the direction of the Naval Undersea Warfare Center (NUWC), Newport, Rhode Island. The test was conducted through the West Palm Beach (WPB) Detachment of the NUWC.

PARTICIPANTS

The following personnel and their organizations participated in this experiment:

Name	Organization	Title
O. J. Oaks	Naval Research Laboratory	Code 8153 , Head
James Wright	Computer Sciences Raytheon	Timing Systems, Leader
Christopher Duffey	Computer Sciences Raytheon	Timing Systems Engineer
Chauncey Dunn	Computer Sciences Raytheon	Timing Systems O&M, Mgr.
Charles Williams	Computer Sciences Raytheon	Timing Systems O&M , Tech.
Hugh Warren	SFA, Inc.	Engineer
Wilson Reid	Naval Research Laboratory	Code 8153
Ernie Moody	NUWC, Newport	Code 3891, Head
Jack Cecil	AUTEC WPB	Code 3814, Head
Tom Zeh	AUTEC WPB	Program Manager
Dave Cooney	AUTEC Andros Island	Program Test Conductor
Jeff Byrne	AUTEC WPB	Engineer
Linda Tough	AUTEC Andros Island	Range User Coordinator
Laurie Robinson	AUTEC Andros Island	Data Analysis Group
Ed Cote	AUTEC Andros Island	Launch Recovery Sys. Eng.
Gerald Phifer	AUTEC Andros Island	Security Engineer
Rick Beasley	AUTEC Andros Island	R/V Ranger, Captain
Chris Holly	AUTEC Andros Island	R/V Ranger, 1st Mate
Mike Boyle	AUTEC Andros Island	R/V Ranger, 2nd Mate
James Buisson	Antoine Enterprises	Consultant to SFA, Inc.

METHODOLOGY AND IMPLEMENTATION

To begin the MVE, tests were first conducted in a stationary mode at a known location at the AUTEC pier to assure calibration and initial data validation. The GPS TTR antenna was located directly above a Defense Mapping Agency (DMA) benchmark survey point (Photo 1). Two receivers were used and configured as shown in Figure 1 and Photo 2. The GPS TTR (S/N15) was later removed from the shed on the pier (Photo 3) and used aboard the AUTEC vessel, R/V Ranger. The ship is shown in Photos 4 and 5. While the test was performed on the vessel, the GPS TTR antenna was mounted on the rail adjacent to the bridge of the ship, as shown in Photo 6.

The atomic frequency standards used in the experiment were supplied by Computer Sciences Raytheon (CSR), who is the ER contractor, from their Cape Canaveral Range Operation Control Center (ROCC). The HP 5061A cesium frequency standard (S/N 2383) was maintained in the ROCC laboratory prior to the MVE. Timing data relative to UTC(USNO) were recorded for ten days prior to its being transported. The 5061A was equipped with an external battery supply, and continuous operation of the clock was maintained throughout the test. The test included a 2-hour drive from Cape Canaveral to West Palm Beach, a 45-minute plane ride from WPB to the AUTEC Andros Island Site, and movement from the pier shed to the ship (Photos 7 and 8).

As shown in Figure 1, both STEL GPS TTRs were driven by the 5 MHz signal from the HP5061A (S/N 2383) frequency standard, to assure calibration of the complete system before removing TTR (S/N 15) to the ship. Figures 2 and 3 depict the equipment configuration next employed. Each of the TTRs was driven by independent frequency standards. The HP5061A frequency standard supplied 5 MHz to TTR (S/N 15), and the FTS 4050 (S/N A167) cesium frequency standard supplied the required 5 MHz to TTR (S/N 20).

The FTS 4050 cesium frequency standard was shipped to AUTEC Andros, with no battery supply, in a powered-down condition. Before being connected to the GPS TTR, its phase was adjusted to within 1 nanosecond of that of the HP5061A. This was done so that at the end of the MVE onboard test, the HP frequency standard could again be compared to the FTS 4050 to assure continuous operation of the HP 5061A clock during the test. The two clocks were operated during a 24-hour period to determine the frequency offset between the two clocks prior to the transport of the HP clock onboard the R/V Ranger.

Figure 4 shows the equipment configuration for the STEL TTR S/N 15 driven by the HP5061A as it was used during the MVE sea trial portion of the test. Photos 9, 10, and 11 show the equipment as it was configured on the bridge of the Ranger.

The AUTEC Andros Test Range was chosen because the Navy routinely performs tests using ships such as the Ranger, and NRL could easily procure space and time as a secondary experimenter at a minimum cost to conduct the MVE. The AUTEC Range performs both a surface radar tracking and in-water precise tracking of the Navy vessels. The precise in-water system uses hydrophone pingers. All tracking data of the ship during the MVE were supplied to the experimenters at the conclusion of the test.

