Fisheries and Oceans Canada
Coast Guard

Pêches et Océans Canada
Garde côtière

PRIMER ON GPS AND DGPS

The questions most frequently asked by a ship's navigator are:

- ☛ Where am I?
- ☛ What is the course to steer from my present position to my destination?
- ☛ What is the distance from my present position to my destination?
- ☛ What is my course over the ground?
- ☛ What is my speed over the ground?
- ☛ How long will it take me to reach my destination at my present speed?

Traditional chartwork and mathematical skills have provided the navigator with the tools to answer these questions. In clear weather, visual bearings of prominent charted objects and visual transits, combined with information from the speed and distance log and the depth sounder, have served the navigator well. It is in restricted visibility, when visual contact with the land has been lost, that the questions become more difficult to answer. A Dead Reckoning (DR) position, although not to be dismissed as having no value, becomes increasingly inaccurate with the passage of time.

Electronic aids to navigation have assisted the navigator in his/her quest for answers. Consol, Decca, Radio Direction Finder, Loran-A, Loran-C, Omega, Satnav and Radar have all contributed to the safety of the vessel and the navigator's peace of mind. Most of the foregoing aids, with the exception of Radar, have been, or are scheduled to be, phased out. Fortunately there is now an aid to navigation which is superior in almost all respects to the previously available systems: the Global Positioning System, or GPS.

The Global Positioning System (GPS)

The Global Positioning System, or GPS, is a space-based radionavigation system which permits users with suitable receivers, on land, sea or in the air, to establish their position, speed and time at any time of the day or night, in any weather conditions. The system provides a level of accuracy equal to or better than any other radionavigation system available today.

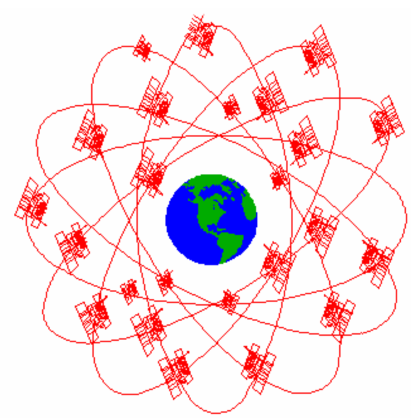
GPS was developed, and is operated and maintained, by the United States Department of Defense. Although originally intended for use by the US military, a Presidential Decision Directive of March 28, 1996, concluded with the following statement:

"We will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial and scientific use on a continuous, worldwide basis, free of direct user fees."

The Global Positioning System can be described in terms of its three elements: the space segment, the control segment and the user segment.

Space Segment

This consists of 24 operational satellites in six circular orbits, 10,900 nautical miles above the earth. Of the 24 satellites, 21 are navigational Space Vehicles (SVs) and 3 are active spares. The orbits are inclined at 55° to the plane of the equator and the orbital period is approximately 12 hours. This pattern allows a receiver on or above the earth to receive signals from five to eight SVs, 24 hours a day. The satellites continuously transmit position and time data which is received and processed by GPS receivers to determine the user's three-dimensional position (latitude, longitude, altitude), velocity and time.



The Control Segment

This consists of a master control station in Colorado Springs, with five monitor stations and three ground antennas located around the world. The monitor stations track all GPS satellites in view and collect information from the satellite broadcasts. These remote stations are capable of tracking and monitoring the position of each GPS satellite.

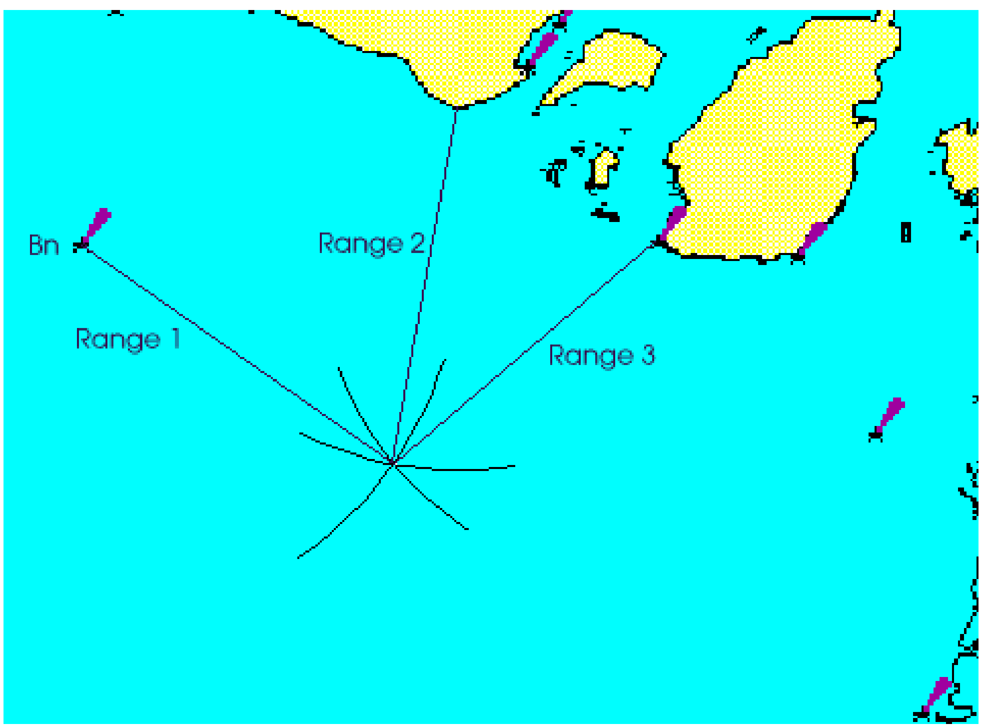
The monitor stations transmit the information collected from the satellites to the master control station, which then computes very precise satellite orbits. This information is then formatted into updated navigation messages for each satellite. The updated information is then uplinked to each satellite via the ground antennas. The ground antennas are also used to transmit and receive satellite control and monitoring signals.

The User Segment

This consists of the receivers, processors and antennas that allow operators at sea, on land and in the air, to receive the transmissions from the GPS satellites and compute their precise position, altitude, velocity and time.

