EUROFIX CONCEPT EVALUATION

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1.0 BIOGRAPHY

Steve Bartlett is presently assigned to the Coast Guard Loran Support Unit (LSU) in Wildwood, New Jersey. He worked as project engineer on the Loran Consolidated Control System and is currently project manager for the Automatic Blink System. Prior to LSU, he was attached to the Naval Sea Systems Command working on the design of the Coast Guard's newest Polar Icebreaker, USCGC Healy. His previous work experience was with the Northrop Corporation as well as the Charles Stark Draper Laboratory. LT Bartlett received a BSEE degree from Northeastern University in 1988 and a MSEE degree from North Carolina State University in 1995.

Lieutenant Commander Schue is the Commanding Officer of the United States Coast Guard's Loran Support Unit (LSU), located in Wildwood, New Jersey. The LSU provides system management, engineering, project, and hot-line support for the entire North American Loran-C System, including Five Control Stations, 29 Transmitting Stations, and 29 Primary Chain Monitor Sites. He holds a Master of Science degree in Electrical Engineering from the Naval Postgraduate School, Monterey, California, where he specialized in robotics. He also holds a Master of Science Degree in Engineering Management from Western New England College. LCDR Schue is a Certified Engineering Technologist and a Certified Quality Engineer.

2.0 ABSTRACT

Eurofix is a developmental system for transmitting Differential GPS (DGPS) corrections on the LORAN signal. Researchers are currently testing a prototype system in Europe to determine the potential of this concept. A Eurofix demonstration was also conducted at the Coast Guard Loran Support Unit in Wildwood, NJ the week of March 30, 1998. The Loran Support Unit, in conjunction with The Technical University of Delft, Megapulse, Incorporated, the Coast Guard Academy, and the Coast Guard Navigation Center, will evaluate the Eurofix concept with Three objectives in mind:

1) evaluate the effect of Eurofix modulation on the Loran signal,
2) evaluate the communications potential of the Eurofix modulation techniques by attempting to quantify bit rate, bit error rate, throughput versus SNR, etc., and
3) validate the navigational accuracy performance of Eurofix.

This paper will concentrate on the first of these Three objectives. The other Two objectives will be discussed along with some anecdotal results.

Eurofix operates by modulating the last Six Loran pulses, in much the same manner as the Coast Guard Two Pulse Communications or Clarinet Pilgrim systems did in the past, although with much more advanced encoding techniques. The Eurofix system is expected to provide similar performance as radio beacon based DGPS at distances up to 1,000 kilometers. Throughput is expected to be lower, but with higher overall availability. The Loran Support Unit testing will allow us to obtain empirical data that will help ascertain the dynamics of the modulation technique.

3.0 INTRODUCTION

Eurofix modulation and encoding techniques are thoroughly covered in References [1-3]. This paper focuses on the results of testing conducted at Wildwood, NJ using the Coast Guard Loran Support Unit's Solid State Transmitter (SSX). The test was conducted for One week, from March 30, 1998 to April 3, 1998. We will cover the test setup used during the evaluation and analyze the data collected, with particular emphasis on the effects of Eurofix Pulse Position Modulation (PPM) on the transmitted Loran-C signal. We will also discuss the performance of the Eurofix datalink and how that relates to DGPS navigational accuracy. Specific evaluation goals are listed below.

1) Measure the impact of modulating the Loran signal on monitor grade receivers and user grade receivers. Specifically, determine the impact on gain number, noise number, SNR, TOA, TD, and ECD. These measurements will be taken with both the modulation turned on and off to provide a baseline measurement.

2) Measure the *raw* bit rate throughput and Bit Error Rate (BER) at full output power. Decrease the output power of the SSX in approximately 5% increments (down to approximately 60% of normal output power) and determine the *raw* bit rate and BER at each discrete point. This will Provide a measurement of *raw* throughput Versus SNR and *raw* BER Versus SNR.