RESULTS

Data obtained on 14 May 1995, with the equipment configured as shown in Figure 1, are presented in Figures 5 and 6. The plots show the phase difference between the HP5061A clock and UTC(USNO), as measured through GPS using the two TTRs. The 9-nanosecond quantization of the receiver output can easily be seen in the graph. Essentially no phase offset exists between the two receivers, and each receiver realized a peak-to-peak variance of approximately 40 nanoseconds, with an rms deviation of 11.8 nanoseconds and 12.3 nanoseconds respectively. This is considered excellent performance for receivers on a stationary platform.

The tests were repeated on 15 May 1995 in the same configuration, and the essentially identical results are presented in Figures 7 and 8. The rms deviation was 11.9 nanoseconds for TTR (S/N 20) and 10.2 nanoseconds for TTR (S/N 15).

The receivers were then configured as shown in Figures 2 and 3, that is, with each receiver on its own frequency standard. TTR (S/N15) was driven by the HP clock, while TTR (S/N 20) was now driven by the FTS clock.

Results obtained during the period of 15 to 16 May are presented in Figures 9 and 10.

Immediately evident is a frequency offset of the FTS clock from the HP clock, as shown in Figure 10. The larger phase offset in Figure 10 can then be attributable to the accumulated phase due to the frequency offset of the FTS clock, since the two clocks were synchronized on 12 May. Figure 11 presents residuals to a linear fit using the data from Figure 10. The rms deviation of each receiver during this period was 15.3 nanoseconds for TTR (S/N 15) and 15.3 nanoseconds for TTR (S/N 20).

The final results were obtained during the sea trials after TTR (S/N 15) and the HP clock had been placed aboard the R/V Ranger. Figure 12 is the data obtained with Receiver 20 at the shed on the pier. The rms deviation of this data set was 10.7 nanoseconds. Figure 13 presents results obtained from the sea trials. During this period, the speed of the ship changed from stationary to about 10 knots, with the heading varying 360 degrees. Because of the nature of the primary experiments, sudden shocks and vibrations were received by the test equipment. As can be seen in Figure 13, the results were excellent during the entire trial. The rms deviation during the sea trial was calculated to be 14.8 nanoseconds.

CONCLUSIONS

Figures 14 and 15 are a succinct summary to the MVE. Depicted on Figure 14 is the measured offset of the HP 5061A clock from UTC(USNO) for the entire period of the experiment. Figure 15 presents the residuals to a linear fit of the data and the accompanying statistics. Data for the first ten days were taken at the ROCC lab prior to deployment to AUTEC. Data for the next six days were obtained at the pier in the AUTEC Andros Range. Data for the 17th day were obtained during the sea trials. The final data points were obtained after the clock had been transported back to its original location at the ROCC. The overall closure has an rms deviation of 13 nanoseconds using all the data collected. This is excellent performance and is well within the system specification.

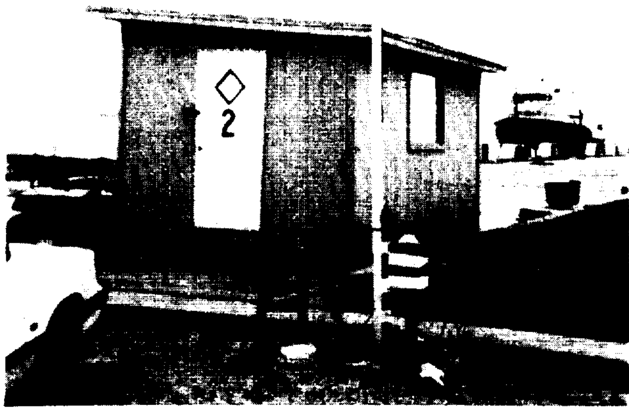

Photo 1 - Initial Set Up on Pier
(2 antennas)

