

# Improving Loran Coverage with Low Power Transmitters

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## BIOGRAPHY

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Tim Hardy is the Head of Engineering at Nautel Limited and has been with the company for 15 years. He has been involved in the design of several generations of AM and FM transmitter systems and played a lead role in the introduction of digital signal processing systems to Nautel's transmitters. His recent work includes the theory and design of a new generation of Loran transmitters.

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## ABSTRACT

Enhanced Loran (*eLoran*) is currently being implemented to provide back up to global navigation satellite system (GNSS) in many critical and essential applications. In order to accomplish this, *eLoran* needs to provide a high level of availability throughout its desired coverage area. While the current Loran system is generally capable of accomplishing this, there remain known areas of where improved coverage is desirable or necessary. Many such areas exist worldwide. One example is in the middle of the continental United States where there inadequate transmitter density to provide the desired availability for applications such as aviation in some parts. This paper examines the use of

lower power, existing assets such as differential GPS (DGPS) and Ground Wave Emergency Network (GWEN) stations to enhance coverage and fill these gaps. Two areas covered by the paper are the feasibility and performance benefits of using the antennas at these sites.

Using DGPS, GWEN or other existing low frequency (LF) broadcast towers requires considering several factors. The first is the ability of transmitting equipment to efficiently broadcast on these antennas, which are significantly shorter than those at a Loran station. Recent tests at the US Coast Guard Loran Support Unit (LSU) demonstrated the performance of a more efficient transmitter. This technology allows for the effective use of smaller antennas at lower power levels. Second is the ability to broadcast a navigation signal that is compatible with the Loran system and the potential DPGS broadcast. The paper examines some possibilities for navigation signals. The goal is to develop a suitable low power signal that enhances navigation and is feasible for the transmission system.

The second part of the paper examines the benefits of using these stations. The benefits depend on the location of the stations and the ability of seamlessly integrating them within the existing Loran infrastructure. Analysis of these factors is presented and the coverage benefits are examined.

## 1.0 INTRODUCTION

Enhanced Loran (*eLoran*) is being implemented around the world as a prime candidate to back up position navigation and timing (PNT) capabilities of Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) [1]. While GNSS offers high performance and availability, its popularity has made this performance indispensable to many parts of the global economy. In particular, aviation and maritime navigation as well as timing and frequency users depend heavily on the

capabilities of GNSS. In recognition of the dependency, the United States (US) Department of Homeland Security (DHS) announced in February 2008 that *eLoran* will be implemented to provide “an independent national positioning, navigation and timing system that complements the Global Positioning System in the event of an outage or disruption in service [2].” This came as a result of many years of research by the US Federal Aviation Administration (FAA) Loran evaluation team to demonstrate the feasibility of an enhanced Loran system to support the requirements of aviation non precision approach (NPA), maritime harbor entrance and approach (HEA) and stratum 1 frequency and precise timing needs [3]. Europe has also recognized this need with the General Lighthouse Authorities (GLAs) of the United Kingdom and Ireland also promulgating the development of *eLoran* for maritime use [4].

The utility of a backup system comes from its ability to provide similar operational performance as the primary system. Providing these operational capabilities requires meeting high requirements factors such as integrity, accuracy and continuity. Coverage performance of this level is beyond the scope of the original Loran design. New transmitters are necessary to meet these requirements in many areas. However, new full sized Loran transmitters are expensive in terms of land, equipment and operational costs. This motivates an examination of the use of existing antenna assets and lower power transmitters.

The paper analyzes the benefits of using these and other similar assets. In using these assets, there are some constraints such as power, or in the case of using Loran signals, the capability of the current chain configuration to accommodate the additional station. We assume the existing chain configuration and determine which existing low power transmitters can be used. An analysis of the ability of different chains to support a given low frequency (LF) asset is conducted. This determines the possible broadcasts available. The Loran coverage availability simulation tool is used to assess the performance benefits of using different feasible combinations of these existing lower powered transmitters. As a case study, we examine areas of reduced availability in the United States such as the midcontinent gap and southern California and determine the performance gains from utilizing a few well selected, existing LF broadcast sites.

## 2.0 BACKGROUND

The emergence of enhanced Loran has provided impetus for the consideration of additional Loran transmitters. For *eLoran* to provide backup to GNSS for safety and economically critical applications, it must have high availability – preferably greater than 95%. This availability is the ability to provide that the high level of integrity, accuracy and continuity required for supporting the desired applications. The performance standards are significantly higher than required for Loran-C operations. The result is that availability is strongly influenced by having strong geometry and a multitude of usable signals. So areas where there exist one critical station (i.e., South Florida) may not adequately yield the desired *eLoran* availability even though the performance was suitable under Loran-C specifications. While it would be desirable to have new Loran stations in some of these regions, this may not be feasible financially or geographically. This is because new towers and their support equipment are expensive. Furthermore, land is costly and may not be available at ideal location. So one solution is to use low power transmitters at existing antenna sites to cover gaps and reduce cost. Hence, low power transmitters that can use existing assets are studied.

