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Improving Loran Coverage with Low Power Transmitters

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Enhanced Loran (*eLoran*) is currently being implemented to provide back up to global navigation satellite systems (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, worldwide, there remain a number of known areas where improved coverage is desirable or necessary. One example is in the middle of the continental United States where the transmitter density is not adequate for providing 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 the consideration of several factors. The first is the ability of the 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 (when using a DGPS antenna). 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 seamlessly to integrate them within the existing Loran infrastructure. Analysis of these factors is presented and the coverage benefits are examined.

KEY WORDS

1. eLoran. 2. DGPS antenna. 3. GWEN. 4. LF broadcast towers.

1. 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 indispensible 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 harbour 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 the meeting of 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 mid-continent gap and southern California and determine the performance gains from utilizing a few well selected, existing LF broadcast sites.

2. 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 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 the desired locations. 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 of the currently existing Loran system. This is not a design deficiency of the system but rather a historical result from Loran development. The desired scope of Loran, both in terms of coverage and supported applications, has increased steadily with time. These changes have increased performance requirements on the system. One area that could significantly benefit from additional transmitters is the mid-continent US. Originally, there were no mid-continent stations because 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 mid-continent gap. While six stations were desired, only five were built due to various constraints. The result is areas of weak coverage in the mid-continent.

Other areas of poor coverage in the US include southern California and Florida. These result from geometry issues with one station being critical for 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 make 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 implementations 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.

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.

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Figure 1. Loran worldwide (courtesy Megapulse).

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 magnified input Loran waveform into the antenna. Current state-of-the-art transmitters use solid state technology using a half cycle generator to create the output waveform. Multiple generations of solid state transmitters (SSX) based on half cycle generators are employed throughout most of the world. The current generation, termed new SSX (NSSX), is scheduled to replace the last remaining TTX in the US.

Transmitter efficiency and power requirements drive Loran station costs. Lower efficiency means that higher power is required to achieve a specified emission power. This affects the amount of fuel a station must keep for back-up power. It also means that 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 system and operation costs.

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

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other uses such as Nationwide DGPS (NDGPS). The Loran signal may be diplexed onto these towers or be the sole signal.

3. 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 should be examined to provide more efficient use of the bandwidth and to make up for some of the lower transmitted power and efficiency loss associated 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 also to 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 and less heat is generated. 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 1/8th 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 is to allow 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.

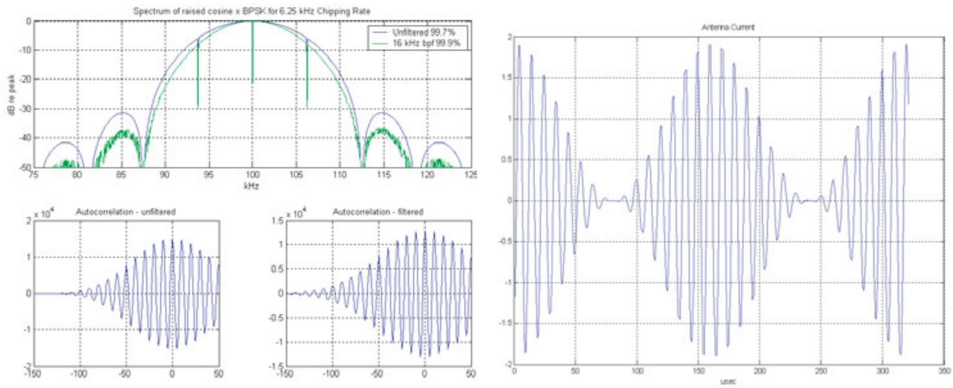

Figure 2. Candidate BPSK ranging signal. Left: frequency domain & autocorrelation. Right: time domain.

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 (RC). One example of the BPSK-RC design, using a 6·25 kHz chipping rate, is seen in Figure 2. The left side shows the spectrum of the design and a filtered version of the design. Both versions meet bandwidth requirements. The right side of the figure 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.

