On Air With the New Solid State Transmitter

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The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the Commandant or the U.S. Coast Guard.

Abstract

The effort to finish the development of the new Solid State Transmitter (nSSX) equipment suite and the required control and monitoring equipment for the Loran Recapitalization Project is completed. The Coast Guard Loran Support Unit coordinated the integration of the nSSX equipment suite with the new control and monitoring equipment. This paper tells the story of the work accomplished to test the new equipment at the Loran Support Unit, Wildwood, NJ. The story follows the efforts through the installation at the new Loran Station at George, WA and the U. S. Coast Guard on air transmission using the nSSX equipment suite.

Introduction

In 1998, the LSU was sponsored by the Federal Aviation Administration (FAA) to recapitalize the United States Loran-C radio-navigation system. With funding from the FAA, LSU systematically began making improvements to the system, installing new functions, and replacing equipment with cutting-edge, off-the-shelf (OTS) technology. Early examples of new technology were the Automatic Blink System (ABS) and Back-Up Communications (BUC).

Early in the process it was apparent that the aging tube transmitters would have to be replaced if the Loran system's performance was to be improved. A project was started to replace all eleven Tube Type Transmitters (TTX) with a new, state-of-the-art, Solid-State Transmitter (nSSX). This project became the catalyst to replace not only the aging transmitters, but also to provide new buildings, a new ensemble of Timing, Frequency, & Control equipment, and a data network that could support the new equipment. These projects were merged together into a large group effort called the Loran Recapitalization Project (LRP).

LRP equipment was to replace the aging equipment installed at 24 Loran transmitting stations and 24 Loran monitoring sites in the U. S. Loran-C radio-navigation system. The new suite of equipment filled requirements to transmit precisely timed Loran pulses, as well as provide local and remote control and monitoring.

This effort required a two-pronged approach for completion. One effort would be to replace the timing / control and transmitting equipment at eleven TTX stations with new LRP equipment. Another effort would be to replace the timing / control equipment, and upgrade the current thirteen SSX transmitters at legacy stations.

Several projects installed in the field during the early phases of LRP, achieved significant improvements to the system, and paved the way for the future:

- Automatic Blink System (ABS) 1998. ABS improved integrity of the system by auto detecting out of tolerance conditions.
- Back-Up Communications (BUC) 1999. BUC provided contingency communications in the event of a network outage or telco problem at the Loran station or the control station.
- Primary Chain Monitor Site (PCMS) 2000. The upgraded Primary Chain Monitor Site improved remote monitoring capabilities.
- Primary Frequency Standards (PFS) 2001. The PFS included three cesium beam atomic clocks with vastly improved time-base.

With the implementation of new technologies, and growth in bandwidth requirements, it became apparent that the aging X.25 data network and equipment needed replaced. By December of 2002, LSU had replaced the data communications network with a high speed, Frame Relay data network using Cisco router technology. The communications system in Figure 1 was installed at all Control stations, Figure 2 depicts the communications system at all Loran stations, and Figure 3 shows the communications configuration at all monitoring sites.

Figure 1: Control Station Network Communications

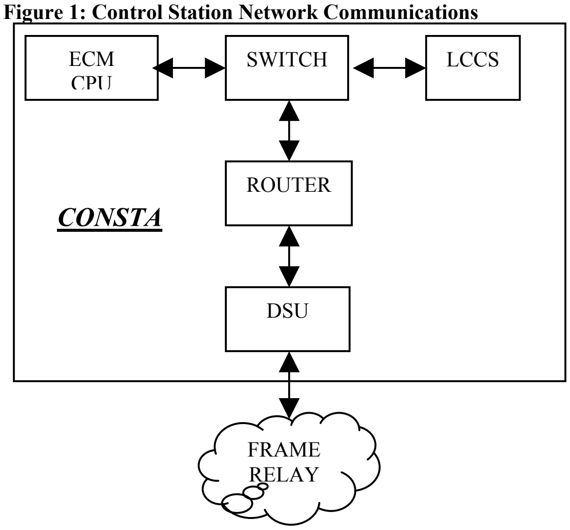
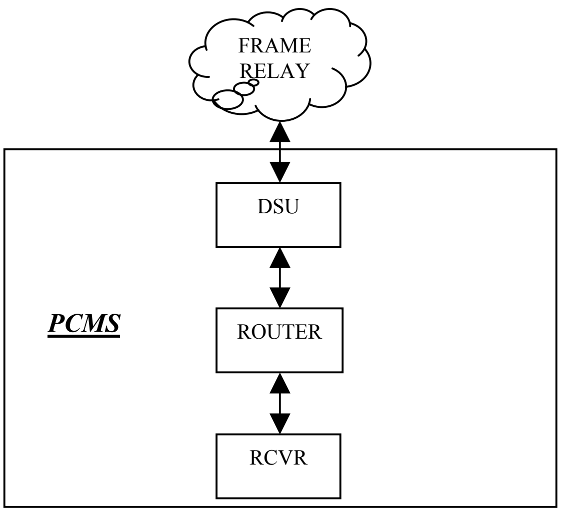


