SECTION 9
POSITION REFERENCE SYSTEMS

Extracts of
IMO, INTERNATIONAL MARITIME ORGANISATION MSC/Circ. 645

GUIDELINES FOR VESSELS WITH DYNAMIC POSITIONING SYSTEMS

3.4.3 Position reference systems

1. Position reference systems should be selected with due consideration to operational requirements, both with regard to restrictions caused by the manner of deployment and expected performance in working situation.

2. For equipment classes 2 and 3, at least three position reference systems should be installed and simultaneously available to the DP-control system during operation.

3. When two or more position reference systems are required, they should not all be of the same type, but based on different principles and suitable for the operating conditions.

4. The position reference systems should produce data with adequate accuracy for the intended DP-operation.

5. The performance of position reference systems should be monitored and warnings provided when the signals from the position reference systems are either incorrect or substantially degraded.

6. For equipment class 3, at least one of the position reference systems should be connected directly to the back-up control system and separated by A-60 class divisions from the other position reference systems.

Use of DGPS/DARPS Alone for Dynamic Positioning

Reproduced from information note IMCA M 24/01, August 2001

When DGPS first became available, it was only used as one of two or three other position references. As deepwater exploration started to increase, the pressure to use dual DGPS increased and DPVOA commissioned Global Maritime in 1994 to study the reliability of dual DGPS. This study concluded that the risk associated with using two position references that were the same could be mitigated if two different systems were used and different satellites as far as possible by antenna positioning.

Since this time the increase in the use of DGPS has been enormous and some vessels are using four DGPSs. IMCA commissioned a risk comparison last year which showed that in deep water the use of dual acoustics an dual DGPS is reasonable on the basis of two independent acoustic inputs.

After an unacceptable number of shuttle tanker incidents (see IMCA M150*) one operator decided to increase the number of DARPS from one to two on the basis that the second was a back up for the first and not as an Artemis replacement.

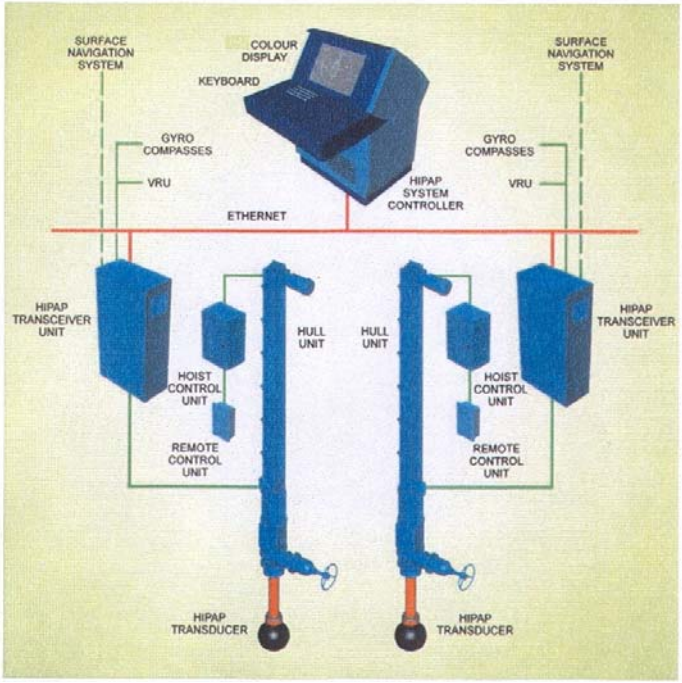
At the present moment there is concern that the use of two DGPS is as good as two independent position references. It is not, and nothing published by IMCA (or DPVOA before) would support this view. This does not mean that working with just two DGPS is unsafe; this judgment depends on the consequences of a loss of position. However, operators must anticipate a loss of position as a frequent event if operating in this manner.

The Marine Division Management Committee will be reviewing this note at its 2nd October meeting. Members are invited to present their views for consideration at that meeting.

** IMCA M 150 – Quantified Frequency of Shuttle Tanker Collision During Offtake Operations*

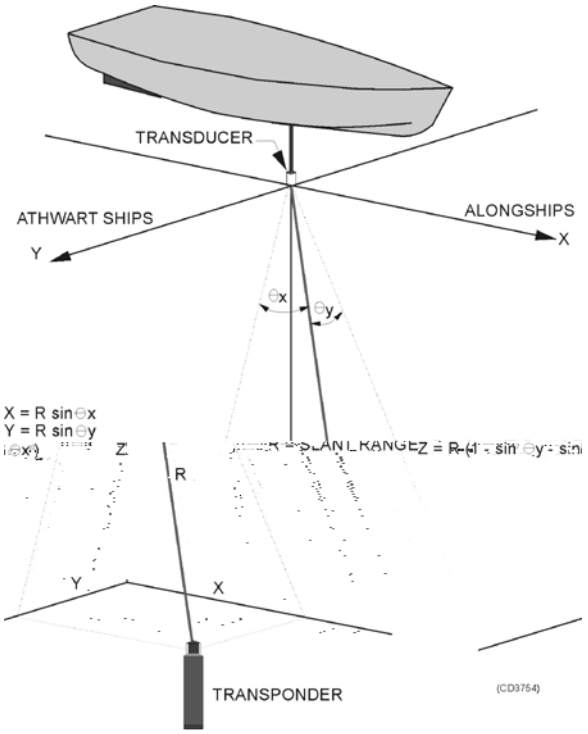
Hydroacoustic Position Reference System

The principle of position measurement involves communication at hydroacoustic frequencies between a hull-mounted transducer and one or more seabed located transponders.
The system is based upon the SuperShort BaseLine (SSBL) principle with all acoustic transmit/receive elements mounted in a single transducer unit. Alternatively, Long BaseLine (LBL) acoustics may be used.
In the SSBL system, an interrogating pulse is transmitted from the transducer. This pulse is received by the transponder on the seabed, which is triggered to reply. The transmitted reply is received at the transducer. The transmit/receive time delay is proportional to slant range. The hull mounted transducer is able, by means of its SuperShort BaseLine configuration, to determine the angles of the incoming reply with respect to the vertical, both longitudinal and athwartships. These angles and range define the position of the ship relative to that of the transponder. A number of corrections are automatically made. The angles must be compensated for values of roll and pitch (from the VRS). The determined position will be the position of the transducer, and offsets will be allowed for to give the position of the Centre of Rotation (CR) of the vessel. If the Centre of Rotation is changed, or if a different transducer is used, then the offsets within the DP system automatically change to provide correct coordinates.



The basic elements of an HPR systems are shown above. Frequencies used are in the 20-40 KHz range. The Kongsberg HPR 400 system uses a discrete range of channels of transponder communication; each channel has two designated interrogation frequencies, and one reply frequency. Position reference may take place from a single transponder laid on the seabed. Greater reliability and accuracy can be obtained from using more transponders. Any number of transponders can be used provided they operate upon different channels, the limitation being the number of channels the HPR system installed is capable of working with (normally 5).

SSBL HPR Principles



Transducers are fitted to the bottom of the vessel in the form of a probe, able to extend approximately four meters below the shell plating. Accordingly they are provided with means to extend and retract (electric motor driven Hull Unit) with controls both local and remote (at the HPR display unit). A ship's bottom sea chest or gate valve is provided to ensure the watertight integrity of the vessel when the probe is withdrawn

that the operator can monitor its position, but its input will be ignored by the DP as regards position measurement.

Transponders

The Kongsberg MPT transponder may be configured for SSBL or LBL positioning, array calibration, and with telemetry commands. These commands include sensor readings for depth, temperature, inclination and heading, plus acoustic release. It is also possible to switch transponder channel by telemetry command from the surface. The SPT transponder is used in SSBL positioning, while the RPT transponder is used for ROV or Tow Fish positioning.

A standard transponder may be secured by bracket to subsea structure, or it may be moored to the sea bed. The recommended method of mooring is to fit the transponder with a divinycell float, and attach it to a 150kg sinker by means of 1-2 meters of mooring chain. The unit is then deployed onto the sea bed by means of a light wire line, either from the deck of the ship or from a small boat, with the wire buoyed off, or simply left slack. Another method of deploying a transponder is to secure it into a purpose built tripod which is then lowered to the sea bed on a wire rope. Once located, sufficient slack is paid out to accommodate subsequent vessel movement. Deployment and recovery is by a winch and davit arrangement.

Other transponder functions are available for use in special circumstances. An Acoustic Release Transponder may be laid upon the sea bed without a down-line. Operating normally the transponder provides position reference. After use the transponder can be recovered by acoustic command, releasing it from the sea bed. The transponder floats to the surface and can be recovered by boat or from the ship.

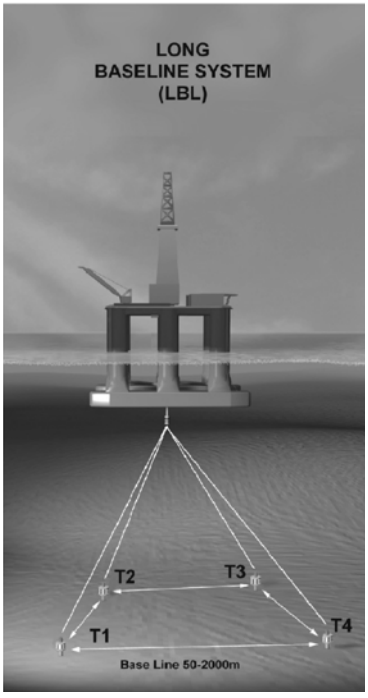
An inclinometer transponder facility provides information not only for position reference but also regarding angular attitude. A unit of this type may be used in subsea installation, or in drilling. In the latter case the transponder would be secured to the lower flex joint of the marine riser. In a DP drillship information upon flex joint angle is used to position the vessel, the object being to maintain the riser vertical at the sea bed in the face of constantly varying tides.

A standard transponder may be approximately 1 meter in height by 120mm in diameter. For small vehicles, such as RCVS (Remotely-controlled submersible camera vehicles) miniature transponders are available, of much smaller dimensions. Transponders such as these can also be carried by a diver.

For ROV positioning, more reliable communication may be obtained by using a responder instead of a transponder. A responder is used where a hard-line umbilical is available. Vehicles of this type are usually very noisy, providing poor acoustic conditions for HPR. Using a responder eliminates one through-water journey for the acoustics. A spare umbilical channel is used to trigger the responder.