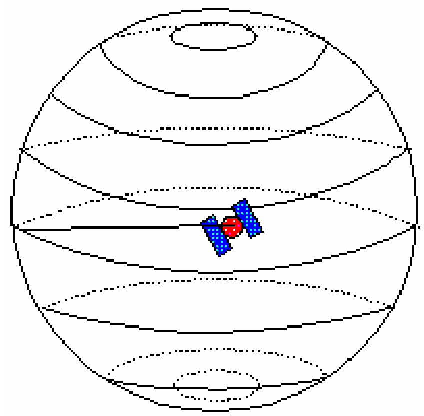
How it Works

On a vessel fitted with radar, the navigator can obtain an accurate position by measuring the distance to three prominent charted objects. If three circles are then drawn on the chart, each having a radius equal to the measured distance off the object, the position of the vessel is at the intersection of the three circles.



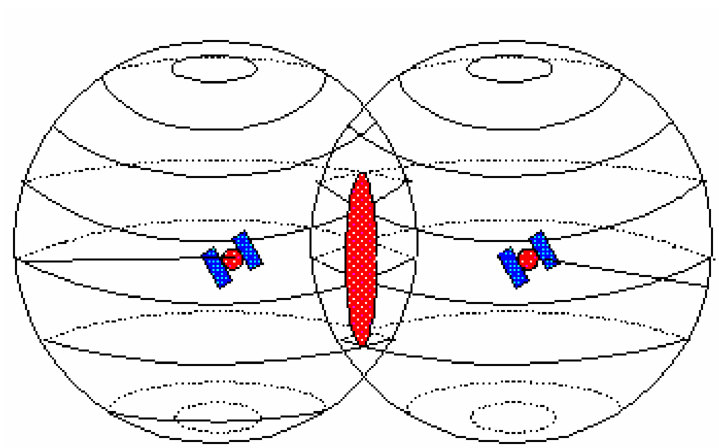
The distance to the three objects is found by measuring the time taken for a radar pulse to travel from the vessel to the object and back again to the vessel. If the speed of transmission of the radar pulse is known, this time can be converted to distance, and the distance to the radar target is half the distance traveled by the radar pulse.

The GPS system enables the navigator to fix his/her position in a manner that has similarities to that described for radar. In the GPS system the transmissions originate at the satellite, and contain information that enables the receiver to compute its distance from the satellite. This distance then places the receiver on the surface of a sphere centered on the satellite, with a radius equal to the range of the satellite. If the transmissions from several satellites are received and processed, then the receiver can be placed at the intersection of three spheres, giving a three-dimensional fix in latitude, longitude and elevation.

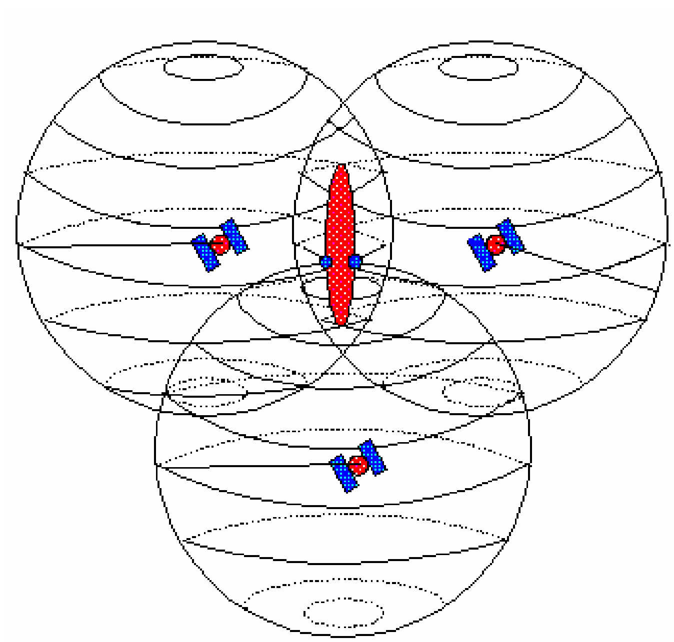


One Satellite

Two Satellites



Three Satellites



There are other significant differences between fixing a position by radar and by the GPS system, but these differences only serve to illustrate the inherent simplicity of the GPS system. Like radar, the interval between the transmission of the outgoing pulse and the reception of the incoming pulse is measured at the receiver to determine distance. The absolute time of transmission is not required, only the interval between the transmitted and received pulses. In the GPS system the transmission originates at the satellite and the receiver receives that transmission some time afterwards, the time interval being dependent on the distance of the receiver from the satellite. Unlike three prominent charted objects, satellites are moving targets. For the receiver to determine its position with accuracy, the exact time of transmission of the signal and the position of the satellite in its orbit at that time must be known.

What Time Is It?

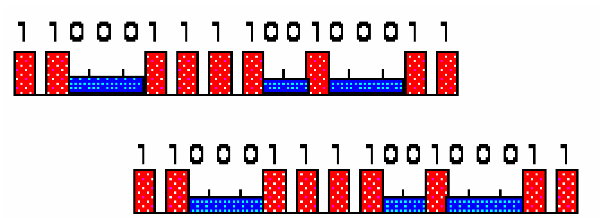
The satellite transmits information describing its position in orbit at a precise time. The receiver detects this transmission and compares the time of arrival, as shown by a clock in the receiver, with the time of transmission as determined by a clock in the satellite. If the clock in the receiver was perfectly synchronized with the clock in the satellite, and thus the delay between transmission and reception accurately measured, then three such measurements, from three different satellites, would yield accurate latitude, longitude and elevation. To achieve this level of synchronization between receiver clock and satellite clock would require much more than the relatively inexpensive quartz crystal oscillators found in GPS receivers.

GPS satellites carry four extremely accurate clocks: two cesium atomic clocks and two rubidium atomic clocks. The design specifications for these clocks required an accuracy of one second in 30,000 years, but this has been substantially exceeded and the accuracy is closer to one second in 150,000 years. To ensure their continuing accuracy, clock correction factors are transmitted to the satellites on a daily basis.

