PERFORMANCE PARAMETER TRADEOFF ANALYSIS FOR A NATIONWIDE DIFFERENTIAL GPS SERVICE

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PREFACE

This report is provided by the Institute for Telecommunication Sciences (ITS), National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce (DOC), to the Federal Highway Administration (FHWA), U.S. Department of Transportation (DOT), in fulfillment of Interagency Agreement Number DTFH61-93-Y-00110.

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Management, administration, and technical monitoring of this Agreement have been provided by Mr. James A. Arnold, Electronics Engineer, FHWA.

FIGURES

TABLES

Abstract

Analyses have been conducted to develop scenarios of nationwide coverage of a differential global positioning system (DGPS) correction signal. These scenarios are based on extensions of an existing network of DGPS radiobeacons. Various parameters and tradeoffs among these parameters have been taken into account, including the numbers and locations of broadcast sites, the effective radiated powers of the sites, and their frequency assignments. The goal of the analyses has been to develop coverage scenarios that maximize cost effectiveness, minimize interference problems, and meet the minimum requirements for level of service.

Key words: differential global positioning system (DGPS); radiobeacons; propagation models; Ground Wave Emergency Network (GWEN)

1. INTRODUCTION

The U.S. Coast Guard and U.S. Army Corps of Engineers have installed a network of radiobeacons that broadcast a differential global positioning system (DGPS) correction signal in coastal regions and inland waterways. The Department of Transportation has determined that there is substantial public benefit in the establishment of a national DGPS radiobeacon service, which would provide a nationwide navigation and positioning signal. The purpose of this report is to describe the analyses that were conducted to develop scenarios of nationwide coverage of a DGPS correction signal. A number of parameters need to be considered, including the number and locations of broadcast sites, the effective radiated powers of the sites, and their frequency assignments. Various tradeoffs exist among these parameters. For example, increasing the effective radiated powers of the sites may result in greater coverage, and hence, fewer sites. However, the increased signal levels may cause interference problems with other users of the spectrum, necessitating either reductions in power or reassignments of frequencies. Furthermore, the accuracy of the correction signal decreases with increasing distance from the broadcast site, which limits the desirable coverage to an area that depends on the required accuracy.

The objective of the tradeoff analysis has been to develop coverage scenarios that optimize cost effectiveness and minimize potential interference problems, but meet minimum requirements for level of service. In addition, the effects of skywave propagation and irregular terrain on the coverage scenarios have been examined.

2. SITE LOCATIONS

A number of sources of DGPS beacon transmitter sites have been utilized to provide nationwide coverage of the DGPS correction signal. These sources include:

- a. Existing U.S. Coast Guard and U.S. Army Corps of Engineers radiobeacon DGPS broadcast sites.
- b. Proposed U.S. Coast Guard and U.S. Army Corps of Engineers radiobeacon DGPS broadcast sites.
- c. A proposed Tennessee Valley Authority radiobeacon DGPS broadcast site.
- d. Ground Wave Emergency Network (GWEN) transmitter sites, converted to radiobeacon DGPS broadcast sites.
- e. Additional U.S. Coast Guard type radiobeacon DGPS broadcast sites that were added to complete the signal coverage.

In order to achieve the most cost effective implementation of this service all of the existing and proposed DGPS broadcast sites were included. The GWEN transmitter sites were then utilized, to the maximum extent possible, due to the low cost of adding these sites. The use of these sites was limited by the physical location of the existing sites. Additional U.S. Coast Guard type DGPS broadcast sites were then added at locations that were chosen to complete the nationwide coverage of the DGPS correction signal.