3) Measure the *effective* bit rate throughput and *effective* BER at full output power. Decrease the output power of the SSX in approximately 5% increments (down to approximately 60% of normal output power) and determine the *effective* bit rate and *effective* BER at each discrete point. This will Provide a measurement of *effective* throughput Versus SNR and *effective* BER Versus SNR.

4) Measure message throughput rate and the message error rate at full output power. Decrease the output power of the SSX in approximately 5% increments (down to approximately 60% of normal output power) and determine the message throughput rate and message error rate at each discrete point. This will Provide a measurement of message throughput Versus SNR and message error rate versus SNR.

5) Evaluate the short text message capability of the Eurofix data link to determine the suitability of Eurofix for backup or emergency communication.

6) Evaluate the impact of different Reed-Solomon code lengths on the message throughput rate and message error rate.

7) Evaluate the navigational accuracy of the Eurofix datalink. Determine the effective position accuracy of the Eurofix system and the underlying factors effecting this accuracy (i.e. erasure rate, error rate, failure rate, and effects of temporal and spatial de-correlation).

8) Evaluate the effects of cross rate interference, cross rate blanking, (use 8090M if possible), diurnal effects, night versus day impact, and the impact of LPAs.

9) If possible, evaluate the effects of timing jumps, weather effects, the effects of momentary off airs, and the impact of blink on the datalink.

4.0 EUROFIX EVALUATION EQUIPMENT SETUP

The Eurofix evaluation equipment set up is shown in figure 4.1.

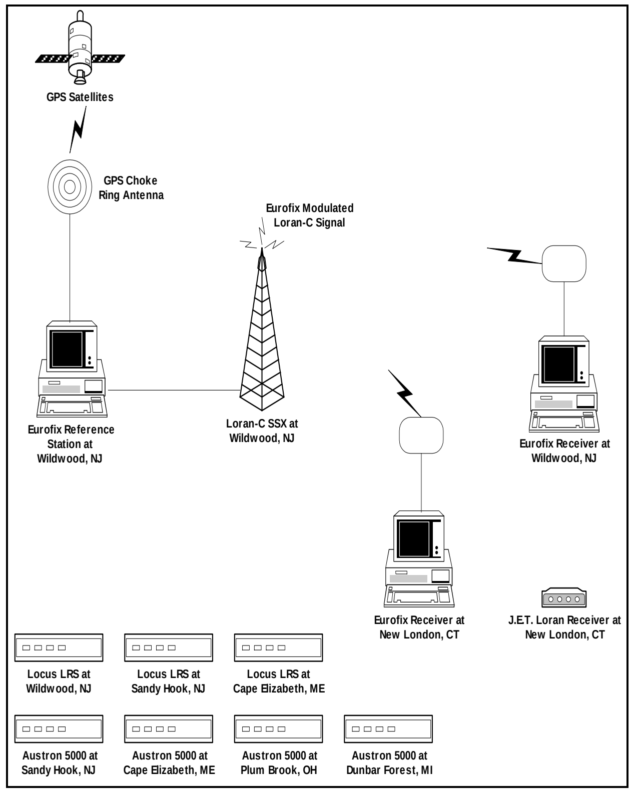
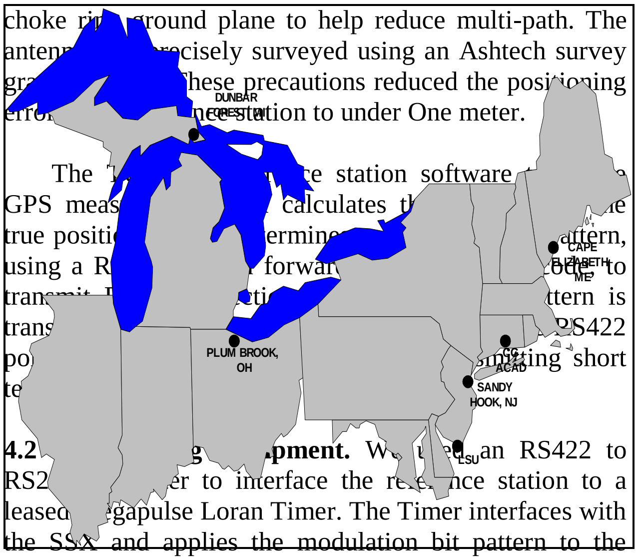


