Airborne Loran-C H-Field Receiver Development

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Abstract

Loran-C has recently been put in the spotlight as a feasible means for navigation and data transmission. The Federal Aviation Administration is very interested in this program to help increase the reliability and redundancy of their current navigational systems. By proving that Loran can be used for non-precision approaches, the current Loran system will able to be justified and integrated into the National Airspace System (NAS). The question that is being asked is "Will Loran as a stand alone system be sufficient for navigational purposes?" The answer to this question is being explored by several agencies. The Coast Guard Academy specifically is looking into the testing and development of their PC-104 receiver and comparing it to the Locus SatMate, a commercial receiver. These results and further flight test will eventually determine the fate of the Loran-C system according to the 1999 Federal Radionavigational Plan.

Introduction

In the early 1980's, general aviator's initiated a program to research Loran and the possible integration into the National Airspace System (NAS). This program, known as the Early Implementation Project (EIP), provided research and testing to eliminate the "mid-continental gap."

These forward progressions made the general aviation community begin to install Loran receivers without FAA approval. Many of the reasons for such a rush into the area of Loran was it allowed a capability of instrument approaches at air fields too small to house a dedicated navigation aid. Many of these tests were carried out in the New England region.

In the early 1990's, the progress in GPS brought Loran to a staggering halt. The system research and deployment were being brought to an end. Today, Loran-C serves as a supplemental system to GPS and there are currently no active Loran approaches in the NAS.

The 1999 Federal Radionavigation Plan tells the progress and future of Loran-C quite vaguely:

> "While the Administration continues to evaluate the long-term need for the continuation of the Loran-C radionavigation system the government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost-effective, so that users will have the opportunity to transition to alternative navigation aids. With this continued sustainment of the Loran-C service, users will be able to realize additional benefits. Improvement of GPS time synchronization of the Loran-C

chains and the use of digital receivers may support improved accuracy and the coverage of the service. Loran-C will continue to provide a supplemental means of navigation. Current Loran-C receivers do not support non-precision instrument approach operations."

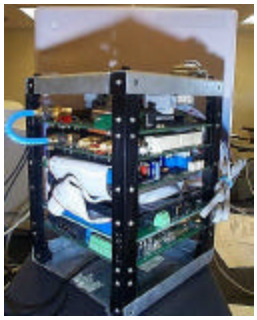
Para 3.2.5 B 1999 US Federal Radionavigation Plan

This problem has been noted and is why the Coast Guard and FAA are working to build a prototype receiver with an integrated GPS and data channel. The FAA has submitted a budget of $20+ million to support these efforts. The need to develop a prototype receiver has attracted many organizations to the Loran recapitalization project. Such key players involved in development of the prototype Loran-C H-field receiver include Federal Aviation Administration, Stanford University, United States Coast Guard Loran Support Unit, Peterson Intergrated Geolocation systems, University of Rhode Island, Ohio University, ILGEN Simulations, Booz-Allen and Hamilton, Locus, Inc., and Megapulse.

Background

Based on the development of a self-contained low-power Loran H-field sensor in 1999 using PC-104 technology, the United States Coast Guard (USCG) and the Federal Aviation Administration (FAA) entered into an agreement for further development. The Coast Guard has agreed to modify this Loran-C H-Field receiver so it can be integrated with a GPS sensor and used for high dynamic flight operations. These efforts are being focused to increase the Wide Area Augmentation System (WAAS) redundancy. (Statement of Work)

Many organizations, including Peterson's Intergrated Geolocation systems, Ohio University, and Loran Support Unit, are adamantly pursuing efforts in revitalizing the Loran system and making full use of its capability in the area of data transmission. A consulting firm was just hired by the Coast Guard to determine the capability of integrating dGPS correcting across a Loran system. Another area of interest is data transmission over the receiver. Specifically, Dr. Peterson is working on this issue to determine how capable the Loran system is. A question he is facing is can Pulse Position Modulation (PPM) be used to transmit data? PPM allows the pulse to be shifted in time and the receiver to determine that shift. This allows for ternary data to be transmitted, while still maintaining the navigational signal shape. Lately, he has been exploring the use of Interpulse Frequency Modulation (IFM), where the data will be transferred in the latter part of the pulse shape. This allows the navigational signal to not be affected and Legacy receivers to still be utilized.



PC-104 Digital Loran Receiver (Actual Height 7")

The enhanced Loran-C navigation system to be developed must have availability, accuracy, integrity, and continuity. Many things have changed within the receiver technology over the past several years to

improve these four aspects. Some of the problems with availability were precipitation static, loss of power at the station, lightning, chain availability, and tube overloads.
Technology has improved to the point where all these problems can be dealt with. H-Field antennas are used instead of E-Field eliminating the effect of precipitation static. Lightning protection enclosures are used to protect the receiver. Power loss is prevented by the use of a Universal Power Supply (UPS). In addition, chain availabity is increased with All-in-view receivers. Lastly, solid-state transmitters are being used. Accuracy problems include old timing sources, old timing equipment, and tube technology. Timing issues were mitigated with the use of Cesium clocks and new algorithms being developed and tested by Illgen Simulation Technologies, Inc. Tube technology is in the process of being replaced with Solid-State technology. Integrity will be improved by changing the Loran systems from manual to automatic blinking systems (ABS), and changing the single rate receivers to all-in-view receivers and improving processing time by using new technology such as Digital Down Converter Technology and other forms of fast DSP processing are improving continuity.