Coverage is defined as that area within which the field strength of the signal is greater than 37.5 dBμV/m, as specified by the U.S. Coast Guard for 100 bps transmissions. A minimum field strength of 40 dBμV/m is specified for 200 bps transmissions. However, 100 bps transmissions have been assumed in this analysis, because most of the existing sites are broadcasting 100 bps transmissions, and the few that are broadcasting at 200 bps will change to 100 bps when selective availability is turned off, which is expected to happen by the year 2006. The 37.5 dBμV/m field strength contours, which outline the coverage areas of the sites, were predicted using a medium frequency propagation model, which has been described by Haakinson et al. [1].

The network of broadcast sites was first planned to provide single coverage of the DGPS correction signal. Additional sites were then added to provide double coverage so that a minimum of two DGPS correction signals would be available at most points, nationwide.

3. POWER LEVELS

The coverage areas of the sites, and hence the locations and number of sites required to achieve nationwide coverage, depend on the effective radiated powers of the sites. Initially, the power levels of the existing and planned Coast Guard and Army Corps of Engineers sites that were used in the analysis were those that the Coast Guard has reported in its database of sites. The maximum radiated power of these sites is 170 W, corresponding to an efficiency of 17% for a 1 kW transmitter. Later in the analysis the powers of some of the sites that were initially less than 170 W were turned up to 170 W to increase the coverage. However, when the interference analysis discussed in Section 4 was performed, it was found that the power levels of some of these sites had to be turned back down to avoid interference problems.

The effective radiated powers of the Coast Guard type sites that were added to the network were all assumed to be 170 W.

The maximum effective radiated powers of the GWEN sites was assumed to be 300 W, corresponding to an efficiency of 30% for a 1 kW Coast Guard type transmitter. The GWEN sites, which currently operate in the 150-175 kHz band, have efficiencies which are at least 30% in this band. We expect greater efficiencies at 300 kHz (shorter wavelengths); thus, 300 W effective radiated power is a conservative assumption.

Initially, the effective radiated powers of the GWEN sites that were added to the network were all assumed to be 300 W. However, the interference analysis later required the power levels of three of these sites to be turned down.

4. INTERFERENCE

The assignments of operating frequencies and effective radiated powers to the broadcast sites are constrained by the requirement that there be no interference problems among DGPS signals or between DGPS signals and the signals broadcast by other users of the 285-325 kHz band. These other users include Canadian DGPS beacons, Canadian aviation beacons, Mexican aviation beacons, FAA beacons, and radiobeacons licensed by the FCC. An interfering signal is considered to be an interference problem to a desired signal if the ratio of the field strength of the interfering signal to that of the desired signal exceeds the specified protection ratio at any location within the coverage area of the desired signal. The protection ratios that were used in this study are shown in Table 1.

Interference analyses were conducted as follows. First, databases of the radiobeacons were searched and pairs of radiobeacons were identified that could potentially interfere with each other, based on the physical proximity and frequency separation of the beacons. Then the ratio of the interfering to desired signal strengths was computed for each pair at that location within the coverage area of the desired signal where the ratio is expected to be greatest, and therefore where the desired signal is most vulnerable to the interfering signal. It was assumed that this location is the point on the perimeter of the coverage area of the desired signal that is closest to the transmitter of the interfering signal. This ratio was then compared to the appropriate protection ratio using Table 1 and a tentative set of frequency assignments for the DGPS radiobeacons to be added to the network was developed. When interference problems arose, either new frequencies or lower powers were chosen for the DGPS sites. When new frequencies were chosen, new pairs of potentially interfering radiobeacons were identified and the analysis was repeated. This process was continued until a set of frequency assignments for the DGPS beacons was obtained that minimized the number of interference problems.

A total of 517 beacons were taken into consideration: 102 DGPS beacons, 18 Canadian DGPS beacons, 138 Canadian aviation beacons, 33 Mexican aviation beacons, 117 FAA beacons, and 109 beacons licensed by the FCC. Four general categories of interference problems were examined: interference among the DGPS beacons, interference between the DGPS beacons and the Canadian aviation beacons, interference between the DGPS beacons and the FAA beacons, and interference between the DGPS beacons and the FCC beacons. The Mexican aviation beacons are so far removed from the proposed DGPS beacons in location and/or frequency that further analyses for these beacons were not performed.