Due to the lack of synchronization between the highly accurate and stable satellite clocks and the receiver clock, the time interval as measured by the receiver will be in error. This will result in an error in the measured ranges and the final latitude, longitude and elevation will be in error. The incorrect range as measured by the receiver is known as the pseudo range. All of the pseudo ranges measured by the receiver are in error by the same amount, being due to the same clock bias error. Fortunately this clock bias error can be easily determined by measuring the pseudo ranges to four satellites, instead of three. With the clock bias error known and allowed for, the latitude, longitude and elevation can be determined to a higher order of accuracy, and the GPS receiver clock becomes a much more reliable timekeeping device.

Who Are You?

All GPS satellites transmit on the same frequency. There are, in fact, two frequencies, but only one is utilized in receivers normally found in small vessels. This is known as the L1 frequency (1575.42 MHz). This frequency carries the navigation message and the Standard Positioning System (SPS) code signals. With all satellites transmitting on the same frequency, and the receiver having five or more satellites above the horizon, there must be some manner in which the receiver can identify the unique source of each signal that is being received. The transmissions from each satellite are, in fact, differentiated from one another by means of a Pseudo Random Noise (PRN) code. Each satellite has a different PRN and the GPS satellites are often identified by their PRN number.



Sequence from satellite

Sequence from receiver

Each Navstar satellite transmits two pulse trains, copies of which are created in real time by the receiver. An automatic feedback control loop in the receiver skews its pulse train to bring it into correspondence with the identical pulse train being broadcast by the satellite. When correspondence is achieved, the receiver can establish the signal travel time plus or minus the clock error. This procedure is repeated for at least three other satellites, to obtain the timing measurements necessary to determine the users' three position coordinates.

How Accurate Did You Say?

The GPS system provides two levels of service; a Standard Positioning Service (SPS) for general public use, and a Precise Positioning Service (PPS) primarily intended for the use of the military. The SPS provides accuracy's within 20 metres in the horizontal plane, 95 percent of the time.

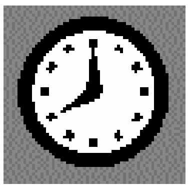
The Perfect Aid to Navigation?

Well, nearly but not quite. The accuracy of the system using the L1 signal approaches 20 metres. There are other sources of error which can introduce inaccuracies into the final position ranging from 1 metre to hundreds of metres. These error sources are:

- uncorrected satellite clock errors
- orbital parameter data errors
- ionospheric and tropospheric delays

- multi-path errors
- geometric errors
- datum selection errors.

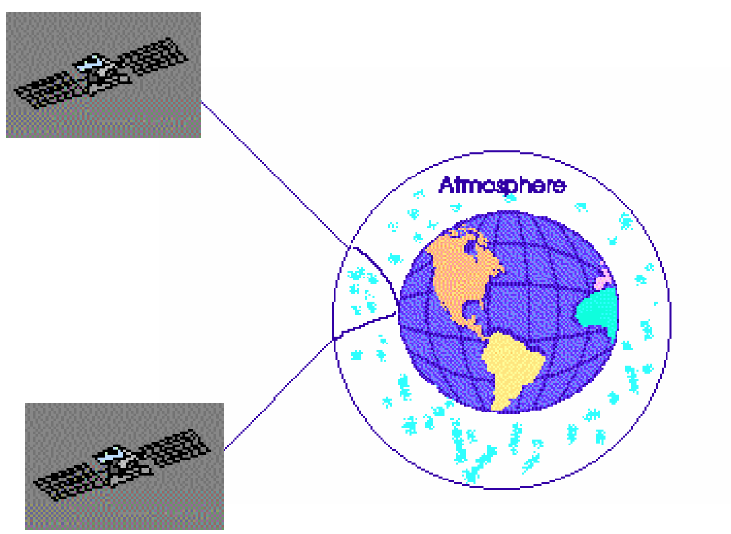
Errors Originating at the Satellite.



Although the clocks on the SVs are extremely accurate and stable, and despite their accuracy being checked on a regular basis, very small errors in timing are still possible. These timing errors, coupled with small errors in the broadcast position of the SVs, can result in ranging errors of approximately 3 metres.

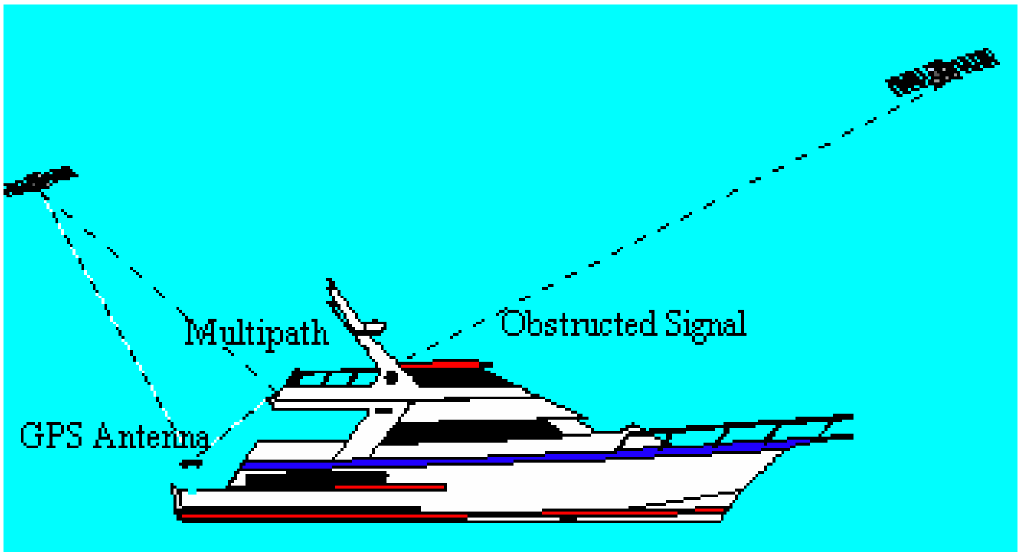
Errors due to the Signal Path

The fundamental assumption when measuring the range of an SV is that the speed of transmission of the signal is constant. This is only true in free space and, as the signal travels through the electrically charged particles of the earth's ionosphere, and then through the water vapour of the earth's troposphere, the speed of transmission changes. This may result in errors in the measured range to the SV of 10 to 12 metres.



