LORAN-C Band Data Collection Efforts at Ohio University

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ABSTRACT

The ability of a LORAN-C receiver to provide accurate navigation information is obviously affected by the quality of the signal received at the antenna. In order to accurately assess the quality of LORAN signal reception, it is important to use data collection equipment that is designed to receive signals in the LORAN-C band. The bandwidth, dynamic range, sampling rate, and filtering of the data collection equipment are all key factors in this design. In addition, data from other sources (such as independent position data) is needed to allow for accurate data analysis.

Ohio University has fielded this type of data collection system for its research and analysis effort to determine the impact of noise on the LORAN-C signal. This system uses a two-channel data collection device to simultaneously collect radio frequency (RF) data from two independent antennas: an e-field and h-field. Analysis of the data allows the performance of each antenna, under varying environmental conditions, can to be investigated.

This paper will detail the specifications of the data collection system being used at Ohio University. Both the laboratory and airborne installations will be discussed. Examples of the data collected using each system will be shown to illustrate the data collection capabilities of the system.

1. INTRODUCTION

Long Range Navigation (LORAN) has been in use since World War II as a position, navigation, and timing system. LORAN-C is the third evolution of the system since its initial design. LORAN is a hyperbolic system providing coverage over most of the United States. Since it operates in the 90-110 KHz frequency range, it uses groundwave propagation as its means of transmission and is therefore not limited to line-of-sight range for its users.

However, LORAN has typically had fairly large (100-500 meter) errors in its position solution performance. In addition, its use as an airborne navigation system has been hampered by problems of integrity, availability, continuity, and accuracy caused by climatic (changes in propagation path), aircraft induced (precipitation static), and atmospheric (lightning) effects. The preceding list is certainly not exhaustive but does illustrate some of the major obstacles faced by the LORAN community over the years.

The introduction of new navigation systems has gradually reduced the use of LORAN as a primary means of point-to-point navigation, especially for aviation. Most notably, the Global Positioning System (GPS) has provided the capability for worldwide navigation using a single system with accuracy, integrity, availability, and continuity performance far exceeding that typical of LORAN. Combined with the increasing numbers of aircraft equipped to use Non-directional Beacon (NDB), Instrument Landing System (ILS), and VHF Omni-Range (VOR), this has led to the continuing decrease in the apparent need to maintain the LORAN system in the United States. As the available accuracy of GPS continued to increase with the elimination of the error caused by Selective Availability (SA) and the design of new augmentation systems such as the Local Area Augmentation System (LAAS) and the Wide Area Augmentation System (WAAS), the prospect that the navigation requirements of the National Airspace System (NAS) could be met solely through the use of a single system, such as GPS, increased.

This perception was changed by two events in September 2001. On September 10, the Volpe National Transportation Center released its report [1] on the vulnerabilities associated with using GPS as a sole means of positioning within the NAS. The terrorist attacks the following day in New York City, Washington D.C., and Pennsylvania tragically underscored the vulnerability of the commercial aviation industry. These events precipitated a change in thinking on the use of GPS as the source of positioning in the NAS. In addition, the timing and frequency communities began to realize their need for a backup system to reduce their dependence on GPS.

The changes brought on by these events led to the desire in the transportation community to find suitable backup systems for GPS that provide for redundancy for position, navigation, and timing (PNT) [2][3]. LORAN is one of the systems being evaluated as a possible backup system. In order to facilitate the evaluation of LORAN as a backup, two panels were formed to bring together people capable of determining the current capabilities of the system and of suggesting changes that would be required to allow LORAN to serve as a suitable backup. One of these panels was the LORAN Integrity and Performance Panel (LORIPP) formed by the Federal Aviation Administration (FAA) LORAN-C Program Office.

As part of this panel, the Avionics Engineering Center (AEC) at Ohio University was tasked to evaluate the effects of atmospheric noise and precipitation static (p-static) on LORAN performance. This task was to be accomplished by collecting airborne data under varying weather conditions, determining the effects those weather conditions had on the LORAN signal, and mitigating those effects when and where required. Collecting data that would allow these weather-related effects to be observed required that a data collection system capable of capturing radio frequency (RF) signals in the LORAN frequency band be fielded and installed on a suitable aircraft. This paper will present the efforts to date of AEC to field such a system.