### 2.1 Reasons for Low Power Transmitters

There are numerous reasons for developing low power Loran compatible transmitters. The foremost is improving Loran coverage and availability at a reasonable cost by using existing assets. Another reason is to support portable, tactical Loran capable of enabling jam resistant positioning.

A primary reason for low power transmitters is to improve coverage performance in the currently existing in Loran. This is not a design deficiency of the system but rather result a historical result from Loran development. The desired scope of Loran, both in terms of coverage and supported applications, has increased with steadily with time. These changes have increased performance requirements on the system.

One area that could significantly benefit from additional transmitters is the midcontinent US. Originally, there were no midcontinent stations as Loran was envisioned to be a maritime system. However, in the 1970s and 80s, it was desired that Loran support land and aviation applications. As a result, construction began in the 1980s to fill the “midcontinent gap”. While six stations were desired, only five were built due to various constraints. The result is areas of weak coverage in the midcontinent.

Other areas of poor coverage in the US included southern California and Florida. These result from geometry issues with one station being critical to coverage in those regions. Improving coverage in these regions would ideally place Loran stations in Mexico and Cuba. The political difficulties of such an arrangement made the option undesirable.

Similar examples can be found around the world. One case is in Northern Europe, where shipping lanes around the North Sea suffered coverage and availability deficiencies. These have been mitigated by the recent operation of the Loran transmitter in Anthorn. As seen in Figure 1, while Loran has significant coverage worldwide, there are many areas that would benefit from an additional station.

A second reason is to facilitate or enable the deployment of tactical Loran stations to enhance coverage and robustness in selected regions. One method is to employ a concept similar to Loran-D, whereby smaller, low power, stationary transmitters can be used to improve performance in a region [5]. Another idea, termed LC-Delta, utilizes a mobile tactical transmitter [6]. The transmitter would be carried aboard a moving vehicle. Possible implementation include placement aboard an aircraft and broadcast using a trailing whip antenna. Obviously, an efficient, low power and low weight transmitter is essential to this purpose.



**Figure 1. Loran Worldwide (courtesy Megapulse)**

## 2.2 Loran Transmitter Technology

The key to developing low power and low cost Loran stations is having efficient transmission systems. One factor affecting efficiency is the effective antenna height with taller antennas being more efficient. A 625 foot top loaded monopole (TLM) is one of the most common Loran antennas in service. Antennas as tall as 1350 feet (411.48 m) have been used. Antenna efficiency, up to a certain point, goes with the square of the antenna height. If smaller antennas are to be used, the loss in efficiency has to

be made up by an increase in power, more efficient transmitter equipment or both. The former is not desirable for cost reasons. So this paper discusses the transmitter equipment technology and the possibilities for improved efficiency.

The second important factor is Loran transmitter equipment. This section briefly covers those currently in operational use. The first generation Loran transmitters used vacuum tube technology and were known as tube type transmitters (TTX). These tubes essentially acted as power amplifiers which magnify input Loran waveform into the antenna. Current state of the art transmitters use solid state technology using half cycle generator to create the output waveform. Multiple generations of solid state transmitters (SSX) based on half cycle generators are employed through most of the world. The current generation, termed new SSX (NSSX), are scheduled to replace the last remaining TTX in the US.

Transmitter efficiency and power requirements drive Loran station costs. Lower efficiency means higher power required to achieve a specified emission power. This affects the amount of fuel a station must keep for back up power. It also means more heat is generated requiring additional power and equipment for cooling. Low heat generation allows for the use of a small trailer rather than a larger fixed building with cooling. Current operational Loran transmitters require extensive cooling, back up fuel and a large structure to support these units. This results in significant construction and operations costs. Hence, increased efficiency can have a marked effect on cost.

## 2.3 Existing Assets

Minimizing the cost of station infrastructure can be accomplished by using existing assets and infrastructure. One idea is to use existing differential GPS (DGPS) or Ground Wave Emergency Network (GWEN) sites to support a Loran compatible signal. DGPS towers come in four common sizes: 74 foot whip, 90, 120, and 150 foot towers [7]. The towers of interest for Loran are the larger ones. GWEN was set up to transmit LF signals for emergency U.S. military communications. As such, each site has a roughly 299 ft (91 m) tall tower and several shelters. GWEN has been decommissioned and its assets are being recapitalized for other uses such as Nationwide DGPS (NDGPS). The Loran signal may be multiplexed onto these towers or be the sole signal.