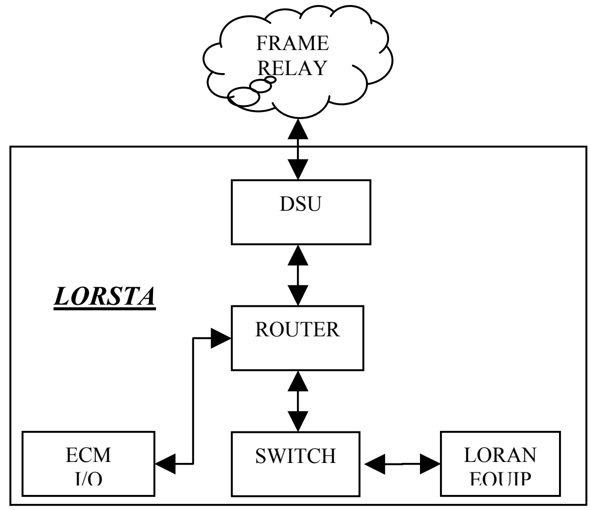
Figure 3: Control Station to PCMS Communications



September 2003 saw the completion of several other very important portions of the LRP effort at both SSX and TTX stations and the completion of backup power to the legacy SSX transmitter.

- Remote Automated Integrated Loran (RAIL). Includes COTS computer system, and custom programmed application which serves as the clearing house for all LORSTA signal parameters.
- Casualty Control Receiver Set (CCRS). Includes All-In-View receiver and antenna system.
- Switch Cabinet Replacement. Provided upgraded circuitry and reliability.
- SSX/nSSX Transmitter Un-interruptible Power Supply (XMTR UPS). Provides continuous transmission of the Loran signal in the absence of primary power.
- Operations Room Un-interruptible Power Supply (OPS UPS). Provides continuous transmission of the Loran signal in the absence of primary power.

Figure 2: Control Station to Loran Station Communications



Now begins the replacement of all equipment at TTX stations. Each TTX location will receive: a new building, a new SSX transmitter set, and the Timing, Control and Monitor equipment.

- A New Building.
- Operations Room UPS (OPS UPS)
- Transmitter UPS (XMTR UPS)
- A Solid State Transmitter Set (nSSX)
- Timing Frequency Equipment (TFE)
- Primary Frequency Standards (PFS)
- Communications Package (Router, Switch, etc.)
- Remote Automated Integrated Loran (RAIL)
- Timing Monitor System (Locus receiver)
- Equipment Control and Monitoring (ECM)

The first newly outfitted station was Loran Station George, WA. The station was commissioned and put “On-Air” on October 23, 2003 at 16:35Z.