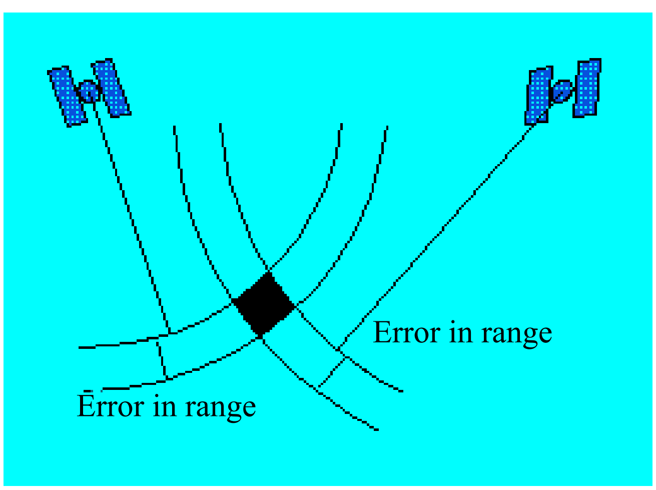
Multi-Path Error

The true range of the SV is the slant range, i.e., the range in a direct line. If there are nearby obstructions to the signal, either within the vessel or externally, the signal may reach the antenna after one or more reflections.



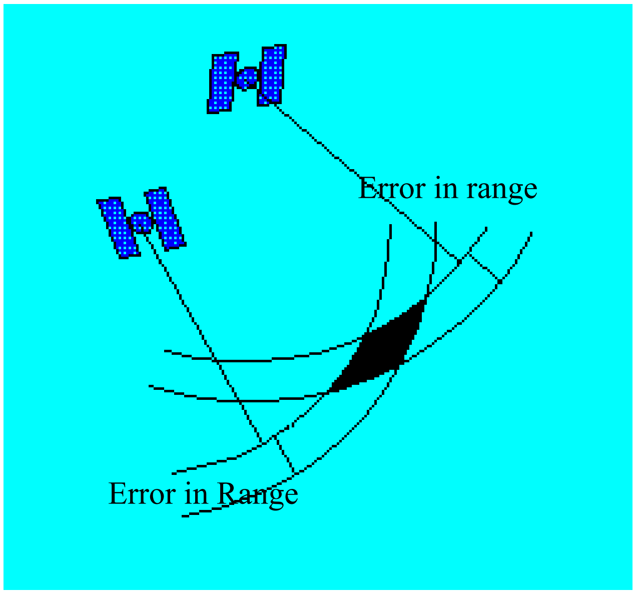
Geometric Errors

These are errors which occur in GPS, and other position fixing systems, when the angle of cut between the position lines is very small. A small error in the measured information can produce a significant area of uncertainty when the angle of cut is small. Conversely, the same error in position lines intersecting at 90^o produces a small area of uncertainty. In GPS, SVs on nearly the same bearing will place the receiver on the surfaces of spheres which intersect at small angles. Any accumulated ranging error will lead to a large displacement of the fix.



Satellites widely separated
Good angle of cut

A factor known as the Geometric Dilution of Precision (GDOP) can be calculated, depending on the geometry of the SVs. The mariner is principally interested in latitude and longitude, elevation not generally being an issue, and the Horizontal Dilution of Precision (HDOP) is of more relevance. (Generally, an HDOP reading on the receiver of less than 2.0 is considered a good fix.)



- **Satellites nearly in line.**
- **Poor angle of cut.**

Datum Selection Errors

If the datum used by the GPS receiver in calculating latitude and longitude is different from the datum of the chart in use, errors will occur when GPS derived positions are plotted on the chart. GPS receivers can be programmed to output latitude and longitude based on a number of datums. Since 1986 the Canadian Hydrographic Service has converted some CHS charts to NAD 83. Information on the chart will describe the horizontal datum used for that chart and for those not referenced to NAD 83, corrections will be given to convert NAD 83 positions to the datum of the chart. The title block of the chart will describe the horizontal datums used for the chart and will give the corrections to convert from the datum of the chart to NAD 83 and vice versa.

Introduction to Differential GPS (DGPS)

What is it?

Differential GPS is a method of significantly improving the accuracy of the positions derived from GPS receivers used by small vessel operators.

Differential position accuracies of better than 10 metres are possible with DGPS using only the Standard Positioning Service signals.

How Does it Work?

A DGPS reference station is established along a coastal waterway in a fixed, accurately located position. The station's GPS receiver measures the signals from all SVs in view. As the station is in a known location, it is capable of solving equation for the actual travel time and the theoretical travel time of each satellite signal. The reference station can then determine any timing errors. The differential station transmitter corrects these timing errors for all SVs in view. The ship-borne receiver then incorporates only those corrections applicable to the SVs it is using for the navigation solution.

