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Canadian Marine Differential Global Positioning System (DGPS) Broadcast Standard

Canadian Coast Guard

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Canada

Document Control Sheet

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1. INTRODUCTION

1.1 PURPOSE

The Canadian Coast Guard Differential Global Positioning System (DGPS) Broadcast Standard is a reference document that specifies the format; information content, modulation parameters, coverage area, and use of the signal that is broadcast from a network of Canadian Coast Guard operated marine radio beacons. This network provides coverage to Canadian coastal areas, major waterways, Vessel Traffic Services zones and ports. It also overlaps US DGPS coverage of contiguous waters.

This Standard also specifies the system performance that can be achieved with the use of proper DGPS user equipment. Key performance and functional elements essential for the user equipment suite are addressed.

1.2 SCOPE

The Canadian DGPS Navigation Service augments the Navstar Global Positioning System (GPS) by providing localized pseudo range correction factors and ancillary information that are broadcast over a network of strategically located MF marine radio beacons. This service will provide the mariner with a horizontal accuracy of 10 meters or better, 95 % of the time in all coverage areas.

The user equipment receives system status and data updates on a continuous basis. The DGPS Reference Station utilizes a NAD 83 datum for its antenna surveyed position. Therefore, the user equipment suite will compute the NAD 83 Datum when operating in the differential mode. The DGPS Navigation Service not only enhances the accuracy of the Standard Positioning Service (SPS), but also provides real time integrity, monitoring and reporting (for further information on the SPS, see the Global Positioning System Standard Positioning Service Signal Specification dated November 5, 1993, published by the US Department of Defense).

DGPS transmissions will be broadcast in the 285 KHz to 325 KHz band that is allocated for maritime radio navigation (radio beacons). Marine radio beacons will be exclusively used to broadcast DGPS signals on the main carrier using Minimum Shift Keying (MSK) Modulation. There will be no radiobeacon identity tone. The modulated signal will contain DGPS information and the identification of the transmitting DGPS station.

Figure 1 contains a system concept of the DGPS Navigation Service. A typical DGPS station comprises control stations (CSs), reference stations (RSs), their associated integrity monitors (IMs) to ascertain the status and the integrity of the broadcast, and the MF radio beacon transmitter to broadcast DGPS information to users. A control monitor (CM) located at a 24 hour staffed Coast Guard operational site maintains two-way communications via dial up lines with the DGPS stations. The CM monitors the status of the system.

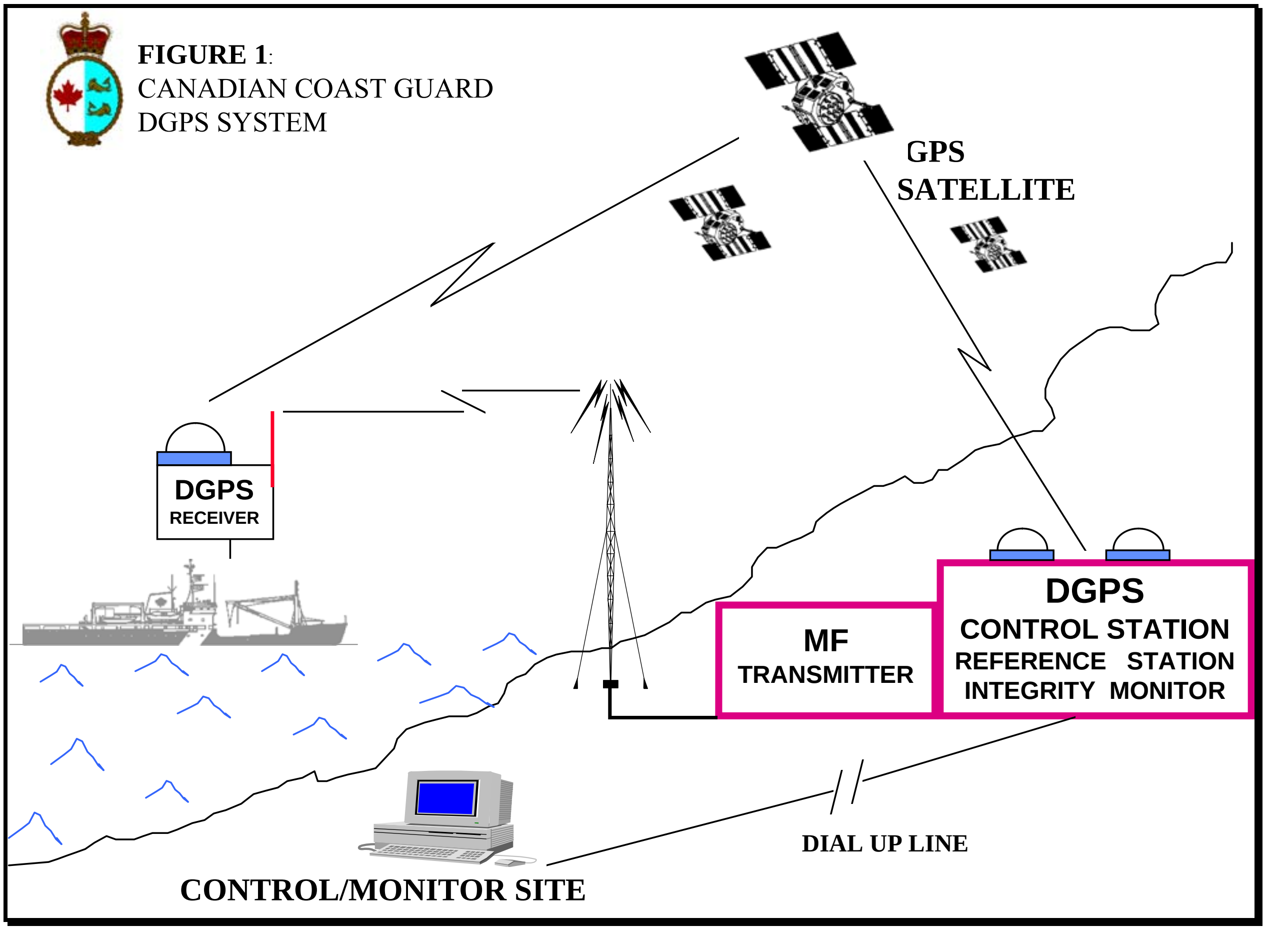

Figure 1 DGPS System

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2. SIGNAL FORMAT

2.1 GENERAL

The broadcast data consists of a selected subset of the message types contained in the RTCM Special Committee No. 104, "Recommended Standards for Differential Navstar GPS Service", dated January 3, 1994 herein referred to as "RTCM SC104 (Version 2.1.). All selected message types will be broadcast in the format of this document unless otherwise noted or amended by a later version.