### 3.0 USING EXISTING ASSETS TO TRANSMIT A NAVIGATION SIGNAL

There are many issues associated with using an existing antenna to transmit a Loran signal. As the GWEN and DGPS antennas are significantly shorter than a typical Loran antenna, transmitter technology, particularly efficiency needs to be considered. Additionally, signal design need to be examined primarily to efficient use of the bandwidth and its properties to make up some of the lower transmitted power and efficiency loss with shorter antenna. Inherent in the design is its compatibility with the transmitter equipment and Loran signal specifications. Finally, we need to examine how to use antennas, such as DGPS, that need to also be used for other purposes.

#### 3.1 Transmitter Technology

The key technology needed for using existing smaller, low power Loran stations is an efficient transmitter. The current transmitters existing in the Loran system are unlikely to be efficient or cost effective enough for low cost, low power sites. However, new technology is capable of providing such performance and efficiency. One possibility is the Loran transmitter being developed by Nautel [8]. This technology has been tested at the Loran Support Unit (LSU) transmitter at Wildwood, NJ. Other technology may produce similar performance and efficiency. This paper uses the Nautel system as reference as it has been implemented and tested.

The Nautel transmitter is designed to efficiently recover power from the pulse tail. This becomes more important with short antennas as these antennas are very high Q (greater than 100). For high Q antennas, most of the energy delivered to the antenna is not radiated or dissipated. By recovering the excess energy instead of damping it, more efficient use of power is achieved. Additionally, the transmitter can handle high duty cycles and is being designed to provide at least 600 pulses per second. It is expected that this equipment can output about 12.5 kW and 1.25 kW peak power from a GWEN and DGPS antenna, respectively. With higher duty cycles and non standard Loran signal design, the output signal can have the effective range performance of a standard Loran transmitter at 50 kW and 5 kW, respectively.

#### 3.2 Compatible Signal Design

The standard Loran signal may be used for transmission from these sites. However, this may not be the best choice for low power stations. These

transmitters have shorter range due to the lower power resulting in less skywave interference. With peak transmission power at most  $1/8^{\text{th}}$  of that of a nominal Loran station, the range will be roughly 500 km or less. As a result, the skywave will have less effect (greater delays and lower relative amplitudes) and the same bandwidth is not necessary. The signal can be designed to use a narrower bandwidth and dwell longer at peak power. The primary reason for the relatively fast rise time and wide bandwidth of a standard Loran pulse enables a receiver to isolate groundwave and skywave at ranges of 1000 km and more. Additionally, with skywave not being as significant an issue, a higher duty cycle may be employed which will enhance the average signal to noise ratio (SNR) over a given time period and increase performance despite the lower peak power. The higher duty cycles can be accomplished in several ways such as increased number of pulses (like in Loran-D) or in longer pulses.

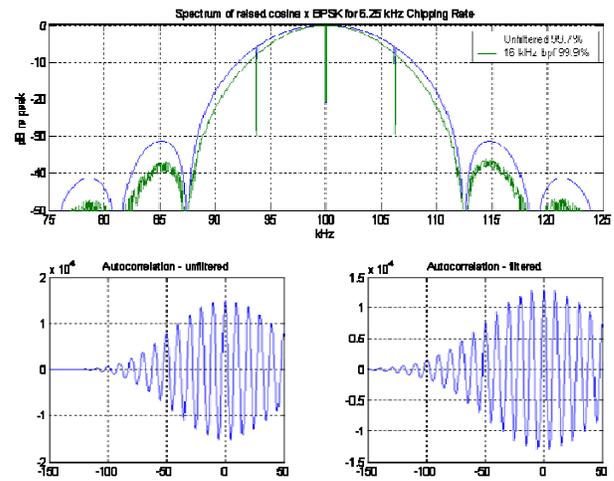


Figure 2. Candidate BPSK ranging signal (frequency domain & autocorrelation)

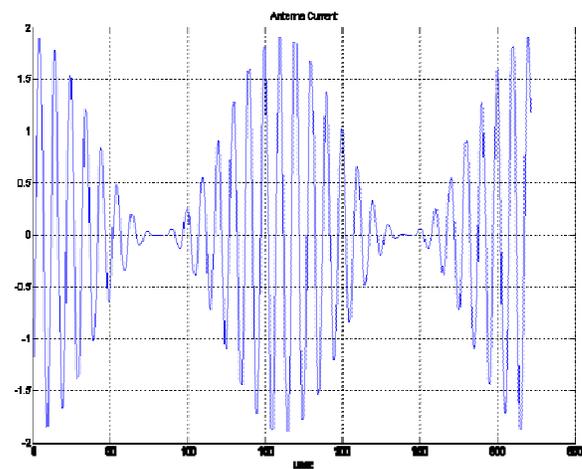
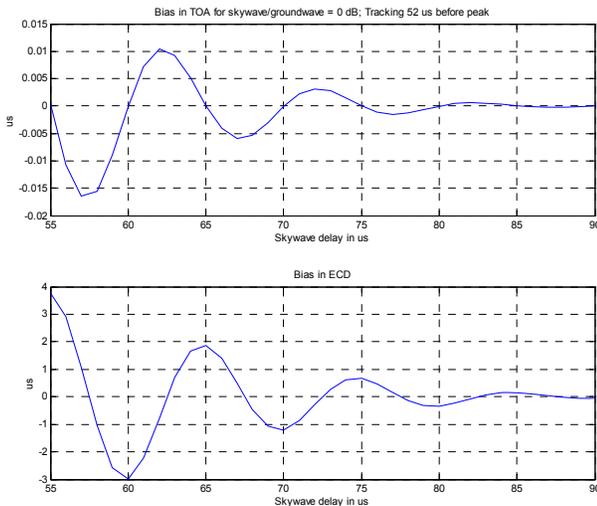