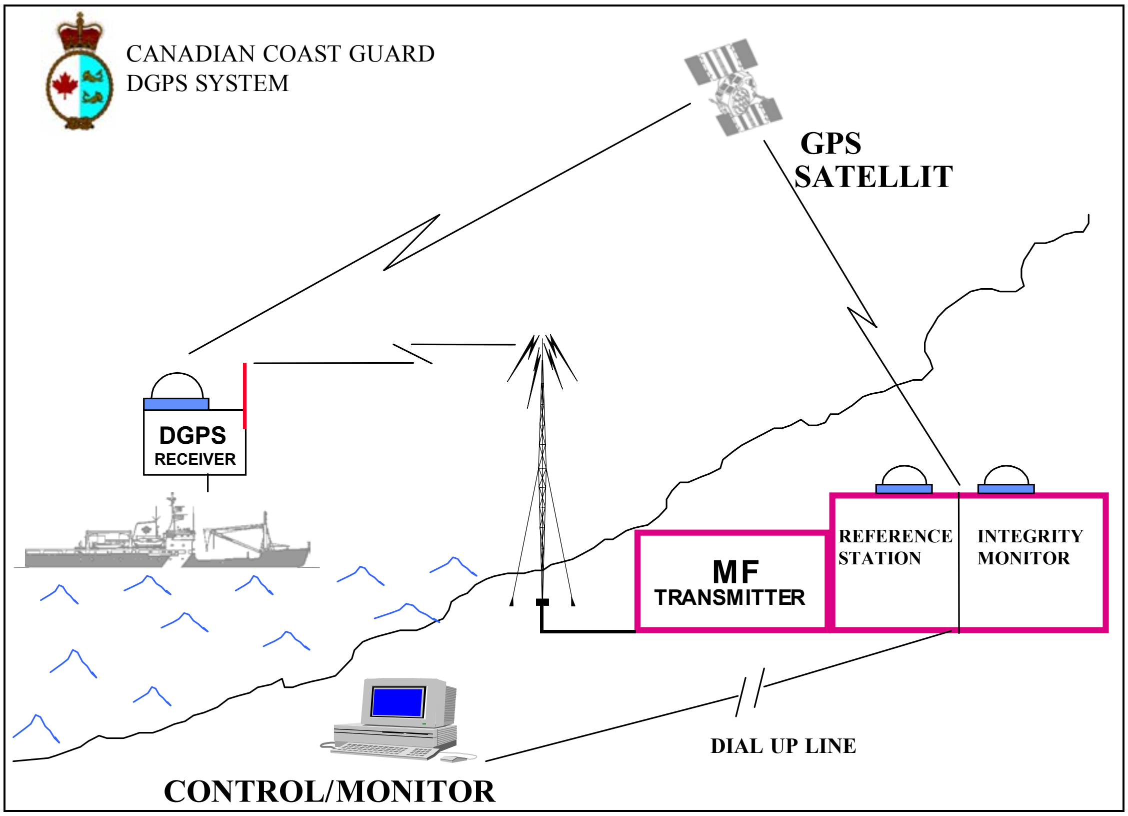
The Canadian Coast Guard has implemented a DGPS network in most southern Canadian waters using existing Medium Frequency (MF) radiobeacon transmitters, operating on a frequency between 285 KHz and 325 KHz. The system consists of a network of DGPS stations (reference/broadcast) linked to Control Monitors situated at Marine Communications Traffic Centers in each Coast Guard region. The highly reliable system is designed to operate autonomously, and to tolerate faults without failure. The Canadian DGPS network also provides integrity monitoring. In this sense, a warning signal advising the mariner that the service is unreliable will be automatically transmitted in any case where the accuracy provided by the reference station falls below established limits. Should the differential signal be lost, a DGPS receiver can continue to operate in the GPS mode using the SPS signal.

The primary operational requirements for the Canadian DGPS service are to provide:

- precise navigation service in Canadian waters where traffic and waterway conditions warrant;
- precise positioning in support of Coast Guard operations where cost-beneficial; and,
- precise positioning services to other government marine agencies where fixed site broadcasts installed for the above purposes will meet their needs.

How Does DGPS Work In Canada

The following illustrates the DGPS navigation service concept. A typical DGPS station comprises of a control station (CS), reference station (RS), their associated integrity monitors (IM) 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) is located at a 24-hour staffed Coast Guard operational site and maintains two way communications via dial up lines with the DGPS stations. The CM monitors the status of the system.



Canadian DGPS System

What is the World Geodetic System 1984 (WGS 84).

As it is known that the earth is not a perfect sphere, charts are referenced to a theoretical model which best represents the earth's surface. The World Geodetic System 1984 (WGS 84) is the internationally recognized theoretical model to which many charts are referenced by use of latitude and longitude. Canada, along with the USA and other countries in North America have adopted a referencing system known as North American Datum 1983 (NAD 83). For charting purposes, NAD 83 is considered to be equivalent to WGS 84.
The position obtained by GPS receivers is normally portrayed with reference to WGS

84. Many receivers have the capability of portraying the position in other common datums including NAD 83.

The corrections from the DGPS service are calculated at the reference station in the NAD 83 coordinates. To process the information properly, DGPS receivers should be adjusted to the WGS 84 setting. Although WGS 84 and NAD 83 are essentially the same (only a few centimeters difference), it is highly recommended that all DGPS receivers be set to WGS 84 to take full advantage of the precision of DGPS. When utilizing charts other than NAD 83, DGPS latitude and longitude positions must be adjusted to the appropriate datum using the information contained on the charts.

What information can be obtained from the DGPS Signal?

The broadcast from each DGPS station contains a number of specific "message" groups providing the information mariners need to use the Differential Service. In order for a mariner to take full advantage of all the features of this service, a DGPS receiver should be capable of processing this information. Consult your receiver operating manual to determine the unit's ability to process all DGPS formatted messages. (Refer to APPENDIX B for message specification).

Note: Receivers using the Canadian DGPS service must be capable of processing the Type 9 differential correction message.

The Canadian DGPS Broadcast message format is in accordance with the International Radio Technical Commission for Maritime Service (RTCM) standard (Standard SC 104 version 2.1)

What kind of accuracy can be expected from DGPS and how reliable is the service?

The Levels of Service Standard for DGPS is a description of the performance users can expect when using the differential system. This standard is defined in terms of expected accuracy, broadcast reliability, signal availability and integrity.

The following table is a detailed description of the Levels of Service standards for DGPS in Canada.