FIGURE 4.1 EUROFIX EQUIPMENT SETUP

4.1 Eurofix Reference Station. The reference station consists of a standard "WinTel" PC with a Novatel GPS receiver and a RS-422 communications port installed. The software to run the system was provided by the Technical University of Delft (TU Delft), Delft, The Netherlands. The reference station was located in a building approximately 200 meters from the SSX building. We chose this location to minimize multi-path interference from the Loran-C transmitting antenna. We also used a



choke ri[illegible] ground plane to help reduce multi-path. The antenn[illegible] precisely surveyed using an Ashtech survey gra[illegible] These precautions reduced the positioning erro[illegible] nce station to under One meter.

The [illegible] ce station software [illegible] GPS meas[illegible] calculates th[illegible] true positi[illegible] ermine[illegible] attern, using a R[illegible] forwar[illegible] code, to transmit [illegible] ectio[illegible] ttern is trans[illegible] RS422 po[illegible] mitting short te[illegible]

4.2 [illegible] **g** [illegible] **pment.** W[illegible] ed an RS422 to RS2[illegible] er to interface the re[illegible] nce station to a leased [illegible] egapulse Loran Timer. The Timer interfaces with the SSX and applies the modulation bit pattern to the transmitted Loran signal. We configured the LSU test transmitter for dual rate operations. We used the Tango slot in rate 9960. This rate is relatively slow and therefore, a good test rate for the Eurofix datalink.

4.3 Loran-C Receiver Equipment. We used several different types of receivers for this evaluation: Locus LRS III Loran receivers, Austron 5000 Loran receivers, and a J.E.T. Model 7202IB Loran receiver. The Locus and Austron are monitor grade receivers, while the J.E.T is a user grade receiver. Many Loran-C user grade receivers do not have the capability to track the 9960 Tango (9960T) station. The J.E.T. receiver has a debug mode that allows it to track 9960T. It also has very good logging capabilities.

The Austron receivers are located at the 9960 GRI chain monitoring sites. Sandy Hook, NJ is approximately 184 Km (114 miles) from Wildwood, NJ. Cape Elizabeth is approximately 645 Km (400 miles), while Plumbrook, OH is approximately 716 Km (445 miles) and Dunbar Forest, MI is approximately 1121 Km (696 miles). The Loran Consolidated Control System (LCCS) test setup located at LSU was used to collect data from these monitor sites.

Locus receivers, temporarily located at Wildwood, NJ, Sandy Hook, NJ, and Cape Elizabeth, ME, were connected to laptop computers at LSU to collect additional data. The flexibility of the LORan Packet Switching System (LORPSS) made this possible. In addition, the Coast Guard Academy, located approximately 358 Km (222 miles) from Wildwood, collected data using the J.E.T. receiver attached to a laptop. Figure 4.2 shows the location of each test site.

FIGURE 4.2 EUROFIX TEST SITES

4.4 Eurofix Receiver Equipment. We constructed a prototype Eurofix receiver at the LSU to collect Eurofix performance data. The receiver consists of a standard “WinTel” PC with an off-the-shelf Analog/Digital Converter (ADC) installed. We used a standard 12 bit, 16 channel, 1 MHz ADC. TU Delft supplied the software to run the receiver as well as an antenna front end. The front end consists of a band pass filter and an Automatic Gain Controller (AGC). We collocated the receiver with the reference station, approximately 200 meters from the SSX building. Since the receiver was so near the Loran-C transmitter, we found that we needed to use a loop antenna with the null pointed directly at the transmitter. We used this receiver to determine the “zero baseline” performance of the Eurofix data link. That is, the performance of the data link with no cross rate or other types of interference. A similar receiver setup was used to collect data at the Coast Guard Academy in New London, CT.

The receiver software takes the filtered and digitized RF and decodes the bit stream to determine the DGPS corrections. These standard RTCM 104 type 9-1 messages can be applied to either an external or internal DGPS receiver. We used the external configuration for our tests. The software will also decode any short text messages sent from the reference station.