Figure 3. Candidate BPSK ranging signal (time domain)

Several designs were analyzed for their ability to meet Loran bandwidth requirements. One design using the product of a binary phase shift keying (BPSK) and a raised cosine is seen in Figure 2 and Figure 3. Figure 2 shows the spectrum of the BPSK design and a filtered version of the design. Both versions meet bandwidth requirements. Figure 3 shows the design in the time domain. The phase shift occurs in the time nulls of the signal and is compatible with current transmitter technology. The transmission is similar to those already being broadcast using the Nautel technology.



**Figure 4. TD Phase (top) and ECD Bias (bottom) in usec for skywave delays (in usec) with SGR = 0 dB. Tracking at 52 usec before peak**

The design must be robust against anticipated skywave. The conservative case of a skywave to groundwave ratio (SGR) of 0 dB is studied. This level of skywave is not expected for ranges less than 500 to 600 km. At this range, expected delays are generally at least 55 microseconds ( $\mu\text{sec}$ ) given a 60 km ionospheric reflection layer height. Different tracking points are examined. Figure 4 shows the effect of skywave with SGR = 0 dB for tracking at 52  $\mu\text{sec}$  before the peak. In this case the worst case phase error is about 5 m (.016  $\mu\text{sec}$ ).

Other designs, such as those using minimum shift keying (MSK) were examined. MSK requires frequency changes within the pulse which should be feasible using the Nautel equipment but has not been demonstrated.

### 3.3 Diplex

The ideal situation is to have an antenna dedicated for Loran transmissions. However, this will often not

be feasible. Some GWEN and all DGPS antennas will have to support the broadcast of DGPS. As a result, the Loran signal would share the bandwidth with DGPS. While this has not been demonstrated, diplexing with the Nautel DGPS/Loran transmission equipment should be feasible with some design additions. However, the economics of the design is yet unknown.

## 4.0 USING EXISTING CHAIN STRUCTURE

The previous section examines the feasibility of producing a reasonable navigation signal from these existing towers. However, compatibility with and benefit to the existing Loran system also need be studied. Additional towers must be properly fitted into the Loran chain structure in order to maintain backward compatibility and minimize intrasystem interference. This section shows the analysis the ability of each chain to adopt additional stations and where those stations can be located.

### 4.1 Chain Capacity

For the new station transmitter to be compatible with the existing Loran system, it must be able to exist within a local chain. In the United States, each station broadcasting in a chain maintains a time difference (TD) of at least 10400  $\mu\text{sec}$  between the station and the station broadcasting prior to it<sup>1</sup>. This TD represents the time difference between the start of the pulses of the two stations. This specification ensures that signals from the same chain (and their skywave) do not interfere with other signals in the chain. The emission delay (ED) is chosen such that the specification is met. The Equation 1 shows how the minimum TD is calculated between station  $n$  and  $n-1$  in the chain. It depends on the propagation time from station  $n$  to  $n-1$ . This is given by the second term with  $dist_{n,n-1}$  being the distance between the station and  $c$  being the propagation speed. The minimum TD occurs on the baseline between the two stations. It is the time between the start of reception of the signal from station  $n-1$  at station  $n$  to the start of transmission of the signal from station  $n$ . Equation 2 defines the time between pulses (TBP), which is the time between the reception of the end of the last pulse of the earlier station ( $n-1$ ) to the start of the pulse of the later station ( $n$ ). The difference between TD and TBP is the time from the between the start of the first pulse to the end of the last pulse

<sup>1</sup> The US Coast Guard specification is a bit more complicated with the time difference between any two secondaries being 9900  $\mu\text{sec}$ . The actual minimum TD is 10411  $\mu\text{sec}$  on the 9610, hence we use 10400  $\mu\text{sec}$  [10].

of station  $n-1$ , denoted by  $GRIpulseinterval_{n-1}$ . For  $eLoran$ , this is roughly 9250  $\mu\text{sec}$  (even if 10<sup>th</sup> pulse modulation is used). Given US specifications, this leaves at least 1150  $\mu\text{sec}$  of buffer between signals from station  $n$  and  $n-1$ .