Long BaseLine Systems

Another system, the Long BaseLine system, uses an array of three or more transponders laid on the sea bed in the vicinity of the worksite. One transducer upon the vessel interrogates the transponder array, but instead of measuring range and angular information, ranges only are measured. Position reference is obtained from range geometry from the transponder locations. This principal provides greater accuracy than the SuperShort BaseLine (SSBL) system since the baseline length is not limited by ship dimensions, but it is reliant upon two-way acoustic communication. This system is dependent upon the vessel calibrating the positions of the individual transponders forming the sea bed array, before use.



The Kongsberg HPR 418 is able to operate both SSBL mode, with one or more transponders, or in LBL mode using three or more transponders for greater accuracy. With the LBL system, it is necessary for the array of transponders to be laid and then

calibrated. This calibration is done by allowing each transponder in turn to interrogate all the others in the array, in turn. If, at the same time, the vessel has a DGPS or other geographically referenced positioning system, then the transponder array may also be geographically calibrated. LBL systems are more suitable for deep water operation, where SSBL systems would suffer from long information update rates. Accuracy is also superior to the SSBL method. LBL systems have a typical accuracy of 0.2%-0.4% of water depth.

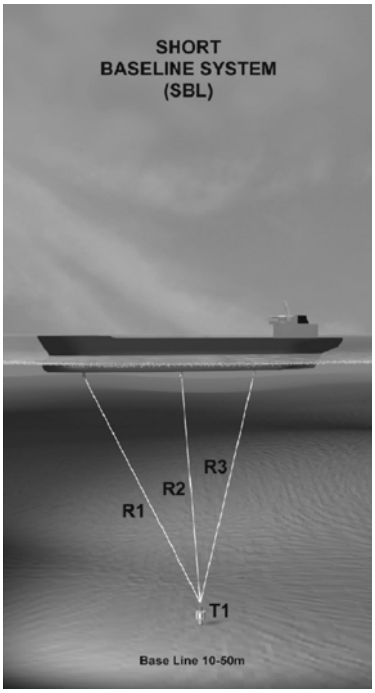
Short BaseLine Acoustics

HPR is a versatile and widely used position reference for DP and other purposes. It does, however, suffer from some limitations.

Typical factors affecting HPR are:

- Noise
- Transmission losses
- Reflection of signals
- Ray bending caused by variations in sound velocity

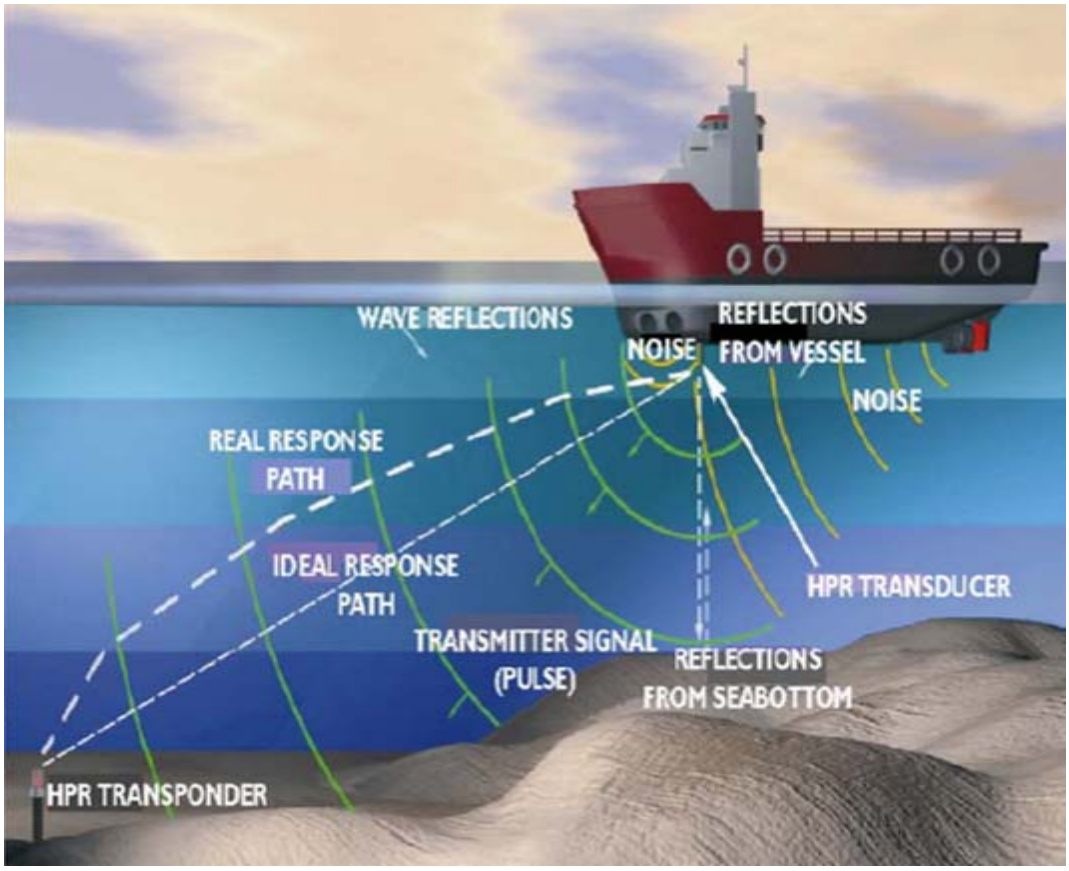
Operationally, noise and aeration are the main problems. Acousticc (noise) interference may originate from the ship's machinery or thrusters, from other vessels or nearby installations, or from any subsea operation in progress (e.g. drilling or ROV work).



Aeration from any cause will result in a loss of signal. Common causes of aeration are thrusters (vessel or ROOV), mud or stone dumping, divers' breathing gases or rough seas.

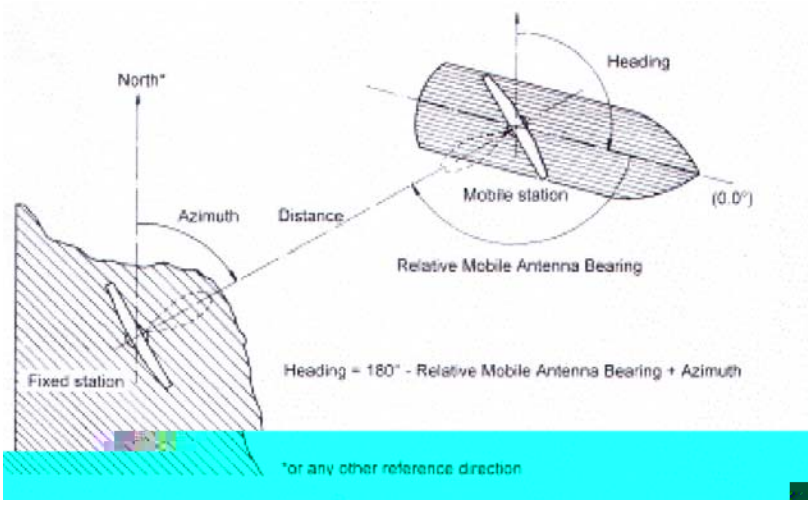
Careful positioning of transponders by the operators can obviate many of these anticipated problems. Other problems result from acoustic refraction, particularly at long horizontal ranges from the transponders, caused by temperature or density layers in the water. Further problems arise in shallow water, where vessel and thruster noise may be a major problem, and also where vertical separation between transducer and transponder is limited.

System accuracy is dependent upon a number of factors, some of which cannot be allowed for, such as water temperature. In general, accuracy can be taken to be between 1% and 3% of slant range for SSBL systems, and 0.2% to 0.4% of water depth for LBL systems. Horizontal range should not exceed water depth for best accuracy; at larger horizontal ranges than this there is an increased risk of loss of signal due to refraction.



The Artemis Microwave Position Reference System

In this system, position reference is obtained by means of communication at 9 GHz (X-band, 3cm wavelength) radio waves, or microwaves. The system described is the Dutch ARTEMIS system and involves two stations; one located on board the DP vessel itself and the other at some fixed location ashore, or upon a platform or FPSO installation.
The position reference is in the form of range and bearing. The station on board ship is referred to as the Mobile station, while that ashore is the Fixed station. Position data is thus obtained as the range and bearing of the Mobile station with reference to the Fixed station. Each station consists of an Operating Unit and an Antenna Unit.



The principle is simple. The two antennae automatically train so as to face each other at all times when a c.w. microwave link is established. The Mobile station transmits a signal, which is received b y the Fixed station and retransmitted as a reply. The time lapse between Mobile station transmission and reply reception is proportional to range between antennae. The azimuth or bearing is measured at the Fixed station and is transmitted, encoded, as part of the reply. The signal used is a very brief interruption or occultation in a continuous wave transmission; this interruption being detected at the Fixed station and a similar reply interruption initiated. For accuracy, successive displayed ranges are obtained by averaging a great number of observed time lapses (one thousand or ten thousand, depending upon function selected).

The Fixed station may be a temporary installation, placed upon a platform for one particular job of limited duration. In this case it is necessary for the equipment to be installed, taking care that the antenna will cover the sea area of the DP vessel's worksite, also that the antenna can rotate without fouling platform structure. It is also necessary to ensure that the antenna position will not interfere with other platform functions. A power supply must be obtained, preferably with a redundant battery back-up supply, and platform staff will need to be instructed in the operation of the system. If the vessel is to work all round the platform then two or maybe more Fixed stations will need to be installed to cover the 360 degrees. The elevations of the Fixed station antennae must be compatible with that of the Mobile station, since, with only a 22 degrees vertical beam width it is possible, at close ranges, for the signals to be lost if Fixed and Mobile antennae are at different heights.

Artemis Operation

Pair number	Mobile Station	Fixed Unit*
0	9200 MHz	9230 MHz
1	9300 MHz	9270 MHz
2	9230 MHz	9200 MHz
3	9270 MHz	9300 MHz

The Artemis has 4 frq. Pair for multi-user operation.

The Mobile and Fixed stations are operated via the keyboard and display of the operating panels. Once a link has been established between the two stations, the complete system can be controlled from one station, generally the Mobile station.

Operator interaction between the keyboard and the display of the operating panels is via a menu structure. This is basically the same for both the Mobile and Fixed station.