Analysis of the performance of BPSK-RC design shows the benefits of the signal for a low power design. White noise is injected into the signal and its effect on time of arrival (TOA) or phase and envelope to cycle difference (ECD) is determined. The result is compared to the effect of the same noise on a standard Loran pulse. The inverse of the TOA variance can be used as a metric for power. This can be seen from Equation 1 which is the result from deriving the TOA variance due to noise. SNR is the signal to noise ratio of one pulse, N_{pulses} is the number of pulses averaged and c is a constant. The model used in [3] to bound TOA variance due to noise is seen in Equation 2. Hence, the equivalent power of the design is the inverse of the BPSK TOA variance relative to a standard Loran signal.

$$\sigma^2_{noise} = \frac{c}{N_{pulses} * SNR} \tag{1}$$

$$\sigma^2_{noise} = \frac{(21 \cdot 1m)^2}{N_{pulses} * SNR} \tag{2}$$

The power performance has to be normalized as the BPSK design has a nominal transmission length of 20·48 milliseconds (ms) and is longer than a standard set of Loran pulses (∼8 ms). The equivalent power is normalized to a 8 ms time period using a factor of 0·39 (=8 divided by 20·48). The result for the design with the tracking point at 42 and 52 microseconds (μsec) prior to the pulse peak is seen in Table 1. Normalized equivalent powers of 14·2 and 8·6 are achievable for the respective designs. The increase suggests that a range performance equivalent to a

Table 1. Nominal performance of BPSK-RC in white noise (20·48 ms transmission).

Tracking Pt. re Peak	sigma TOA re Loran	sigma ECD re Loran	Equivalent Power Ratio	Normalized to 8 ms
−42 μs	0·166	0·329	36·4	14·2
−52 μs	0·213	0·423	22·0	8·6

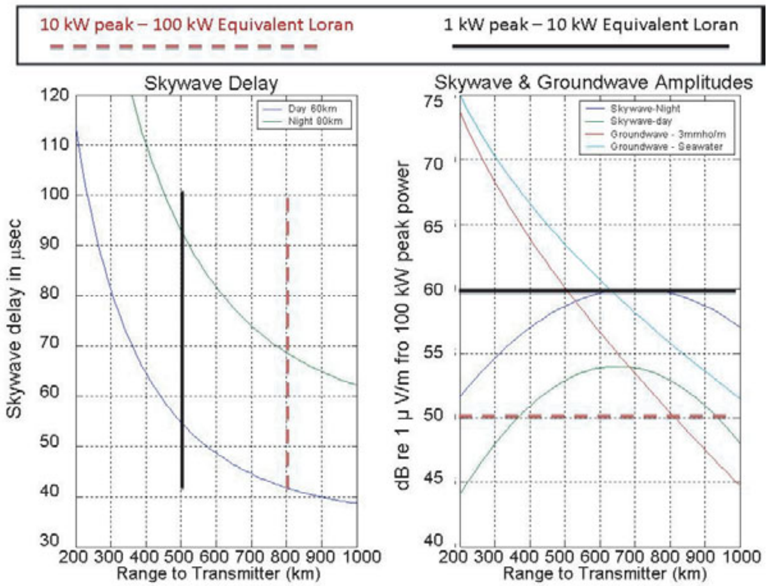

Figure 3. Skywave delay & amplitude at different ranges.

50 kW Loran transmission is very reasonable with 12·5 kW peak power and good signal design. In fact, 100 kW is not unreasonable.

The design must be robust against anticipated skywave. The strength and delay of the skywave depends on its range from the transmitter as seen in Figure 3. The range performance of a 50 kW Loran broadcast is about 500 km. 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 500 km, expected delays are generally at least 55 μsec given a 60 km ionospheric reflection layer height. The delay is only likely during daytime where skywave is generally weaker. Different tracking points are examined. Figure 4 shows the effect of skywave with SGR = 0 dB for tracking at 52 μsec before the peak. In this case, the worst case phase error due to skywave is about 5 m (0.016 μsec).