1. ACCURACY	
Definition:	The expected maximum error in the geographical position between the DGPS readings and your actual position on the face of the earth.
Levels of Service: Standard	The position accuracy of the DGPS service will be 10 metres (95 percent of the time) or better, in all specified coverage areas for suitable user equipment. For the remaining 5 percent of the time, the DGPS service may provide a positioning accuracy outside the 10 metre limit.
2. BROADCAST RELIABILITY	
Definition:	Broadcast Reliability is a function of the expected failure rate, i.e. mean time to failure (MTTF) of the transmitter equipment at a DGPS site and the time to repair the failure, i.e., mean time to repair (MTTR). In statistical terms: Broadcast Reliability = $\frac{\text{MTTF}}{\text{MTTF + MTTR}}$ or $\frac{\text{Up Time}}{\text{Up Time + Down Time}}$
Levels of Service: Standard	The probability that the DGPS broadcast is providing healthy DGPS corrections at specified power when a user selects it, will be at least 99.8 percent of the time.
3. SIGNAL AVAILABILITY	
Definition:	The percentage of time during which a proper DGPS broadcast (i.e. broadcast is healthy, generating accurate corrections and is operating at a specified signal power) can provide, at a specified location, a sufficient signal strength (or signal-to-noise ratio) to enable good quality user equipment to detect the DGPS signal.
Levels of Service: Standard	Signal availability of at least 99 percent should exist in areas of single Canadian DGPS broadcast station coverage. Signal availability of at least 99.8 percent should exist in areas of multiple broadcast station coverage. Corrections are transmitted at the speed of 200 bits per second.
4. INTEGRITY MONITORING	
Definition:	The DGPS station's autonomous ability to detect and warn the user of out-of-tolerance conditions.
Levels of Service: Standard	Warning within 10 seconds to users with suitably equipped receivers.

What is System Integrity?

All Canadian DGPS stations are capable of detecting and automatically warning mariners of any out of tolerance or fault condition that may affect the expected performance from the differential service. For example, if the pseudo-range or differential corrections being transmitted by a DGPS station result in a positioning error greater than 10 metres, the DGPS station will automatically generate a warning signal advising mariners that the service is out of tolerance.

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) more importantly, the DGPS receiver’s ability to process this DGPS alarm.

The reference station is equipped with an integrity monitor (IM) system which verifies the accuracy of the DGPS broadcast. Basically the IM computer, knowing its own surveyed location, is able to assess whether the DGPS broadcast is operating within certain specified limits. If for some reason a fault is detected, a warning signal is transmitted to the mariner within 10 seconds and an alarm is generated at the staffed control monitor (CM) station. As part of the IM system, the DGPS station sends routine station status messages every half hour and any alarm messages to the CM.

Consult the DGPS operator's manual for the receiver's ability to process and display the IM signal.

Other things you should remember when using DGPS to navigate your vessel.

To take full advantage of the DGPS service, the following is important to all DGPS users:

- Follow the manufacturers instructions for the installation, operation and maintenance of the DGPS receiver. When operating a GPS/DGPS receiver for the first time, ensure that the initializing instructions of the operators manual have been followed before using the receiver for navigation.

- The DGPS service provides more than just satellite corrections. Refer to your operators manual to determine what capability your receiver has to process these special message groups. (An explanation of these message groups is provided in Technical Reference Annex B.)

- The antenna must be situated on the vessel such that it is not obstructed by vessel structures, has a clear view of the horizon and is not affected by multipathing.

  Never place a GPS antenna in direct line of transmission beam of a radar antenna.

- For most GPS/DGPS antennas, it is very important for the antenna to be grounded. Improper grounding can seriously affect the performance of a GPS/DGPS receiver. For vessels made of metal, an antenna can be grounded by connecting to a grounding bolt. (Make sure the grounding surface is paint free.) For vessels made of fiberglass or wood, the antenna can be grounded to an engine block. For fiberglass or wooden vessels operating in sea water, the antenna should be grounded to a grounding plate on the exterior of the hull or a keel bolt on a sailboat. Electrical interference, caused by engine spark plug wires, alternator and other electrical devices, can also seriously affect the sensitivity of a GPS/DGPS receiver. Consult your local marine electronics supply dealer for additional information on electronic noise suppression.

  The importance of grounding a receiver antenna cannot be emphasized enough. This is the main reason for poor performance of all on board electronic navigation equipment for non metal vessels.

- GPS and DGPS receivers may also be affected by external sensors such as autopilot, depth sounders, compass, wind measuring instruments, amplifying recreational vehicle TV antennas, etc.

- One specific VHF frequency (harmonic)[1] can interfere directly with the GPS operating frequency. To reduce interference of a VHF transmitter, separate the GPS / DGPS and VHF antenna as much as possible.

- A GPS or DGPS signal can be seriously affected or blocked by hydro power lines, mountains, bridges, buildings and other man-made structures.

- If the display unit is not waterproof, install the receiver in a dry area of the vessel protected from rain or sea spray. Remember, a water resistant receiver is not necessarily waterproof. Receivers should also be protected from excessive vibration due to boat motion.

- In certain applications where the precision of the differential service is essential, it is recommended that high quality DGPS receivers be used. Lower quality receivers can potentially degrade the performance of the DGPS service.

- When navigating with DGPS, care should be taken when selecting the best DGPS

[1]Harmonic is a multiple of a particular transmitted frequency that can affect another frequency under certain circumstances.

station within range of your position. Some receivers are capable of locking automatically onto the best available DGPS beacon signal while maintaining surveillance on all other stations within range. Receivers can be operated in an automatic or manual mode for DGPS station selection. If there is a concern over which station is being used during a voyage, refer to the DGPS receiver operators manual for selection of the appropriate display window for station selection.

For a GPS/DGPS receiver operating in manual mode, it is important to note that the closest DGPS station is generally considered the best for receiving corrections. Keep in mind, however, the signal may be affected or obscured by mountains, man-made electronic interference, thunderstorms, etc.

- When using a DGPS station at the limits of the advertised coverage range, additional errors may be introduced and degradation of the position accuracy can occur. The technical term for this error is latency or correction age. Extended range use of DGPS may also result in a weak and less reliable signal. Always exercise caution when using a DGPS station beyond its advertised coverage range.

- If a differential station becomes unhealthy for whatever reason, and the integrity monitoring signal is displayed on the DGPS receiver, caution should be exercised until the station returns to normal or another DGPS station is acquired.

- Mariners are reminded that paper and electronic charts used to plot a DGPS position may have errors that far exceed the positioning accuracy of the DGPS service.

What is GPS system time rollover, and what does this mean to me?