LSU's Equipment Testing Process

LSU has developed and employs test and acceptance procedures and processes that thoroughly exercise the various equipments, individually and as a system, to insure they meet or exceed operational parameters as required by the equipment operators. The following testing, as described in reference [3] is carried out on each and every equipment suite and system before being released to the field:

- Contract Factory Acceptance Testing (CFAT) – Testing done at the system/equipment vendor's location to ensure system/equipment meets contractual obligations.
- Contract Installation Certification (CIC) – Certification to ensure contract installation meets the performance requirements of the contract. This does not certify the equipment as an approved baseline. If the equipment has been previously certified through formal testing scenarios in this list, then SOVT could start at sign off of CIC.
- Unit Testing (UT) - The project manager shall establish test cases (in terms of inputs, expected results, and evaluation criteria), test procedures, and test data for testing each CI being developed in accordance with the requirements assigned to the CI. The test cases shall cover all aspects of the unit's detailed design. Unit testing shall test the CI ensuring that the algorithms and logic employed are correct and that the item satisfies its specified requirements.
- Integration Testing (IT) – Each delivered CI shall be integrated and tested to ensure the CI's work together as intended.
- Engineering System Testing (EST) - The goal of this step is to ensure that the formal Technical Acceptance is successful. This step will verify that the system appears to be functioning properly in all aspects. It will concentrate on all aspects of newly assigned requirements and functionality and the verification of the resolution to any assigned System Trouble Report (STR). It is a test performed to demonstrate that a system meets the engineering requirements allocated to it. System testing is performed to ensure the delivered product meets the required system and derived requirements and verifies the correction of assigned STR's. Boundary testing will be performed along with regression testing to ensure no loss of functionality against previously delivered segments. The system test shall aggressively test each CI in the system, as well as the integration of each CI to the system. The results of System Testing shall be formally recorded with a Pass/Fail vote assigned by the Engineering Division Chief. A listing of all STR's recommended as corrected during the testing shall be included in the test report as well as a summary of all new STR's created. Only CI's passing System Testing will be forwarded to Systems Division for acceptance testing.
- Final Acceptance Testing (FAT) - FAT testing is designed to demonstrate that a system, subsystem, or CI meets CCB/LCCB approved requirements and is supportable by SDIV. The result of FAT shall be formally recorded with a Pass/Fail designation by the Systems Division Chief in a memo submitted to the CO of LSU and recorded in the LSU archives. The Configuration Management Branch coordinates FAT. CM, with cooperation of all appropriate parties, will develop scenario based testing procedures designed to simulate the target environment for the new system. FAT is normally comprised of scenario base test cases that perform Range Checking, Branch Checking, Database Integrity Testing, and either Stress Testing, or Performance Testing.
- System Operational Verification Test (SOVT) - A SOVT is used to "certify" the installation. The SOVT will be a combined effort between LSU, NAVCEN and the station personnel. The SOVT checklist should contain checks of all of the new or modified system functionality, as well as checking functionality of any ancillary equipment. The list should also contain checks concerning the quality of the installation; cables properly dressed, drawings properly "red-lined", training provided, etc. Signature blocks should be included for the LSU Installation Team Leader, Station CO/OIC, COCO and NAVCEN if they are onsite for the installation. A copy should be left at the station and the original returned to LSU. Close coordination and cooperative development with COCO and NAVCEN's will eliminate the need for a separate certification conducted by NAVCEN.

The Testing Process and LRP Equipment

A diverse group that included engineering companies, electronics vendors and contractors, government agencies, and academia, to name several, were involved in the LRP effort to complete a new Loran equipment suite. As the different vendors, other government agencies and contractors completed work to support LRP research and development, the different systems were run through the LSU's testing policy required to pass LSU's Configuration Control Board. LSU Project Managers integrated the disparate systems into a whole system. This required whole-system extensive testing at the LSU.

Before whole-system testing could start, LSU had to undertake major construction and equipment installation projects to build up a new laboratory with a brand new equipment baseline.

The first task was to locate space at LSU to put the Megapulse, Inc., Accufix 7500 16 HCG transmitter and the TFE, manufactured by Timing Solutions Corporation. The goal was to complete a clean baseline installation that would be a model for all LRP field installations. The desired design would house the entire LRP equipment suite in the same room. Space was at a premium, because LSU also had to maintain their legacy SSX baseline and the TTX baseline. The decision was made to construct a new building to house the new equipment baseline. This construction began in May of 2002 and was completed in February 2003.