2.2 MESSAGE TYPES

RTCM SC104 (Version 2.1.) Message Types 3, 5, 6, 7, 9, and 16 will be broadcast in the DGPS Navigation service. The currently undefined, Type 15 Message (atmospheric parameters) if developed may also be included at a later time. Stated performance of the system is only applicable for user equipment suites that fully incorporate all of the aforementioned message types. RTCM SC104 (Version 2.1) requires that the service provider further specify the content of several message types. Further description is given for Message Types 3, 5, 7, 9 and 16, along with a complete description of the use of the message header when operating within the DGPS Navigation Service. The Type 6 message is a filler message used only when the reference station has no other message to broadcast. Unless otherwise stated, all message types are applied in the manner recommended in RTCM SC104 (Version 2.1). In attempting to provide the user with a seamless North American DGPS service, arrangements will be negotiated with US authorities to provide reciprocal service with respect to information in certain types of messages (e.g. Message Types 7 & 16), especially where adjacent DGPS stations are under US jurisdiction.

2.2.1 MESSAGE HEADER

The "Station Health Field" (bits 22-24) is in the two-word header of all messages, including the Type 9 Message (9-1 and 9-3). Table 1 delineates the pertinent meaning of the bits in this field. The enhancements to the UDRE (user differential range error) resolution will provide a substantial added value to the system. For the Type 9-3 Message, the UDRE scale factor is determined by the satellite with the largest UDRE value. If an unhealthy or unmonitored condition exists, the UDRE Scale Factor registers a value of one.

CODE	INDICATION
111	UNHEALTHY BROADCAST
110	UNMONITORED BROADCAST
101	UDRE SCALE FACTOR = 0.10
100	UDRE SCALE FACTOR = 0.20
011	UDRE SCALE FACTOR = 0.30
010	UDRE SCALE FACTOR = 0.50
001	UDRE SCALE FACTOR = 0.75
000	UDRE SCALE FACTOR = 1.00

Table 1 Message Header Station Health Field

2.2.2 TYPE 3 MESSAGE

A Type 3 message contains information on the identity and surveyed position of the active reference station in the DGPS station. Two reference stations are provided in a DGPS station (dual redundancy). At any given time one will be on air and the other will serve as a "hot standby". In the event of a reference station changeover, the position coordinates which are broadcast in the Type 3 Message will change to reflect the other reference station surveyed position and its identity. The Type 3 Message will contain NAD 83 coordinates since this system is the only one in North America that can take advantage of the centimeter resolution provided in this message.

2.2.3 TYPE 5 MESSAGE

This message type will notify the user equipment suite that a satellite that is deemed unhealthy by its current navigation message is usable for DGPS navigation. This is accomplished by the setting of the "Health Enable Function" in the Type 5 Message by the reference station in order to indicate this condition. An example of this situation is a slowly drifting satellite clock that may render a satellite unhealthy for GPS use, but would be correctable by the reference station for DGPS use. The user equipment suite should not use an unhealthy satellite unless a Type 5 Message allowing the use of an unhealthy satellite was received within the last thirty minutes. If the most recent Type 5 Message received does not indicate that an unhealthy satellite can be utilized, then the use of that satellite should be discontinued if it were being used earlier (i.e. via a previous Type 5 Message).

2.2.4 TYPE 7 MESSAGE

A Type 7 Message provides information of its broadcasting DGPS station and the other two or three adjacent DGPS stations. Where adjacent stations are under US jurisdiction, appropriate arrangements will be made to provide reciprocal information. The user equipment suite should update its internal almanac immediately as new information is received. Nonvolatile memory should be employed to store the internal almanac. When a broadcast becomes unhealthy or unmonitored in a DGPS coverage area, the Type 7 Message will be set to indicate the subject condition. Upon receiving the next Type 7 message, *the* user's equipment suite should immediately update its internal almanac**.** Additionally, the user equipment suite is immediately notified by means of the station health status indicator contained in the second word of the universal message header. The user should be able to view the contents of the current Type 7 Message in order to obtain information on coverage areas that may soon be entered.

2.2.5 TYPE 9 MESSAGE

Due to the advantages of greater impulse noise immunity, lower latency and a timely alarm capability, the Type 9 Message has been selected for broadcasting pseudo range corrections instead of the Type 1 Message. Two methods of transmitting the Type 9 message are possible.

2.2.5.1 TYPE 9-3 MESSAGE

The first method of broadcasting PRC's (Pseudo range Corrections) is based upon "Three-Satellite Type 9 Messages" This is denoted as "Type 9-3" Messages. In this method all satellites for which corrections are broadcast are assigned to either three satellite Type 9 Messages or to a remainder message of either one or two satellites. The transmission rate could be at either 100 or 200 bps. For example, the pseudo range corrections for eight satellites will consist of three Type 9 Messages, two with 3 satellites and one with two satellites. An equal number of corrections are broadcast for each satellite. In order to optimize use of the UDRE Scale Factor in the message header, satellites will be grouped in messages by their UDRE values. At a transmission rate of 200 bps this represents a minimum of a forty percent reduction in message loss as compared to a Type 1 Message under high noise conditions broadcast at the same bit rate. The relative latency of the different PRC message types is illustrated in Figure 2 - note that since the corrections can be applied as soon as the parity is verified for the words that contain a given correction, the latencies in Figure 3 are the maximum latencies. PRC accuracy is for the most part a function of the latency of the Range Rate Correction (RRC) since it is the only PRC component in which the error is a function of time. The error of the PRC (t_0) term is fixed at the time of measurement and any errors that result from its propagation are a function of RRC accuracy. Figure 3 illustrates an additional advantage of the Type 9 Message - the phasing of the PRCs. When the latency for certain satellites is nearing its maximum the latency for others is very low. This provides a built-in immunity factor to high pseudo range accelerations on one or more satellites. The potential to weight pseudo ranges on the basis of latency is readily apparent and should be beneficial to the user.

This method of transmitting a Type 9 message at 100 bps and 200 bps will be used for the standard and enhanced/multiple coverage areas respectively.