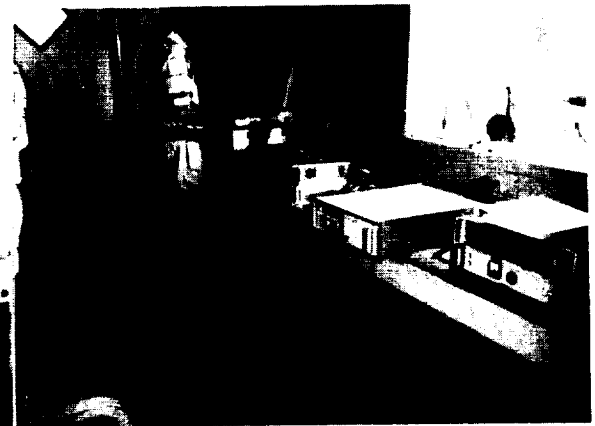

Photo 2 - Equipment in Pier Facility

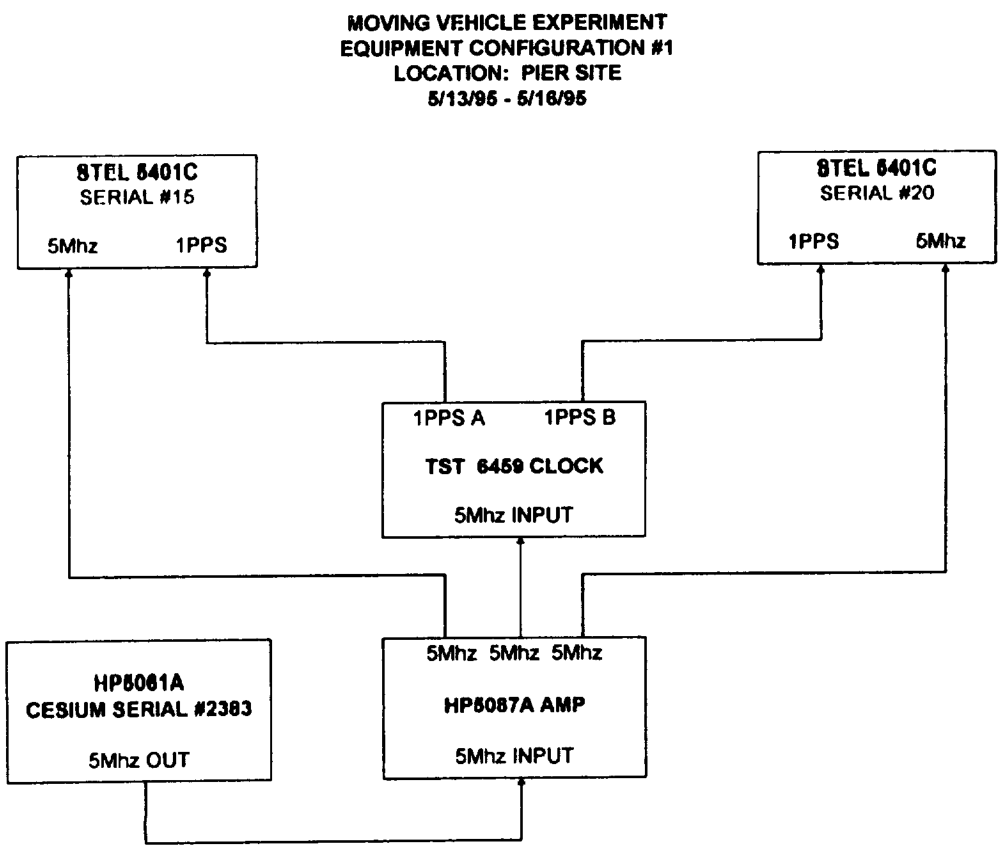

Figure 1 - Initial Equipment Configuration Pier Site

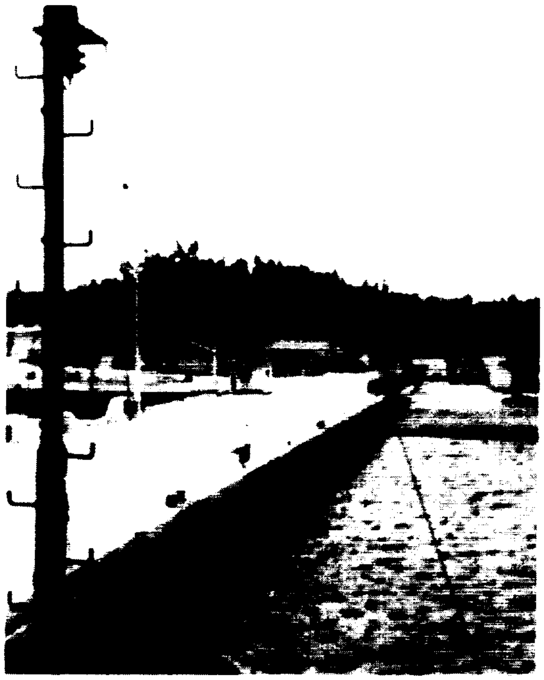

Photo 3 - Pier Site From RV Ranger Bridge

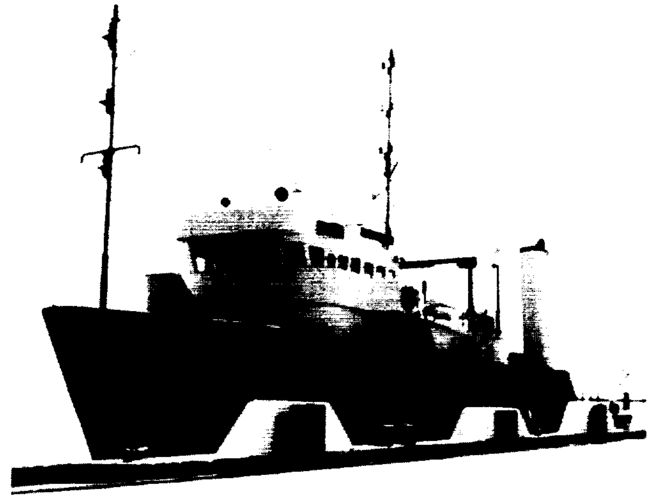

Photo 4 - RV Ranger Vehicle

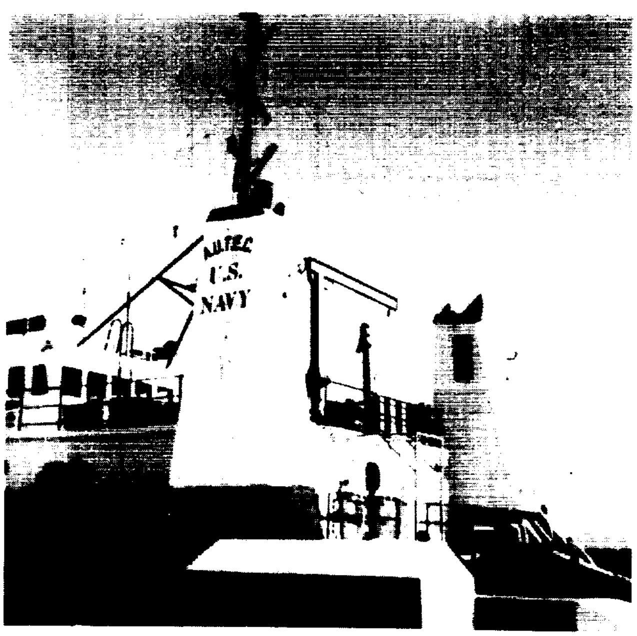

Photo 5 - RV Ranger View of Outside Bridge

Photo 6 - GPS Antenna on RV Ranger Bridge Area