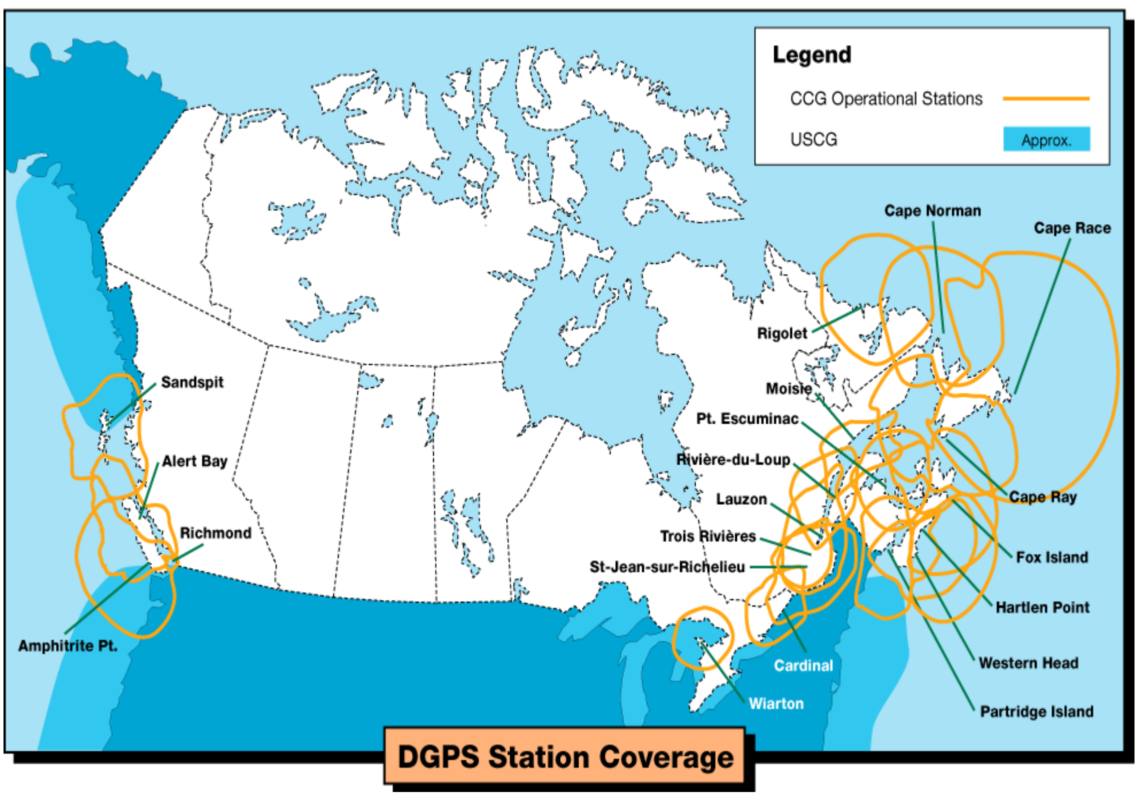
The Global Positioning System accounts for time by using a number for every week the service is in operation and accounts for the seconds within each numeric week. It started counting weeks using a starting point of midnight (0000) on the evening of January 5, 1980/morning of January 6, 1980 (UTC), and has increased its count by 1 for each week since then. Both week and seconds are broadcast as part of the GPS message provided by the satellites and are used by receivers in their computations. The GPS week number field in this message can only provide for numbers up to 1024 which means that, at the completion of the week 1023, the week number field rolled over from 1023 back to 0. This occurred at midnight 21/22 August 1999. On August 22, 1999, unless repaired, many GPS receivers may have claimed that it was January 6, 1980.

It was the responsibility of the user to account for this changeover; the satellites themselves simply start broadcasting the new week number. How this will affect your particular GPS unit will depend on what brand and model of receiver you have. Some receivers may merely display inaccurate date information, but others may have also calculated incorrect navigation information or may have stopped providing positions. If the rollover wasn't taken into account at the time your GPS receiver was designed and built, the unit might have problems. Some units required a software upgrade. Mariners are advised to consult with the manufacturer concerning their receiver's compliance to GPS rollover.

What does the term "Spatial decorrelation" mean?

Another minor error that can contribute to reduced system performance at the edge of advertised DGPS coverage area is an error known as spatial decorrelation. As a mariner proceeds further away from a DGPS station, the correction calculated at the coastal station becomes progressively inaccurate. The correction assumes that the DGPS station and user receiver are seeing the same distortions of the GPS satellite signal as it passes through the earth's atmosphere (ionosphere). This is not the case if the receiver is a large distance from the DGPS station. It is estimated that error introduced due to spatial decorrelation is 0.5 metres of additional positioning error for every 100 km distance away from the DGPS.

MAP OF THE DGPS SERVICE IN CANADA



Back to the Beginning.

The questions most commonly asked by the small vessel navigator were stated at the beginning of this guide. They are:

- Where am I?
- What is the course to steer from my present position to my destination?
- What is the distance from my present position to my destination?
- What is my course over the ground?
- What is my speed over the ground?
- How long will it take me to reach my destination at my present speed?

A GPS/DGPS receiver will provide the answers to all of these questions.

Where am I?

The previous sections have explained how a GPS receiver provides the navigator with latitude and longitude in any weather conditions, twenty-four hours a day, to an accuracy of 20 metres, 95 percent of the time. A DGPS receiver will improve the accuracy of the position to 10 metres or better, 95 percent of the time.

What is the course to steer from my present position to my destination?

If the destination is entered into the GPS/DGPS receiver as a waypoint, the GPS/DGPS will determine the course to steer from the current position to the destination. Most GPS/DGPS receivers can be configured to give the course to steer in either “True” or “Magnetic.”

What is the distance from my present position to my destination?

In addition to determining the course to the destination, the GPS/DGPS will also calculate the distance to the destination.

What is my course and speed over the ground?

The GPS/DGPS constantly updates the current position and continuously compares the current position with previous positions. This comparison provides an indication of the course and speed made good, i.e., over the ground as opposed to through the water.

How long will it take me to reach my destination at my present speed?