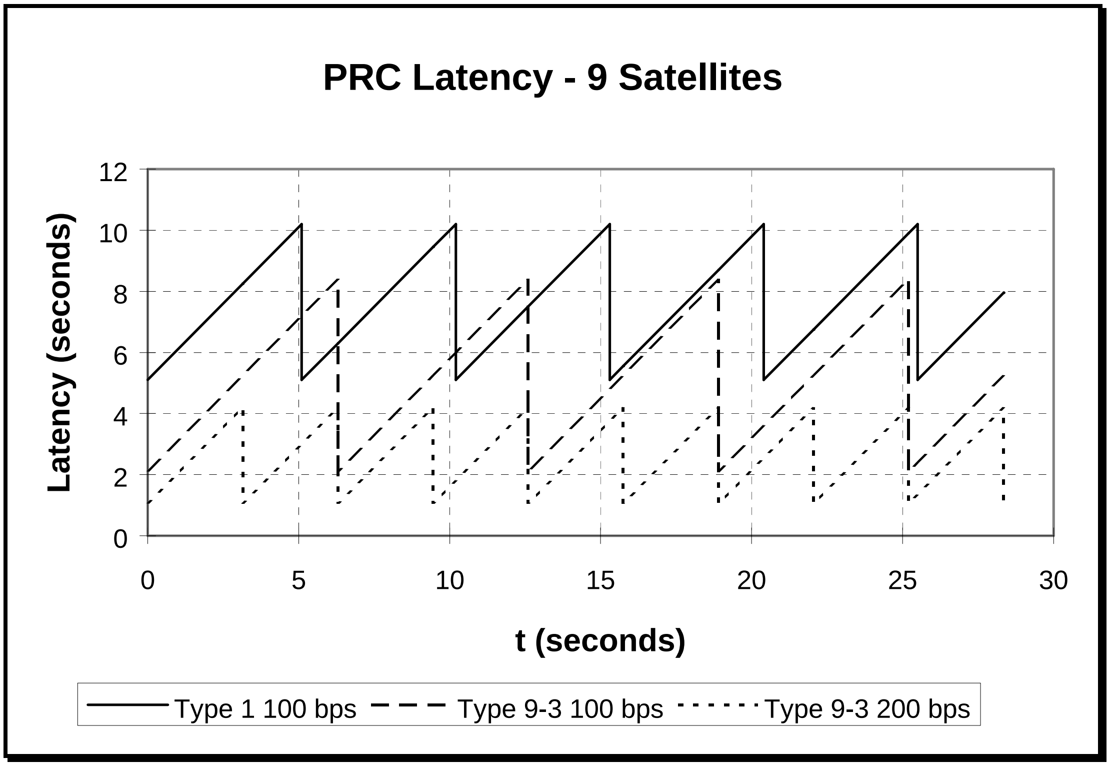

Figure 2 PRC Latency for Type 1 and Type 9-3 Corrections

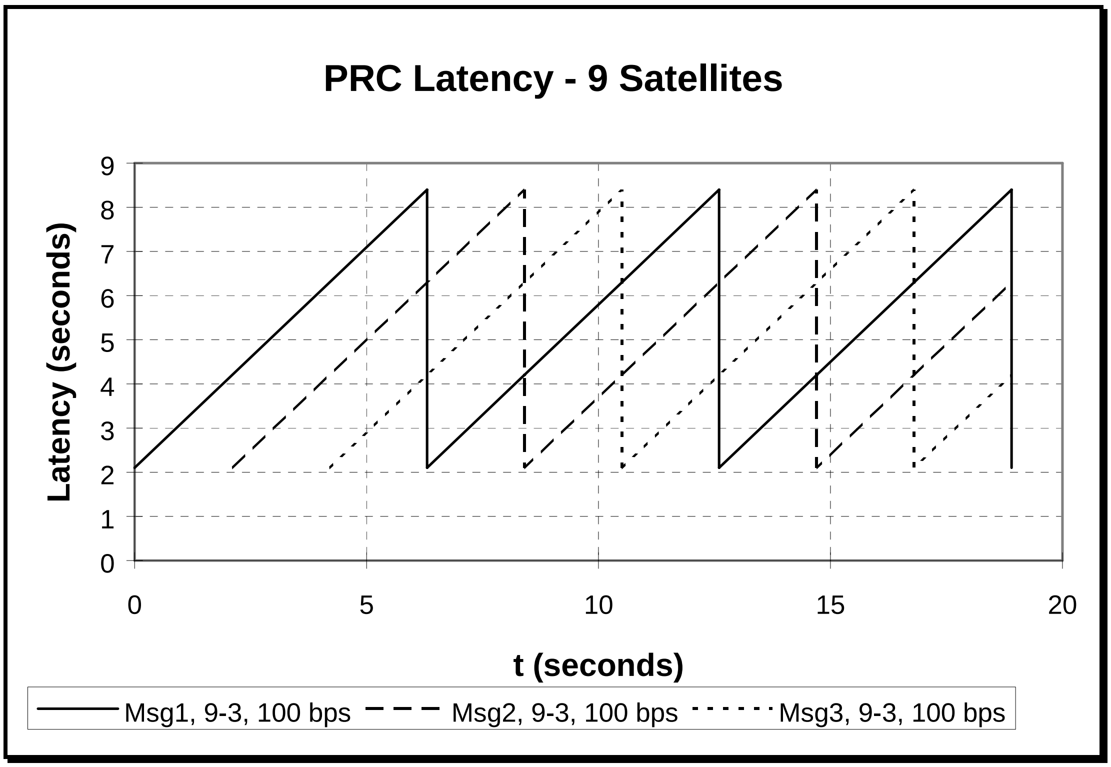

Figure 3 PRC Latency for three 9-3 Messages

2.2.5.2 TYPE 9-1 MESSAGE

The second method of broadcasting pseudo range corrections is to broadcast individual Type 9 Messages for each satellite at a transmission rate of 50bps. This message is referred to as the "Single Satellite Type 9 Message" and is denoted in this document as the "Type 9-1 Message". A high level of impulse noise immunity is achieved by this technique that will extend the effective range of the broadcast. Lower transmission rates such as 50 bps could not be used at this time because of the need to meet the time to alarm requirement due to the length of the PRC Messages. An equal number of corrections are broadcast for all satellites regardless of their pseudo range rates or accelerations

Table 2 summarizes the above mentioned methods of Type 9 message transmission.