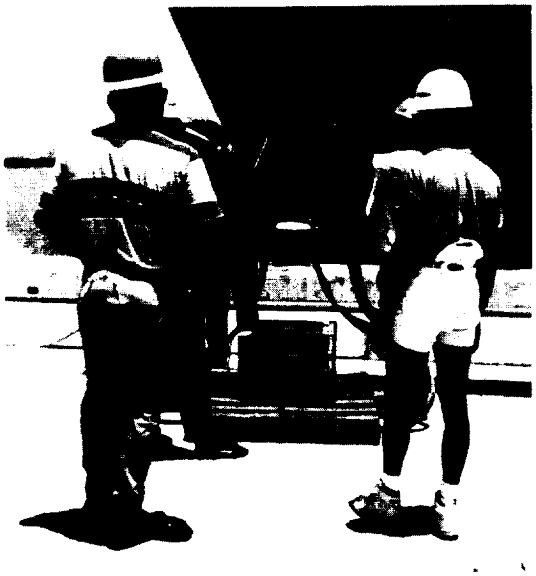

Photo 7 - Cesium Clock on Pier

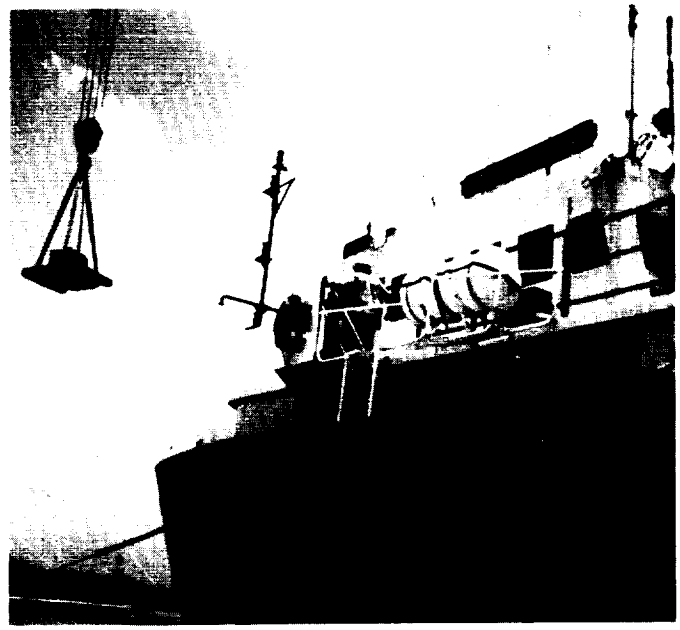

Photo 8 - Cesium Clock in Flight

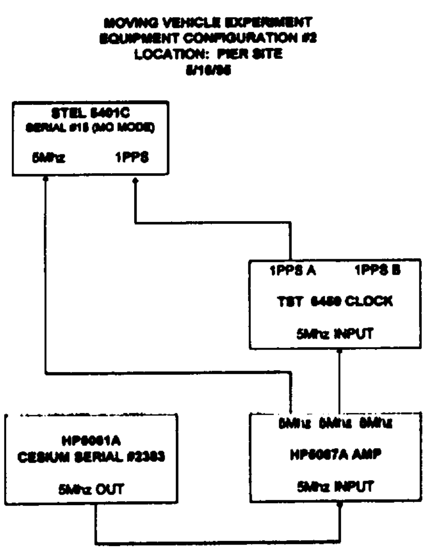

Figure 2 - Equipment Configuration at Pier Site Prior to Shipboard

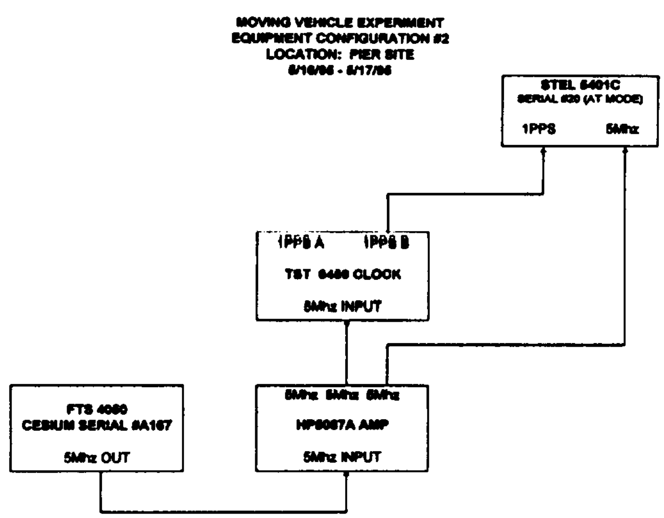

Figure 3 - Final Equipment Configuration at Pier Site

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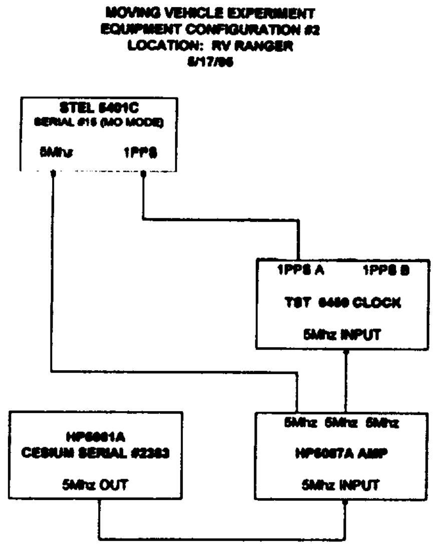