	<MAIN MENU>	MOB	
1	OPERATE	WAKE UP	4
2	MODIFY	FIX	5
3	MONITOR	WAKE UP	6

Main menu Mobile station

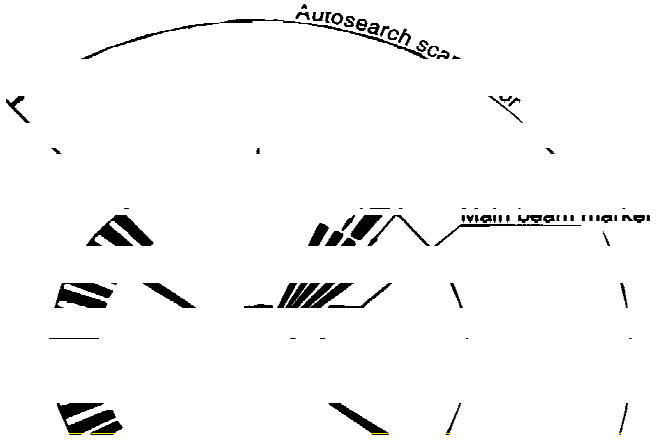
	<MAIN MENU>	FIX	
1	OPERATE	WAKE UP	4
2	MODIFY	MOBILE	5
3	MONITOR	CONFIG	6

Main menu Fixed station

From the main menu a selection can be made from the six categories by keying in the number adjacent to the category.

OPERATE	is selected to display the position parameters distance and azimuth.
MODIFY	is selected to read and/or change station parameters, location parameters, auto search scan angles, clock, operating mode, communication parameters and voice channel volume.
MONITOR	is selected to monitor supply voltages, mixer crystal currents, Automatic Gain Control, tuning and servo signal readings, temperature of wave guide and distance measuring circuit.
WAKE UP	is selected to define the time and date the station is to switch itself on, this function is normally not used.
FIX	(if Mobile station) is selected at the Mobile station to remotely access the Fix menu structure to read and/or modify Fixed station parameters.
MOBILE	(if Fixed station) is selected at the Fixed station to remotely access the Mobile menu structure to read and/or modify Mobile station parameters.
CONFIG	is selected to configure an ABU before it is put into operation for the first time.

Antenna Indicator Display

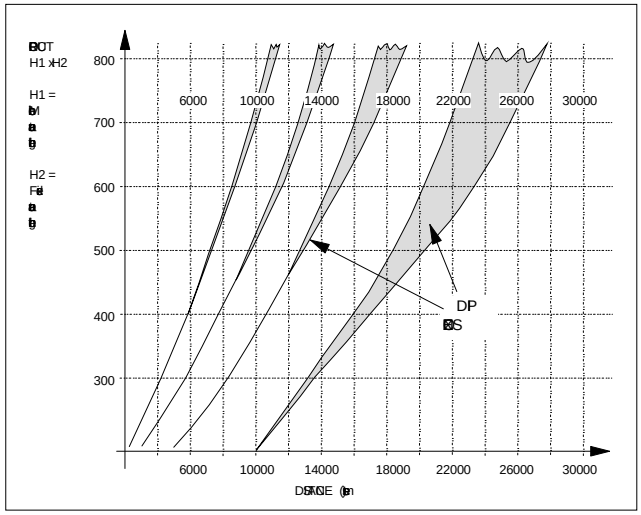


The antenna indicator display shows:

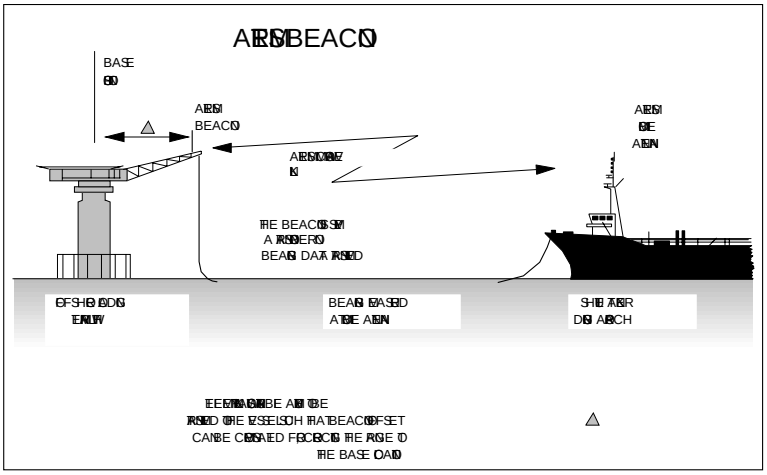
a) The ANTENNA DIRECTION marker, which indicates the direction of the antenna with respect to the chosen reference direction. When the EOP is connected to the Mobile station, the marker indicates the relative antenna bearing. When connected to the Fixed station, the marker indicates the azimuth.
b) The MAIN BEAM marker, if signal containing the correct address code is received and the antenna is locked to the counter station.
c) The AUTO SEARCH SCAN SECTOR marker, if the auto search operating mode is selected and an auto search scan sector is set. The unshaded area indicates the actual scan sector.

Artemis Operational

From the viewpoint of the DP operator, the major advantage of Artemis compared with many other PRS is its range. When approaching the worksite the Artemis link can be established when a mile or more away, and provided line-of-sight is maintained then position reference is available immediately DP is engaged. However, there are drawbacks. Interference can be experienced from radar transmissions from other vessels (or from ones own!) at 3cm frequency. Also, loss of signal will occur due to any line-of-sight break, such as a vessel passing through the beam, or personnel on the platform working in the vicinity of the Fixed antenna. Precipitation may also cause loss of signal. An operational disadvantage is the lack of control over the Fixed station. Being sited upon a remote platform it is not of immediate access to ship's staff and is subject to interference from unauthorized platform staff. Occasionally, for example, the batteries are "borrowed" for another purpose and not replaced.



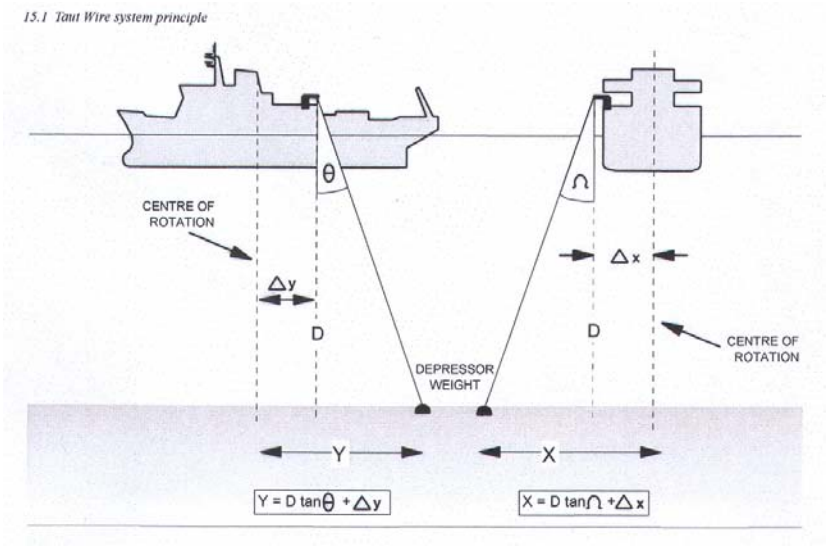
At certain ranges, mutual interference will cause loss of signal. These are known as “Dip zones”. A table of dip zones is provided, entered with elevations of Fixed and Mobile antennae, and yielding dip zone ranges.



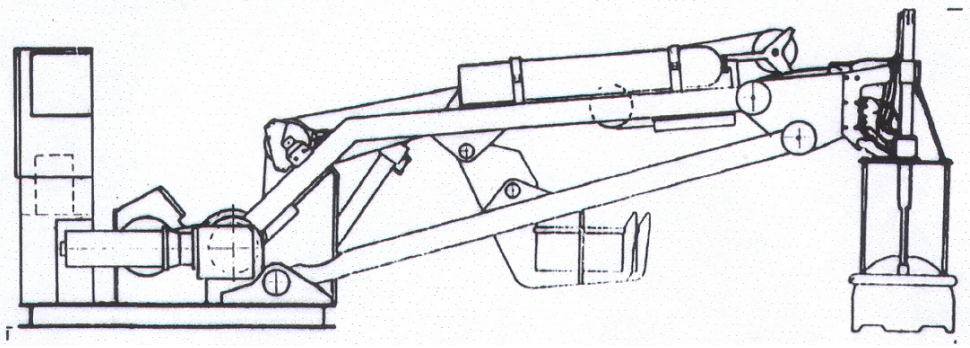
Under some circumstances it may not be possible to establish an Artemis Fixed station. This may be where the fixed station location is not positively “fixed” in position. An example of this situation is an offshore spar buoy used for shuttle tanker loading. Increasingly such tankers are fitted with DP for positioning during the loading operation, and Artemis is used for position reference. The spar buoy, however, is mobile to a certain extent and may be able to rotate. In this case the Fixed station is replaced by an Artemis Beacon. The beacon is a transponder with a broad beam antenna. The antenna itself is fixed. The system is used in exactly the same manner as the standard Artemis, a microwave link may be established without personnel assistance on the installation. This is essential since many Offshore Loading Terminals using Artemis beacons are unmanned. Range data is obtained in the same way as with a Fixed station with identical accuracy. Bearing is obtained at the Mobile station end, using the Mobile antenna direction and gyro heading reference. Bearing accuracy is thus reduced, being only as good as the gyro compass – perhaps 0.25 to 0.5 degrees. For this reason it is suitable for shorter range operations.