Method	Message Type	Data Rate	Trans. Rate
1a	Type 9-3	200 bps	200 bps
1b	Type 9-3	100 bps	100 bps
2[1]	Type 9-1	50 bps	50 bps

Table 2 PRC Message Broadcast Parameters

Since each Type 9 Message contains the freshest possible corrections, the corrections contained in each and every Type 9 Message are computed at different times (i.e. computed at the latest possible time before broadcast). The user equipment suite can mix corrections that may have been computed up to 30 seconds apart, thus the reference station should utilize a highly stable frequency source, within one part in 10^{-11} (30 second Allan Variance). The use of a highly stable frequency reference and a tightly controlled clock provides the additional benefit of allowing corrections for each satellite to be applied as they are received, as long as the parity for both of the words which contain a given correction is verified. This capability should be implemented for the Type 9 Message in all user equipment suites. Generally, the Reference Station clock will be within 100 ns of GPS time. Clock stability is of far greater priority then absolute time accuracy since PRC's are generated relative to each other for a given Reference Station.

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The shorter message length and greater frequency of preambles provided by the Type 9 Message result in a substantially improved impulse noise performance as compared with the Type 1 Message. The higher rate of preambles allows a much faster re-synchronization, especially during high noise periods. As previously discussed, even in low noise conditions the Type 9-3 Message provides a lower latency than the Type 1 Message, making it advantageous when operating with a low data rate as well as in high noise environments. This is especially useful since the position error growth due to latency is non-linear.

If a satellite suddenly becomes unhealthy when in use by a given reference station the PRC (t_o) and the RRC are set to predefined values as delineated in RTCM SC104 (Version 2.1) that designate this condition.

[1] May be used if SA is permanently discontinued by US authorities

2.2.6 TYPE 16 MESSAGE

The Type 16 message will be utilized as a timely supplement to the notice to mariners or shipping, regarding information on the status of the local DGPS service that is not provided in other message types. Additionally, the Type 16 Message may provide limited information on service outages in adjacent coverage areas or planned outages for scheduled maintenance at any broadcast site. In order to keep data link loading to a minimum, Type 16 Messages will contain only system information that is crucial to the safety of navigation. Any broadcast of the Type 16 Message will not exceed 4.8 seconds. At 200 bps this translates into 32 words that allow a maximum 90 characters after accounting for the message header. The Type 16 Message is not intended to act as a substitute for the notice to mariners, even though it pertains to DGPS information. Type 16 Messages will be utilized to alert the user of an outage condition for which a broadcast in an adjacent coverage area may be unhealthy, unmonitored, or unavailable. This information would be useful to the mariner who is planning a transit through an affected area or whose equipment suite is presently incapable of automatic selection from the beacon almanac. Further details of an outage condition can be derived from the Type 7 Message for route planning purposes.

The capability of the TYPE 16 message to inform the mariner of the adjacent coverage areas is not currently implemented. Full capability will be available when the full networking capability is implemented (see also section 4.2).

2.2.7 MESSAGE SCHEDULING

The routine data stream will consist mainly of message types 3, 7, & 9 and broadcast of message types 5, 6 and 16 will be on an exceptional basis. Due to the advent of continuous tracking receivers the Type 2 Message is no longer required and its use would only serve to increase the latency of the broadcast. For each new Issue of Data (IOD) there will be a 90 second delay before the broadcast pseudo range corrections are computed with the new IOD. Ninety seconds should be more than adequate for a continuously tracking DGPS receiver, as it will be able to instantaneously read the navigation messages as they are broadcast from each satellite. Any short term blockage of a satellite at IOD, such as passing under a bridge, is compensated for by the ninety second delay. This method of handling a new IOD requires the user equipment suite to store both the new and the old IOD for the subject period. Message Types 3, 5, 7, 15 and 16 will not be broadcast within 90 seconds of each other under any circumstances.

a) Type 3 Message: Type 3 Messages will be broadcast at fifteen and forty-five minutes past the hour.
b) Type 5 Message: If an unhealthy satellite is deemed usable for DGPS, a Type 5 Message will be broadcast at fifteen minute intervals beginning at five minutes past the hour. If an unhealthy satellite that was deemed usable is later deemed unusable the reference station will no longer broadcast corrections for the subject satellite.
c) Type 7 Message: A routine Type 7 Message will be broadcast at ten minute intervals beginning at seven minutes past the hour. Special Type 7 Messages will be broadcast as soon as possible, subject to the other scheduling constraints, when the status of a beacon in

the almanac changes. This will aid the user equipment suite in its choice of the proper beacon.

d) Type 9 Message: Pseudorange corrections will be broadcast only for satellites at an elevation angle of 7.5 degrees or higher through use of the Type 9 Message. The official GPS coverage is based on elevation angles of ten degrees or higher. Satellites at elevation angles lower than 7.5 degrees are adversely affected by spatial decorrelation, multipath, and minimal processing time between acquisition and actual use. The level of 7.5 degrees is identical to that recommended by RTCA Special Committee 159. Corrections for all satellites in view above the mask angle will be broadcast. Positioning users of the system who are interested in achieving the highest accuracy level possible should use a higher mask angle in order to avoid the more pronounced atmospheric effects associated with satellites at low elevation angles. When a reference station drops a satellite it will broadcast an indication to the user equipment suite to stop applying corrections for that satellite to its navigation solution (see paragraph 4.1 for details).

e) Type 16 Message: This message type will be broadcast as deemed necessary but within strict limits. The interval between successive Type 16 Messages will be no less than three minutes.

3. SYSTEM PERFORMANCE

3.1 ACCURACY

The position accuracy of the DGPS Service will be 10 meters (95% of the time), or better in all specified coverage areas for suitable user equipment (assuming the full 24 GPS satellite constellation and a HDOP < 2.3). As the DGPS Reference Station surveyed antenna position is referenced to the NAD 83 Coordinate System, the user's differentially determined position solution is inherently transformed into the NAD 83 Coordinate System. The user equipment suite need not perform any datum conversion from WGS-84 when working with NAD 83 Charts within the service area.

3.2 AVAILABILITY

A satisfactory DGPS broadcast is defined as one that is

a) healthy[2],
b) the PRC time out limit for at least four satellites has not been reached, and
c) the DGPS Station ID number checks out against that in the beacon almanac.