Figure 4 - Equipment Configuration on RV Ranger

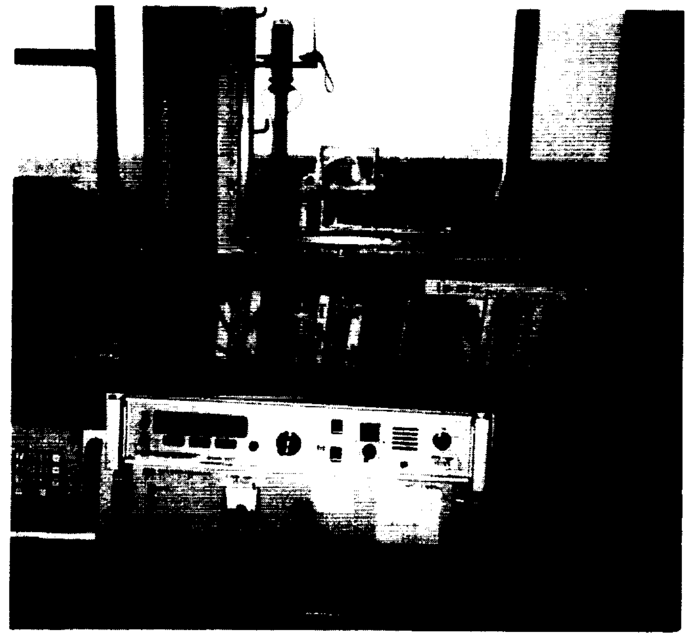

Photo 9 - Equipment in Bridge on RV Ranger

Photo 10 - Equipment on RV Ranger

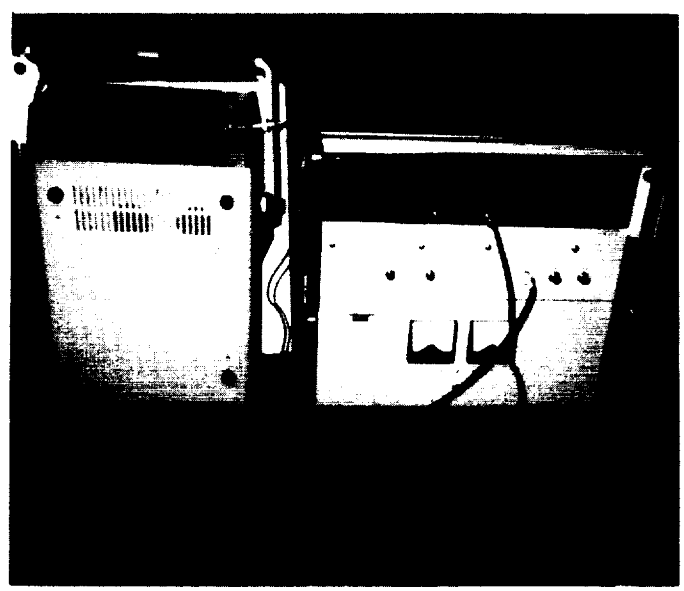

Photo 11 - Clock Onboard RV Ranger

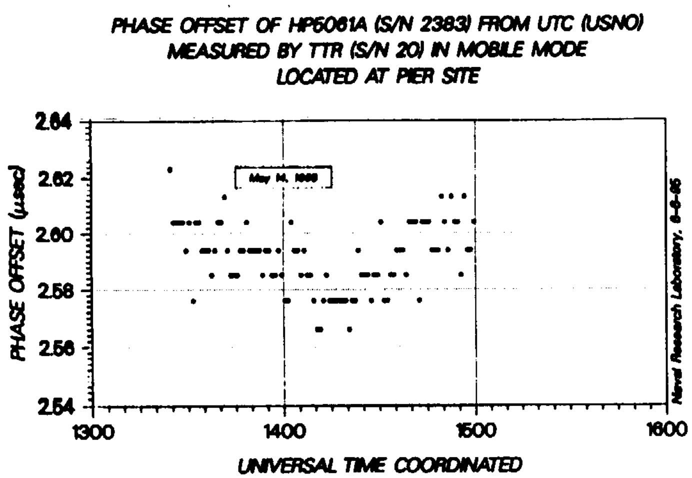

Figure 5

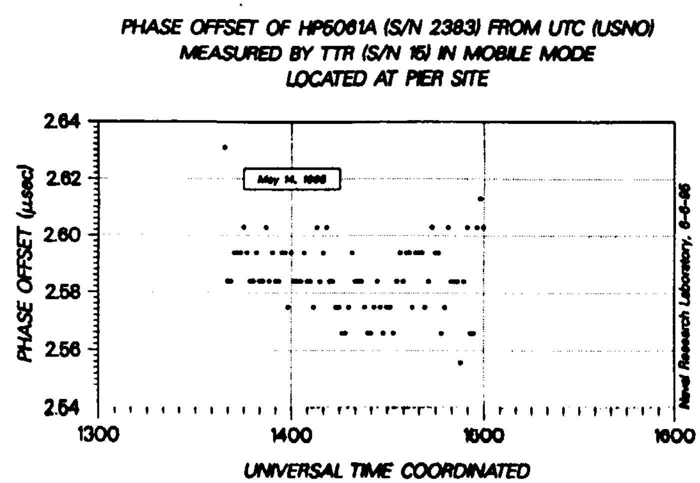

Figure 6

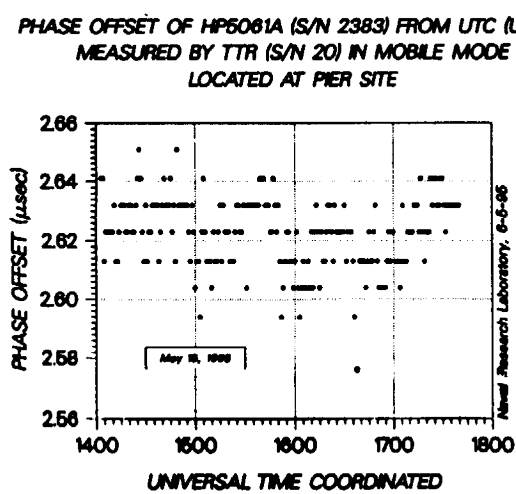

Figure 7

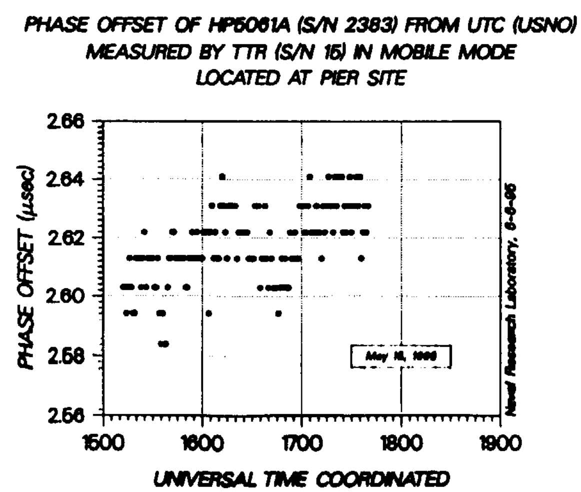

Figure 8

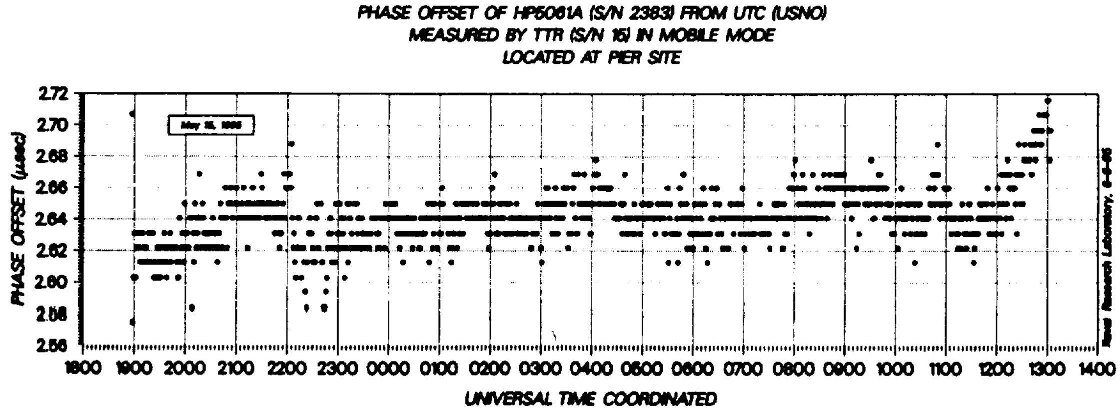

Figure 9

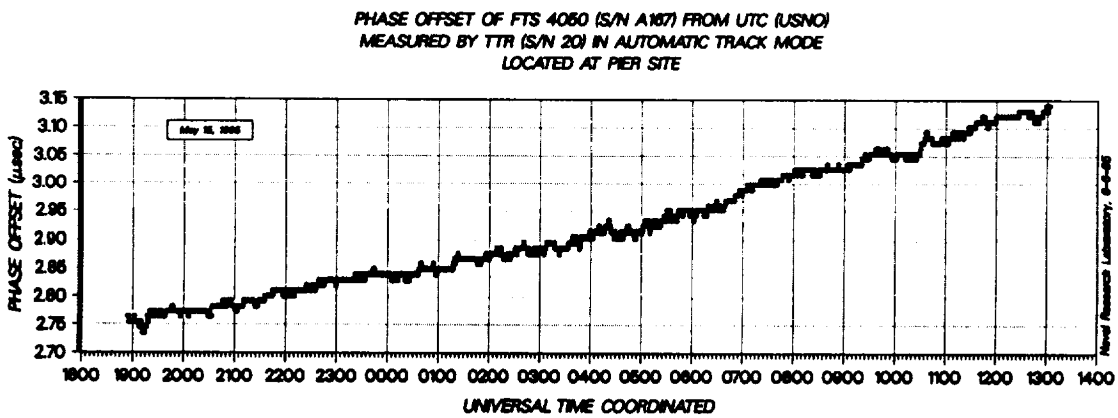

Figure 10

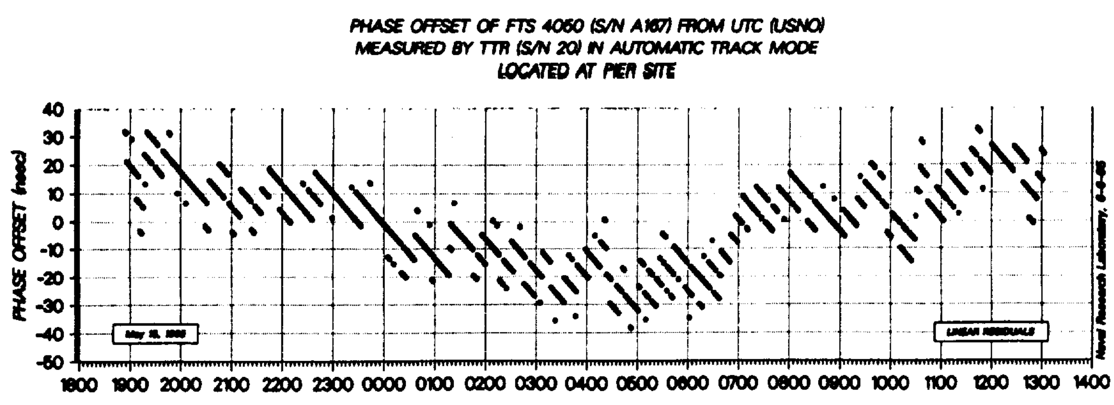

Figure 11

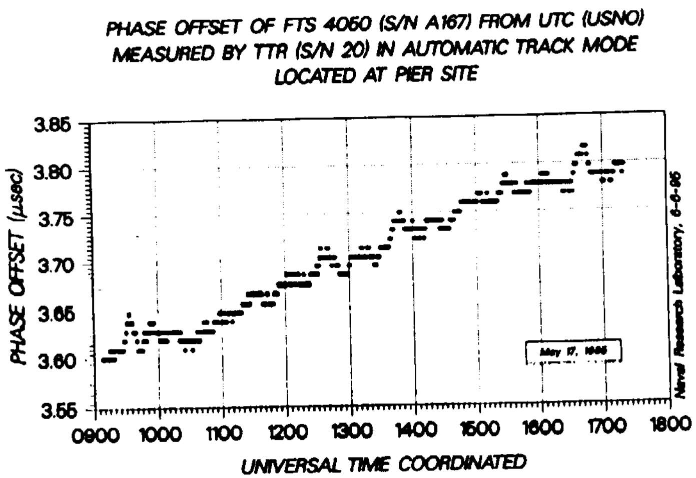

Figure 12

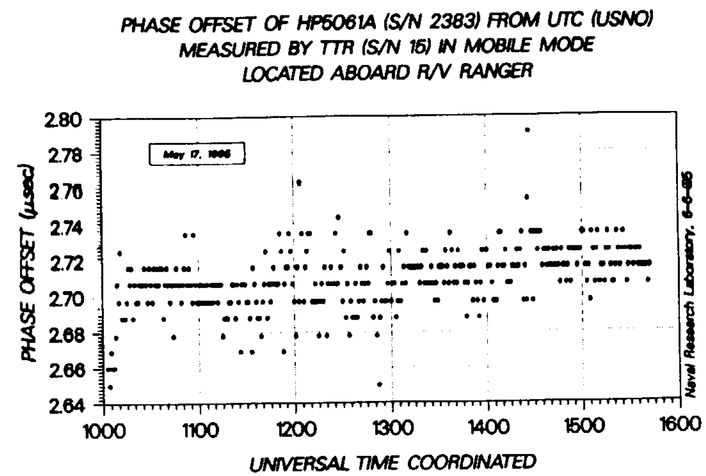

Figure 13

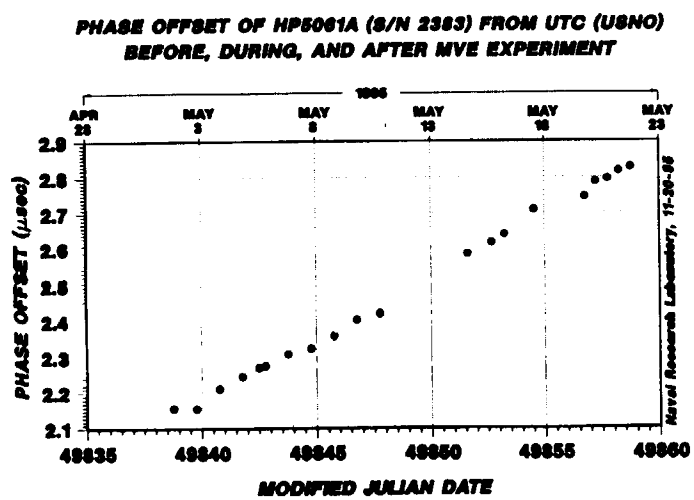