<u>5.0 EFFECTS OF EUROFIX ON THE LORAN-C SIGNAL</u>

Eurofix PPM provides the ability to communicate information digitally using the long range Loran-C signal. Loran-C, transmitting at 100 kHz, has a range of over 1,000 Km. This long range RF signal is a powerful tool, regardless of the type of information that is transmitted on the datalink. For example, this evaluation was conducted by transmitting DGPS corrections, but the underlying technology could just as well be used for transmitting differential Loran corrections, or for time tagging of the Loran-C signal, or for emergency communications and control between Loran-C stations.

One of the most important considerations in changing the Loran-C signal structure is backwards compatibility. Any changes to Loran-C must maintain all current signal specifications for legacy users. That being the case, one of the major goals of this evaluation is to quantify the impact of Eurofix PPM on the Loran-C signal. The parameters of interest are signal strength, SNR, TD measurements, and ECD measurements.
shape for the data to be considered reliable. We used the SSX as opposed to the LSU Tube Type Transmitter (TTX) because of the time constraints involved and the ease of modifying the SSX for Eurofix modulation. The TTX would have provided better gain control as it is a true amplifier but additional engineering time would have been required to modify the TTX timing suite.

As Figure 5.1 (using a LOCUS LRS receiver) illustrates, this method introduced fairly large ECD and TD shifts which negated our ability to reliably analyze the performance of the datalink. For example, the large TD excursions that occurred at 1700Z, 1845Z, and 2030Z correspond with large shifts in ECD and also correspond with the times of power down tests. As further data analysis revealed, these shifts had nothing to do with Eurofix modulation. Despite the large time shifts and the degraded pulse shape, the Eurofix receiver located at the LSU decoded all messages successfully.

5.2 Eurofix PPM Effects On Monitor Grade Receivers. As Figure 5.2 illustrates, the effect of Eurofix PPM on a typical monitor grade receiver is insignificant.

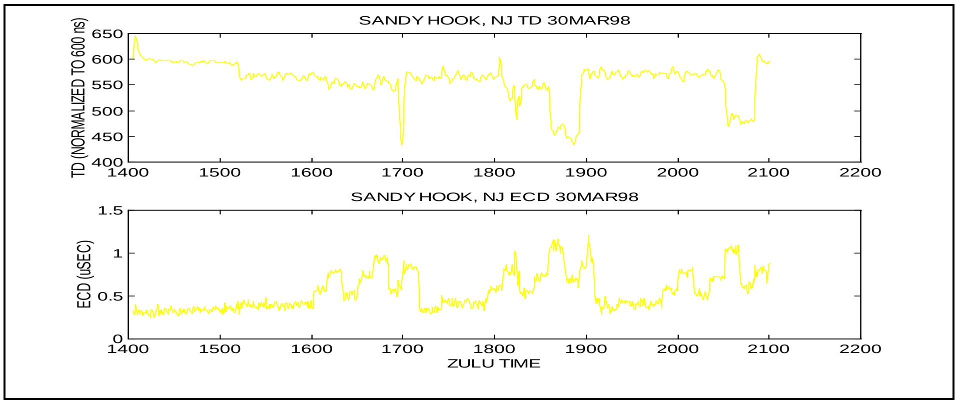


FIGURE 5.1 POWER DOWN TEST RESULTS

5.1 Power Down Testing. As part of the evaluation, we attempted to simulate dynamic movement of the Eurofix receiver by varying the output power of the Loran transmitter. The SSX is not normally operated as a variable output power device but in an attempt to accomplish this testing, a scheme was developed to vary the output power. The method devised involved turning off pairs of Half-Cycle Generators (HCGs) in a specific order. However, while analyzing the data, we realized that shutting down HCGs has too great an impact on pulse

The figure shows approximately Eight hours worth of data collected with a Locus LRS receiver located at Cape Elizabeth, ME. We collected the data while modulating the signal during single rate operations (9960T). Table 5.1 summarizes the pertinent statistics of the data. No corrections were made for Cesium drift during this time period. Despite the lack of corrections, (or possibly in some part due to the lack of corrections) the data shows excellent repeatable accuracy. Standard Deviation of TDs was 14 ns While SNR varied by approximately 4.5%.