$$\min TD_{n,n-1} = ED_n - \frac{dist_{n,n-1}}{c} \quad (1)$$

$$TBP_{n,n-1} = ED_n - \frac{dist_{n,n-1}}{c} - GRIpulseinterval_{n-1} \quad (2)$$

Given a prospective transmitter location, the formula can be applied to determine if it is feasible to add the station. Two minimum TDs need to be calculated – between the prospective station and the station transmitting prior to and after the prospective station. From that, we determine if there is an ED for the prospective station such that the minimum TDs meet the specifications. Note that the minimum TD requirement could change if the prospective transmitter does not transmit the nominal Loran signal. So, even if the minimum TD cannot meet the specifications, the prospective transmitter may still be used. This is because the low power transmitters can broadcast signals that differ from standard  $eLoran$ . Equation 2 can be applied to determine the time ( $GRIpulseinterval$ ) that is available for the low power signal and still have a reasonable (i.e. > 1150  $\mu\text{sec}$ ) margin between signals. Finally, if the minimum TD is sufficiently greater than the requirement, the  $GRIpulseinterval$  can be increased allowing for more pulses to be added.

#### 4.2 Case study

In this paper, the benefit of using GWEN or DGPS towers as additional Loran transmitter is studied. Hence, the conterminous United States (CONUS) will be used as a case study. The focus is on improving coverage for those areas previously discussed by using GWEN and DGPS assets.

There are numerous GWEN/proposed NDGPS stations available. There are at least 44 stations available in the US. The list was examined and reduced to the most reasonable stations for aiding coverage in the Midwest and Southern California. There are no stations in Florida. Additionally, the DGPS station in Point Loma, California and in Key West and Miami, Florida are examined for their benefits. The list for the Midwest is seen in Table 1 and that for Southern Florida and California is seen in Table 2. Figure 5 shows a map of the Midwestern and Californian sites. Figure 6 shows the DGPS assets in Southern Florida.

Location	State	Latitude (N)	Longitude (W)
Mechanicsville	IA	41.9942	91.1415
Topeka	KS	39.04533333	96.0388
Oberlin	KS	39.8275	100.6636
Bobo	MS	34.1100	90.6900
Whitney	NE	42.5	102
Edinburg	ND	48.5586	97.7844
Glenwood	IA	41.0205	95.7769
Fayetteville	AR	36.0632	94.1579

**Table 1. Potential GWEN sites for Midwest US**

Location	State	Latitude (N)	Longitude (W)
Essex	CA	34.7516	115.2303
Point Loma*	CA	32.665	117.2433
Key West*	FL	24.582333	81.6530
Miami*	FL	25.732833	80.1602

**Table 2. Potential GWEN/DGPS sites for Southern Florida/California (\* = DGPS)**



**Figure 5. GWEN/DGPS sites for Midwest and Southern California**



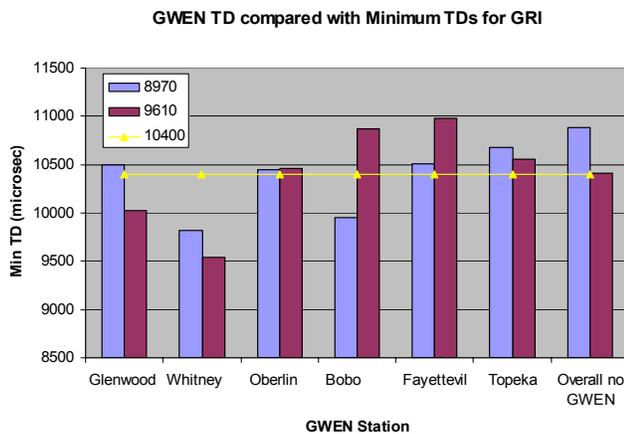
**Figure 6. DGPS sites in Southern Florida**

The chain capacity analysis now can be used to determine how many and which stations can be added to a given chain. In the Midwest, there are three chains, given by their group repetition interval

(GRI), of interest: 8290 (North Central US), 8970 (Great Lakes), and 9610 (South Central US). Based on the minimum TD analysis and assuming the standard pulse interval during a GRI (*GRIpulseinterval*), each of these chains can accommodate a maximum of one station. The stations that can be accommodated are shown in Table 3. These stations are added to the end of the GRI sequence.