A user is primarily concerned with being able to receive a satisfactory DGPS broadcast with minimal disruption. Known as user availability, this parameter is a function of three components:

a) the reliability of the DGPS station;
b) the effect of atmospheric noise preventing user equipment from receiving an otherwise healthy DGPS broadcast.
c) whether a user is in a standard/enhanced coverage or in a multiple coverage area.

The first component of user availability depends on the reliability of the entire set of DGPS broadcast station equipment (see Figure 2). Known as broadcast reliability, it is specified to be at least 99.7 % (see the DEFINITIONS Section A.2 for an elaboration of this term.). A user may view this reliability as the probability that the DGPS broadcast is providing healthy DGPS corrections at a specified power when a user selects that particular broadcast.

The second component of user availability is called broadcast availability. As atmospheric noise varies over time and region, modeling to derive signal availability's at the various DGPS broadcast station sites using CCIR noise figures is used. This process also estimates the required effective radiated power for each radiobeacon transmitter and the coverage region in which this

[2] A DGPS broadcast is considered to be healthy if it meets the following requirements:
a) The protection limit has not been exceeded.
b) The broadcast is monitored.
c) The RS receives a correct RS ID
d) The IM position error is within the position threshold

availability is assured (see DEFINITIONS Section A.2 for details and related paragraph 3.4 for definition of broadcast coverage). Broadcast availability will be at least 99% at the edge of the advertised coverage area for a DGPS station.

The third component will provide the best service availability since service will still be available from an alternate DGPS station in the event of a total DGPS station failure.

Prolonged empirical DGPS data collection and operational experience will be needed in order to arrive at an accurate user availability figure.

3.3 DGPS BROADCAST STATION DESIGN

Redundancy of equipment is provided in order to attain the 99.7 % equipment reliability (see Figure 4). Figure 4 is a representative DGPS Station configuration.

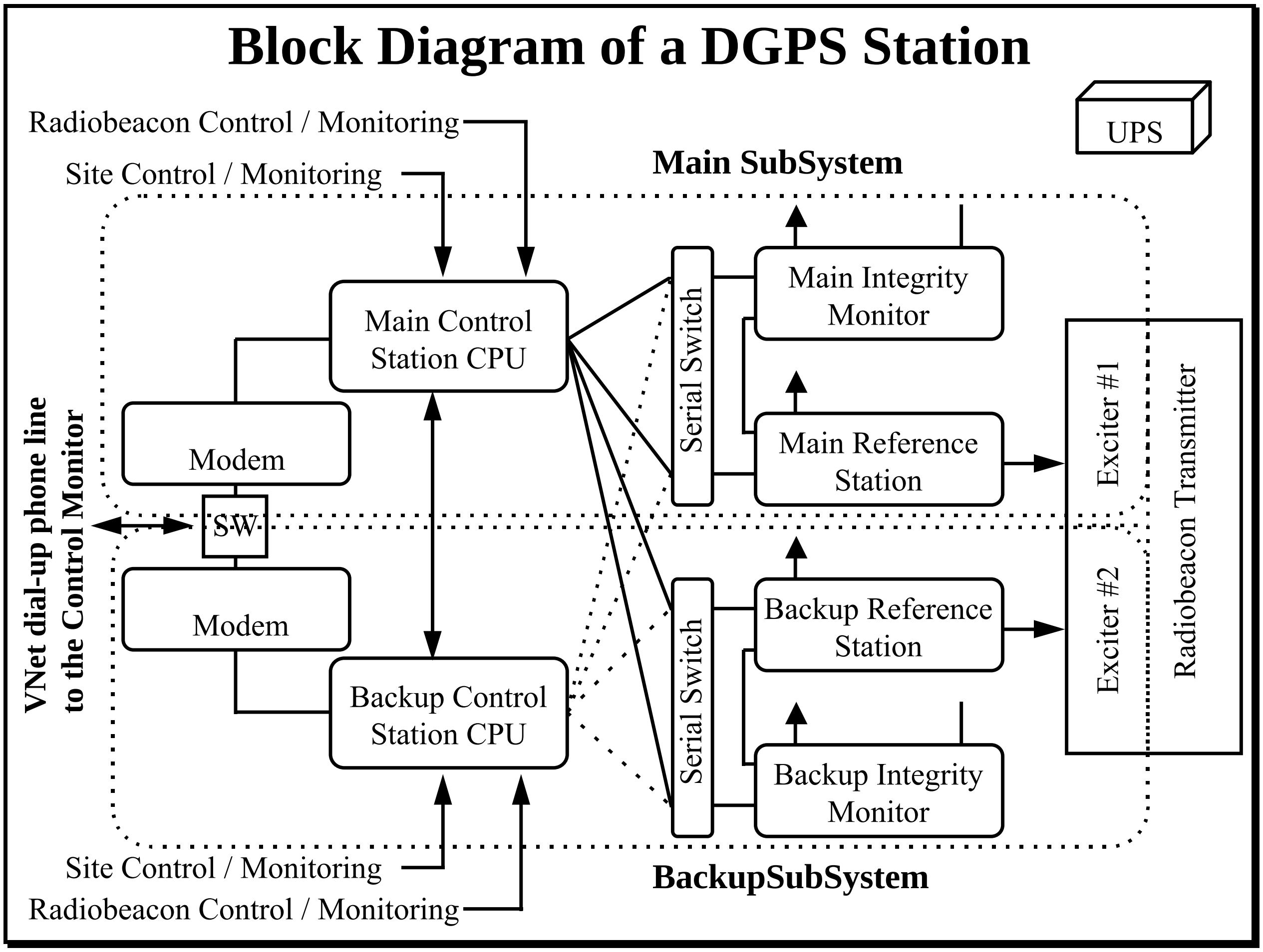

Figure 4 DGPS Station Block Diagram

The Reference Station (RS) and Integrity Monitor (IM) operate autonomously. In the event of a RS or IM malfunction, the redundant equipment should come on line either through the control station (CS) or by commands from the control monitor (CM). Restoration of DGPS signal transmission in the latter case will take longer as it requires operator instructions.