4.1 Interference among DGPS Radiobeacons

Field strength computations for the DGPS radiobeacons were performed by using the medium frequency propagation model to determine the coverage areas of the beacons, defined by the 37.5 dBμV/m contours. If the coverage areas of two beacons do not overlap, the protection ratios in Table 1 indicate that there is no interference problem if the beacons do not have cochannel frequency assignments. If the coverage areas do overlap, it was assumed that the stronger signal is the desired signal at any location within the overlap region. Thus, by definition of which signal is desired and which is interfering, the protection ratios in Table 1 are still not violated if the beacons have different frequency assignments. It follows that there will not be interference problems among DGPS beacons that do not have cochannel frequency assignments. *4.2 Interference between DGPS Beacons and Canadian Aviation Beacons*

Effective radiated powers for the Canadian aviation beacons were not available in our database. Instead, the range of coverage and a field strength were listed for each beacon. Therefore, it was assumed that this field strength is the minimum field strength at the corresponding range. The coverage areas of the aviation beacons were assumed to be circles centered around the beacons with radii equal to the ranges of the beacons. The locations on the perimeters of the coverage areas closest to potentially interfering DGPS beacons were determined. Then the field strengths at these locations generated by the DGPS beacons were computed using the medium frequency propagation model. The ratios of the interfering to desired field strengths were compared to the applicable protection ratios in Table 1.

The problems of interference to DGPS beacons from the Canadian aviation beacons were not analyzed because the DGPS beacons radiate more power and have greater ranges than the aviation beacons. Therefore, if interference from the DGPS beacons to the aviation beacons is not a problem, interference from the aviation beacons to the DGPS beacons will not be a problem.

4.3 Interference between DGPS Beacons and FAA Beacons

These analyses were conducted similarly to those for the DGPS and Canadian aviation beacons discussed above. However, ranges and field strenths for the FAA beacons were not listed in our database. Instead, it was assumed that the minimum field strength is 70 μV/m (36.9 dBμV/m), as specified by the FAA. The ranges of the FAA beacons are usually 25 nautical miles, but are occasionally 50 nautical miles. Therefore, to be conservative, it was assumed that the ranges are 50 nautical miles.

4.4 Interference between DGPS Beacons and FCC Beacons

Our database for the FCC licensed beacons contained neither ranges nor minimum field strengths. Therefore, assumptions identical to those used for the FAA beacons were used for these analyses (ranges of 50 nautical miles with minimum field strengths of 36.9 dBμV/m).

5. NATIONWIDE COVERAGE SCENARIOS

The analyses described above were used to determine locations, operating frequencies, and effective radiated powers for the new DGPS broadcast sites required for nationwide coverage of the DGPS correction signal. Scenarios for both single and redundant (double) coverage were developed. All operating frequencies are multiples of 1 kHz in the 285 to 325 kHz band, as authorized by NTIA.

The existing U.S. Coast Guard and U.S. Army Corps of Engineers radiobeacon DGPS broadcast sites incorporated into the network are shown in Table 2.

The proposed radiobeacon DGPS broadcast sites incorporated into the network are shown in Table 3.

The GWEN transmitter sites required for single coverage of the DGPS correction signal are shown in Table 4.

The additional U.S. Coast Guard type radiobeacon DGPS broadcast sites that were added to complete the single signal coverage are shown in Table 5.

The single coverage of the DGPS correction signal obtained from these transmitter sites (Tables 2 through 5) is shown in Figure 5.1. It should be noted that northern Maine, which is not covered in this scenario, is covered by Canadian DGPS sites.

The GWEN transmitter sites added to provide double coverage of the DGPS correction signal are shown in Table 6.

The additional U.S. Coast Guard type radiobeacon DGPS broadcast sites that were added to complete the double signal coverage are shown in Table 7.