Chain	Number	GWEN sites
8290	1	Edinburg, ND, Whitney, NE
8970	1	Glenwood, IA; Oberlin, KS; Fayetteville, AR; Topeka, KS
9610	1	Oberlin, KS; Bobo, MS; Fayetteville, AR; Topeka, KS

**Table 3. Chain capacity and potential stations**



**Figure 7. TD with GWEN stations & Minimum TD of the Chain**

In the west coast, the 9940 chain, the TD between the current last (Zulu) station (Searchlight, NV) and the master (Fallon, NV) is 55467 microseconds. The time gap is adequate for the addition of three or more transmitters, depending on location. Another use is to have only one or two additional station which broadcasts for a longer period – that is have *GRIpulseinterval* that is larger than the standard. This results in a higher duty cycle by having an extended pulse set. As mentioned previously, this allows for more effective power while using the same peak power. For example, with one additional station in 9940, the time gap allows for transmission of more pulses – around five times more pulses for the standard Loran transmission. So, a 1.25 W peak transmitter at Point Loma can effectively perform like a 6.25 kW transmitter. Coupling that with a higher duty cycle on peak power, the result is that the transmitter can reasonably achieve performance similar to a standard Loran transmitter with 10 kW peak power. A similar situation occurs to a lesser extent with 8290 where it is possible to achieve a

minimum TD of 18400 between Edinburg and master (Havre). The additional time is not enough to add another station but could be used to have an extended pulse set for Edinburg.

In the southern Florida, the only chain that operates in the region is the 7980 (Southeast US) chain. However, the minimum TD between the Zulu station (Carolina Beach) and Master (Malone) is only 15721 microseconds. This is not adequate value for having an additional station. In fact, if a station were placed in Miami or Key West, it could transmit for only 1000 or 500  $\mu$ sec, respectively (and maintain 1150  $\mu$ sec TD). The other possibility is to create another chain containing either DGPS towers or both.

### 4.3 Coverage Results

The Loran coverage availability simulation tool (LCAST) is used to examine the availability benefits of additional stations for aviation NPA [11]. While several different models can be used in the coverage tool, the conservative noise model from the 2004 report is used. However, the improved temporal ASF model based on weather data will be used [12] as it is the currently preferred model. Our analysis examined the performance changes for all possible model options and [11] show the results from use a less conservative noise model. For the analysis, it is assumed that the GWEN and DGPS sites can produce the equivalent range performance of a standard Loran tower radiating 50 kW and 5 kW peak power, respectively. These values seem reasonable given the technology and the peak power of 12.5 kW and 1.25 kW.

#### Midwest United States

Several different combinations of GWEN stations examined for the Midwest, Southern California and Florida. The scenarios are shown in Table 4 with the stations added for each chain (GRI).

Scenario	7980	8290	8970	9610	9940
1	---	Edinburg	Glenwood	Bobo	Essex
2	---	Edinburg	Oberlin	Bobo	Essex
3	---	Edinburg	Glenwood	Fayetteville	Essex
4	---	Edinburg	Glenwood	Oberlin	Essex
5	Miami	Whitney	Glenwood	Bobo	Point Loma
6	Key West	Whitney	Glenwood	Bobo	Point Loma

**Table 4. Scenarios Examined for Improved Coverage**

Figure 8 shows the performance of the nominal case. One notices poor (< 90%, in orange and red) coverage in two locations: the Midwest and Central Southeast. Figure 9 to Figure 12 show the performance of Scenario 1 to 4, respectively. These

pertain primarily to the Midwest. As seen, each configuration still has some deficiencies. None completely eliminates both areas of poor coverage. Scenarios 2 and 5 seem better in terms of eliminating areas of poor coverage. Scenario 4 is good because the Midwest effectively has coverage of 95% or higher. If the goal is to eliminate areas of below 90% coverage, the preferred configuration is Scenario 5. The results are dependent on the model assumptions though the trend is similar. Results vary slightly depending on which ASF model is used. There are noticeable improvements depending on noise clipping model with generally greater than 90% availability for 2004 Report Noise Model and greater than 95% availability for the newer "Pessimistic" Noise Model [13].