3.4 DGPS BROADCAST COVERAGE

DGPS coverage performance is adversely affected by atmospheric and man-made noise that falls within the radiobeacon's bandwidth. Experience has shown that the noise level in inland areas is considerably higher than in offshore areas. Therefore, two levels of advertised coverage are provided:

> **Offshore Coverage**: The service area of each DGPS broadcast will be defined as the area within which the DGPS signal strength is at least 75 µv/m or signal availability is at least 99% in average yearly noise conditions, whichever is the more stringent criteria.
>
> **Inland Coverage:** The service area of each DGPS broadcast will be defined as the area within which the DGPS signal strength is at least 100 µv/m or signal availability is at least 99% in average yearly noise conditions, whichever is the more stringent criteria.

DGPS signal levels may be reduced locally within an advertised coverage area because of obstructive terrain such as fiords and bridges. As long as the receiver continues to track and properly decode the DGPS correction data in the reduced signal, the user receiver position output will not be adversely affected.

All Canadian radio beacons broadcast at 200 bits per second, regardless of whether they provide inland or offshore coverage.

Overlapping coverage from adjacent Canadian and American radiobeacons is available in many areas.

See the Fisheries and Oceans publications (DFO 5470 and 5471) - Radio Aids to Marine Documentation (RAMN) for details of the DGPS Coverage in Canada.

4. SYSTEM OPERATIONS

4.1 SYSTEM INTEGRITY

System Integrity depends on the ability of:

a) the DGPS station to provide a satisfactory broadcast;
b) the system to alert the user of any out of tolerance or unhealthy conditions in the DGPS corrections; and
c) the user equipment suite to process the DGPS alarms

The reference station is augmented by a collocated integrity monitor (IM). The IM verifies the accuracy of the broadcast PRCs at the pseudorange and positional levels. The process utilized by the IM is shown in Figure 5. In essence, by knowing its own surveyed (GPS antenna) location, the IM is able to assess whether the broadcast PRCs and derived DGPS positions are within certain specified limits, and if not, will alert the 24 hour staffed control monitor (CM) and the user. As part of augmenting system integrity, the DGPS station sends routine station status messages every half hour and any alarm messages to the CM.

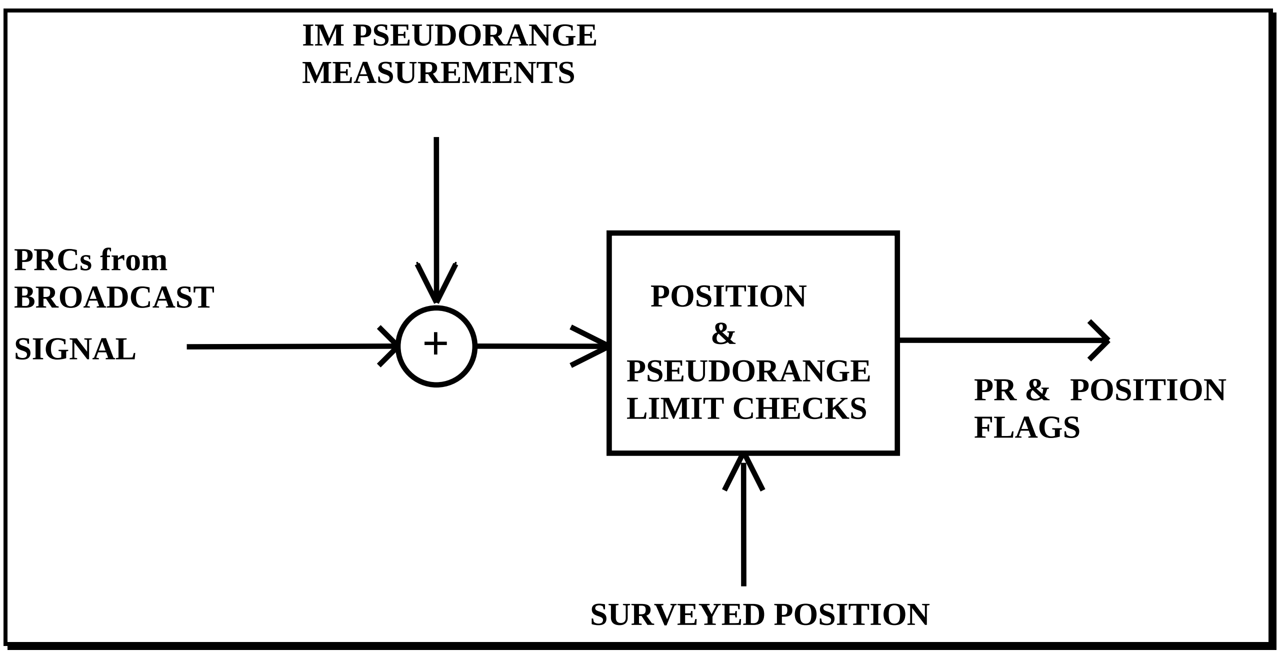

Figure 5 Integrity Monitor Process

The integrity monitor (IM) performs integrity verification of pseudorange and positional accuracies, and takes appropriate action as described below:

a) if the pseudorange residual is high, a pseudorange alarm is broadcast by the setting of the PRC (to) Field to a value of binary 1000 0000 0000 0000 along with the setting of the RRC Field to a value of 1000 0000. Should the user equipment suite detect either one of these settings it should immediately stop applying any PRC derived information for that satellite until the alarm condition ends. This broadcast will occur for a maximum thirty second period.
b) for positional verification, a protection limit for the over determined (position) solution shall be set at the IM to warn the user in the event that the accuracy is out of specified tolerance. The IM utilizes the broadcast UDRE values to weight the pseudoranges in computing the over determined solution. The known position of the IM is not included in the over determined solution that it computes. If the set value is exceeded after a defined interval, the broadcast will become unhealthy. The time from when a protection limit is exceeded to when the user equipment suite/user is alarmed by the broadcast will not exceed ten seconds. This time includes the length of the longest possible message and the header of the following message. The use of the Type 9 message as the exclusive PRC message results in these low time to alarm values.

4.2 DGPS SYSTEM FAILURE / DEFAULT MODE

A system failure is said to occur when any one of the following conditions apply:

a) unhealthy broadcast;
b) absence of pseudo range corrections in message transmission;
c) unmonitored broadcast (e.g. integrity monitor failure)
d) no broadcast

Should any of the above mentioned prolonged system failure conditions occur, appropriate action will be taken by the Operator to alert the mariner. If a radio beacon is identified as being "unhealthy" or "unmonitored" over a prolonged period, this condition will be broadcast to the user as an automatic Type 16.