The double signal coverage obtained by adding these transmitter sites (Tables 6 and 7) is shown in Figure 5.2.

It may be necessary to change the frequency assignments of three FAA beacons because of interference from recommended DGPS radiobeacon broadcast sites for single coverage. These three FAA beacons are described in Table 8.

It may be necessary to change the frequency assignments of seven FAA beacons because of interference from recommended DGPS radiobeacon broadcast sites for double coverage. These seven FAA beacons are described in Table 9.

6. SKYWAVE PROPAGATION

The signal coverage scenarios discussed above correspond to daytime hours, when medium frequency signals propagate via the groundwave. During nighttime hours, skywave propagation is also present, and the signals can propagate to much greater distances. To assess the effects of skywave propagation on area coverage, the propagation model was used to compute the area coverage for two sites during both daytime and nighttime hours. The two sites chosen correspond to relatively high and low values of the ground conductivity, and therefore to relatively long and short ranges of the groundwave, respectively.

Figures 6.1 and 6.2 show the area coverage during the daytime and nighttime for the GWEN site at Edinburg, ND. The effective radiated power was assumed to be 300 W. Here the ground conductivity is relatively high, the groundwave propagates to a relatively large distance, and the presence of skywave propagation at night is expected to have a minimal effect on the area coverage. Comparison of Figures 6.1 and 6.2 indicates that the skywave increases the range of the coverage from approximately 500 km to 550 km.

Figures 6.3 and 6.4 show the area coverage during the daytime and nighttime for the GWEN site at Penobscot, ME, again assuming an effective radiated power of 300 W. This example corresponds to relatively low ground conductivity and a relatively short range for the groundwave. The presence of the skywave is therefore expected to have a maximal effect on area coverage. It can be seen that the skywave increases the range of the coverage from approximately 200 km to 350 km in this case.

It should be noted that the recommended effective radiated power for Penobscot, initially chosen to be 300 W, was ultimately reduced to 13 W to eliminate interference problems with Canadian aviation beacons. Therefore, the increase of approximately 150 km in the range of the coverage in this case is an overestimate of the effect that skywave propagation will have on the actual coverage, and can be viewed as an upper bound on the maximal effect of skywave propagation on area coverage. Increases between 50 and 150 km in the ranges of area coverage due to skywave propagation are not expected to have a significant impact on the nationwide coverage scenarios discussed above.

Propagation effects of this magnitude are also not expected to cause serious interference problems among the DGPS radiobeacons because, as explained in Section 4.1, only beacons with cochannel frequency assignments are expected to have potential interference problems, and the cochannel beacons are widely separated geographically. However, the 15 dB protection ratio for cochannel DGPS radiobeacons in Table 1 means that the skywave field strength from an interfering cochannel beacon must be less than 22.5 dBμV/m within the coverage area of the desired signal. Computations with the medium frequency propagation model, assuming 170 W effective radiated power and a latitude of 40 , indicate that the skywave field strength may not be less than 22.5 dBμV/m for distances as large as 850 km from the transmitter. This distance is uncertain due to diurnal and seasonal variations and the stochastic nature of skywave propagation. Thus, skywave propagation could cause occasional interference problems among the DGPS beacons. The times and locations of such problems are difficult to predict. However, the probability that such an interference problem would occur at the same time and place at two different frequencies is much less than the probability of interference at one frequency. Thus, redundant coverage is expected to greatly reduce the probability of such problems causing a loss of DGPS service.

On the other hand, skywave propagation could cause interference problems between the DGPS radiobeacons and the aviation and FCC licensed beacons. The cochannel protection ratio of 15 dB requires skywave field strengths as low as 22 dBμV/m, and, as indicated above, skywave signals of this strength may occur at distances on the order of 850 km or more from the transmitter. The redundant coverage of the DGPS signal will not eliminate outages caused by interference to non-DGPS services. Again, the times and locations of such problems are difficult to predict, but if such problems do occur, they will have to be dealt with on a case-by-case basis.