The design and tracking point selection represents a trade off between having good nominal performance and limiting the effect of skywave. If stronger and shorter delay skywave is anticipated, a wider bandwidth signal (i.e. higher chipping rate) can be used. This results in a narrower correlation peak and better immunity to skywave. Selection of tracking point also affects skywave performance. The effects of skywave are lessened the earlier the tracking point. This can be seen in Table 2 which shows the

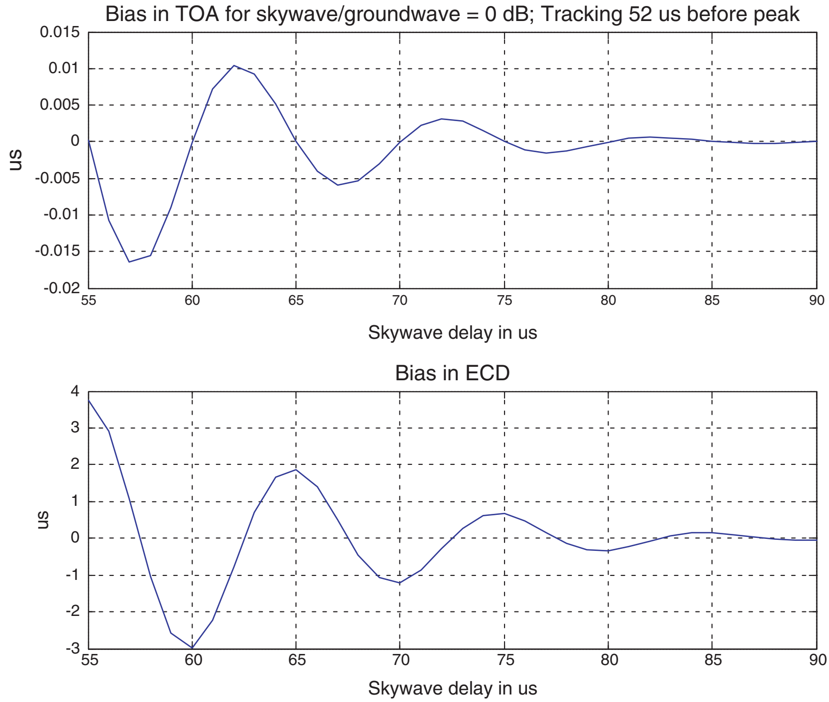

Figure 4. TD Phase (top) and ECD Bias (bottom) in μsec for skywave delays (in μsec) with SGR = 0 dB. Tracking at 52 μsec before peak.

skywave performance for the BPSK with the tracking point at 42 and 52 microseconds (μsec) prior to the pulse peak.

Other designs, such as those using minimum shift keying (MSK) have been examined. MSK requires frequency changes within the pulse which should be feasible using the Nautel equipment but has not been demonstrated. Additionally, preliminary assessments indicate that a shaped BPSK signal is preferred over MSK.

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 are as yet unknown.

4. USING EXISTING CHAIN STRUCTURE.

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

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Table 2. Performance of BPSK-RC with skywave.

Tracking Pt.	Max TOA Bias SGR = 0 dB		Max ECD Bias	
re Peak	Skywave > 60 us	> 50 us	> 60 us	> 50 us
− 42 μs	25 ns	45 ns	3·5 us	5·8 us
− 52 μs	12 ns	24 ns	1·85 us	3·7 us

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 10 400 μsec between the station and the station broadcasting prior to it[1]. 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) of secondary station n (ED_n) is the delay between the transmission time of the chain master and the secondary. It is chosen such that the specification is met. Equation 3 shows how the minimum TD is calculated between station n and n-1 in the chain. It depends on the respective EDs and on the propagation time from station n to n-1. This is given by the second term with $dist_{n,n\text{-}1}$ 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 4 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 between the start of the first pulse to the end of the last pulse of station n-1, denoted by $GRIpulseinterval_{n\text{-}1}$. For *eLoran*, this is roughly 9250 μsec (even if 10th pulse modulation is used [10]). Given US specifications, this leaves at least 1150 μsec of buffer between signals from station n and n-1.

$$minTD_{n,n-1} = ED_n - ED_{n-1} - \frac{dist_{n,n-1}}{c} \tag{3}$$

$$TBP_{n,n-1} = ED_n - ED_{n-1} - \frac{dist_{n,n-1}}{c} - GRIpulseinterval_{n-1} \tag{4}$$

Given a prospective transmitter location, the formula can be applied to determine if it is feasible to add the station to a given chain. 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

[1] The US Coast Guard specification specifies the time difference between any two secondaries to be at least 9900 μsec. The actual minimum TD is 10 411 μsec, occurring between 2 secondaries on the 9610, hence we use 10 400 μsec [10].