An RTCM Type 6 message will be broadcast when the reference station has no other message to send e.g. no Pseudo range corrections.

The Almanac of a defective station will be automatically updated upon instant recognition of an "unmonitored" or "unhealthy" indication. The updating of the adjacent station almanacs will be provided when full networking capability is implemented.

Reference station modulator failures may result in the broadcast of alternating ones and zeros, a single carrier tone, or no output at all.

If an out of tolerance condition (e.g. station is "off the air") is expected to continue for more than two hours or as advised by Marine Aids Superintendent, a "Notice To Mariners" and/or "Notice to Shipping" will be issued as appropriate.

5. USER EQUIPMENT CAPABILITIES

In order to ensure end-to-end system integrity, the user equipment suite should have the following capabilities:

a) receive and process all the various types of messages broadcast by the DGPS station as described in Section 2.
b) receive and process all the various messages at 200 bps, 100 bps and 50 bps.
c) receive and process the various messages arising from out of tolerance and alarm conditions detected at the broadcast station site as described above;
d) alert the user for pseudo range level alarms if an inadequate satellite constellation exists at that time in that user location.
e) alert the user when the protection limit is exceeded (see paragraph 4.1 for details);
f) select automatically the appropriate radio beacon with priority given to proximity first and signal strength second.
g) have a minimum of nine parallel channels to be used for GPS reception (recommended for navigation in restricted waterways); otherwise a minimum five channel receiver should be used for normal navigation;
h) combine the UDRE values with localized error factors such as user receiver noise, interference, multipath, HDOP, and PRC latency in order to provide a confidence level about the user's displayed position;
i) detect the absence of RTCM messages containing pseudo range corrections in the data stream and if available tune to a different marine radio beacon in advance of the "PRC Time Out Limit". The broadcast of alternating ones and zeros should not cause any false acquisitions since the subject broadcast will be listed as unhealthy by the Type 7 Message;
j) display a textual message based on information in the header of any broadcast DGPS type message concerning unhealthy or unmonitored conditions existing at the reference station. Additionally, unhealthy or unmonitored conditions should cause a visual alarm to activate;
k) Type 16 messages should also be treated in the same manner as in j);
l) if a marine radiobeacon is utilized beyond 260 nautical miles the user equipment suite should display this condition in order to indicate that additional unaccounted for error components are present. The use of the broadcast signal beyond its specified range is further discussed in Section 7;
m) retain the ability to process Type 9-1 messages at 50 bps rate in the event that SA is withdrawn permanently;
n) retain the ability to process Type 1 messages in the event that SA is withdrawn permanently;
o) discard all pseudo range corrections from the previous broadcast when switching broadcasts before utilizing any pseudorange corrections from the new broadcast
p) immediately stop applying any PRC derived information for a satellite until the alarm condition ends, when any pseudorange alarm messages are received from the DGPS station. This is accomplished by the setting of the PRC (t_o) field to a value of binary 1000 0000 0000 0000 and the RRC field to a value of 1000 0000;

q) alert the user of positional alarms generated by the DGPS station due to a lack of healthy pseudo ranges because of insufficient satellites or a failure of the pseudo range weighting or monitoring functions. These conditions are indicated by the message header which allows the broadcast of an alarm without breaking frame synchronization;
r) alert the user of an unmonitored condition alarm (e.g. IM failure). This is indicated by the message header and will generally occur for duration's of only several minutes. During this time the redundant IM is used to perform an initial assessment of the broadcast before the status of the system returns to the monitored condition. As the 'hot' and standby reference stations usually maintain a time base to within 15 ns of each other, the IM may be able verify the broadcast health status for the new reference station in a few seconds. However, if both IMs malfunction, the unmonitored condition can last for a prolonged period;
s) stop using the pseudorange correction if its age exceeds 30 seconds since this PRC should not be applied to the user's navigation solution. When Type 9-3 Messages are broadcast at 200 bps the user would have to miss nine consecutive updates before the time out limit is reached for a given pseudo range; and
t) exit the differential navigation mode and revert to GPS if there are insufficient satellites with valid pseudorange corrections

6. DGPS INFORMATION

This document and other general information concerning the Canadian DGPS system can be obtained from:

Canadian Coast Guard
Maritime Services, Navigation Systems Directorate
200 Kent Street
Ottawa, ON
K1A 0E6

Important information concerning day-to-day DGPS operations affecting users will be communicated through appropriate Coast Guard communication channels such as “NOTICE TO MARINERS” and/or “NOTICE TO SHIPPING”, as appropriate.

Any changes to this Standard may result in the release of a revised version or communicated to the user through the above-mentioned appropriate channels.

The RTCM Special Committee No.104 (Version 2.1) “Recommended Standards for Differential NAVSTAR GPS Service” document can be purchased from the RTCM by telephoning (703) 527-2000 or by writing to*:*

Radio Technical Commission for Maritime Services
1800 N. Kent Street
Suite 1060
Arlington, Virginia
22209
USA
Fax. 1-703-351-9932

7. DGPS STATION SELECTION

The latency of a pseudorange correction increases and the position accuracy consequently degrades, when there is a weak and less reliable DGPS signal. This will usually occur when a vessel navigates beyond the edge of an advertised DGPS coverage. Another error contribution due to spatial decorrelation, becomes pronounced when a broadcast emanating from a DGPS Station more than 260 nautical miles from the vessel is used. The user should be aware of these factors when using a broadcast from a DGPS Station.

An unhealthy broadcast should not be used under any circumstances.

The user equipment suite will encounter three DGPS station selection scenarios in Canadian waters:

a) user is within the advertised coverage of one CG designated DGPS Station
b) user is within the advertised coverage of two or more CG designated DGPS Stations
c) user is outside the advertised coverage of any DGPS Station

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In the first scenario, the user equipment suite should use the broadcast from the designated DGPS station and continually monitor its health and various parameters. If the broadcast becomes unhealthy, the user equipment should follow the guidelines described below.

The second scenario occurs in a multiple coverage area. In a limited number of locations where several broadcasts are available, the closest one may not necessarily be the one with the highest received power. The closest station, provided it is healthy, should be used even if its signal strength is low relative to other received signals. The alternate designated DGPS Station(s) will be selected in the event that the broadcast from the closest station becomes unhealthy or unmonitored. If the alternate designated DGPS Station also becomes unhealthy, it should attempt to check out the status of the "faulty" designated DGPS Station(s) before attempting to scan for a satisfactory broadcast from a non-designated DGPS Station, as in the guidelines described below.