2. DATA COLLECTION SYSTEM

2.1. Overview

The primary goal of the LORAN data collection system being designed at Ohio University is to collect RF data in the LORAN frequency band. However, it is also important that the data being collected provide an accurate representation of the data that would be seen by a typical LORAN receiver. Therefore it is important to use equipment that is designed to work in the LORAN frequency range as well as with the proper bandwidth to capture the entire LORAN spectrum.

Figure 1 shows a block diagram of the data collection system installed on AEC's King Air C-90SE, which is shown in Figure 3.

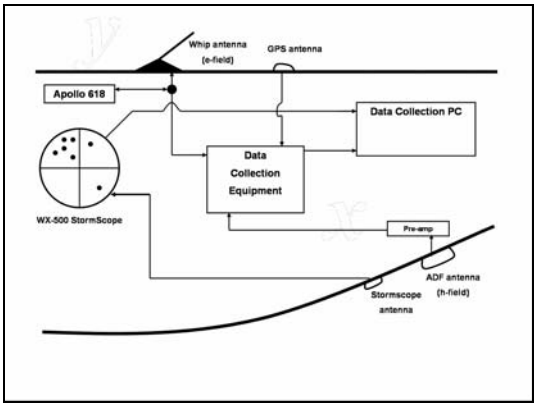


Figure 1: Data collection system block diagram

The data collection PC and the box containing the data collection equipment are mounted in a 19-inch rack that is installed on the seat rails of the aircraft. A WX-500 StormScope is part of the aircraft avionics package. Both the e-field and h-field LORAN antennas and the GPS antenna are used exclusively the data collection equipment.

Figure 2: Data collection equipment rack

The Apollo 618 LORAN receiver is mounted in a 19-inch rack mount chassis and is used only to power the e-field antenna preamplifier. The signal going to the data collection equipment is split from that antenna and sent to the data collection box.

The data collection box contains the Reelektronika DataGrabber, which is used to collect LORAN RF data and a GPS receiver from which position data is collected during flight.

Figure 3: Ohio University's King Air C-90A

2.2. Equipment Descriptions

2.2.1. WX-500 StormScope

As mentioned earlier, the WX-500 StormScope system is part of the aircraft avionics package. The StormScope has a range of up to 200nm. Lightning strikes are displayed relative to the aircraft heading and the system is heading stabilized using the aircraft gyros to prevent the display of inaccurate or erroneous data. Data is output using the RS-232 format at a rate of 9600 Baud. At the present time the data is not being processed, but eventually the capability to process the data will allow us to compare in-flight lightning strike data with data collected using a system such as the National Lightning Detection Network (NLDN). A plug has been installed under the copilot instrument rack that is connected to the equipment that interfaces with the aircraft display. This multifunction display (also used for the StormScope) provides the RS-232 output signal from the StormScope processor. Data is collected using serial port capture software written at AEC.

2.2.2. Data Collection PC

The data collection computer being used was built by CyberResearch®. It contains two 933MHz Pentium III single board computers on a dual backplane. These single board computers have the option of supporting RAID arrays on an IDE bus. This feature enhances the capability of the system considering the large amount of data being stored at relatively high rates. The chassis is also equipped with dual redundant 250W power supplies that provide the capability to continue data collection if one supply fails.

2.2.3. Data Collection Equipment

This box, shown in Figure 4, was assembled at AEC and contains various pieces of equipment used in the data collection system that are not available in rack mountable enclosures. This makes the system easier to install in the aircraft. In addition, having the smaller individual units securely mounted inside the rack mount chassis makes the system safer and more capable of withstanding the turbulence. The latter is likely to be encountered when flying in atmospheric conditions that are conducive to the noise phenomena being studied.

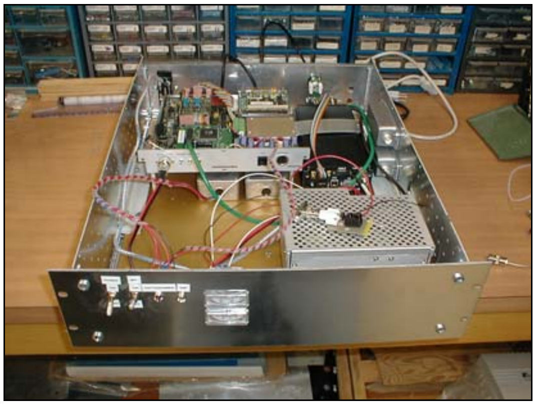


Figure 4: Data collection equipment chassis

Descriptions of the two major components of the data collection equipment chassis, the DataGrabber and the Novatel GPS receiver, are contained in the following paragraphs. The chassis also contains a DC power supply used to power the equipment installed in the chassis.