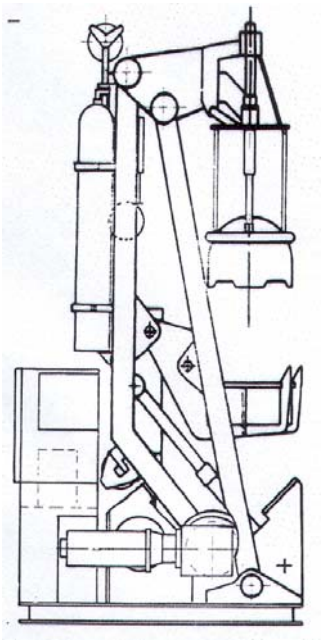
The Taut Wire Position Reference System

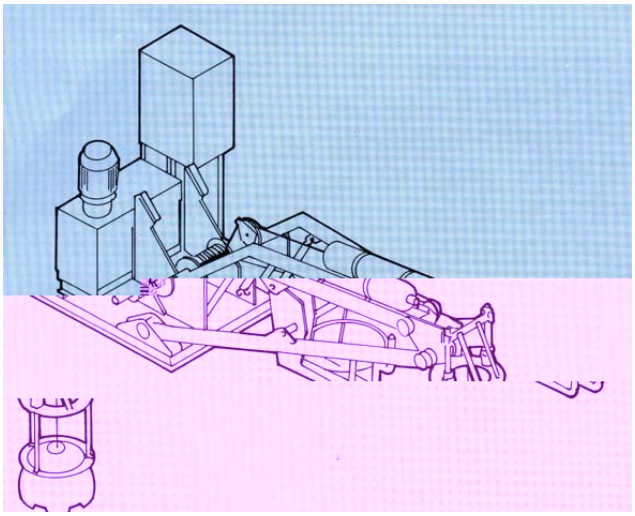
Taut Wire differs from other position reference systems by being chiefly mechanical in principle, not reliant upon radio or acoustic transmissions.



A Taut Wire system consists of a constant tension winch unit fitted on deck, with a boom or 'A'-frame projecting over the side of the vessel. Wire from the winch drum passes over a sheave at the end of the boom, through a sensor head, and terminating in a depressor weight on the seabed. Position reference is obtained from measurements of wire angle and water depth, the position of the vessel being defined relative to the location of the stationary depressor weight.







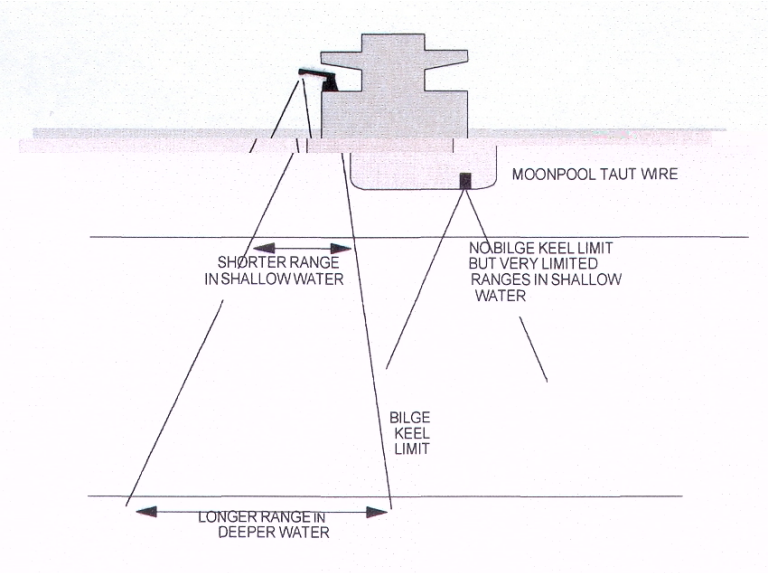
Bandak Mk VIII

A typical Taut Wire system is the Bandak Light Weight Taut Wire Mark VIII. In this system the depressor weight has a mass of 350 kg, while 500m of 5mm wire is provided. Maximum wire angle is 30 degrees to the vertical in any direction, and the maximum water depth for use is 350m. The motor and drive unit is mounted on deck at the side of the ship, with the system control panel adjacent.

The deployment method uses an ‘A’ frame, which stows in the vertical position. To deploy, the ‘A’ frame is lowered to the horizontal, projecting overside.
The weight is then lowered to the seabed. Once at the seabed the system automatically puts the winch into tension or "mooring" mode. At this moment the wire length deployed is read by the system. Subsequent movements of the vessel are accommodated by the spooling of the winch, while wire angles to the vertical, both in the longitudinal (fore-andaft) and in the athwartships plane are continuously monitored by the sensor units at the end of the boom.
Taut wire signals are fed back to the DP through a suitable interface and can be accepted by the operator at the DP console. The system continually corrects input data for values of roll and pitch such that wire angles are relative to the true vertical instead of the local ship vertical. Corrections are also applied to allow for the offset distance of the position of the sensor head relative to the Centre of Rotation of the vessel.

Frequently, the Taut Wire system is fitted with remote controls such that the DP operator may deploy the boom and weight from the bridge. Often, however, this facility is not used unless the operator can actually see the system he is deploying; it is not a particularly safe practice to remotely operate the Taut Wire without being able to see what is happening.

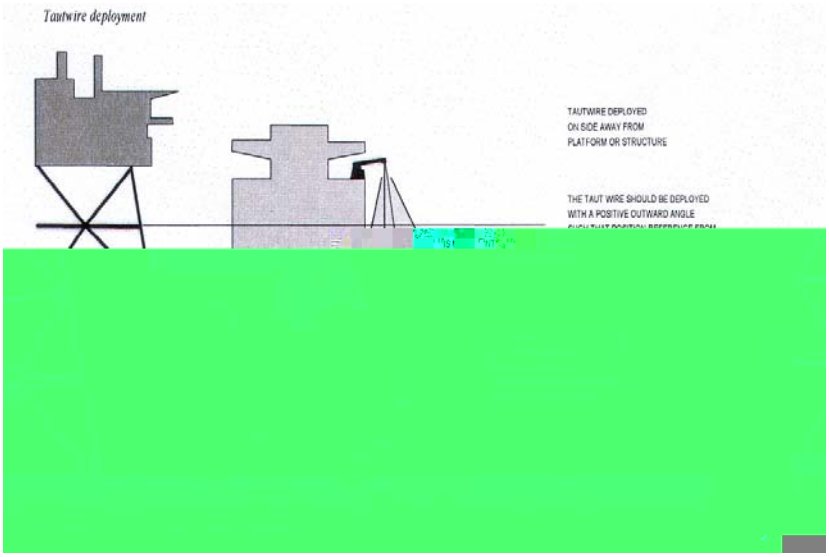
A Taut Wire system is particularly robust and reliable, together with being accurate. Maintenance is necessary but this is under the control of the vessel operators - there is no remote and inaccessible equipment involved. Spare wires and depressor weights can be carried and the system may be regularly oiled and serviced to schedule. A worn, stranded or frayed wire can be replaced. In constant use the wire may wear at the same spot all the time. To overcome this problem the wire can be unshipped from the weight and cropped back approximately ten metres every couple of weeks or so. This brings a new portion of wire onto the sheaves when working and also freshens the connection to the depressor weight - another point of possible failure. It is important to log the remaining wire length at each "crop".



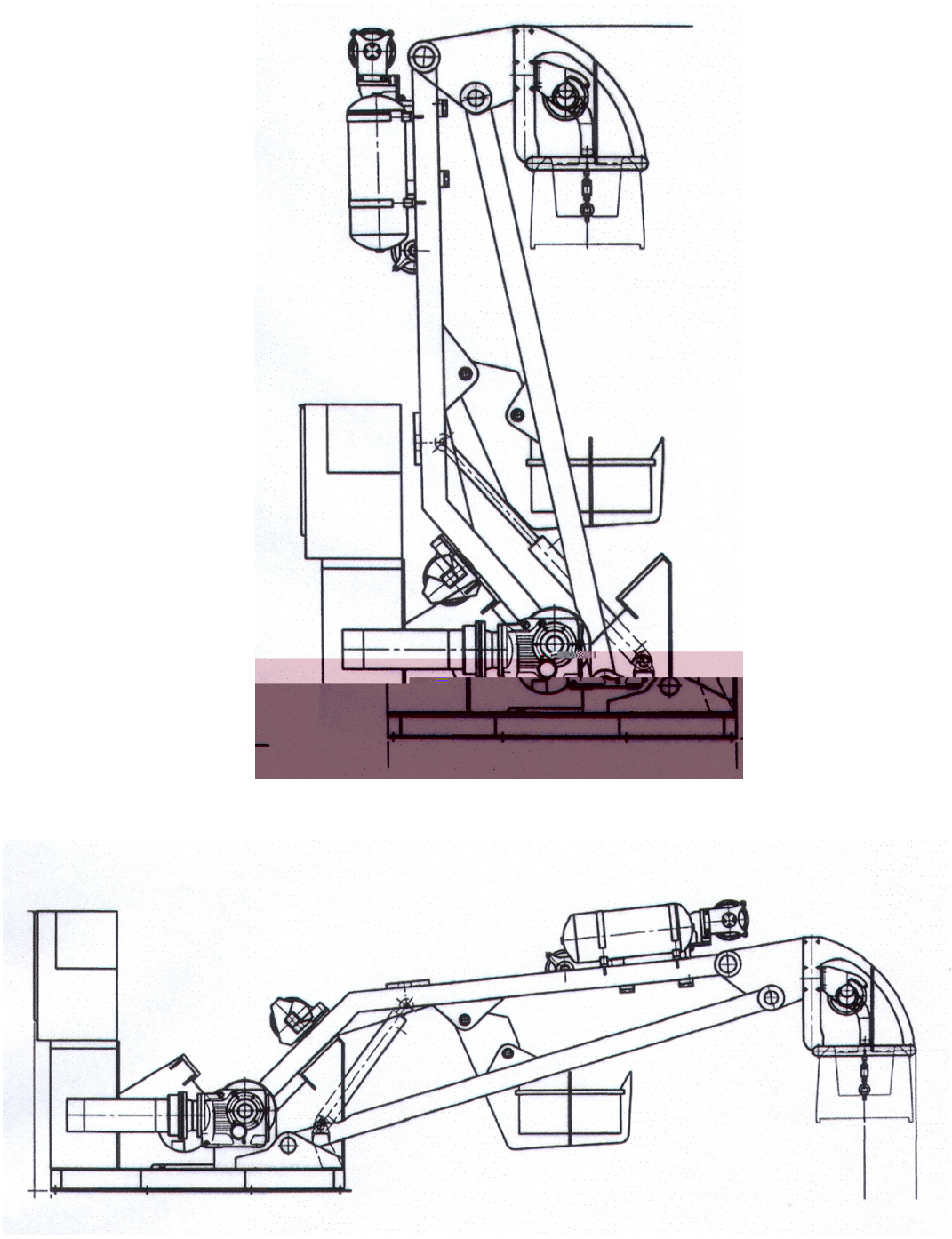
One drawback of the system is its limited operating range, due to the 30-degree wire angle limit. This limit is imposed due to the increasing risk of dragging the weight at larger angles. A dragging weight could, of course, lead to immediate position errors from the system. The operating range is thus dependent upon water depth; the deeper the water the greater the range of cover. Another limit is imposed by the bilge keel of the vessel impinging upon the wire before the 30-degree angle is reached.