In the third scenario where there are no designated DGPS Stations, the user equipment suite should use a satisfactory broadcast from the nearest DGPS Station, subject to the applicable constraints in the guidelines described below.

The following guidelines should be used in seeking a satisfactory broadcast:

1) scan for and use a satisfactory broadcast from the nearest non-designated DGPS Station);
2) a satisfactory broadcast emanating from a DGPS Station more than 260 nautical miles away should be used with caution; and
3) an unmonitored broadcast of any DGPS Station should be used with caution, only after the procedures described in 1) and 2) have been attempted unsuccessfully.

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GLOSSARY

ACRONYMS

bps	bits per second
CM	control monitor
CS	control station
dB	decibel
DGPS	Differential Global Positioning System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
Hz	Hertz
IM	Integrity Monitor
IOD	Issue of Data
KHz	Kilo-Hertz
m	metre
MF	Medium Frequency
MSK	Minimum Shift Keying
NAD 83	North American Datum of 1983
nm	nautical mile
ns	nano-second
PR	pseudorange
PRC	Pseudorange Correction
RRC	Range Rate Correction
RS	Reference Station
RTCM	Radio Technical Commission for Maritime Services
SNR	Signal to Noise Ratio
SPS	Standard Positioning Service
µV/m	Micro-Volt/metre
UDRE	User Differential Range Error

DEFINITIONS

Accuracy: Absolute accuracy is defined as the expected maximum error in the geographical position as computed by the DGPS user equipment within some specified statistical limit. For DGPS systems the limit is usually the horizontal two dimensional error measure called 2 drms (twice the root mean square error). For the Canadian DGPS system, the error limit is 95%, which is the minimum 2 drms value for bivariate normal error distribution. The position accuracy of the DGPS Service will be 10 meters, 95% of the time; or better in all specified coverage areas (assuming the full 24 GPS satellite constellation and a HDOP < 2.3).

Availability-broadcast: The percentage of time during which a proper DGPS broadcast (i.e. healthy and at specified signal power) can provide at a specified location, a sufficient signal-to-noise level to enable good quality user equipment to detect and demodulate the signal.

Availability-user: The percentage of time in which a DGPS signal is available to a user at any given part of an coverage area which allows the position accuracy specification to be met. It is a product of broadcast availability and broadcast reliability.

Broadcast Coverage: The area where a user can expect DGPS service provided by a particular DGPS station. It has a limit defined either by a specified signal level (e.g. 75 or 100 μv/m) or a specified broadcast availability (normally 99%); whichever is more stringent. For a DGPS station, this is called the advertised coverage area.

Broadcast Reliability: It is a function of the expected failure rate i.e. mean time between failure (MTBF) of the DGPS and transmitter equipment at a site and the time to repair the failure i.e. mean time to repair (MTTR). In statistical terms:

$$\mathrm{Re}\,liability = \frac{MTBF}{MTBF + MTTR}$$

Broadcast Reliability can also be expressed as the probability of a healthy broadcast being on the air at specified power when a user randomly selects it.

Data Rate: The number of information bits per second that are broadcast.

Datum: A geodetic coordinate system that is specific to a given geographical region.

Integrity: The ability of a system to provide timely warnings to users when it should not be used for navigation and also to verify the validity of the DGPS broadcast.

Latency: The difference between the time at which the first bit of a given message is broadcast and the time tag in the header of the pseudo range correction messages. The time tag in the message header is the Z-Count that is closest to the time of last measurement upon which a correction is based. Latency is specified as an average in order to take into account the difference between the Z-Count and the time of measurement that can be up to 0.6 seconds.

Protection Limit: The user position error as measured by an IM, which shall not be exceeded for a specified interval without the broadcast of an alarm.

Time to Alarm: The maximum allowable time between the appearance of an error outside the protection limit at the integrity monitor and the broadcast of the alarm.

Transmission Rate: The total number of bits per second that are broadcast.

UDRE: A one sigma estimate of the pseudo range correction error due to ambient noise and residual multipath.

Unhealthy: Unable to operate within tolerance.

Unmonitored: Not monitored by an integrity monitor (IM)

DGPS Beacon Information

Pacific

Site	ID of Ref Stations	DGPS Station ID	Position	Frequency [KHz]	BPS
Alert Bay	300, 301	909	50 35 N 126 55 W	309	200
Amphritrite Pt.	302, 303	908	48 55 N 125 33 W	315	200
Richmond	304, 305	907	49 06 N 123 11W	320	200
Sandspit	306, 307	906	53 14 N 131 49 W	300	200

Central

Site	ID of Ref Stations	DGPS Station ID	Position	Frequency [KHz]	BPS
Wiarton	310, 311	918	44 45 N 81 07 W	286	200
Cardinal	308, 309	919	44 47 N 75 25 W	306	200

Maritimes

Site	ID of Ref Stations	DGPS Station ID	Position	Frequency [KHz]	BPS
Partridge Island	326, 327	939	45 14 N 66 03 W	295	200
Pt. Escuminiac	332, 333	936	47 04 N 64 48 W	319	200
Fox Island	336, 337	934	45 20 N 61 05 W	307	200
Western Head	334, 335	935	43 59 N 64 40 W	312	200
Hartlen Point	330, 331	937	44 36N 63 27 W	298	200

Newfoundland

Site	ID of Ref Stations	DGPS Station ID	Position	Frequency [KHz]	BPS
Cape Race	338, 339	940	46 46 N 53 11 W	315	200
Cape Ray	340, 341	942	47 38 N 59 14 W	288	200
Cape Norman	342, 343	944	51 30 N 55 49 W	310	200
Rigolet	344, 345	946	54 11 N 58 27 W	299	200

Laurentian

Site	ID of Ref Stations	DGPS Station ID	Position	Frequency [KHz]	BPS
St.-Jean-sur-Richelieu	312, 313	929	45 19 N 73 19 W	296	200
Lauzon	316, 317	927	46 49 N 71 10 W	309	200
Riviere du Loup	318, 319	926	47 46 N 69 36 W	300	200
Moisie	320, 321	925	50 12 N 66 07 W	313	200