The building is a 100 square foot open room in which the new baseline equipment was installed. LSU personnel installed the Ops equipment UPS, auxiliary equipment rack, TFE, and the Hi and Lo rate RAIL racks. Megapulse then installed the Accufix 7500 transmitter and transmitter control consoles. The final configuration is shown in Figures 4 (transmitter) and 5 (timing and control). The baseline includes six equipment racks at a dual rate station and five equipment racks for a single rate station. From left to right in Figure 5:

- Transmitter Control Console #1
- Transmitter Control Console #2
- Timing and Frequency Equipment
- Auxiliary (Cesiums, Comms, Equipment Monitor)
- RAIL/Locus Low Rate
- RAIL/Locus High Rate

Figure 4: LSU's 16 HCG Transmitter

Figure 5: LSU Ops Room Equipment Baseline

Unit testing was completed for each individual system: TCS, TFE, RAIL, and ECM. Discrepancies found during unit testing were either fixed on-site or at the manufacturers' facilities. The LSU project mangers for each of the three systems were responsible for testing their equipment. Testing was completed with the cooperation of the manufacturers in the case of TFE and TCS, and with the LSU programmer in the case of RAIL. Once the installation and unit testing was complete, system integration began.

Engineering System Testing

Once unit testing was completed, the arduous task of engineering system testing and integration began. The three software driven systems (TCC, TFE, and RAIL) were of particular concern to the system integration team. These three systems interact to allow control to the whole system from the RAIL computer. The RAIL computer interfaces with the remote control computer, the Loran Consolidated Control System (LCCS).

A complete function test was run for each of these three sub-systems from their own graphical user interface (GUI), and from the LCCS GUI. As each function was tested, all other systems were monitored for proper reaction and equipment operation.

This data was gathered in the System Integration Test Plan and Engineering Check List as good or bad. Of course, failures were fixed as quickly as possible. System integration testing, which began in June 2003, lasted approximately six weeks.

Configuration Management and FAT Testing

After Engineering System Testing was completed, Final Acceptance Testing (FAT) was immediately started. FAT for the whole-system was based on industry proven Configuration Management (CM) Standards to certify the systems for field installation. The FAT team consisted of Loran-C experts and operators from the Navigation Centers running the system through multiple scenario based functions and system test. The goal of the FAT team was leave no stones un-turned, ensuring LSU could field the best possible product with minimal risk. Therefore, all equipment was run through their paces over an eight-week period.

The FAT team used a comprehensive test plan to document all functions of the system, System Trouble Reports (STR's) and System Improvement Requests (SIR's). The FAT team also worked extensively with NAVCEN representatives during this phase of testing. The NAVCEN reps were able to gain some significant training and insight as to how the equipment operated. The NAVCEN reps, along with LSU FAT Team also began developing the System Operational Verification Test (SOVT).

A big part of the FAT was to ensure the system was thoroughly documented with maintenance manuals, operations manuals and equipment support sheets.

Systems Operational Verification Test

The SOVT certifies the physical installation of the equipment, as well as the operational performance. The SOVT established system operation parameters and certification procedures to accept the nSSX system for operational use. The SOVT started a full week ahead of the scheduled turn on date and lasted through the AUTM period. It included verification of operational control from NAVCEN detachment Petaluma, CA, the St. Anthony, New Foundland, Control Site and the Loran station at George, WA.

Installation at Loran Station George

The installation at Loran station George was completed well in advance of the actual turn on date. As each system development was completed, they were each placed through FAT testing at the LSU. Some systems (i.e. Locus, RAIL, UPS's, etc.) were installed at operational Loran stations and integrated into the current iteration of the SSX and TTX Loran stations. Other systems (i.e. TFE, ECM) had their first installation at Loran station George, and subsequently, their first operational performance began on October 23, 2003.

Installing the entire system at a Loran station required a great deal of coordination with multiple contractors. Megapulse installed the transmitter and transmitter control consoles, APC, Inc. installed the transmitter and operations room UPS's and LSU installed the timing, RAIL and ECM hardware.