The interference between the groundwave and skywave signals originating from the same DGPS beacon could cause deep fades if the strengths of the two signals are of comparable magnitude at the same time and location. Computations with the medium frequency propagation model indicate that for low ground conductivities this can occur at field strengths as large as 40 dBμV/m or more, which is well within the area coverage. It is extremely unlikely that a deep fade would occur at the same time and location at two different frequencies. Thus, redundant coverage of the DGPS signal is expected to eliminate service outages caused by this type of interference.

7. IRREGULAR TERRAIN EFFECTS

The coverage scenarios discussed in this report were developed using a smooth earth propagation model. Irregular terrain can cause groundwave field strengths to differ from their corresponding smooth-earth values. These effects are not expected to be large at 300 kHz. For example, the report by DeMinco [2] contains numerous comparisons of predicted field strengths using both the smooth earth and irregular terrain models for a variety of path profiles and frequencies between 0.5 MHz and 1.6 MHz. These comparisons show differences between smooth earth and irregular terrain predictions that are typically not more than several dB, although differences as large as 10 dB do occasionally occur. These differences are expected to be smaller at lower frequencies, e.g., 300 kHz. It is worth noting that these predictions are also compared with measured field strengths and show good agreement with the measured values.

Field strength measurements of DGPS and FAA beacons in the 285 to 325 kHz band that were conducted by ITS generally show good agreement between the measured field strengths and the smooth earth model [3]. However, measurements of an FAA beacon at 321 kHz that were conducted while crossing the Rocky Mountains between Denver and Grand Junction, Colorado show deviations as large as 15 dB or more between the measured values and the smooth earth model. It has been shown by Furutsu et al. [4] that deviations as large as 15 dB are possible in extremely irregular terrain for certain configurations of the transmitter and receiver. In fact, these large propagation losses are well described by the irregular terrain model. Thus, the irregular terrain effects observed between Denver and Grand Junction appear to be unusual but theoretically possible.

It was concluded that irregular terrain is unlikely to have a significant effect on area coverage at these frequencies; however, the effects need to be investigated on a case-by-case basis in extremely irregular terrain. To this end, comparisons between the smooth earth and irregular terrain models were made for two other paths with lengths of 250 km in extremely mountainous regions: a path going west from Colorado Springs, Colorado over the continental divide in the Rocky Mountains and a path going northeast from Sacramento, California into the Sierra Nevadas. In both cases the differences between the field strength predictions of the two models are not more than 0.1 dB.

It therefore appears that irregular terrain effects will not have a significant effect on the coverage scenarios, although large propagation losses could occur in very localized regions. Since these losses depend upon particular transmitter/receiver configurations, the unlikely event of a loss of DGPS service caused by irregular terrain effects may be eliminated in a redundant coverage scenario.

8. SUMMARY

Scenarios of nationwide coverage of a DGPS correction signal have been developed. Tradeoffs among a number of parameters have been considered, including cost, locations and number of sites, transmitter powers, frequency assignments, accuracy, interference problems, and the effects of skywave propagation and irregular terrain.

Potential interference problems do not appear to be entirely avoidable for any choice of the number of sites, power levels, and frequency assignments. For example, decreasing the power levels of the sites and increasing the number of sites will result in fewer interference problems associated with a given site, but will cause a proportionate increase in the number of sites that can cause problems in a given region. Therefore, to minimize cost, the minimum number of sites and maximum power levels should be used that fulfill the accuracy requirements of the system.

The DGPS correction signal loses approximately 1 m of accuracy for every 150 km of distance from the reference station. Based upon potential user requirements, the maximum useful range of a beacon was restricted to 600 km. The maximum range of the beacons in these scenarios (even during nighttime hours) is only 550 km, so that the accuracy requirement has not been violated.