2.2.3.1. LORADD-DS DataGrabber

The LORAN-C LORADD-DS DataGrabber was developed by Reelektronika b.v. in The

Netherlands. It was designed to collect raw RF data in the LORAN-C band with minimal requirements for external hardware such as filters or amplifiers. The DataGrabber is capable of sampling two antenna input channels simultaneously at 400 kHz with 16 bits of resolution [4]. The antenna inputs can accept either e-field or h-field antennas. Data is transferred from the DataGrabber via an Ethernet connection to the data collection PC. Figure 5 shows the DataGrabber in its' enclosure.

Figure 5: LORADD-DS DataGrabber

This enclosure was removed before it was installed in the data collection equipment chassis to allow switches and indicators to be moved to the front panel of the rack-mount enclosure and simplify the task of mounting it in the new chassis.

2.2.3.2. Novatel OEM4 GPS Receiver

A dual frequency, WAAS enabled OEM4 GPS receiver from Novatel was installed to provide position data during flight testing. Data is collected from the receiver at a 1 Hz rate using Novatel's GPSolution software. The GPS time is also used to synchronize the position data and LORAN data files. A dual frequency Novatel Model 512 GPS antenna is used for the data collection flights.

2.2.4. ADF Antenna

A King Model KA42A Automatic Direction Finding (ADF) antenna is used as the h-field antenna for the data collection system. This antenna has two independent loops wrapped around the ferrite core. A pre-amplifier (designed by Dick van Graas at DHG Consulting and Frank van Graas at Ohio University) is used to combine the output of each loop to form an omni-directional phase pattern. The pre-amplifier also sets the bandwidth of the antenna to the 30 kHz bandwidth of LORAN-C centered around the 100 kHz center frequency.

2.2.5. Whip Antenna

The e-field antenna used in the data collection system is a Model A16 LORAN-C antenna from UPSAT. It is a standard LORAN-C e-field antenna and has a built-in preamplifier. The antenna pre-amp is powered by an Apollo 618 LORAN-C receiver also from UPSAT.

3. FLIGHT TEST OVERVIEW

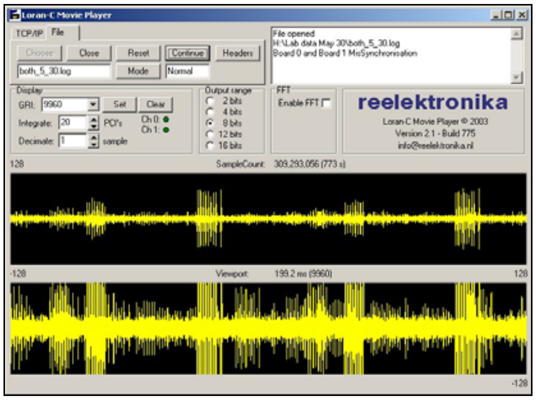
3.1. Equipment Checkout

The data collection equipment was installed and checked on the ground prior to the initial flight testing. Ground testing was conducted using hangar power, an aircraft ground power unit (GPU), and aircraft power. These tests were performed to determine if aircraft noise would have a significant impact on the data. Data collected using hangar power showed significantly higher noise levels than those collected using the GPU or aircraft power. This was believed to be the result of interference sources affecting the utility company power. Checks performed using the GPU and aircraft power showed comparable noise levels. Testing was also performed to determine if aircraft systems would pose a problem for the data collection system. Data was collected using the GPU and aircraft power and major systems were turned on individually. No detrimental effects were noted.

3.2. Initial Flight Test

An initial flight test was conducted in Athens, OH on July 25, 2003. The flight remained in the local area and was used to collect data for comparison with the ground checks described in Section 3.1 and data collected in the AEC antenna laboratory in Stocker Center. The flight departed Ohio University Airport (UNI) and an orbit over Stocker Center was established. While in the orbit, the checks of the systems that had been performed on the ground were, to the extent possible, repeated. Data sets with all aircraft systems in their normal flight settings and with all possible systems shutdown were also collected to help characterize the aircraft noise.