Often a vessel is fitted with two Taut Wire systems, one on each side, allowing the operator to select the most advantageous system for the circumstances. If the vessel is working close alongside a platform, with divers or ROV deployed into the platform, then the Taut Wire on the side away from the platform will be used. This keeps the wire away from the operation and also allows the vessel to deploy the Taut Wire before making her final move onto the worksite without the wire coming onto the bilge keel.

In some vessels the Taut Wire system is fitted at the forward extremity - right on the bow of the vessel. One problem associated with this location is the large accelerations experienced in moderate to rough seas due to vessel pitching. Occasionally system dropout will result from the winch spooling rate being unable to cope with the pitching.



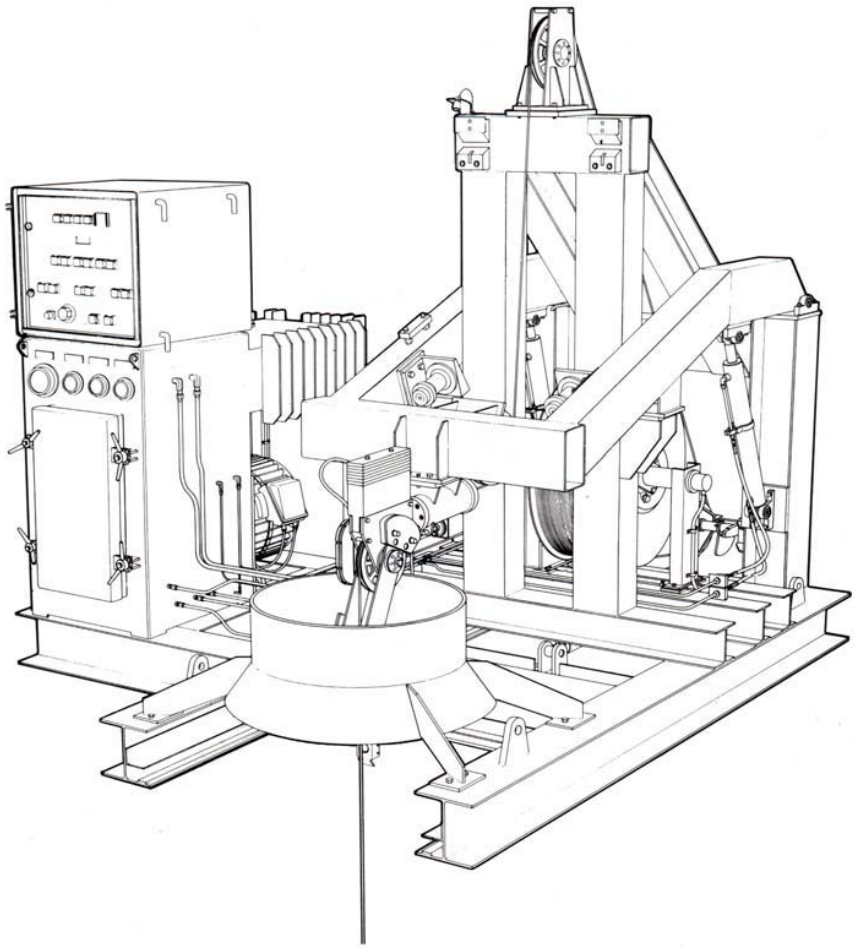
When using Taut Wire as a position reference, it is necessary to plan with care the position for deployment of the depressor weight. The seabed can be a cluttered place and often a field operator will stipulate that there must be nothing placed on the seabed within a certain distance (perhaps ten or twenty metres) of pipelines, control lines or other seabed installations. In addition to this constraint the operator would aim to place the weight in a position so that the final working position of the vessel does not result in the wire angle almost at its 30-degree limit. This would prevent the vessel moving in one direction. In practice, a working limit of 20 degrees is recommended.



Mk 12 model from Bandak.

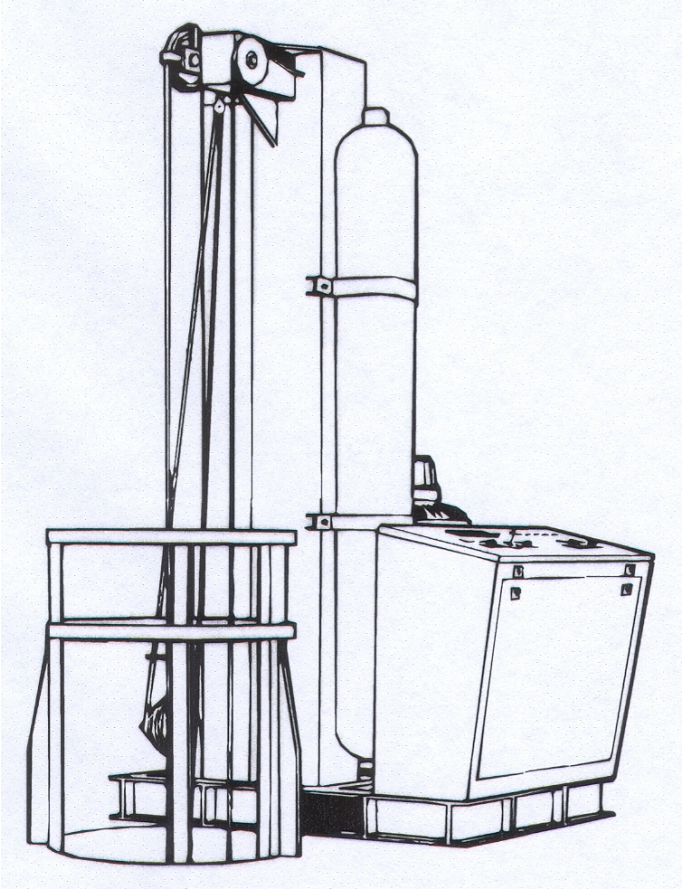
This model does not have the hydraulic weight catcher but uses a depressor weight with a special shape.

Taut Wire System, rig version



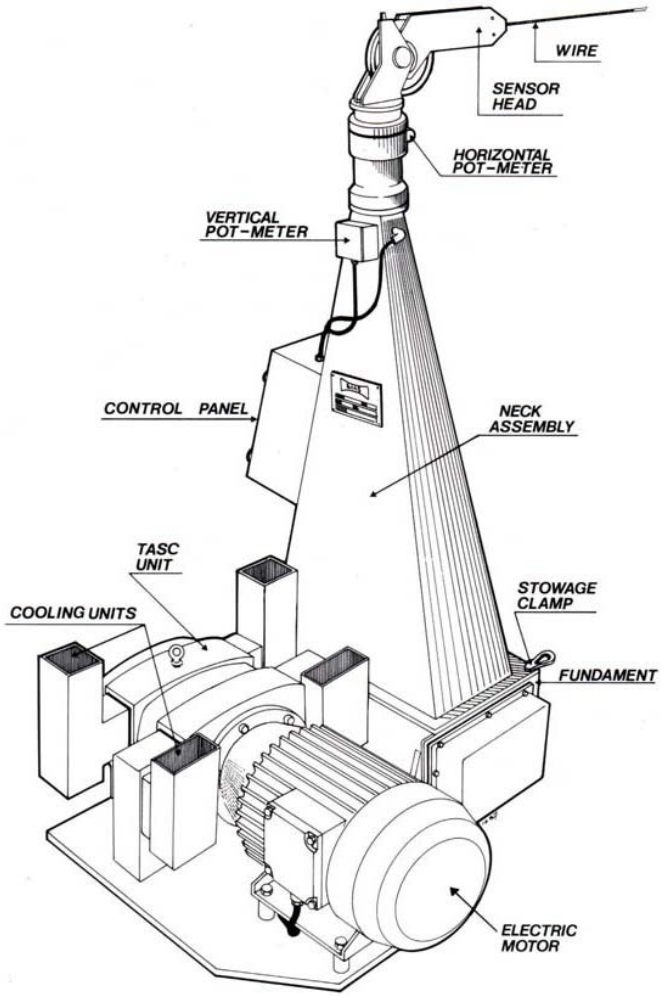
For some types of vessel a platform type of Taut Wire can be used. This may be fitted in a bridge or cellar deck of a semi-submersible vessel where access to the sea is available directly beneath the Taut Wire location platform. While similar to the type already described, this unit dispenses with the extending telescopic boom. Instead the weight simply lowers directly away from its housing structure. Often, this type of Taut Wire is housed in a deckhouse structure, so it is protected from the elements when in use and at other times.