Objectives

The ultimate goal of the project is to design and build an integrated Navigation/Data Channel Loran-C receiver using Digital Down Converter technology. In order to accomplish these efforts, the following must happen: (1) Take raw data with the receiver and plot the spectrum to measure signal strength, (2) Use on-site surveying to determine limitations on mounting the antenna and positioning of antenna, (3) Determine and create the ARINC 429 interface for the Convair 580 aircraft, (not being actively sought after due to new information from FAA) (4) Conduct flight tests on Cessna 172, and Convair 580 in June and August, (5) Identify the tolerance limitation of turning and accelerating, (6) Determine if an enhanced Loran-C system can satisfy: Availability, Accuracy, Integrity, and continuity (7) Determine the packaging of the Digital Down Converter (DDC) and optimal rack mounts for Convair 580 and making the mount more durable for aircraft testing, (8) Identify the durability of the receiver by shutting the power off in mid-flight and seeing if it can reacquire. (9) Compare PC-104 receiver to Locus SatMate receiver. Once Loran is determined to be an effective and reliable means navigation, the FAA will begin investigating using Loran to certify non-precision approaches, allowing the FAA to turn off VHF Omni-directional Range (VOR). The FAA is interested in Loran-C's capabilities because VOR's are very costly in operating due to the antiquated components within them.

Technical Approach

In order to accomplish our objectives and deliver a product, many technical considerations need to be taken into account. First, while taking raw data to measure signal strength, we need to ask ourselves whether the data we are collecting is legitimate. In order to determine whether data is legitimate, we must know a little about Loran and how it works.

Prior to beginning the project, we had to understand how the Loran system itself operated. The research involved included reading articles on the Loran system and it's functionality. Many of the operation standards came from the Loran-C User's Guide, COMDTPUB P16562.6.

After we generally understood the Loran system, we had to learn and become experts with the receiver. In order to do this, we first read about the hardware boards and how they operate to make the system function. (Loran-C H-Field Research Receiver, Prof Holland, Ken Dykstra)

In addition to the understanding the hardware, we had to learn all the code modifications to make it capable of flying in an aircraft. Some of the modifications that were made were decreasing tacking

point sensitivity, decreasing the SNR value that is used to get a fix, decreasing the time constant to 3 seconds, the most capable setting given the current Gatefield board.

One way to check the data is to look at a plot of the raw signal that we receive and see if we are getting any good Loran pulses. This is a quick check but does not ensure a properly functioning receiver. Other considerations that must be accounted for are: (1) properly functioning oscillator, (2) clock cycles, (3) Times of arrival (TOA), (4) cross rate cancellations, and (5) antenna locations. Many of these problems came up in the testing of the PC-104 hardware. When problems arose, they were addressed, looked at in detail, and eliminated.

Secondly, when the antenna is moved from one position to the next, there could be technical problems that make it functionality less accurate. For instance, having taken several trips to Westerly airport, we discovered that the position of the antenna on the plane makes a world of difference. These results will be different on every aircraft platform we place the receiver and antenna on. For instance, the effect of corona on the antenna when placed near the engine will be significantly different when placed in the Convair 580, which uses turbines. The specific antenna location results will be addressed later in the results section.

Thirdly, the ARINC 429 bus is the bus that the FAA uses in the Convair 580. This bus structure needs to be looked at before any further progress can be made in receiver design for aircraft use. This process is something that will be undertaken next semester.

Lastly, when transferring the code to DDC technology, we must take into consideration the efforts into which we must focus on. With deliverables due in February, we cannot get tied up in the development of a DDC receiver and not keep working on the PC-104 receiver GPS integration. This is obvious, but constantly needs to be considered with such a short period to the deliverable due date.

This semester, mounting became a significant issue on the design of the system. We experienced great difficulty last semester in finding an optimal location for the antenna on board the Cessna. Would we face this problem again on a different platform? After determining the optimal location for the antenna on the underside of the Cessna, we created a template and had the antenna mounted onto the metal inspection plate.

Later in the year, the FAA proposed an alternative Loran-C receiver for Coast Guard Academy to test. This was the Locus SatMate Receiver that can be purchased commercially. We were tasked with finding how well the PC-104 receiver compared to the commercial Satmate receiver. Most of the tests conducted using the Satmate involved using a less dynamic platform than that of an aircraft. More specifically, we used an automobile to test the receiver. Endurance tests were performed at highway and city speeds. We wanted to ensure the Satmate, which was designed to be a timing receiver, could support a higher dynamic environment. The mobile tests of the receiver were tested before any further developments with this receiver could be explored.

Two receiver issues that had to be looked at quickly and solved were how much storage space are we going to need to record data for a flight of approximately four hours, and what will happen if the receiver gets turned off in mid flight? Will it reacquire? We had to look at what chains we were receiving through our all-in-view receiver and determine the size of the raw file of data that was being collected. The size is 194 KB when tracking three chains. With a 3 second time constant, this equates to 3.88 MB per minute, 3232.8 MB per hour. The answer for whether the receiver will reacquire is still presently being tested and discussed.

DDC issues will later consist of developing software that was user-friendly. The eventual user-friendly environment would allow anyone to use it. A Gatefield object would be created. In development of a DDC receiver, we had to incorporate all the functions in the Gatefield Board into the software. The old Gatefield board in the PC-104 package had a front-end built into board. We are researching the front-end Gatefield used and trying to duplicate it. This step is paramount to moving on in the area of DDC technology with this receiver. We have to investigate what type of front end the Gatefield uses. In our case, we are exploring the LM7131 operational amplifier for its low noise and quick response times. After investigation, we will duplicate the product.