The data from these flights were processed and compared to the other data sets that had been collected. As with the ground checks, no significant effects were noted from the aircraft systems. Differences in the signal-to-noise ratio (SNR) of the LORAN signals present in the data were found when the aircraft data was compared to data collected in the laboratory. The SNR differences were attributed to possible increased noise in the lab data due to the proximity of the antennas on the rooftop of Stocker Center to other equipment and boundary condition effects caused by large structures on the rooftop of Stocker Center and other nearby buildings. Although these differences were noted, the initial flight test was considered to be a successful demonstration of the data collection system capability to collect LORAN data. Typical results from data collected during a normal day are shown in Figure 6 and Figure 7. In these figures the top image is the signal being received on the h-field antenna and the bottom is the e-field signal.



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Board 0 and Board 1 MisSynchronisation
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both_5_30.log
Mode: Normal
GRI: 9960
Integrate: 20 PCI's
Decimate: 1 sample
Output range: ○ 2 bits ○ 4 bits ● 8 bits ○ 12 bits ○ 16 bits
Enable FFT ☐
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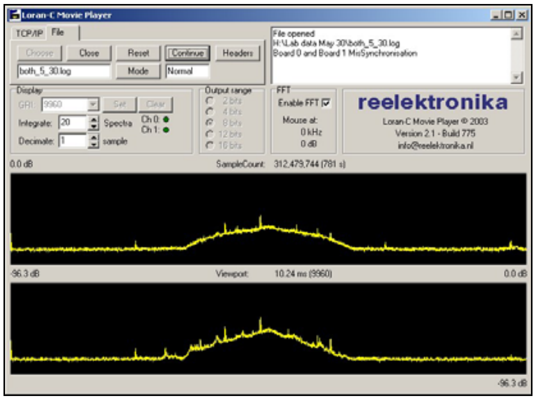
Viewport: 199.2 ms (9960)

Figure 6: Time domain LORAN-C RF signal



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Board 0 and Board 1 MisSynchronisation
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both_5_30.log
Mode: Normal
GRI: 9960
Integrate: 20 Spectra
Decimate: 1 sample
Output range: ○ 2 bits ○ 4 bits ● 8 bits ○ 12 bits ○ 16 bits
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Mouse at: 0 kHz 0 dB
SampleCount: 312,479,744 (781 s)
Viewport: 10.24 ms (9960)

Figure 7: Frequency spectrum of LORAN-C RF signal

The LORAN pulses are clearly visible in the RF signal. The frequency spectrum shows the filtered signal around the 30kHz LORAN-C bandwidth. Several continuous wave (CW) interference sources are also visible in the RF spectrum; however they have no significant impact on the LORAN signal.

3.3. Flight Test Results

Two series of flight tests were conducted following the testing of the data collection system. On August 13-14, 2003 data was collected during roundtrip flights from UNI to Craig Municipal Airport (CRG) in Jacksonville, FL. The second set of data was collected in the Northeast U.S. These flights were from UNI to Portland International Airport (PWM) in Portland, ME from August 18-20, 2003. The ground tracks for these flights are shown in Figure 8.

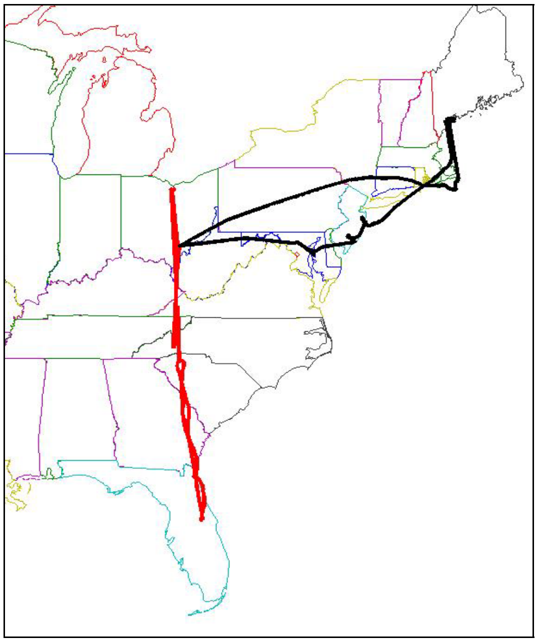

Figure 8: Data collection flight paths

On the August 14 flight leg that departed CRG for the return to UNI it was noted that severe thunderstorms were developing in the vicinity of the Orlando International Airport (MCO). Since the primary goal of the work being performed is to characterize the impact of atmospheric noise on the LORAN-C signal, the flight proceeded south to allow for data collection in close proximity to the thunderstorm activity. The images in Figure 9 and Figure 10 show an example of the time and frequency domain depiction of the LORAN RF band data collected during the flight in the vicinity of thunderstorms.