As the GPS/DGPS is continuously calculating speed over the ground and distance to the destination, it will determine the time to reach the destination at the current speed.

These are, in fact, only a few of the features available in most GPS/DGPS receivers. Even the moderately priced, hand held, GPS receivers provide for route planning, position in several coordinate systems, datum selection, time in UTC or user defined output, cross-track error indication, 2-D or 3-D position and the ability to communicate with other instruments such as radars, plotters and auto pilots.

If the user remains aware of the potential sources of error, in particular:

- incorrect datum selection,
- multi-path error and masking,
- poor geometry,
- inherent error to the differential service,

then the GPS/DGPS receiver is a highly accurate and dependable aid to navigation.

The Internet.

There are many excellent sources of information on GPS and DGPS on the Internet. The Canadian Coast Guard web site at

http://www.ccg-gcc.gc.ca/dgps/main.htm

has a very detailed description of the Canadian DGPS system.

A site at the University of Colorado:

http://www.colorado.Edu/geography/gcraft/notes/gps/gps_f.html

contains an excellent overview of GPS and DGPS.

If you have any comments or questions on the DGPS service in Canada, please write to :

Canadian Coast Guard
Dept of Fisheries & Oceans
200 Kent Street
Ottawa, Ontario
K1A OE6

ANNEX A

Table of DGPS Reference Stations in Canada

Station Name	Id. #s of Reference Stations	DGPS Station ID	Geog. Position Latitude Longitude	Frequency [khz]	Bit/s
Cape Race, NFLD	338,339	940	46 46 N 53 11 W	315	200
Cape Ray, NFLD	340,341	942	47 38 N 59 14 W	288	200
Cape Norman, NFLD	342,343	944	51 30 N 55 49 W	310	200
Rigolet, NFLD	344,345	946	54 15 N 58 30 W	299	200
Partridge Island, NB	326,327	939	45 14 N 66 03 W	295	200
Pt. Escuminiac, NB	332,333	936	47 04 N 64 48 W	319	200
Fox Island, NS	336,337	934	45 20 N 61 05 W	307	200
Hartlen Point, NS	330,331	937	44 35 N 63 27 W	298	200
Western Head, NS	334,335	935	43 59 N 64 40 W	312	200
St.-Jean-sur-Richelieu, QC	312,313	929	45 19 N 73 19 W	296	200
Trois Rivières, QC	314,315	928	46 23 N 72 27 W	321	200
Lauzon, QC	316,317	927	46 49 N 71 10 W	309	200
Rivière-du-Loup, QC	318,319	926	47 46 N 69 36 W	300	200
Moisie, QC	320,321	925	50 12 N 66 07 W	313	200
Wiarton, ON	310,311	918	44 45 N 81 07 W	286	200
Cardinal, ON	308,309	919	44 47 N 75 25 W	306	200
Alert Bay, BC	300,301	909	50 35 N 126 55 W	309	200
Amphritrite Pt., BC	302,303	908	48 55 N 125 33 W	315	200
Richmond, BC	304,305	907	49 11 N 123 07 W	320	200
Sandspit, BC	306,307	906	53 14 N 131 49 W	300	200

TECHNICAL REFERENCE ANNEX B

DGPS MESSAGE GROUPS

The Canadian DGPS Broadcast is designed to transmit message Types 3, 5, 6, 7, 9 and 16 (Type 15 message, which is currently undefined, may also be included at a later time to the DGPS service). A complete description of each message type is as follows:

(Note: The Canadian Coast Guard is currently negotiating with the United States Coast Guard (USCG) to ensure that mariners are provided with a seamless North American DGPS service.)

TYPE 3 MESSAGE

A Type 3 message contains information on the identity and surveyed position of the active reference station in the DGPS station. The Type 3 Message will contain NAD 83 coordinates.

TYPE 5 MESSAGE

This message type will notify the user equipment that a satellite which is deemed unhealthy by its current navigation message is usable for DGPS navigation. An example of this situation is a slowly drifting satellite clock which may render a satellite unhealthy for GPS use, but would be correctable by the reference station for DGPS use. The user equipment 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).

TYPE 6 MESSAGE

The type 6 message is a filler for the DGPS Broadcast and used only when the reference station has no other message to transmit.

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 should update its internal almanac immediately as new information is received. 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 should immediately update its internal almanac. 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.

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 DGPS pseudo range corrections instead of the Type 1 Message.

This method of transmitting a Type 9 message at 100 bits per second (bps also known as baud rate) and 200 bps will be used by the Canadian Coast Guard for the standard and enhanced/multiple coverage areas respectively. (This message type is also transmitted in version type 9-3 200 baud, 9-3 100 baud and 9-2 50 baud)

TYPE 16 MESSAGE

The Type 16 message will be utilized as a timely supplement to the notice to mariners or notice to shipping, regarding information on the status of the local DGPS service which 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. 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 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.

TECHNICAL REFERENCE ANNEX C

GLOSSARY

ACRONYMS OF COMMONLY USED DGPS TERMS

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
uV/m	Micro-Volt per metre
UDRE	User Differential Range Error

TECHNICAL REFERENCE ANNEX D

DEFINITIONS OF COMMONLY USED DGPS TERMS

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 95percent, which is the minimum 2 drms value for bivariate normal error distribution. The position accuracy of the DGPS Service will be 10 metres, 95percent of the time; or better in all specified coverage areas (assuming the full 24 GPS satellite constellation and a HDOP < 2.3).

Signal Availability: 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.

Broadcast Coverage: The area where a user can expect DGPS service provided by a particular DGPS station (see map page 20). It has a limit defined by a specified signal level of 75 uv/m (Offshore Coverage) or 100uv/m (Inshore Coverage).

Broadcast Reliability: It is a function of the expected failure rate i.e. mean time to failure (MTTF) 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:

$$\frac{\text{MTTF}}{\text{MTTF + MTTR}} \quad \text{or} \quad \frac{\text{UPTIME}}{\text{UPTIME + DOWNTIME (Mission Time)}}$$

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, which are broadcast.

Datum: A geodetic coordinate system, which 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 which 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 which 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 which 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).