Results

After collecting good data in lab, we began to test the PC-104 on a slightly less dynamic platform. More specifically, we incorporated the system in the platform of an automobile. The two antennas, Walt Fowler and Megapulse, were placed in the back of a Ford Ranger. Besides using the PC-104 receiver, we added AAA Map n' Go® to track the trucks movement. The receiver kept track of our position without losing lock. We even increased our speed in the truck to above average highway speeds to see how a faster platform would affect the performance of the PC-104 board. The PC-104 receiver responded and tracked the movement of the automobile accurately and reputably despite the high speed.

The problems in acquiring results earlier were an unstable 12.8 MHz oscillator could not keep lock onto a station because clock drift was too high and cross rate cancellations could not be calculated effectively. Also, different antenna locations would lose a lot of signal strength. For instance, placing the antenna outside the aircraft in the back would have a strong signal, but bringing it into the shell of the aircraft near a window decreased the signal-to-noise by nearly 20 dB. A the result of the trails in different locations gave us these results:

Table 1. Table of SNR's from expected results

Location	Without Engine	With Engine
Inside, on the dash	Normal	-15 dB
Inside, near the back window	-20 dB	-20dB
Outside, back of the aircraft	Normal	Normal
Outside, on the step	-6 dB	N/A
Outside, under the belly	Normal	Normal

Note: *Normal* denotes receiver tracked 3 stations and Nantucket's SNR is approximately +17 dB.

The latest result for antenna positioning and the effect of the aircrafts avionics and engine are as follows:

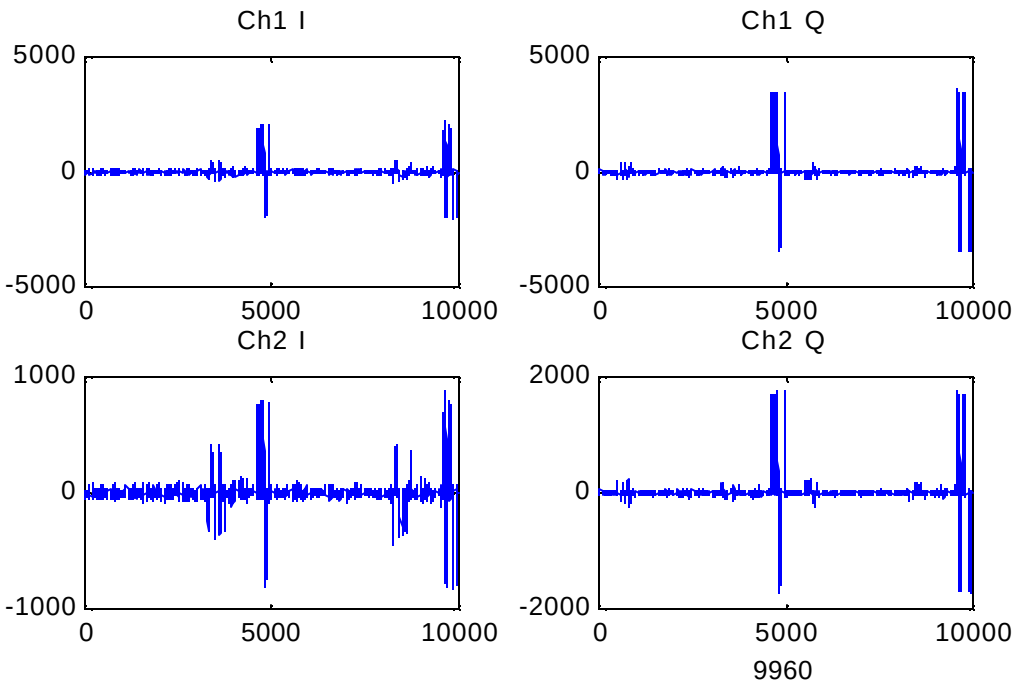


Figure 1. Loran Chain 9960 taken with no avionics or engine running. (Max signal at 123.6328kHz)

These graphs are deciphering the two channels and the in-phase and quadrature components. This means that the loops are looking for a Loran pulse, a 100 kHz t-squared pulse shape. This pulse is received and a time difference is calculated to determine a position. The plots above show a time domain representation of Loran signals entering the system from both channels. The pulse found at approximately 5000 is Nantucket, station 2 of the 9960 chain. The pulse on all channels at that time is the same station. In the lower left hand plot, Seneca can easily be seen. Seneca is the master station and is the pulse preceding Nantucket. Now, we will look at the results of the other tests to understand what is going to affect the antennas receiving capability.

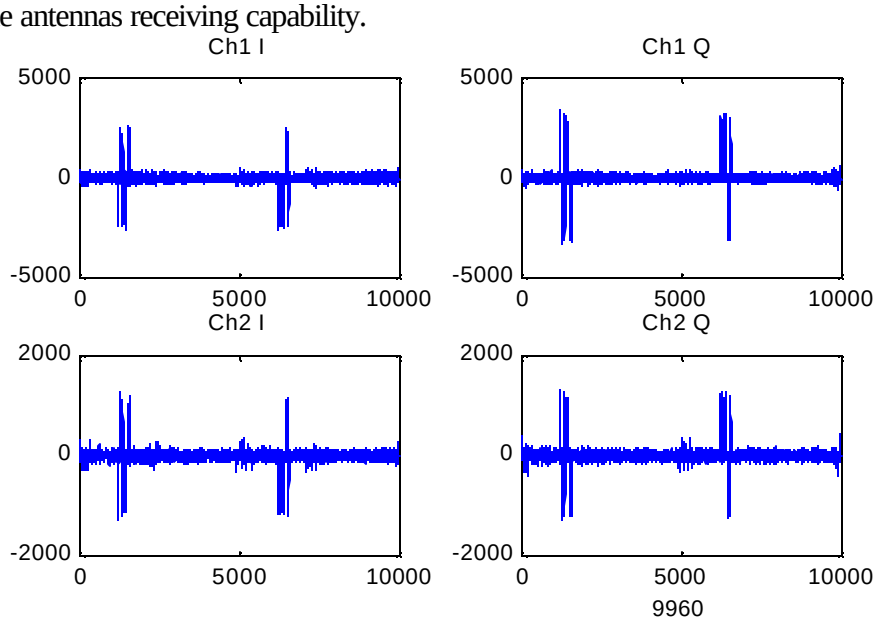


Figure 2. Loran Chain 9960 taken with avionics only. (Max signal at 120.6055kHz)

Avionics raised the noise level and lowered the SNR by an insignificant amount.