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Table 3. Potential GWEN sites for Midwest US.

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 4. Potential GWEN/DGPS sites for Southern Florida/California (* = DGPS).

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

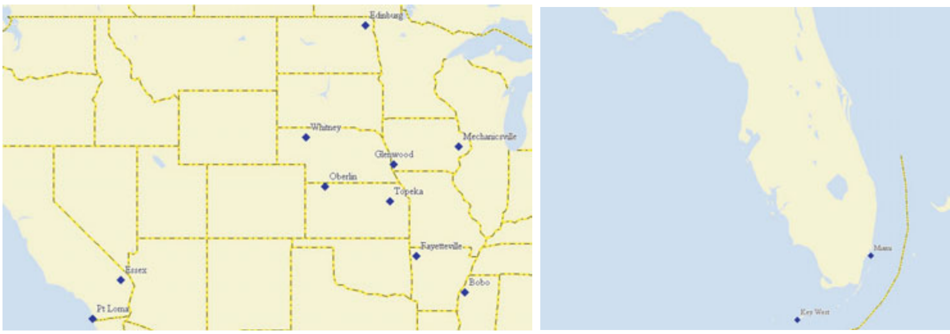

Figure 5. GWEN/DGPS sites for Midwest and Southern California (Left) and Southern Florida (Right).

power transmitters can broadcast signals that differ from standard eLoran. Equation 4 can be applied to determine the time (*GRIpulseinterval*) that is available for the low power signal and still have a reasonable (i.e. >1150 μsec) 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 transmitters is studied. Hence, the contiguous 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

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Table 5. Chain capacity and potential stations.

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

and Miami, Florida are examined for their benefits. The list for the Midwest is seen in Table 3 and that for Southern Florida and California is seen in Table 4. Figure 5 shows a map of the Midwestern and Californian sites and the DGPS assets in Southern Florida.

The chain capacity analysis can now 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 5. These stations are added to the end of the GRI sequence.

On the West Coast, the 9940 chain, the TD between the current last (Zulu) station (Searchlight, NV) and the master (Fallon, NV) is 55 467 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 stations which broadcast 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 2·8 kW ($=\sqrt{5}*1.25$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 18 400 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 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 15 721 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 μsec, respectively (and maintain 1150 μsec TD). The other possibility is to create another chain containing either the Miami or Key West DGPS towers or both.

5. COVERAGE RESULTS.

The Loran coverage availability simulation tool (LCAST) was used to examine the availability benefits of additional stations for aviation required navigation performance 0·3 (RNP 0·3) NPA operations [11].

Table 6. Scenarios examined for improved coverage.

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

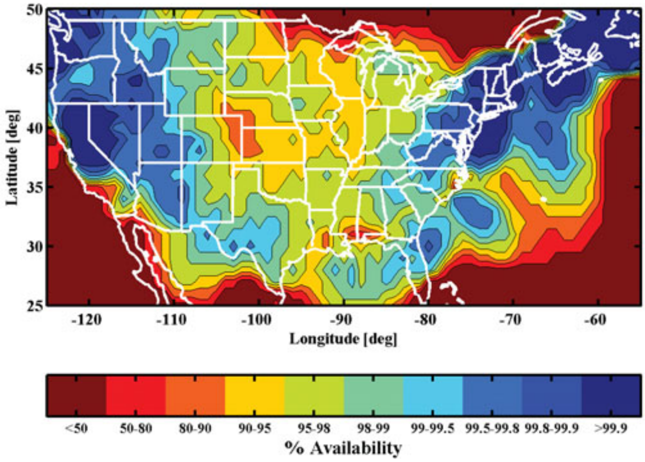

Figure 6. Nominal performance for NPA (RNP 0·3) coverage.

While several different models can be used in the coverage tool, the conservative noise model from the 2004 FAA report is used [3]. However, the improved temporal ASF model based on weather data is 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 of 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.

5.1. *Midwest United States.* Several different combinations of GWEN stations were examined for the Midwest, Southern California and Florida. The scenarios are shown in Table 6 with the stations added for each chain (GRI).