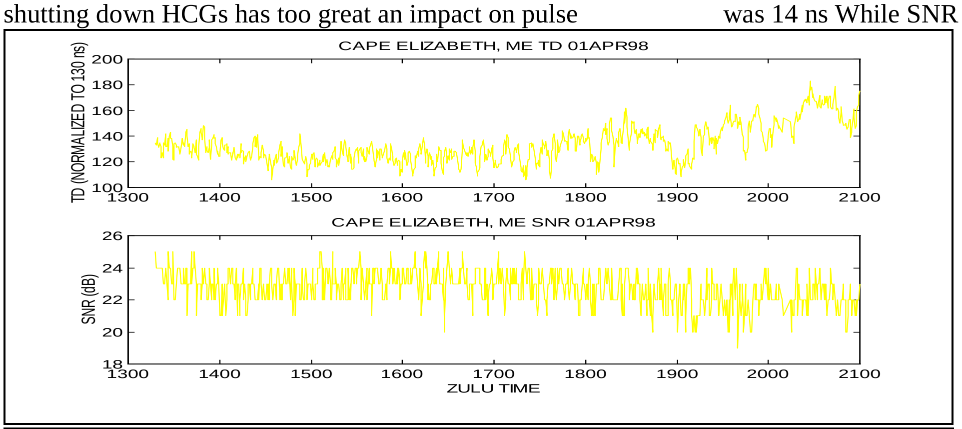


FIGURE 5.2 EFFECT OF MODULATION ON TD & SNR

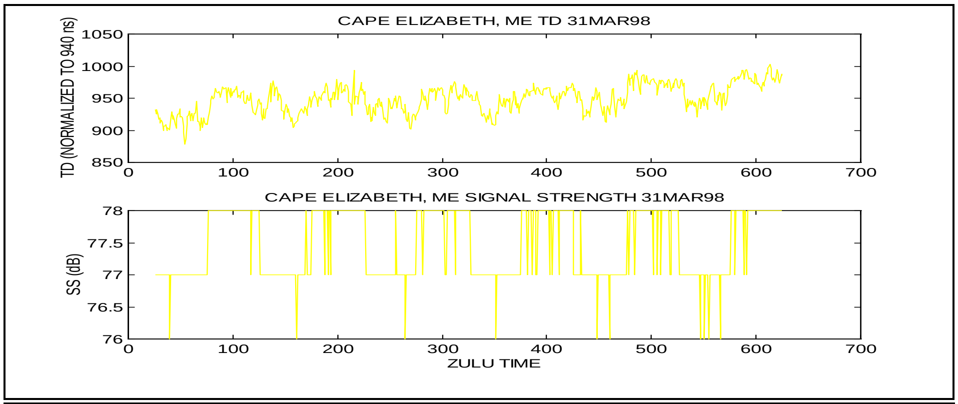


FIGURE 5.3 EUROFIX EFFECT ON MONITOR GRADE RECEIVER

Average TD	81825.133 µS
TD Standard Deviation	14 ns
Average ECD	-0.76 µS
ECD Standard Deviation	0.1 µS
Average Signal Strength	76.9 dB
SS Standard Deviation	0.1 dB
Average SNR	22.7 dB
SNR Standard Deviation	1.0 dB

TABLE 5.1 TYPICAL EUROFIX PPM STATISTICS

Figure 5.3 shows a typical Six hour period of time during which the Eurofix PPM was cycled on and off every 30 minutes. This figure shows data collected at Cape Elizabeth, ME using a Locus LRS receiver but identical signal characteristics were present at all receiver sites for both the Locus LRS and the Austron 5000 receiver. Most notable in the figure is the consistent 1dB drop in Signal strength when the modulation is turned on.