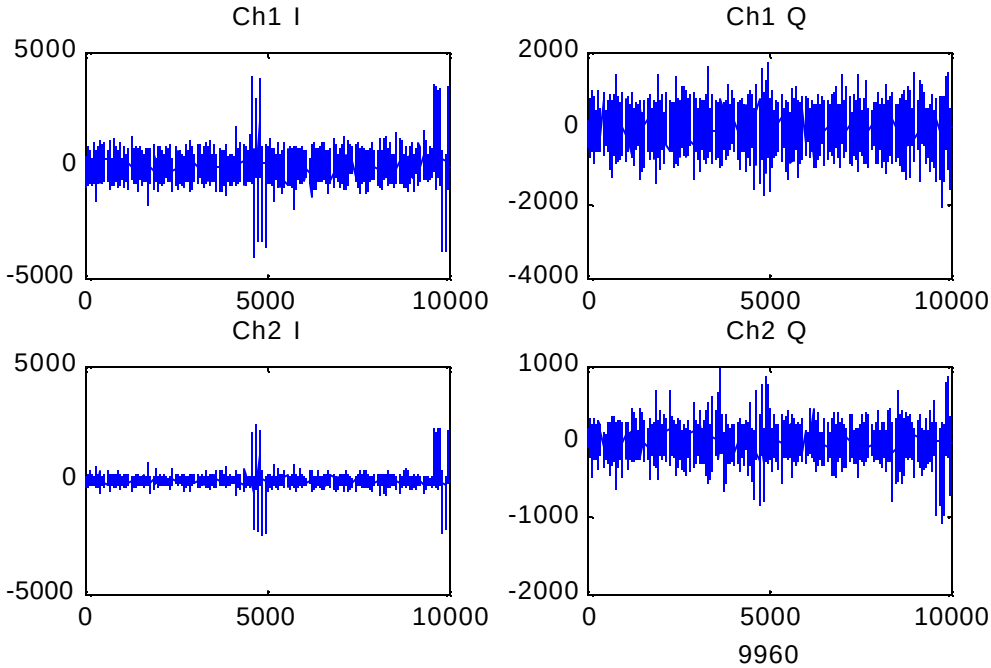


Figure 3. Loran Chain 9960 taken with avionics and engine running. (Max signal at 108.5938kHz)

With the engine running, the noise from corona increases significantly on the quadrature component and degrades the signal integrity by approximately 15 dB.

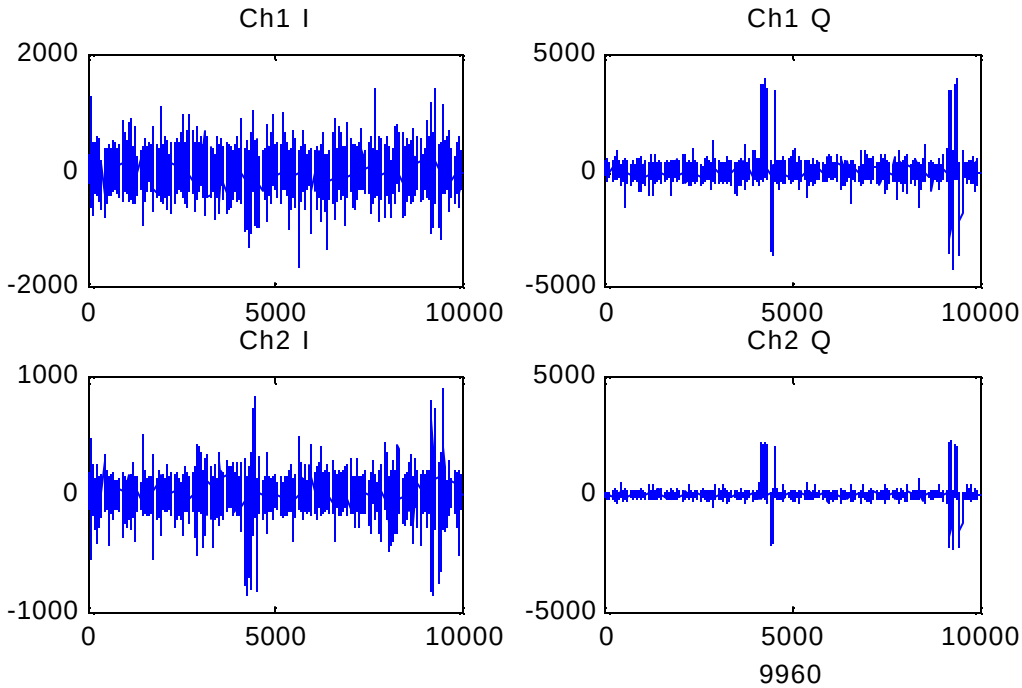


Figure 4. Loran Chain 9960 taken with engine only. (Max signal at 111.7676kHz)

This result of simply running the engine proves that the avionics have little to no effect on the signal degradation. The placement of the antenna next to the engine seems unfeasible at the present time.