One goal of the installation was to keep tight equipment configuration control, with an eye to standardization. To accomplish this, the Operations Room equipment racks and the transmitter were installed to look exactly like the nSSX Lab at LSU. By comparing Figures 6 (George's transmitter) and 7 (George's Ops Room Equipment) with Figures 4 (LSU's transmitter) and 5 (LSU's Ops Room Equipment), this goal was accomplished.

Figure 6: Loran Station George's 48 HCG Transmitter

Figure 7: Loran Station George's Timing and Control

Upon completion of the system installation, the Loran station personnel received training on the various sub-systems from each major equipment manufacturer or LSU. LSU provided overall training of the whole-system.

The final element to complete the whole system was loading of a new version of LCCS software at all three Control Sites (i.e. NAVCENs Alexandria, Petaluma, and CCG St. Anthony). This software version provided control features to accommodate the new timing and transmitter equipment. LSU then provided training to the operators, to ensure they could properly control the nSSX Loran station signal remotely.

The Day of Reckoning – On Air at Lorsta George

The preparation for this momentous occasion spanned years, culminating in the 23 October operational turn on for Loran Station George. The SOVT was executed in several stages. Key personnel arrived early to perform Quality Assurance checks of the nSSX system and perform communication checks with NAVCEN. The remainder of the team arrived to install FAT certified final software versions. Then, the SOVT team executed the checklists and verification of the system.

The original turn on date was 22 October with a backup date of 23 October. As sometimes happens in these situations, it was good to have a contingency date as the nSSX transmitter experienced a failure on 21 October, the day before the initial AUTM, in an Output Coupling Net and a failure in No. 1 Transmitter Control Console. The transmitter main breaker (CB1) tripped while running into the antenna simulator. Troubleshooting identified 1A5A1 CR1 (CN1), TCC1 power supply 1 and TCA slots 7 and 8 signal conditioning and digital I/O circuit cards to be the cause of failure.

Megapulse dispatched a technician, who arrived the next day to effect repairs. After making the necessary repairs, it was decided to use the alternative date of 23 October for the four-hour AUTM. At 1500Z the AUTM began and the switch was made to the nSSX. The nSSX was placed on-air and the respective Control sites "walked" Loran station back to the assigned Controlling Standard Time Difference (CSTD) for both rates.

The operational portion of the SOVT was completed without incident and the new transmitting station was certified for operational use. However, another problem occurred approximately six hours after the transmitter was placed into operations, 1A5A1 CR1 failed in TCC2. Loran station techs fixed this problem by replacing the failed component and the transmitter was returned to normal operations.

Present U. S. Coast Guard Control

The Coast Guard currently uses System Area Monitor (SAM) control using the Locus III D all in view receiver at Primary Chain Monitor Sites (PCMS) located throughout the coverage area. This type control is called Alpha control. In the event SAM control is not available to a secondary station, then the signal is controlled locally using a Locus receiver at the transmitting station. This type control is called Delta control.

In some cases, the Loran chain's Master station will be used to control all the secondary stations in the chain. The Locus receiver monitors the time interval number of its phase code interval (PCI) TTL pulse to the secondary station's received transmission. This type control is called Bravo control. This discussion is limited to Alpha and Delta control.

Alpha control is considered a normal condition. The transmission of each Loran station is controlled such that the Time Difference (TD) of each baseline, as observed at a designated PCMS far-field monitoring site remains a constant value. The USCG also maintains a Delta receiver at each secondary Loran station. When the Alpha receiver is not available (e.g., communications problems), and during certain casualty scenarios, the USCG will control the transmission time of the secondary Loran station based upon the timing information from this Delta receiver.

Functionally, the main difference between an Alpha and Delta receiver is that the Delta receiver can generate a TINO (Time Interval Number), while the Alpha receiver can generate only TDs.

A TD is the measurement of the time interval that begins with the arrival of the Loran Signal from a Master Station and ends with the arrival of the Loran Signal from the secondary station.

A TINO (for a Delta Receiver) is the measurement of the time interval that begins with the arrival of the Loran signal from a Master station and ends with the generation of the local station timing equipment's PCI TTL pulse.

A TINO has two advantages over a TD. First, because the TTL pulse from the timing equipment is available, even when the secondary station is off-air, the TINO can be used to get a secondary station into its correct timing slot BEFORE transmission begins.