Moonpool Taut Wire

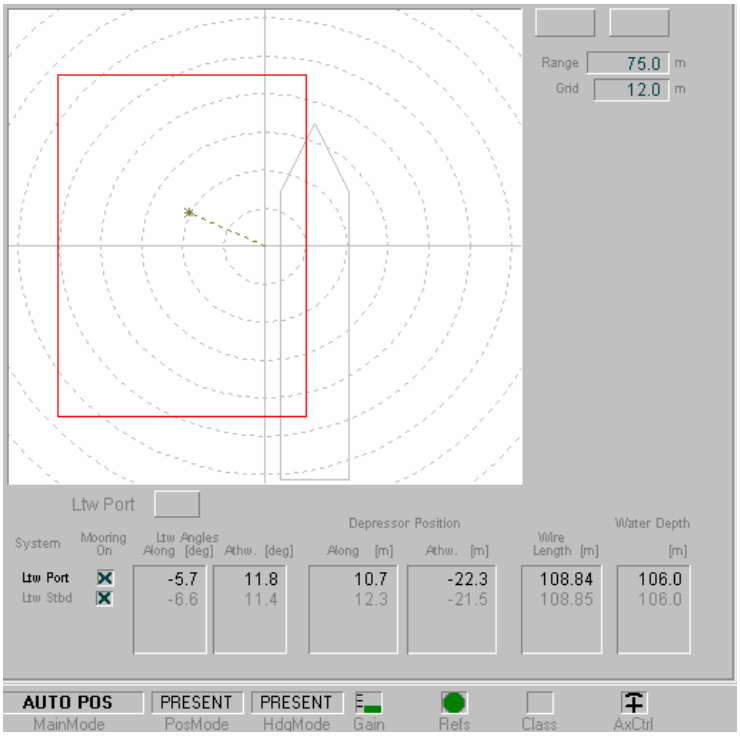


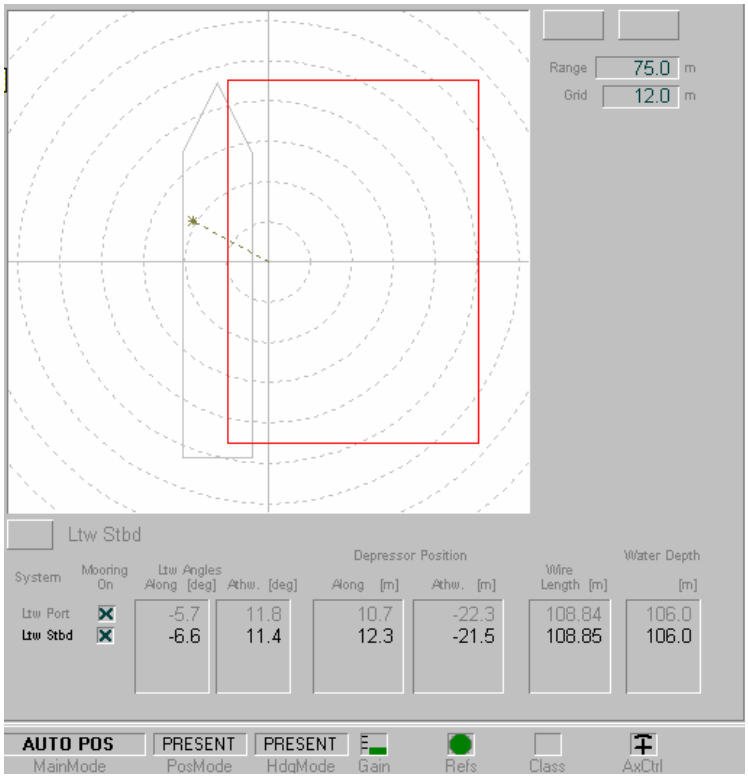
For some vessels a Moonpool Taut Wire is suited. This unit is mounted inboard with a depressor weight deployed through the bottom of the vessel through a small moonpool or wet well. The sensor head is incorporated into an elevator unit that is lowered from the tweendeck stowage level down to the keel level. The depressor weight and wire are then lowered onwards from there. Hydraulic accumulator provides movement compensation and positional data is obtained and processed in exactly the same way as in the types previously described. The function of a Moonpool Taut Wire is to enable a DP vessel to operate in surface ice conditions. It also has the advantage of obviating the bilge keel angular limit. A disadvantage arises, with this type of installation, in shallow water, since the sensor head is that much closer to the seabed than with a deck mounted unit. This further reduces the horizontal scope of the system, already limited in shallow water.

Surface Taut Wire system



Another style of taut wire is the Horizontal or Surface Taut Wire system. This unit gives position reference relative to a fixed structure. The wire is passed across to the platform adjacent and secured. The geometry is different to the Vertical Taut Wire but principles are the same. No boom is needed, instead the sensor is located atop a short vertical tower. Range is limited to about 100 m wire length but the wire is wholly "in view" unlike the Vertical Taut Wire system.





Taut wire display page Kongsberg SDP XX

Fanbeam system

Fanbeam is an auto tracking laser system for one or a number of targets. Used with DP, only one target is tracked at a time.

Scanner unit

Control unit

The system is made up of 4 parts:
- Scanning head
- Control unit
- Display
- Power supply

Display unit

Power unit

The scanning head is placed on the top of the mast to achieve full 360° viewing. The laser has two lenses, one for transmitting and one for receiving, the right-hand lens when facing forward being the transmitter. The lenses must be kept clean. When the laser is parked, the lenses will face astern.

The laser can be tilted vertically so that the centre axis will point towards the target. A telescope is mounted on top of the laser for this use. The laser is classified as a Class 1 laser, the same as the laser used in a CD player.

Targets

The targets must be equipped with reflectors, preferably retro prisms that return incoming light inside ±30° of the centre of the prism. Reflective tape, “Diamond Grade White Reflective Tape” is recommended, can be used at short range only because the quality of the return signals is poor. The longer the distance, the more prisms must be used, stacked on top of each other.

- For distances up to 1 km three prisms should be used.
- For distances over 1 km six prisms should be used.
- To make a target visible from all angles the prisms should be formed as a circle consisting of 8 prisms and the circles stacked on top of each other.

Range Measurements

The laser measures range with great accuracy.

Theoretical maximum range = 30.000 m
Theoretical minimum range = 3,75 m
The laser beam:

20° vertical fan shape (± 10°) from the centre axis of the lens.
The fan shape is made by the lens.
Due to loss, this fan will be reduced to approx. 6° (± 3°) at 2 km. 2 cm horizontal beam. Laser is parallel light beams.

Bearing Measurements

The scanner contains a motor which rotates the laser in the horizontal axis and an encoder which measures the bearing. To find the bearing the system has to find the target centre. This is achieved through the laser scanning the target in a specified sector. Based on the reflected light the target's horizontal centre of gravity is calculated. The system will automatically adjust the centre of the sector to the target's centre of gravity. The sector has to be large enough for the system to be able to follow the target if the vessel suddenly changes heading, and the effects of pitch and roll.

The laser's horizontal bearings are measured with an optic encoder with a resolution of 0,01°. This makes the accuracy better than 0,02°. At a distance of 1 km the inaccuracy will be 35 cm.

The system gives bearing and range to target relative to the vessel. To find the vessel's position the DP system must know the vessel's heading. The accuracy of the measurements of an ordinary gyro is approx. 0,5°. At a distance of 1 km the inaccuracy will be 8,8 m, and thus making the gyro the limiting factor for the system.

In addition, the scanning head's position in relation to the vessel's centre of gravity must be corrected for pitch and roll by VRS signals.

Operation

The operation is simple:

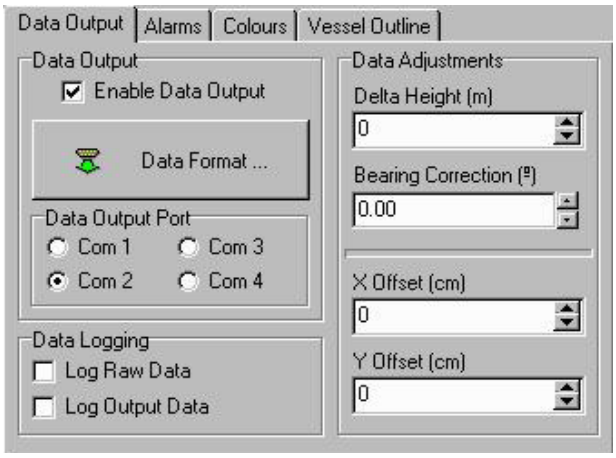
1. Search for targets
2. Select a target
3. Park the laser after use

Use the arrows to go between the different commands, and select command by pressing the ENT button. On older versions with a plasma display, the command line refers to buttons just underneath the display, or function keys (F keys) on a keyboard when using a PC.

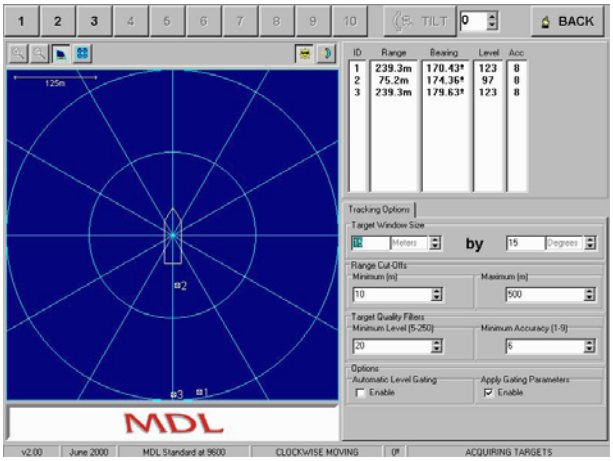
Main Menu

The main menu consists of 4 commands:

If you suspect that you have changed something that should not have been changed, switch the system off and on, the values will then be reset.

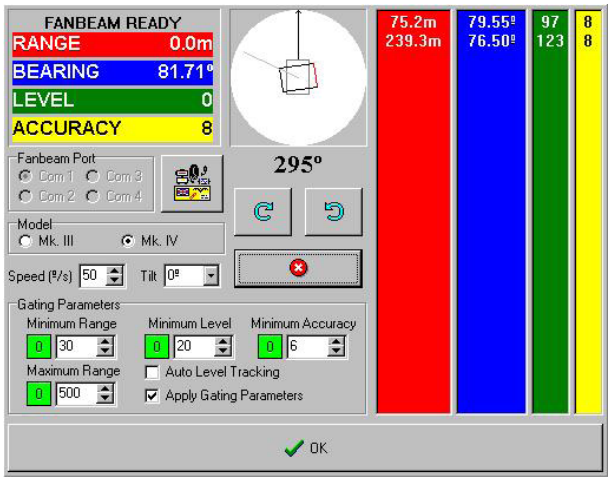


- 1. Setup - used for initial setup as data output, Alarms Colours and Vessel Outline