The maximum power for proposed Coast Guard type sites (170 W) has been utilized, and increasing the powers of the GWEN sites from 300 W to powers somewthat greater than this (which may be feasible) will not result in significanly greater area coverages. Using existing GWEN sites and equipment will result in additional cost savings. Thus, it is felt that the coverage scenarios that have been developed represent the optimum choice of performance parameters.

It should be realized, however, that these scenarios will not provide 100% availability of DGPS services. Shadowing due to buildings, underpasses, foliage, etc. can cause temporary losses of the DGPS signal as well as the GPS satellite signals. In addition, sufficiently high levels of natural and manmade noise will degrade DGPS beacon receiver performance.

When field strength measurements of DGPS and FAA beacons were conducted by ITS, atmospheric noise with a field strength as high as 85 dBµV/m was encountered on the plains of Nevada during local thunderstorms; when acquiring data in Denver, the noise (presumably manmade) reached levels on the order of 50 dBµV/m [3]. These noise levels are much greater than the threshold field strength of 37.5 dBµV/m that defines the coverage of the DGPS signal and can be expected to disrupt DGPS service.

To quantify when and where these outages are expected to occur would require simultaneous measurements of signal and noise levels and DGPS beacon receiver performance. However, the fact that they are expected to occur underscores the need for complimentary technologies to provide accurate navigation and positioning information to support surface users.

9. ACKNOWLEDGMENT

The authors wish to thank Mr. James A. Arnold of the Federal Highway Administration, Department of Transportation for funding this work.

10. REFERENCES

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Table 1. DGPS Protection Ratios

Frequency	Wanted:	DGPS	DGPS	Canadian	FAA/FCC

Separation (kHz)				Beacon	Beacon
	Interfering:	DGPS	Radiobeacon	DGPS	DGPS
co-channel		15 dB	15 dB	15 dB	15 dB
0.5		-22 dB	-25 dB		
1.0		-36 dB	-45 dB	12 dB	-1 dB
1.5		-42 dB	-50 dB	9 dB	
2.0		-47 dB	-55 dB	3 dB	-5 dB
3.0				-12 dB	-17 dB
4.0				-27 dB	-31 dB

Table 2. Existing DGPS Broadcast Sites

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
CG	286	Sandy Hook	NJ	40 28 17	074 00 42	5
CG	286	Key West	FL	24 00 00	082 00 00	4
CG	287	Fort Stevens	OR	46 12 18	123 57 21	27
CG	287	Pigeon Point	CA	37 10 55	122 23 35	27/170**
CG	288	Portsmouth Harbor	ME	43 04 15	070 42 37	3
CG	289	Cape Henry	VA	36 55 38	076 00 24	7/170*
CG	289	Cape Canaveral	FL	28 27 35	080 32 35	35/170**
CG	290	Louisville	KY	38 15 00	085 45 00	170
CG	292	Cheboygan	MI	45 39 10	084 28 00	15
CG	292	Cape Mendocino	CA	40 26 29	124 23 56	27/170*
CG	293	English Turn	LA	29 52 44	089 56 31	42
CG	293	Montauk Point	NY	41 04 02	071 51 38	7
CG	294	Fort Macon	NC	34 41 52	076 40 59	7

CG	295	Virginia Key	FL	25 15 00	080 30 00	2
CG	296	Galveston	TX	29 19 45	094 44 10	22/170**
CG	296	Wisconsin Point	WI	46 42 16	092 01 01	1
CG	297	Milwaukee	WI	43 00 06	087 53 18	10/170*
CG	298	Cape Henlopen	DE	38 46 36	075 05 16	22
CG	298	Charleston	SC	32 45 28	079 59 35	11/170*
CG	298	Upper Keweenaw	WI	47 13 21	088 37 18	20
CG	298	Omaha	NE	41 46 42	095 54 39	13
CG	299	Sallisaw	OK	35 30 00	095 00 00	170