Figure 14

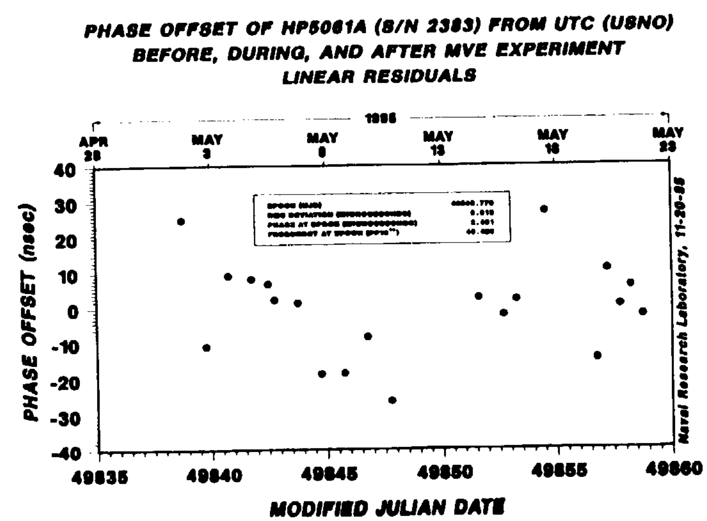

Figure 15

Questions and Answers

HAROLD CHADSEY (USNO): Chris and I had talked earlier about this, this is a loaded question for him. When I gave my presentation, I said it was part of a much larger report. It turns out that Chris's report is the final section that I was unable to do. The question is for you: What type of processing did you do to get such smooth results; because, if you do it out on six-second data points, the six-second data points will vary by more than 50 nanoseconds? When you do your moving position, what was your offset standing still?

The receivers that I was using had offsets in latitude and longitude by approximately a meter; and the altitude was approximately two