These results are based on the Loran chain 9960, which is the chain that we use to navigate with. These results were with the Megapulse antenna only and were taken with the antenna on the dash of the Cessna

172. The placement of the antenna makes it very susceptible to engine noise, which can be seen in the result of the Figures 3 and 4.

The lab results from the Walt Fowler antenna were very good and showed an antenna that was comparable to the Megapulse antenna, if not better. The results are as follows:

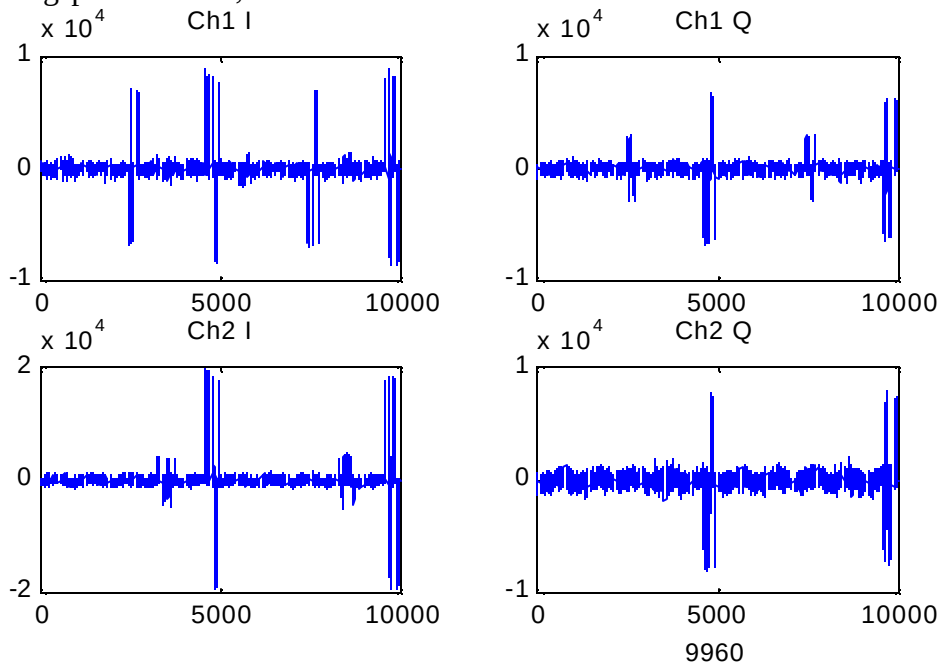


Figure 5. Loran Chain 9960 taken with the Walt Folwer antenna. (Max signal at 115.5762kHz)

The lab results from the same day with the Megapulse antenna was:

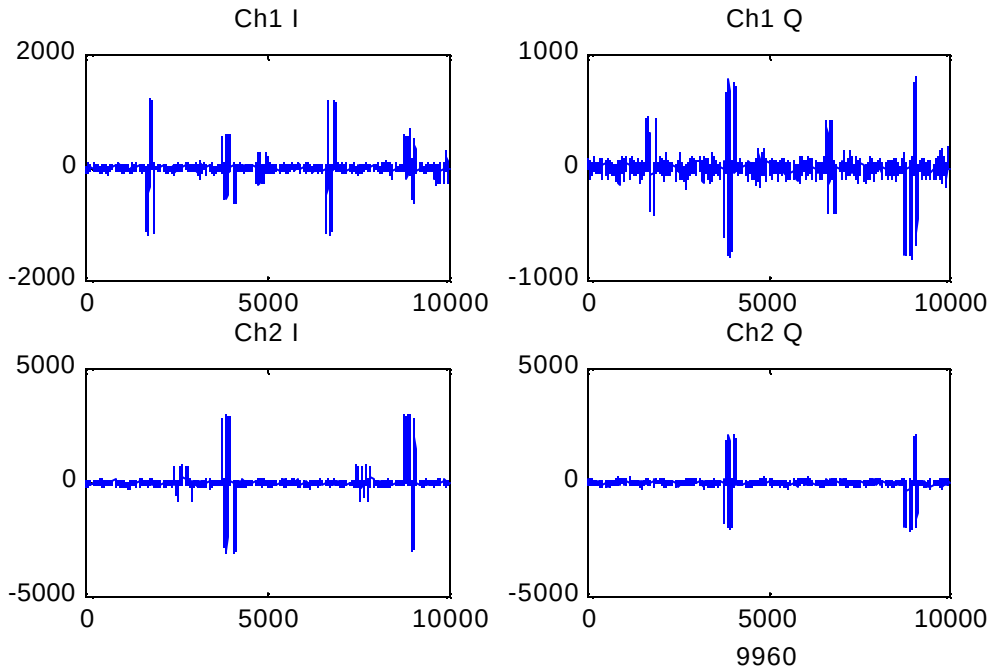


Figure 6. Loran Chain 9960 taken with the Megapulse antenna. (Max signal at 76.3184kHz)

There is a definite difference in the spectrum of the two antennas as can be seen where the max signal frequency lies.

During an initial test flight we recorded all the pertinent data and later plotted the Signal to Noise ratios of the 9960 chain while in flight. The winds were out of the northwest at 18 kts and we took of from runway 32. Three miles out we made a standard rate turn to follow I-95. Compare the following flight in Figure 8 with the signal to noise ratios. At or around the 800th second through the flight, the signal to noise ratio for the Carolina Beach Loran station and the Caribou Loran station dropped significantly due to a steep turn that was initiated at the time. This turn caused the receiver to lose lock. Later the signal reacquired and the receiver functioned properly again.