TD shifts of approximately 60 ns are visible at 0045Z and 0115Z, as well as at other points when the modulation is cycled either on or off. These shifts are due to the symmetrical modulation scheme used in Eurofix PPM. This scheme shifts each Loran pulse in a GRI (except the first Two which are used for integrity or “blink” purposes) such that it is either prompt, advanced 1 µS or retarded 1 µS Even though the modulation scheme is balanced over each GRI, the cumulative effect is to introduce a 60 ns bias into the TD.

The bias is notable but not particularly worrisome since it is only present when the modulation is either turned on or off. If the modulation were always present, this effect would not exist. Also, it may be possible to modulate the pulse using an asymmetrical shift (ie. + 0.9 µS and -1 µS) that could eliminate this bias.

Table 5.2 summarizes the standard deviation of the pertinent measurements for all data collected from both Locus and Austron receivers at all test sites while the modulation was cycled off and on. The standard Deviation of TD increased by Four ns. Differences in the Standard Deviation of ECD, Signal Strength, and SNR are very small and actually show less deviation when the

	PPM ON	**PPM OFF**
TD Standard Deviation	14 ns	10 ns
ECD Standard Deviation	0.19 µS	0.20 µS
SS Standard Deviation	0.22 dB	0.26 dB
SNR Standard Deviation	1.1 dB	1.1 dB

TABLE 5.2 STANDARD DEVIATIONS OF SIGNAL PARAMETERS FOR MONITOR RECEIVERS

	PPM ON	**PPM OFF**
TD Standard Deviation	67 ns	30 ns
ECD Standard Deviation	0.76 µS	0.83 µS
SS Standard Deviation	0.46 dB	0.32 dB
SNR Standard Deviation	1.28 dB	0.49 dB

TABLE 5.3 STANDARD DEVIATIONS OF SIGNAL PARAMETERS FOR J.E.T. RECEIVER

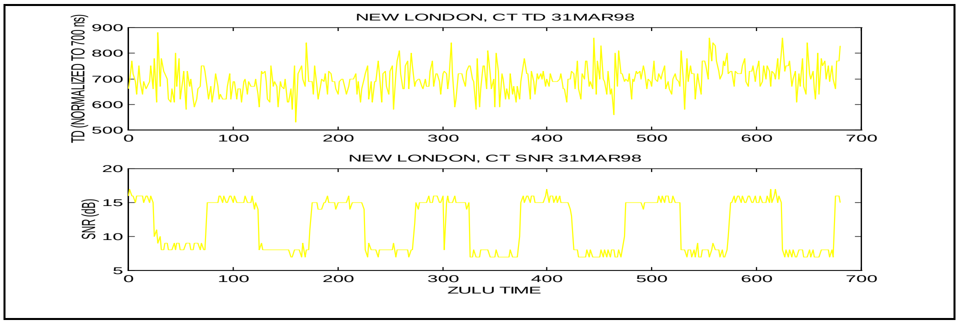


FIGURE 5.4 EUROFIX EFFECT ON J.E.T. USER GRADE RECEIVER

signal is modulated compared to when it is not modulated. The average decrease in signal strength for all monitor grade receivers at all sites during modulation periods is 1.0 dB. On average, SNR decreased by 0.6 dB.

5.3 Eurofix PPM Effects On User Grade Receivers. Figure 5.4 shows a typical Seven hour period of time during which the Eurofix PPM was cycled on and off every 30 minutes. This figure shows data collected at New London, CT using a J.E.T. receiver. Clearly visible in the figure is the consistent 7dB drop in SNR when the modulation is turned on. Average signal strength only dropped 0.5 dB while the average SNR drop was 7.3 dB. This translates into the receiver seeing a significant increase in noise power. This rather significant drop in SNR was accompanied by an average increase in the Standard deviation of the TD measurements of approximately 37 ns. It is unknown at this time why this particular receiver showed such degradation in signal quality due to the Eurofix PPM. We hypothesize that this particular receiver does not look at all pulses of a GRI. This would result in the receiver seeing an unbalanced modulation pattern, resulting in the large decrease of SNR. Further testing is required to confirm this hypothesis and to determine if this effect is isolated to this particular receiver or if it is more widespread among user grade receivers.