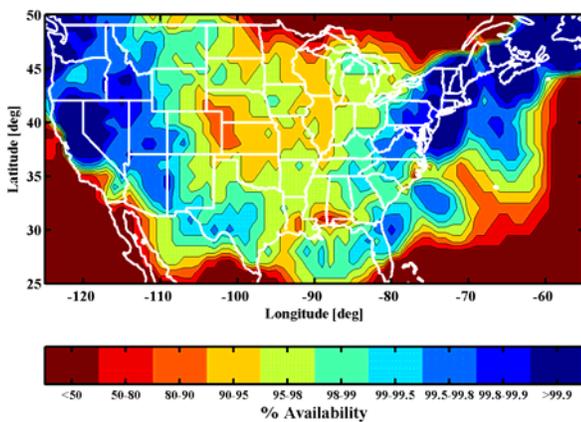


Figure 8. Nominal Performance

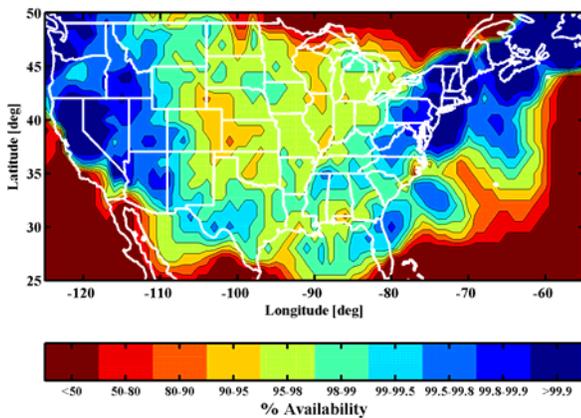


Figure 9. Scenario 1

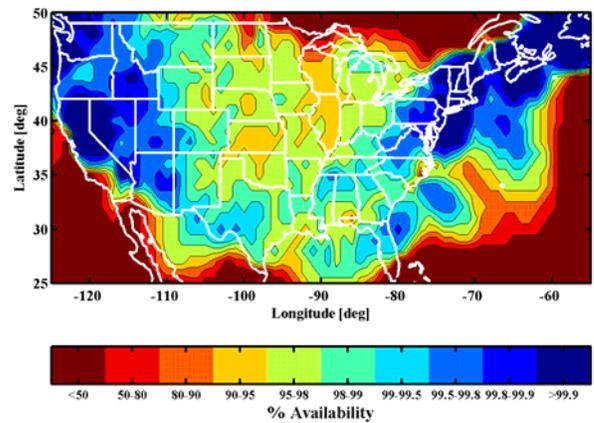


Figure 10. Scenario 2

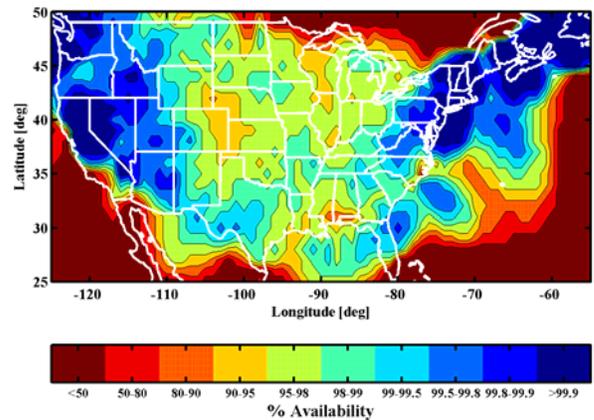


Figure 11. Scenario 3

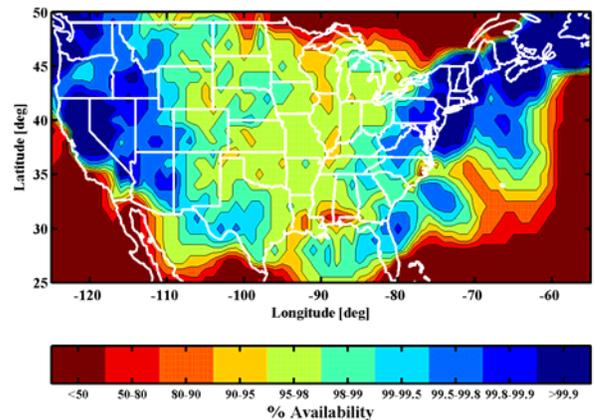


Figure 12. Scenario 4

Scenarios 5 and 6, presented in Figure 13 and Figure 14, show the difference between using Whitney instead of Edinburg in 8290. Since Whitney is more to the south, coverage in the US is slightly better with this station.

#### Southern California and Florida

The two scenarios also allow us to examine the performance possibilities for Southern California and

Florida. In the scenarios, a small 5 kW transmitter at Point Loma, CA (near San Diego) is used instead of a 50 kW transmitter at the Essex, CA GWEN site. From the figures, it is seen that the Point Loma location is preferable, especially for coastal and harbor performance (such as in San Diego or Los Angeles). For South Florida, a small transmitter (5 kw) is assumed to exist at either Miami (Figure 13) or Key West (Figure 14). Both have benefits with the preference depending on which areas are more important. For aviation and RNP 0.3, Miami is preferred since it provides better performance inland.