• 2. Track - used when searching and selecting target

• 3. Park - used when the laser returns to parked position



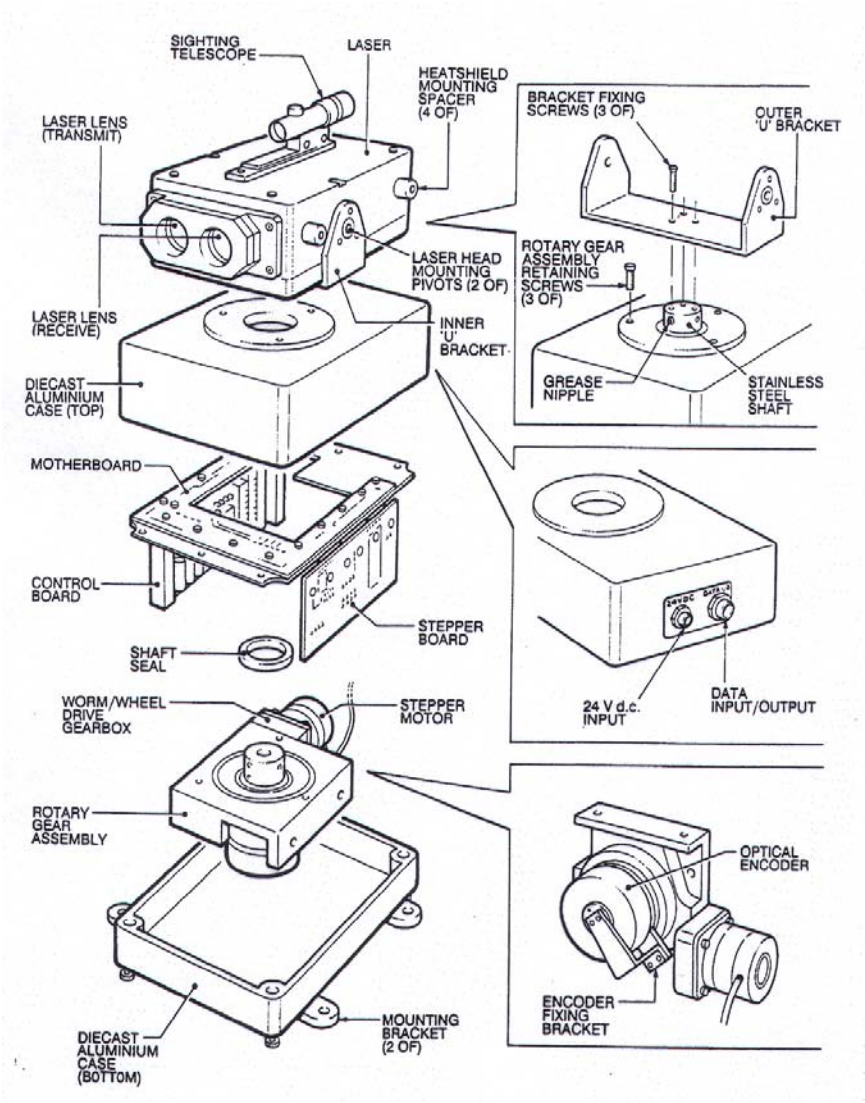
• 4. – The COMMAND menu used for different command functions

Fanbeam Maintenance

Control and wash scanning head regularly. Wash with a mild detergent. Clean lenses using a proprietary lens cloth. The connectors to be greased with silicon grease.

Every 6 month the shaft seal has to be lubricated. Apply a grease gun to the nipple under the laser until grease is just seen appearing from the upper lip. Use lithium based multipurpose grease.

If greasing is neglected, the shaft seal has to be replaced. The result might also be ingress of water with resulting problems.



CyScan system

CyScan is a high performance, laser based, location tracking system specifically engineered to aid the automatic positioning of vessels in marine applications. It can serve as the primary or back-up location device and is applicable to virtually any type of vessel.

CyScan comprises a scanning sensor system and associated PC based data processing software. The system is usually permanently installed on a vessel as an integrated part of its navigation or dynamic positioning system.

The scanner takes range and bearing measurements to pre-positioned passive retro-reflective targets with high precision. The target(s) are typically located in the vicinity of a required docking station or on another vessel. The measurements are used to determine the vessel's position and heading in relation to the target location. Readings can automatically feed into the vessel's navigation control system via an industry standard data interface.

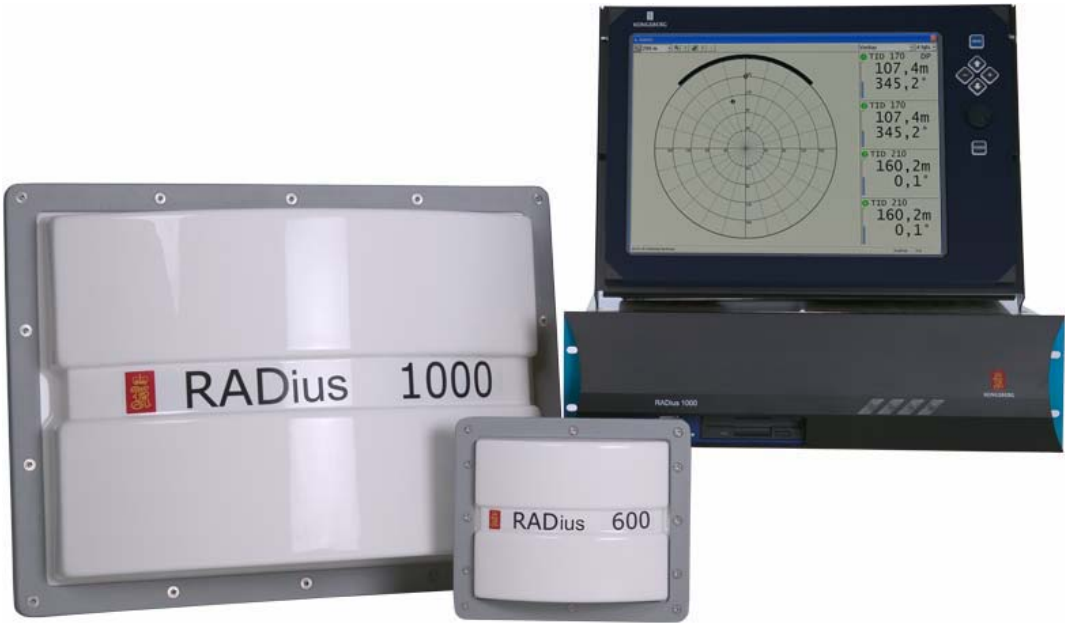
Typical applications include dynamic positioning, docking control, shuttle mooring, tanker berthing, diver / ROV support and hydrographic surveying.

RadaScan system

RadaScan is an advanced position reference system for use in DP and other vessel control applications. It has been specifically designed for the offshore sector with a usable range out to 1000m under all weather conditions.
Its typical measurement accuracy is 0.05%.

The system comprises an FMCW radar operating in the 9.25 GHz maritime radiolocation band. This picks up reflections from pre-mounted retro-reflective targets. These are non-powered and introduce a unique code into the reflected signal allowing reliable identification of the targets by digital signal processing. A network interface provides a convenient connection to any DP system.

RADius system



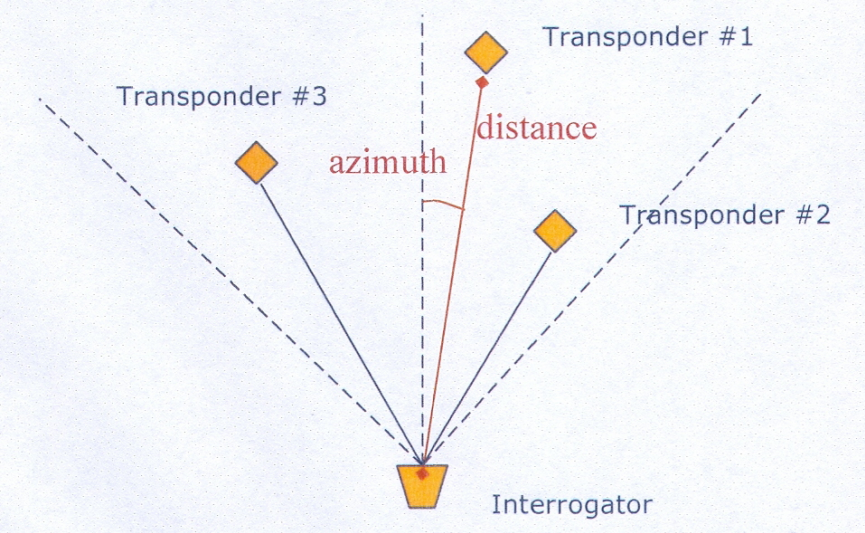
RADius is a relative positioning system developed for operation in harsh and demanding environment utilizing radar technology.

New technology

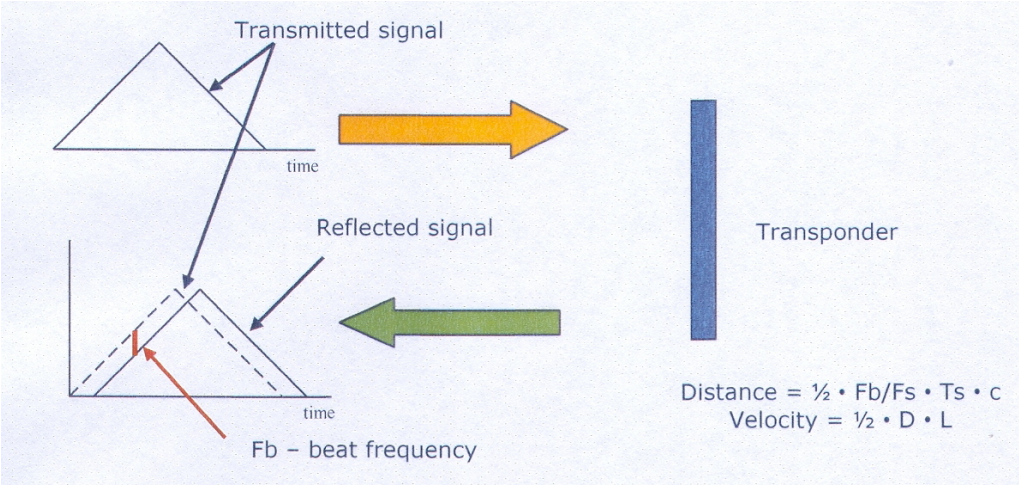
RADius represents a new way of utilizing radar technology in short range and direction monitoring. The system is primarily designed for use in harsh and demanding offshore environments where GPS may be inaccurate, and the need for an accurate, independent and available system is crucial. A typical application for RADius is to control or assist the dynamic positioning of a vessel next to a platform or in alongside operations.