Table 5.3 summarizes the standard deviation of TD, ECD, signal strength, and SNR for the data collected from the J.E.T. receiver while the modulation was cycled off and on. Most of the difference in SNR Standard Deviation is due to the large dip when the modulation is cycled rather than a large increase in the variance of SNR.

6.0 DATALINK PERFORMANCE AND DGPS NAVIGATIONAL ACCURACY

As discussed in paragraph 5.1, we attempted to simulate the dynamic movement of a Eurofix receiver by reducing the output power of the transmitter. The method used to reduce power had a negative effect on pulse shape and also caused large shifts in TD. We determined it would be almost impossible to analyze the performance of the datalink during these power down tests because we would not be able to distinguish between the effects of Eurofix PPM vice the effects of changes in pulse shape caused by the power down tests. We decided it was best to concentrate our analysis on testing periods where the transmitter was at full output power. Interestingly enough, the Eurofix receiver located at the LSU correctly decoded all information despite the degraded pulse shape.

Two Eurofix receivers were used in the test setup, one located at the LSU in Wildwood, NJ and the second located at the Coast Guard Academy in New London, CT. The LSU Eurofix receiver provides us information on the "zero baseline" performance of the datalink. We call this the "zero baseline receiver" because it provides data on the optimal performance of Eurofix. Since the receiver is so close to the transmitter, signal strength is very strong, practically eliminating the effects of cross rate interference as well as other types of interference.

The LSU receiver also helped us troubleshoot the equipment configuration. For instance, while the test was ongoing, we saw periods of time where the datalink completely failed. The "zero baseline receiver" helped us trace the problem back to a failure to modulate the signal. We quickly determined that the failure only occurred while transmitting a dual rate signal. Due to the time constraints of the test, we decided to transmit only the 9960T rate. We were unable to determine the cause of the dual rate datalink failure, although we are fairly certain that the problem was related to the unique configuration of the hardware test setup and unrelated to any failure in the Eurofix concept itself. Unfortunately, test constraints did not allow time to prove this hypothesis.

6.1 Datalink Zero Baseline Performance at Wildwood. "Zero baseline" performance statistics are summarized in Table 6.1. Data was collected during an uninterrupted Eight hour period, while transmitting single rated (9960T) using a 30/10 Reed-Solomon code length. No datalink failures occurred during this test period. The 9960 GRI is one of the slowest rates possible, so this performance is very close to the optimal worst case data rate. The Eurofix message length is 56 bits which translates to about One

DGPS satellite update message every Three seconds for this particular GRI and code length.

Raw Bit Rate	56.1 bits/sec
Effective Bit Rate	18.7 bits/sec
Effective Message Rate	2.99 sec/message

TABLE 6.1 ZERO BASELINE DATALINK PERFORMANCE FOR 30/10 LENGTH CODE

"Zero baseline" performance statistics are summarized in Table 6.2 for a 20/10 Reed-Solomon code length. Data was collected during an uninterrupted Eight hour period, while transmitting single rated (9960T). No datalink failures occurred during this test. The 9960 GRI is one of the slowest rates possible, so this performance is very close to the optimal worst case data rate. The Eurofix message length is 56 bits which translates to about One DGPS satellite update message every Two seconds for this particular GRI and code length.

Raw Bit Rate	56.1 bits/sec
Effective Bit Rate	28.1 bits/sec
Effective Message Rate	1.99 sec/message

TABLE 6.2 ZERO BASELINE DATALINK PERFORMANCE FOR 20/10 LENGTH CODE

6.2 Zero Baseline DGPS Navigational Accuracy.
Figures 6.1 and 6.2 demonstrate the relative performance of the Eurofix datalink when used as a DGPS data source. The scatter plot in Figure 6.1 was collected at the LSU using a Novatel GPS receiver, with DGPS corrections supplied by the Eurofix receiver. It shows the typical "zero baseline" position error of under Three meters. The scatter plot in Figure 6.2 shows the typical 30 meter position error of the Novatel GPS receiver with no DGPS service. The accuracy provided by the Eurofix DGPS corrections is quite good considering the limited bandwidth of the datalink. Of course this is optimal performance for this specific test GRI. The Eurofix/DGPS receiver is collocated with the transmitter source, so spatial and temporal de-correlation effects are minimal. Also there is no interference to impact the performance of the datalink, so all bandwidth available is utilized.