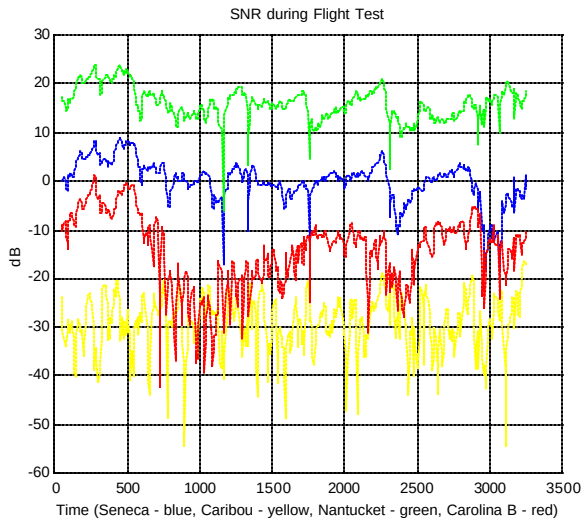


Figure 7. Loran Chain 9960 SNR's.

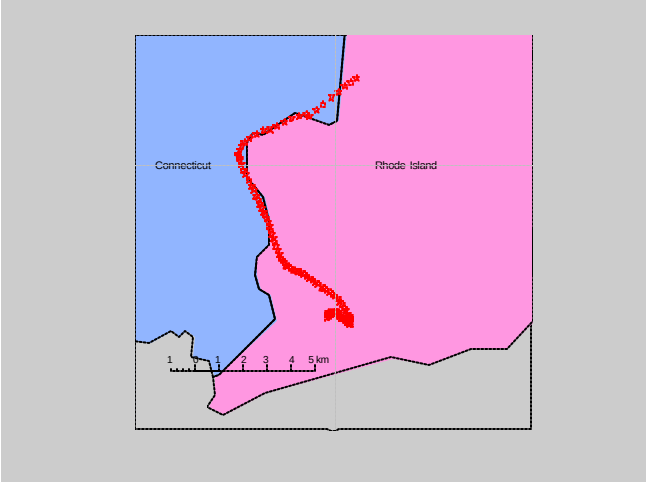


Figure 8. Results of December 12, 2000 flight test from Westerly.

Later, we plotted the loop around Westerly that we took and noticed something peculiar about the way the plot was lining up. It seemed as if we had been flying sideways, but from the actual flight, we knew we were not. After looking at the results, the gaps, and seeing how the receiver acquired the signal again, we took note the cause of the lower than normal SNR values was due to the antenna averaging values that were not in line with its own actual heading. In fact, the values are approximately 40 degrees off to the right. This averaging would cause the receiver to believe it is flying in a direction that it is not. After a few cycles of averaging, the receiver always seemed to relocate itself properly.

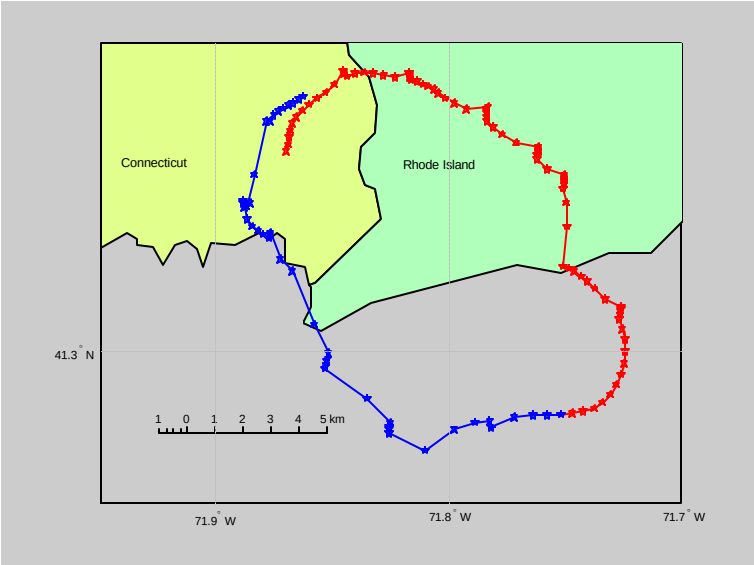


Figure 9. Result of lap around Westerly Airport. (December 12 2000 flight test)

Another major area of our research this semester was to test and report the findings of a commercial receiver that would be tested against the Coast Guard's PC-104 receiver in the upcoming flight tests. The first long test conducted was from New London, CT to Falmouth, MA (Cape Cod). This test was conducted with the Sat Mate receiver settings set to what out team thought would be appropriate. The settings were set as follows:

Table 2. Table of settings for Cape Cod SatMate tests

Receiver Command	Setting
EC average	3 seconds
TD average	3 seconds
Update	30 seconds
Batch limit	3 seconds

The results, although poor, somewhat resembled the path until it got past the turn onto I-195. Once this turn was made, the receiver did not lock onto any signal that gave reasonable information. Figure 10 shows the trip as the receiver say it. Although we are the Coast Guard, I think it is safe to say that we did not take our truck into the water.