The second advantage involves a casualty scenario called a Timer Jump. During this type of casualty, the timing equipment of a secondary station suddenly jumps far out of its assigned transmission slot. It can be next to impossible for an Alpha receiver to quickly locate the secondary station, as its pulses might be buried under those of a stronger station. The Delta receiver, by contrast, does not have to find the Loran signal of the wayward station. It uses the TTL PCI signal generated by the Timing Equipment of that station. This signal is always available and never obscured by bad weather or other Loran stations. The TINO generated by a Delta receiver will update instantly during a Timer Jump, while it might take several minutes to generate an accurate TD via an Alpha receiver. Casualty Control and Recovery is faster with a Delta receiver, which is why it is also known as the Casualty Control Receiver Set (CCRS).

In order to complete the control of the Loran transmission, other pertinent data is required, particularly pulse amplitude and shape. From the far field at the PCMS receiver, the Envelope to Cycle Difference (ECD) and the signal strength of the received signal is measured. This data is transmitted back to the remote control site and provides a far-field indication of the pulse signal strength and pulse shape.

Additionally, the locally transmitted ECD and pulse amplitude is derived and sent to the remote controller. The Loran transmitting station uses a digital storage oscilloscope to sample the RF feedback energy. This device is a dual channel 50MS/s sampling rate waveform digitizer that plugs into the PCI expansion bus of the Remote Automated Integrated Loran (RAIL) computer. The RAIL Envelope Pulse Analyzer (EPA) provides the following critical Loran signal data:

- Local Envelope Number (LEN)
- Peak Volts/Antenna Current
- Transmit Envelope to Cycle Difference (ECD)
- Sync (By adding the TINO from the Locus receiver and the derived LEN)

SAM Control and Preliminary Results from the Far Field

Because the Loran signal is controlled from the far field (SAM control), data was extracted from the primary monitor site for Loran station George. This data was extracted to confirm whether the transmission from the nSSX was stable. Data was extracted from the A1 PCMS site Whidbey Island, Loran station George's 5990 rate primary monitor site. The Locus receiver at Whidbey Island monitors the transmitted signal from George and outputs the signal strength, signal to noise ratio (SNR), ECD, and TD into a formatted report. This report is automatically sent to the remote controller at specified intervals, usually every fifteen minutes.

The reports were extracted beginning one hour after the switchover to the nSSX for fifteen hours. The switchover occurred at 1600Z (0900) PST. The data analyzed was from reports delivered to the remote controller at St. Anthony, New Foundland from 1700Z (1000 PST) the 23rd of October until 0800Z (0400 PST) the 24th of October. For comparison purposes, data was also extracted for the same time period on the 15th and 16th of October.

Three of the four parameters, TD, SNR, and ECD, were graphed. The signal strength was not graphed, because it was clear from the reports that the signal strength reading at the receiver for both the 15th and 23rd of October was extremely stable. The signal strength for the 15th remained a rock solid 87dB throughout the fifteen hour time period, and the signal strength for the 23rd remained a rock solid 88dB throughout the fifteen hour time period. The three data elements' graphed are shown in Figures 8, 9, and 10.

Figure 8 shows the 5990 M-Y TD over two fifteen hour periods (the 15th and 23rd of October). The TD nominal is 28405.260. The mean, median, max, and min values were also calculated and are displayed in Table 1. This data shows initial promising results in terms of more stable time base in the far field. The APA loops that control the actual Time of Transmission (TOT) was being controlled by the TFE's Automatic Phase Adjustment (APA) loop. It must be noted that no LPAs were inserted from LCCS during the fifteen hour time period the data was collected.

Table 1: TD Data 5990 M-Y

	OCTOBER 15	OCTOBER 23
MEAN	28405.259	28405.264
MEDIAN	28405.261	28405.263
MAX	28405.286	28405.291
MIN	28405.218	28405.240

Figure 9 shows 5990 Y SNR data and Figure 10 shows 5990 Y ECD data from Whidbey Island over the same two fifteen hour periods. The mean, median, max, and min are displayed in Table 2.