Table 2. Existing DGPS Broadcast Sites (continued)

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
CG	300	Mobile Point	AL	30 13 38	088 01 24	17
CG	301	Saginaw Bay	MI	43 37 43	083 50 17	4
CG	302	Whidbey Island	WA	48 18 46	122 41 46	4
CG	302	Point Loma	CA	32 39 54	117 14 33	27
CG	304	Aransas Pass	TX	27 50 18	097 03 33	22/170*
CG	305	Kansas City	KS	39 10 00	094 45 00	170
CG	309	Neebish Island	MI	46 19 17	084 09 02	3
CG	309	Reedy Point	NJ	39 33 41	075 34 11	3
CG	310	Memphis	TN	35 27 56	090 12 21	35/170**
CG	310	Point Blunt	CA	37 51 12	122 25 04	2
CG	311	Rock Island	IA	42 00 30	090 14 00	120/170**
CG	312	Egmont Key	FL	27 36 16	082 45 40	42/170**
CG	313	Vicksburg	MS	32 19 53	090 55 11	60/170**
CG	316	Brunswick	ME	43 53 42	069 56 17	7
CG	317	St. Paul	MN	44 18 15	091 54 14	120/170**
CG	18	Whitefish Point	MI	46 46 17	084 57 29	3
CG	319	Detroit	MI	42 17 49	083 05 41	7
CG	320	Millers Ferry	AL	32 05 24	087 23 44	170
CG	321	Point Arguello	CA	34 34 39	120 38 38	27/170*
CG	322	Miami	FL	25 43 56	080 09 38	25

CG	322	Sturgeon Bay	WI	44 47 40	087 18 49	10
CG	322	Youngstown	NY	43 14 10	079 01 03	30
CG	322	St. Louis	MO	38 36 41	089 45 31	120/170**
CG	323	Robinson Point	WA	47 23 15	122 22 29	3
CG	325	Chatham	MA	41 40 17	069 57 02	5

Notes:
* indicates DGPS broadcast sites that are recommended to be turned up to 170 watts effective radiated power (ERP) to provide single coverage of the DGPS correction signal.
** indicates DGPS broadcast sites that can be operated at the specified ERP for single coverage, but are recommended to be turned up to 170 watts ERP for double coverage.

Table 3. Proposed DGPS Broadcast Sites

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
CG	296	Huntington	WV	38 50 00	082 30 00	170
CG	312	Pittsburgh	PA	40 15 00	080 00 00	170
CG	314	Andrews Locks	FL	31 00 00	085 00 00	170
CG	323	Gunthersville	AL	34 30 00	086 20 00	170
CG	325	Chattanooga	TN	35 05 00	085 40 00	170
TVA	306	Knoxville	TN	35 58 00	083 55 00	170

Table 4. GWEN Transmitter Sites Required for Single Coverage

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
ITS/GWEN	286	Goodland	KS	39 49 39	100 39 49	300
ITS/GWEN	287	Ronan	MT	47 34 47	114 06 50	170
ITS/GWEN	290	Penobscot	ME	44 26 07	068 47 22	13
ITS/GWEN	291	Kirtland	NM	34 57 26	106 29 32	300
ITS/GWEN	300	Appleton	WA	45 46 55	121 19 34	300
ITS/GWEN	301	Macon	GA	34 41 39	083 33 38	300
ITS/GWEN	306	Medora	ND	46 54 22	103 16 29	100
ITS/GWEN	307	Edinburg	ND	48 33 31	097 47 04	300
ITS/GWEN	309	Clark	SD	44 56 03	097 57 38	300

ITS/GWEN	310	Whitney	NE	42 30 00	102 00 00	300
ITS/GWEN	312	Austin	NV	39 30 00	117 30 00	300
ITS/GWEN	313	Billings	MT	45 58 19	107 59 47	300
ITS/GWEN	319	Flagstaff	AZ	35 13 18	111 49 06	300
ITS/GWEN	324	Hudson Falls	NY	43 16 13	073 32 19	300
ITS/GWEN	325	Pueblo	CO	38 51 54	104 34 31	300