to three meters, on average, but would exceed 20 meters on the six-second level. I'm just wondering, what did you see?

CHRISTOPHER S. DUFFEY (COMPUTER SCIENCES RAYTHEON): We didn't – there's no processing done on this data to smooth it out or correct any – other than removal of the frequency drift in that one cesium. In fact, we were quite surprised that the initial results came up on the prediction for cesium because it's so close. Maybe we've got a couple good receivers.

I haven't shown – we ditched the difference data of the lat, long and altitude of the AUTEC-provided coordinates, they had finger data on our vessels during the whole time. And we haven't quite finished crunching it all. But you do see some small offsets, less than 10 meters, for sure, and probably rms-positioning errors of around six meters difference.

HAROLD CHADSEY (USNO): Your results are obviously not six-second data points. How did you get the data points?

CHRISTOPHER S. DUFFEY (COMPUTER SCIENCES RAYTHEON): All of those data points were out of RS-232 port of the receiver. And, I look back on it and they were one-minute points.

HAROLD CHADSEY (USNO): One-minute averages?

CHRISTOPHER S. DUFFEY (COMPUTER SCIENCES RAYTHEON): Yes. The receiver has a Kalman filter in it. So unless you disable that, you are going to get some smoothing in the operation.

HAROLD CHADSEY (USNO): Okay, that would be the difference between ours; because, I wasn't using the internal Kalman filtering; we avoided that and wired around it.