Table 2: SNR Data 5990 Y at Whidbey

	OCTOBER 15	OCTOBER 23
MEAN	35.00	31.77
MEDIAN	36.00	33.00
MAX	38.00	37.00
MIN	31.00	23.00

Table 3: ECD Data 5990 Y at Whidbey

	OCTOBER 15	OCTOBER 23
MEAN	2.37	1.65
MEDIAN	2.36	1.64
MAX	2.78	1.78
MIN	2.22	1.55

Figure 8: Whidbey Island TD 5990 M-Y Comparison Between 15 and 23 October

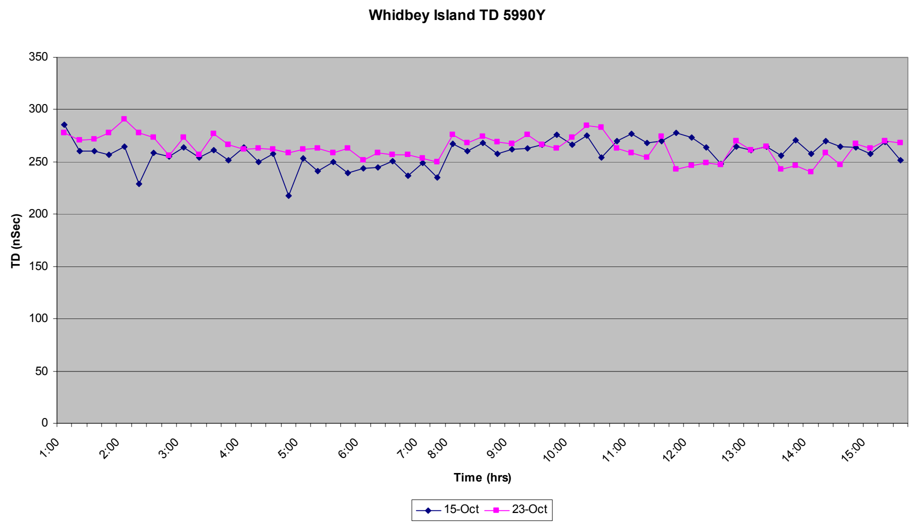


Figure 9: Whidbey Island SNR 5990 Y Comparison Between 15 and 23 October

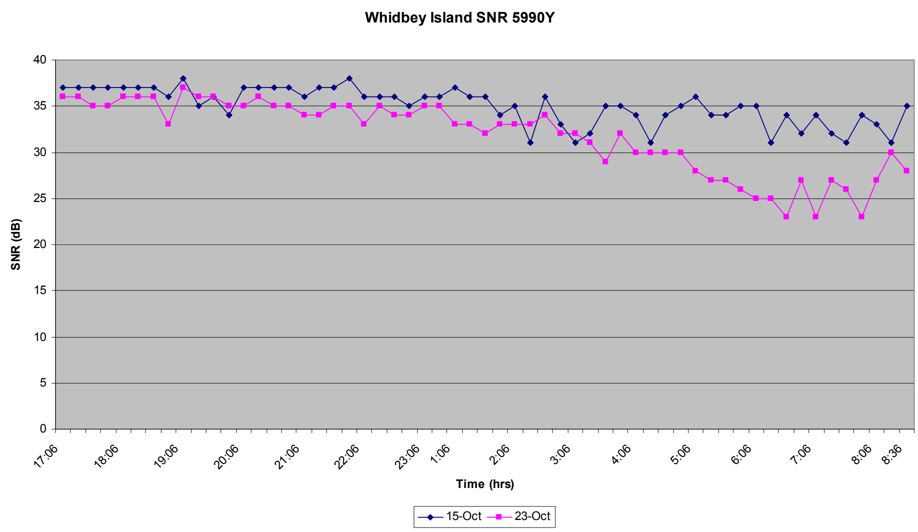
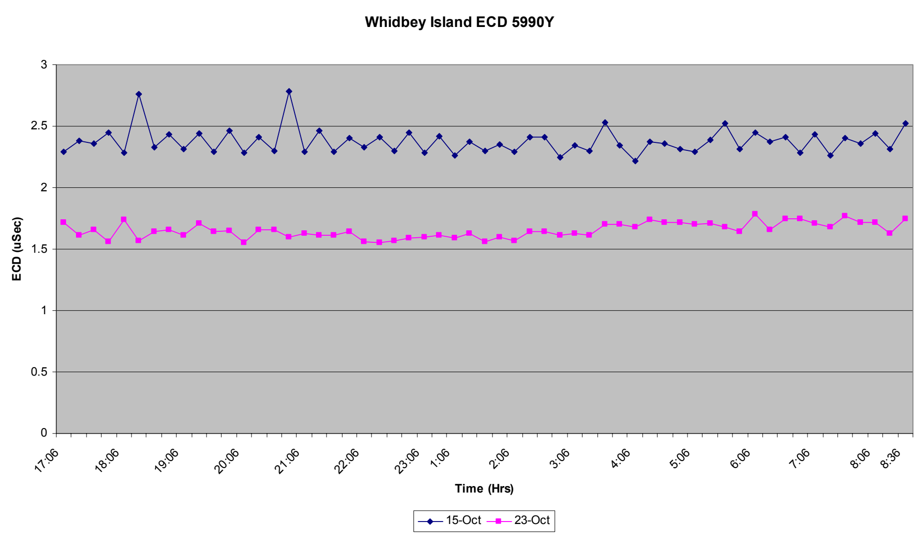