Table 5. Additional Coast Guard Type Sites Required for Single Coverage

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
ITS	285	Odessa	TX	31 50 00	102 20 00	170
ITS	294	Arlington	TX	32 40 00	097 00 00	170
ITS	301	Jackson	WY	44 00 00	110 06 00	170
ITS	303	Greensboro	NC	36 00 00	079 30 00	170
ITS	303	Duchesne	UT	40 36 00	110 24 00	170
ITS	316	El Paso	TX	32 00 00	106 20 00	170
ITS	320	Sun Valley	ID	43 00 00	115 00 00	170

Table 6. Additional GWEN Transmitter Sites Required for Double Coverage

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
ITS/GWEN	285	Savannah	GA	32 08 22	081 41 49	300
ITS/GWEN	292	Kensington	SC	33 28 51	079 20 35	300
ITS/GWEN	311	Egg Harbor	NJ	39 36 12	074 22 16	300
ITS/GWEN	314	Great Falls	MT	47 18 13	111 10 19	300
ITS/GWEN	315	Goldwein	VA	38 37 09	076 52 51	300
ITS/GWEN	316	Spokane	WA	47 31 10	117 25 21	300
ITS/GWEN	318	Summerfield	TX	34 49 28	102 30 43	300

Table 7. Additional Coast Guard Type Sites Required for Double Coverage

Source	Frequency	Location	State	Latitude	Longitude	ERP (watts)
ITS	286	Tucson	AZ	32 30 00	111 00 00	170
ITS	289	West Texas	TX	30 00 00	101 30 00	170
ITS	291	Weiser	ID	44 20 00	117 00 00	170
ITS	297	Rawlins	WY	42 00 00	107 00 00	170
ITS	307	South Utah	UT	37 30 00	112 00 00	170
ITS	307	Winchester	VA	39 15 00	078 15 00	170
ITS	310	Martinsville	VA	36 40 00	080 00 00	170
ITS	314	Middleburg	VT	44 00 00	073 15 00	170
ITS	315	North Nevada	NV	41 30 00	116 00 00	170

Table 8. Interference to FAA Beacons in Single Coverage Scenario

FAA Beacon					Source of Interference				
Frequency	Location	State	Latitude	Longitude	Frequency	Location	State	Latitude	Longitude
302.51	Thomaston	GA	32 56 12	084 20 27	301	Macon	GA	34 41 39	083 33 38
287.51	Antioch	NE	42 00 53	102 46 07	286	Goodland	KS	39 49 39	100 39 49
296	Wichita Falls	TX	33 54 39	098 27 17	294	Arlington	TX	32 40 00	097 00 00

Table 9. Interference to FAA Beacons in Double Coverage Scenario

FAA Beacon					Source of Interference				
Frequency	Location	State	Latitude	Longitude	Frequency	Location	State	Latitude	Longitude
317.51	Cumberland	MD	39 39 00	078 44 48	315	Goldwein	VA	38 37 09	076 52 51
290.51	Stamford	TX	32 53 07	099 43 58	289	West Texas	TX	30 00 00	101 30 00
308	Fort Bragg	NC	35 08 00	078 56 00	310	Martinsville	VA	36 40 00	080 00 00
320.51	Clinton	OK	35 32 08	098 56 02	318	Summerfield	TX	34 49 28	102 30 43
293.51	Gastonia	NC	35 11 28	081 09 27	292	Kensington	SC	33 28 51	079 20 35
283	Charleston	SC	32 42 04	080 00 20	285	Savannah	GA	32 08 22	081 41 49
317	Helena	MT	46 36 24	111 56 14	314	Great Falls	MT	47 18 13	111 10 19

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