Figure 6 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 7 shows the performance of six scenarios. 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

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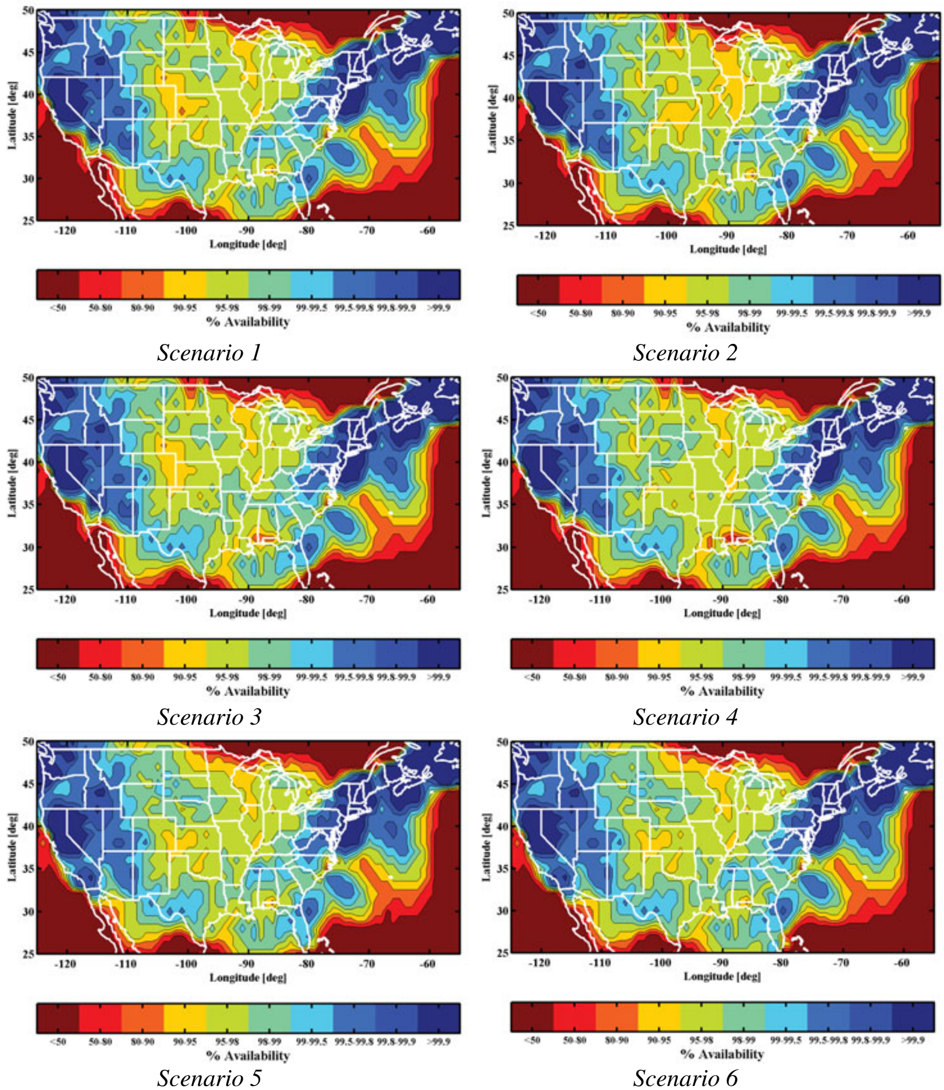

Figure 7. Scenarios 1–6 for NPA (RNP 0·3) coverage.

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 using the noise model from the 2004 FAA Report and greater than 95% availability using the newer Pessimistic Noise Model [13]. Scenarios 5 and 6, 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.

5.2. *Southern California and Florida.* Scenarios 5 and 6 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

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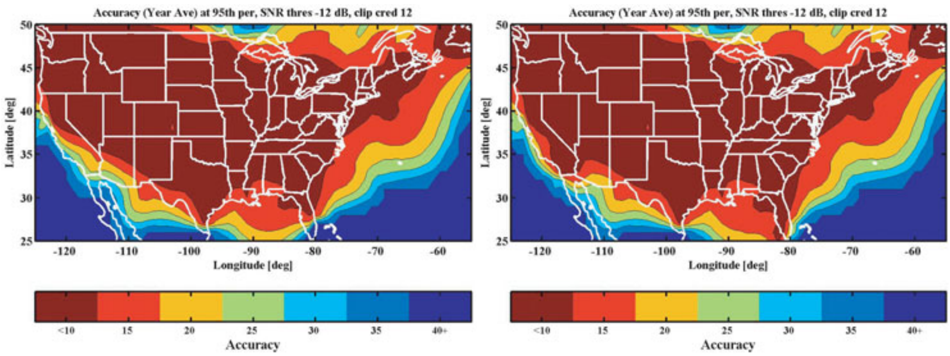

Figure 8. HEA Accuracy at the 95 Percent Noise Level Left: Nominal. Right: With additional stations in Key West, FL & Pt. Loma, CA.