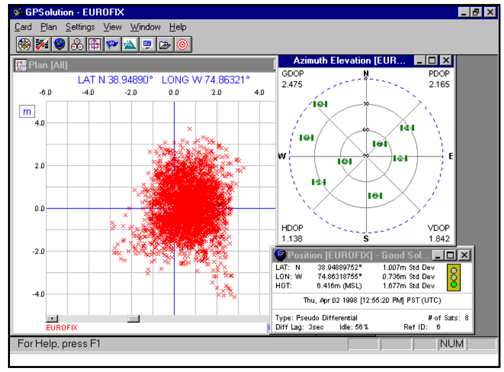


FIGURE 6.1 ZERO BASELINE PERFORMANCE WITH EUROFIX DGPS CORRECTIONS

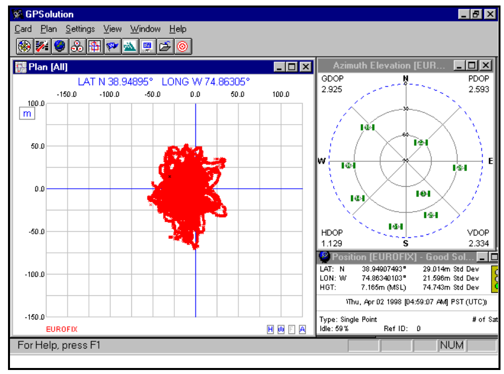


FIGURE 6.2 ZERO BASELINE PERFORMANCE WITHOUT EUROFIX DGPS CORRECTIONS

7.0 CONCLUSIONS

We saw very little impact on the Locus and Austron monitor grade receivers. The One user grade receiver we were able to test showed a fairly significant degradation in SNR as well as in the variance of the TD measurements. Further testing would be required to determine if this negative impact is specific to this one model of Loran receiver or if it is more widespread.

Datalink performance was very good. The evaluation demonstrated the robustness of the Reed-Solomon forward error correction code as well as the underlying Eurofix technology. Position accuracy was very impressive considering the limited bandwidth available in the Loran-C signal.

8.0 ACKNOWLEDGMENTS

Special thanks to ET1 Christopher Frederick, ET2 Michael Seastedt, ET2 William Henry, and Mr. Earnest “Bud” Paulus of the Coast Guard Loran Support Unit for making it all work, despite their heavy project workload. Thanks to Mr. Stewart Shoulta of Coast Guard Headquarters (G-OPN-3) for his excellent international negotiating skills. Also to Mr. Gerard Offermans, Mr. Arthur Helwig, and Dr. Durk Van Willigen of the Delft University of Technology, Delft, The Netherlands, as well as, Mr. Duane Marshall and Mr. William Howell of Megapulse, Inc. for their technical expertise.

9.0 REFERENCES

1. “The Eurofix Datalink Concept: Reliable Data Transmission Using Loran-C”, G. Offermans, A. Helwig, and D. van Willigen, Proceedings of the 25th Annual Technical Symposium of the International Loran Association, San Diego, CA, November 3-7, 1996.

2. “Eurofix DGPS Service Through The Sylt Loran-C Transmitter: Static and Dynamic Test Results”, A. Helwig, G. Offermans, and D. van Willigen, Proceedings of the 25th Annual Technical Symposium of the International Loran Association, San Diego, CA, November 3-7, 1996.

3. “Implementation and testing of Eurofix in Standard Loran-C Receiver Technology”, A. Helwig, G. Offermans, and D. van Willigen, Proceedings of the 25th Annual Technical Symposium of the International Loran Association, San Diego, CA, November 3-7, 1996.