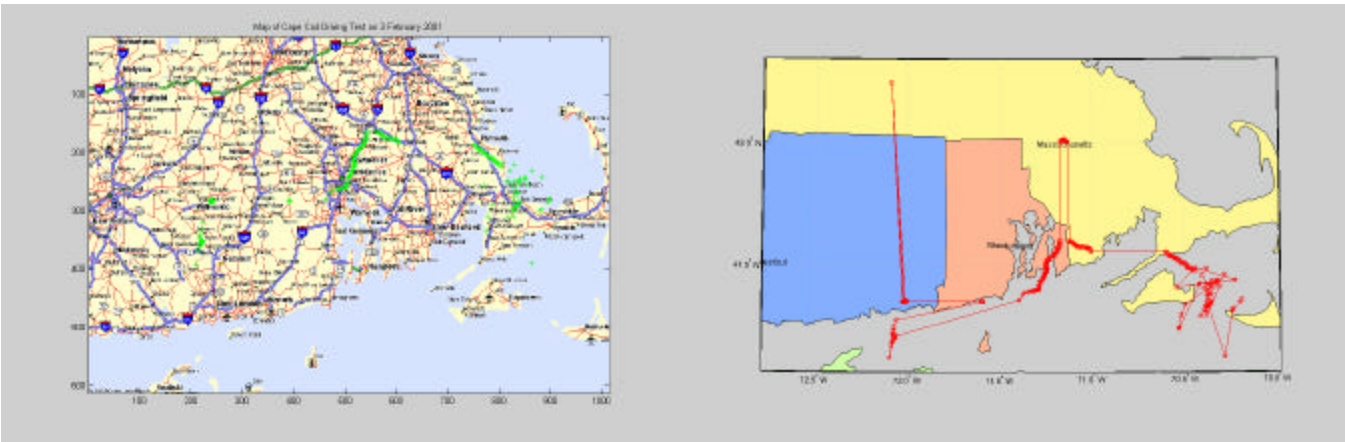


Figure 10. Results of the Cape Cod driving test of the SatMate receiver.

After careful analysis and a few e-mails from Locus, we decided that this was not the way the SatMate should be functioning. The capability of this machine could be greatly enhanced if we knew a little more. Jim Schleim, the chief engineer for the SatMate, sent an e-mail back listing the best settings to use for this receiver given the conditions that it is being tested in. It turns out the receiver settings made a huge difference, but did not solve everything. The new settings given to us by Jim Schleim were:

Table 3. Table of revised settings for Vermont SatMate tests

Receiver Command	Setting
EC average	0 seconds
EC scale	3
Update	30 seconds
TD average	30 seconds

The settings increased the performance of the receiver greatly, but the concern was still the gaps in between the data that were unaccounted for. This required more research. The latest tests have been done on a short trip from New London's Ocean Beach to the Coast Guard Academy using the old software and the new software, provided by Locus, for the receiver. The results have not been analyzed yet, but one of the differences that was noted immediately between the software was the old Locus software was simply a timing software that was a single chain receiver. The new software seemed to change the receiver in to an all-in-view. This, from observation, increased accuracy and redundancy immediately.

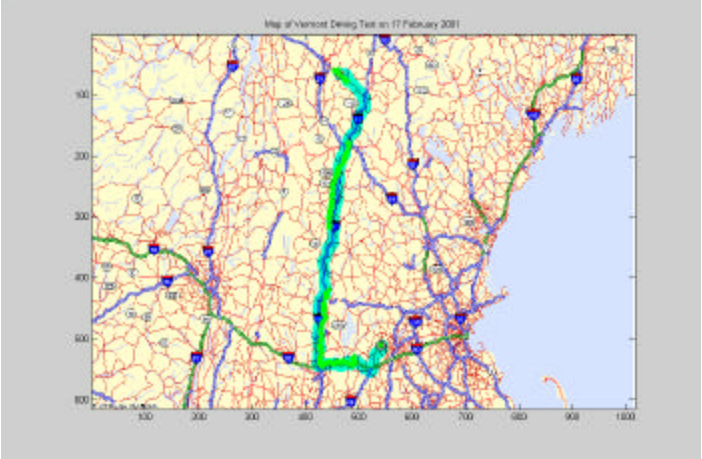


Figure 11. Results of the Vermont driving test of the SatMate receiver.

The project's ultimate goal is to be effectively tested on the FAA tech Center's Convair 580. This test will be taking place in June. Throughout the research and development phases of the PC-104 testing, we have been using a system that we tested and deemed stable. This system setup, which can be seen in Figure 12, is what we have used for all flight tests since the beginning of the project. In the later part of the year, we have needed to explore different mounting options for the receiver. Christian Oates, a contracted employee from Anteon, Inc., has been a key player in getting this mount completed. This new mount had to be tested to comply with t he FAA standards of safe testing equipment. This new fitting can be seen in Figure 13.

Figure 12. Original System setup for all Cessna testing.

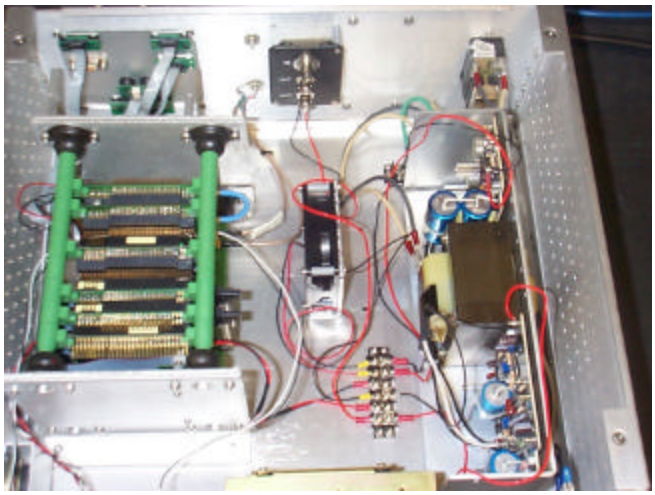


Figure 13. System setup for all Convair 580 testing.