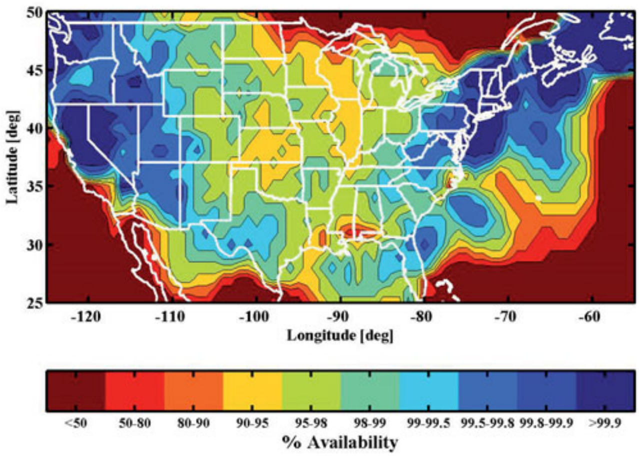

Figure 9. NPA availability with additional stations in Fayetteville, AR, Whitney, NE, Oberlin, KS, Essex, CA (all at 12·5 kW) & Key West, FL (1·25 kW).

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 harbour performance (such as in San Diego or Los Angeles). For South Florida, a small transmitter (5 kW) is assumed to exist at either Miami (Scenario 5) or Key West (Scenario 6). 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.

Analysis of HEA yields a similar conclusion with Point Loma being preferable to Essex. The choice of Miami or Key West depends on the relative importance of the shipping channels in the area. Accuracy at 95% availability is shown in Figure 8 which shows the nominal and two additional stations (Pt. Loma, Key West) cases.

The situation where GWEN and DGPS transmitted with 12·5 kW and 1·25 kW peak power was also examined with LCAST. This would be the result if a standard

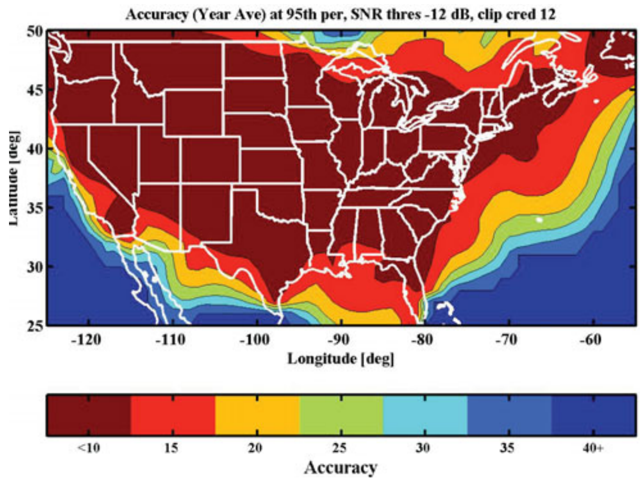

Figure 10. HEA Accuracy at the 95% noise level with additional stations in Key West, FL & Pt. Loma, CA at 1·25 kW.

Loran transmission was used without additional pulses. Figure 9 shows the NPA coverage assuming the addition of Fayetteville, Whitney, Oberlin, and Essex and Key West. The configuration is one of the better ones for reducing areas of poor coverage. Figure 10 shows Scenario 6 (Pt. Loma and Key West). Reduced performance is seen, however there is still significant benefit to areas of interest.

6. CONCLUSIONS.

This paper examines the feasibility of low power Loran transmitters and some possible benefits. New technologies 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 the DGPS sites. Hence the technology enables a 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 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 the Midwest and one station to the West Coast. The three Midwest stations have the potential of improving NPA 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 ten 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.

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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