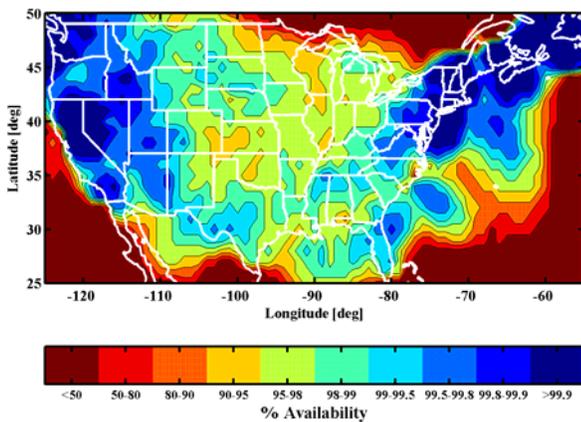


Figure 13. Scenario 5

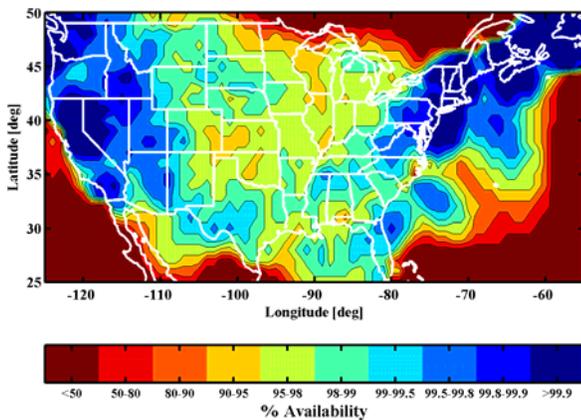


Figure 14. Scenario 6

Analysis of HEA yields a similar conclusion with Point Loma being preferable to Essex. The choice of Miami or Key West depends on which relative importance of shipping channel in the area. Accuracy at 95% availability is shown in Figure 15 and Figure 16 which show the nominal and two additional stations (Pt. Loma, Key West) cases.

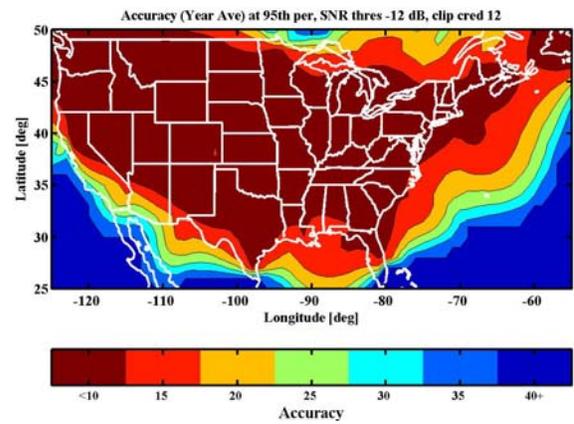


Figure 15. Nominal HEA Accuracy at the 95 Percent Noise Level

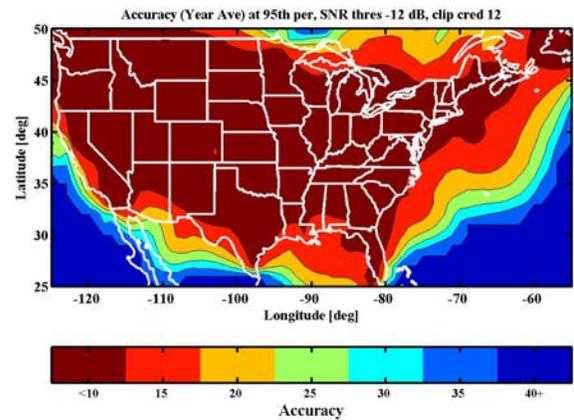


Figure 16. HEA Accuracy at the 95 Percent Noise Level with additional stations in Key West, FL & Pt. Loma, CA

## 5.0 CONCLUSIONS

This paper examines the feasibility of low power Loran transmitters and some possible benefits. New technology significantly increase transmitter efficiency allowing for reasonable broadcast of LF signals from smaller towers such as those found at GWEN and DGPS sites. It is possible to diplex a Loran compatible ranging signal from these sites. Hence the technology enables low cost means of fielding additional Loran stations by using existing assets and requiring less infrastructure.

The paper examines the realizable benefit of having GWEN or DGPS sites provide a Loran ranging signals. It shows that under the current chain configuration in the US, it is possible to add three low power Loran stations (at GWEN sites) to Midwest and one station to West Coast. The three Midwest stations have the potential of improving availability to greater than 90% throughout nearly all the coverage area – eliminating many areas of 50-

80% availability. The results also show the importance of geometry as a transmitter in Point Loma, CA is much better for the ports of San Diego and Los Angeles than a 10 times more powerful transmitter in Essex, CA. Finally, southern Florida coverage could be improved using a very low power (~ 1-5 kW) transmitter in Miami.

While GWEN and DGPS sites are used to study benefits, the benefits of technology go beyond the use of these transmitters. The ability to use 300 ft (91 m) and even 150 ft (41 m) antennas opens up the possibilities of using numerous existing assets and improving coverage throughout the world.

## 6.0 DISCLAIMER

The views expressed herein are those of the authors and are not to be construed as official or reflecting the views of the U.S. Coast Guard, Federal Aviation Administration, Department of Transportation or Department of Homeland Security or any other person or organization.

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