The following setup is the proposed setup for the flight tests taking place in June on the Convair 580. Figure 14 shows a view of the PC-104 mount structure. In figure 15, this can be seen as the box under the black monitor and keyboard. This will be the most utilized receiver of the two being tested as the ISC DDC650 receiver, although completed, is still in its initial phases of tests. Static testing has been completed on the receiver and it shows signs of being more efficient than the PC-104, due to its processing capabilities.

Figure 14. PC-104 rack mounted system.

The ICS DDC650 receiver has been completed and statically tested. The receiver seems to be working effectively, however, many improvements and modifications have to be made. For instance, a front-end band pass filter needed to be implemented, and the antenna needs to receive power. These issues will be looked at and examine more carefully before the receiver goes into its testing phases. Cyber Research 19” rack mount computers were procured and configured for this particular portion of the project. This computer diagram can be seen on Figure 15 as the bottom computer.

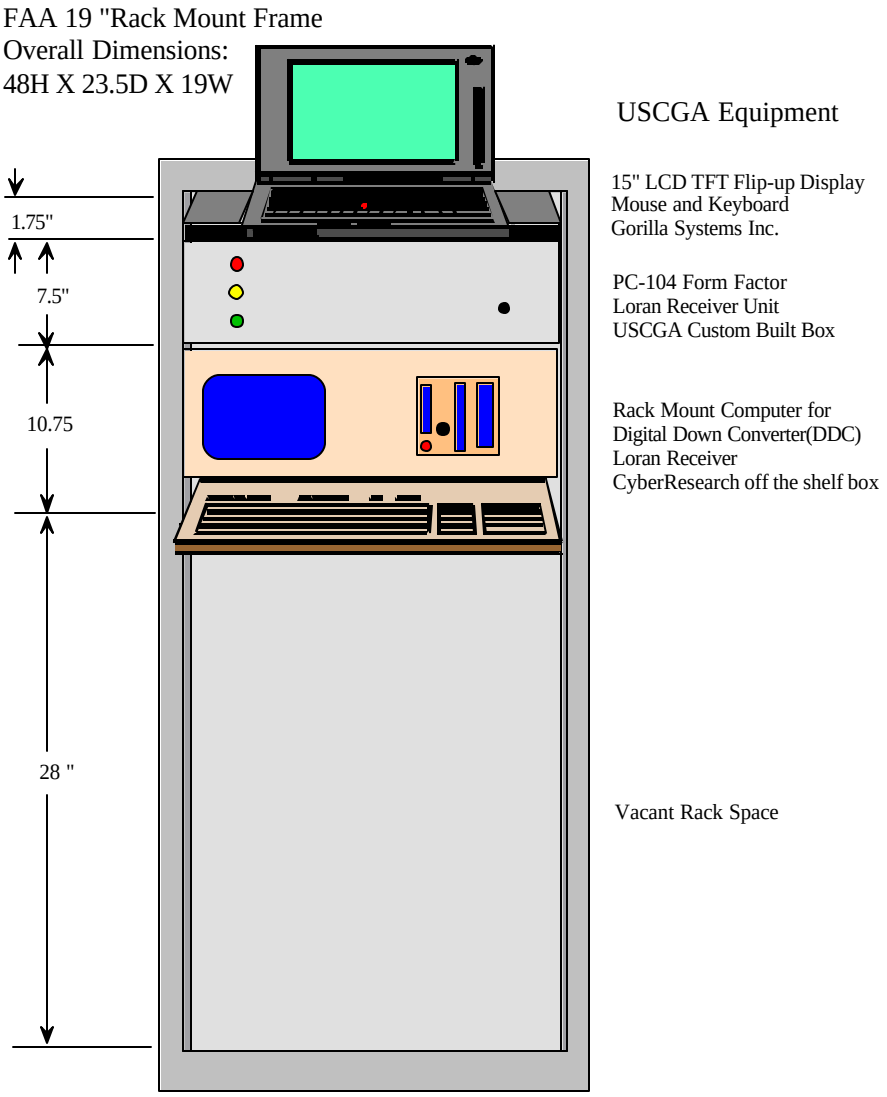


Figure 15. Proposed setup plan for Convair 580 flight tests.

Conclusion

The results that were acquired are much better now than when we first began and will help us to achieve our goals. The data collected still needs to be analyzed, reviewed, and further problems addressed. A few lessons learned were: (1) Positioning of the antenna is everything, (2) oscillator frequency is very important, (3) go with a gut feeling, sometimes your own knowledge of something can really help bring new ideas into the picture. Many of our results lead us into the spring semester with completing the hardware mount and focusing on getting the receiver software over to DDC technology.

The latest results for the project have shown significant signs that Loran-C can work on aircraft. More specifically, the PC-104 receiver has shown tremendous promise in high dynamic platforms. The Locus SatMate receiver has been tested and at the present the PC-104 outperforms this commercialized receiver. Technological advances have aided in the development of an enhanced PC-104 receiver meeting the four areas of availability, accuracy, integrity, and continuity. More tests need to be conducted before an integrated Loran-C/GPS system can replace costly VOR's. The results gained from

this semester will provide a stepping-stone for future developments. Specific flight tests include tests in Alaska where coverage the currently is no GPS/WAAS corrections. In addition, Peterson Integrated Geolocation Systems will conduct research into data encryption. The Loran-C revitalization project is taking shape proceeding in a multi-dimensional environment. Many organizations are contributing to the success of this project. The tests conducted this June at the FAA Tech center will spearhead the movement towards an Integrated Loran-C/GPS system. As a result, PC-104 receiver is a time critical element in this program. Technological advancements in processor technology will help aid in creating a better receiver. DDC technology has provided great promise in PC-104 performance. In conclusion, keep the pulse alive!!

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