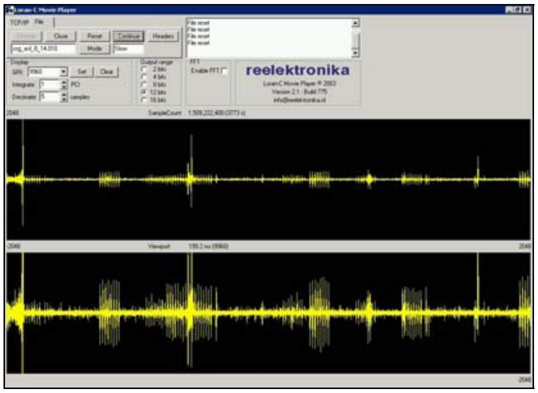

Figure 9: Time domain signal collected over MCO August 14, 2003

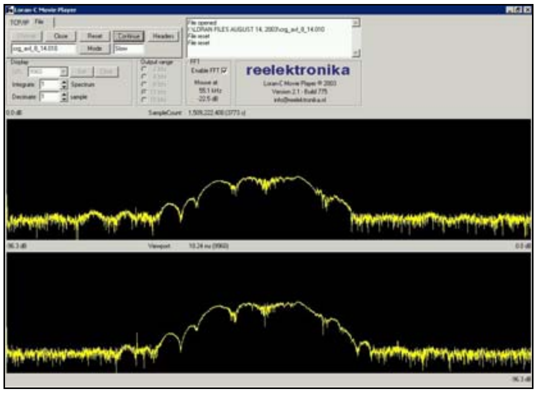

Figure 10: Frequency domain representation of signal collected over MCO August 14, 2003

The effects of the lightning strikes can be clearly seen as spikes in the time domain signal. The lightning, as expected, is visible in both the e-field and h-field antennas. The frequency spectrum of both signals shows the presence of frequencies outside the 30kHz LORAN bandwidth and that their magnitude is larger than the filtering in the data collection system can completely handle.

Figure 11 shows a radar snapshot of the thunderstorm activity occurring during the period in which the above data was collected. The aircraft's stormscope showed what the pilot described as "medium intensity" lightning activity. However, it was noted anecdotally that the Apollo 618 LORAN receiver being used to power the e-field antenna continued to track the southeast LORAN-C chain, GRI 7980, throughout this period of the flight.

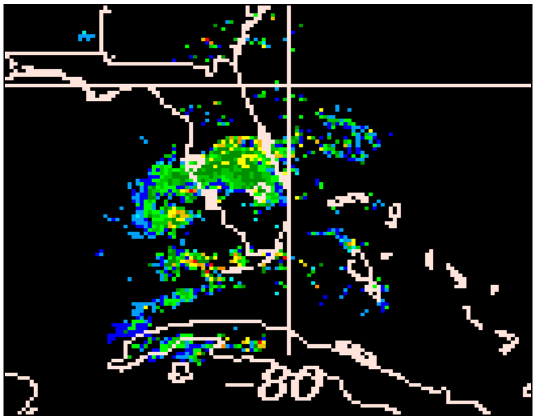

Figure 11: Radar image of thunderstorm activity near MCO August 14, 2003

4. FUTURE WORK

These flight tests have demonstrated that the data collection system is capable of capturing the LORAN-C RF signal adequately for the purposes of characterizing noise in the LORAN-C frequency band. Subsequent data collection will be required to obtain data in the varying weather conditions necessary to evaluate LORAN-C performance in the presence of atmospheric noise such as lightning and p-static.

A more thorough analysis of the data collected during the flight tests discussed in this paper is contained in reference 5.

Acknowledgements

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References

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