Figure 10: Whidbey Island ECD 5990 Y Comparison Between 15 and 23 October



An Unfortunate Event

As is shown in the initial data in Tables 8, 9, and 10, the nSSX was operating within specifications. Unfortunately, on the seventh day, the 29th of October, a catastrophic failure of the transmitter occurred. With over 20 of the HCGs failed and the HCG circuit breakers tripped, the station crew tried valiantly to reset the faults. Several attempts to turn the transmitter back on were fruitless and yielded the same results, multiple HCG failures. Troubleshooting revealed that the HCGs had multiple component failure and would require substantial time and hardware to return to normal operations. With these insurmountable repair requirements it was determined to return operations to the legacy AN/FPN-45 transmitter.

LSU, along with Megapulse and Timing Solutions has been troubleshooting the nSSX system with the crew at Lorsta George since receiving notification of the failure. LSU downloaded RAIL, TFE, and TCC data logs and have been analyzing this data to determine the cause of failure. LSU is currently working with both Megapulse and TSC to repair the system and get it back to normal operations.

The next step is to return the antenna simulator to Lorsta George so the system can be tested with the transmitter on and triggers applied to try and ascertain what caused the catastrophic failure to occur.

Future Plans

LSU plans to work with Megapulse, TSC, and NAVCEN to complete all repair work and run through an extended test period that will run the whole system through all of its paces. Extended testing will occur, first into the antenna simulator, then on air. This testing will occur both at the LSU and Loran station George.

Once the problem is determined and repaired, LSU will turn its sights to the effort to complete the Loran station Dana transmitter, which is currently slated for nSSX installation in January of 2004. The lessons learned from Loran station George will be applied to the Dana installation effort.

Additionally, the installation of the new TFE is being scheduled for currently equipped SSX Loran stations at Baudette, Seneca, Boise City and Malone. Installations will start during Q2 FY04 and will assuredly offer different obstacles to over come and additional opportunities to excel. LSU plans to work closely with NAVCEN to develop AUTM requirements needed to complete the SOVT and operational turn on of the nSSX and the upgrade of the legacy SSX stations.

Conclusions

The transmitter worked well for six days. Several minor problems were overcome, but the catastrophic failure has caused a setback. The cause of this failure will be determined and repaired. A new date will be selected to switch Loran station George to the nSSX operations. Then, the new whole system at Loran station George will provide a more stable transmission. As other stations are outfitted with the new LRP equipment, this stability will be felt throughout the entire Loran-C system enhancing timing and radio-navigation capabilities. The new equipment uses advanced technology that will improve performance and reliability while reducing maintenance and support costs.

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The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the Commandant or the U.S. Coast Guard.