Applications

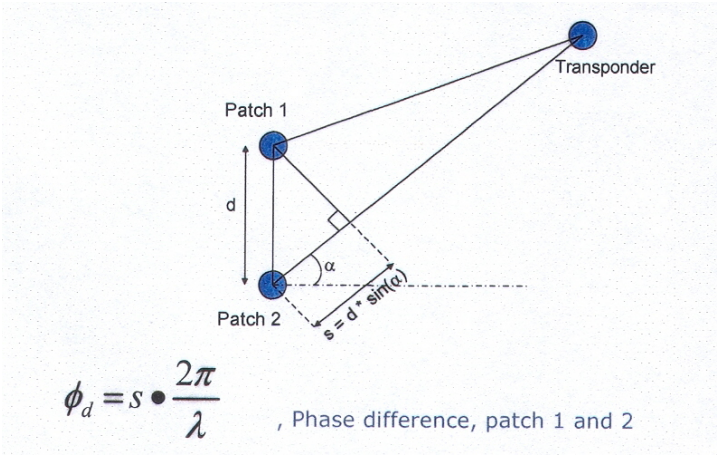
As a stand-alone system, or interfaced with dynamic positioning or integrated bridge systems, RADius provides an extremely accurate and responsive aid to loading and unloading procedures for operations in all weather conditions. Docking and oil loading procedures are also applications that can take advantage of the RADius system.



The RADius system measures distance and angle to the transponders. It can operate on one transponder alone or up to five simultaneously.



RADius measures range based on FMCW (Frequency Modulated Continuous Wave) principle it sweeps the frequency transmitted and mix the transmitted signal with the received signal. The transmitted signal has changed frequency during the flight time of the received signaled and it is the difference between the transmitted frequency and the received frequency that is measured. This frequency difference is proportional to the distance to the transponder.



RADius determines angle to target by utilization of several receiver antennas. The principle is then based on measuring the phase of the carrier simultaneously on the different antenna elements shown in the picture. When the signal source is right in front of the antennas, the carrier will be equal on all the elements showing that the angle to the transponder is 0. When the transponder is off centre of the antennas, the radio beam will hit the antennas different. The difference is then used to determine the angle to the transponder.

Satellites positioning system

GNSS

GNSS (Global Navigation Satellite System) is a satellite system that is used to pinpoint the geographic location of a user's receiver anywhere in the world. Two GNSS systems are currently in operation: the United States' Global Positioning System (GPS) and the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS). A third, Europe's Galileo, is being developed for future use. Each of the GNSS systems employs a constellation of orbiting satellites working in conjunction with a network of ground stations.

GPS is the only present (2007) system fully operational, and thus the one explained in this section. A short description of the GLONASS and GALILEO is included.

All GNSS systems can be divided into three basic segments:
- Space segment (satellites)
- Control segment (control stations)
- User segment (Receivers)

This will be discussed in the following.

GPS

History

The GPS System was created and realized by the American Department of Defense (DOD) and was originally based on and run with 24 satellites (21 satellites being required and 3 satellites as replacement). Nowadays, about 30 active satellites orbit the earth in a distance of 20200 km. GPS satellites transmit signals which enable the exact location of a GPS receiver, if it is positioned on the surface of the earth, in the earth atmosphere or in a low orbit. GPS is being used in aviation, nautical navigation and for the orientation ashore. Further it is used in land surveying and other applications where the determination of the exact position is required. The GPS signal can be used without a fee by any person in possession of a GPS receiver. The only prerequisite is an unobstructed view of the satellites (or rather of the sky).
The correct name of the system is NAVSTAR (Navigation system for Timing and Ranging), but commonly it is referred to as GPS (Global Positioning System).

1973	Decision to develop a satellite navigation system based on the systems TRANSIT, TIMATION and 621B of the U.S. Air Force and the U.S. Navy.
1974-1979	System tests
1977	1977 First receiver tests are performed even before the first satellites are stationed in the orbit. Transmitters are installed on the earth's surface called Pseudolites (Pseudo satellites)
1978-1985	A total of 11 Block I satellites are launched in this period.
1980	Launching of the first Block I satellite carrying sensors to detect atomic explosions. This satellite is meant to control the abidance of the agreement of 1963 between the USA and the Soviet Union to refrain from any nuclear tests on the earth, submarine or in space.
1979	Decision to expand the GPS system. Thereupon the resources are considerably shortened and the program is restructured. At first only 18 satellites should be operated. 1988 the number of satellites is again raised to 24, as the functionality is not satisfying with only 18 satellites.
1980-1982	The financial situation of the project is critical, as the usefulness of the system is questioned again and again by the sponsors.
1983	When a civilian airplane of the Korean Airline (Flight 007) was shot down after it had gone lost over Sovjet territory, it was decided to allow the civilian use of the GPS system.
1986	The accident of the space shuttle "Challenger" means a drawback for the GPS program, as the space shuttles were supposed to transport Block II GPS satellites to their orbit. Finally the operators of the program revert to the Delta rockets intended for the transportation in the first place.
1989	The first Block II satellite was installed and activated.
1990-1991	Temporal deactivation of the selective availability (SA) during the Gulf war. In this period civil receivers should be used as not enough military receivers were available. On July 01, 1991 SA is activated again.
08.12.1993	The Initial Operational Capability (IOC) is announced. In the same year it is also definitely decided to authorize the world wide civilian use free of charge.
March 1994	The last Block II satellite completes the satellite constellation.
17.07.1995	Full Operational Capability (FOC) is announced.

01.05.2000	Final deactivation of the selective availability and therefore improvement of the accuracy for civilian users from about 100 m to 20 m.
20.03.2004	Launching of the 50th GPS satellite.
25.09.2005	Launch of the first IIR-M GPS-satellite. This new type supports the new military M-signal and the second civil signal L2C.

Space Segment

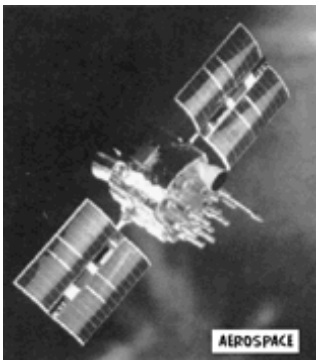
The space segment consists of at least 24 satellites.

Number of Satellites	24 + spares
Number of orbital planes	6
Satellites pr. Plane	4
Orbital inclination	55 deg.
Orbital Radius	20.180 km
Orbital Period	11 h 58m
Repeat ground track	23 h 56m

The first of the satellites was brought to its orbit as early as 1978. During the years the satellites became more and more sophisticated and meanwhile five different types of these satellites exist (Block I, Block II, Block IIA, Block IIR(M) and Block IIF).

Block I Satellites

From 1978 to 1985 11 Block I satellites were launched from California, each having a weight of 845 kg. None of those still operates today. The lifespan was supposed to be 4.5 years, but all of them exceeded this lifespan with about 5 years. The oldest of the satellites, in the beginning designed as prototype for the testing of the system, has been operating for 13 years.
All signals of the Block I satellites were accessible for civil users.



Block II Satellites

GPS-Block IIA Satellite

GPS-Block IIF Satellite

Block II satellites weigh more than 1500 kg and have a wingspan of approximately 5.1 m. The first of these satellites were launched in 1988 from Cape Canaveral. They are constructed for a service life of 7.5 years. In 1990 the first Block IIA satellite (A for "advanced") was launched. A total of 9 Block II and 18 Block IIA satellites were launched till September 1996. Although the satellites are still in six different orbits, each with the same angle to the equator, the newer Block IIA satellites have a slightly different constellation in space.

Block IIRs began replacing older Block II/IIAs in July 1997. There are currently thirteen Block IIR satellites on orbit, the last being a modernized IIR (IIR-M). The Block IIR satellites boast dramatic improvements over the previous blocks. They also have reprogrammable satellite processors enabling problem fixes and upgrades in flight.
In September 2005, the first satellite of a new generation (IIR-M, Replacement-Modernized) was successfully launched. The satellites of this type have the capacity to implement a second civil signal (L2C) and a new military signal with a new code (M-code on L1M and L2M). The satellite now weighs 2 tons and costs $ 75 million.

Initially, the satellites of the Block IIR generation should be brought to their orbit in groups of three by space shuttles. But after the challenger catastrophe in 1986 it was decided to take the satellites to the orbit in pairs with Delta rockets.

Paradoxically, the first two satellites launched with a Delta rocket were lost when the rocket had to be destroyed due to a malfunction shortly after the lift off. This was the first malfunction ever of a rocket of this type.

Block II satellites have a couple of further features which are not related to the GPS system. For example they are equipped with sensors capable of detecting atomic explosions.

The fourth generation (Block IIF) is planned to provide a third frequency for civil use (L5), allowing position determinations with even higher precision.

Timing

Timing is essential for the system to work. Therefore each satellite is equipped with two rubidium and two cesium atomic clocks. From the base frequency of the atomic clocks (10.23 MHz) all other frequencies that are required for the GPS-satellite are derived. The newer satellites of Block IIR and IIR-M are equipped with three rubidium atomic clocks. Their extreme precision of ± 1 second in 1 million years is absolutely necessary for the functioning of the system.

Status:

GPS Satellites in Orbit

BLOCK II/IIA SATELLITE CHARACTERISTICS
Heritage Signals: L1, C/A and L1, L2 P(Y)
First Launch: 14 Apr 89
28 Procured. 16 healthy on-orbit (1 Block IIs, 15 Block IIAs)
Weight (on orbit): 2,175 pounds
Orbit altitude: 10,988 nautical miles
Design life: 7.5 years

BLOCK IIR SATELLITE CHARACTERISTICS
Heritage Signals: L1, C/A and L1, L2 P(Y)
First Launch: 22 Jul 97
21 Procured. 12 healthy on-orbit
Weight (on orbit): 2,370 pounds
Orbit altitude: 10,988 nautical miles
Design life: 10 years

BLOCK IIR-M SATELLITE CHARACTERISTICS
Heritage Signals: Same as Blocks II/IIA/IIR
Modernized Signals: Adds 2nd civil signal on L2
Also adds new L1, L2, & M-Code signal
First Launch: 25 Sep 05
8 Block IIRs to be modernized to IIR-Ms
Weight (on orbit): 2,370 pounds
Orbit altitude: 10,988 nautical miles
Design life: 10 years

GPS Satellites in Development

BLOCK IIF SATELLITE CHARACTERISTICS
Signals: All the capabilities of previous Blocks
Plus a 3rd civil signal on L5
First Launch: 2008
12 satellite production run
Weight (on orbit): 3,439 pounds
Orbit altitude: 10,988 nautical miles

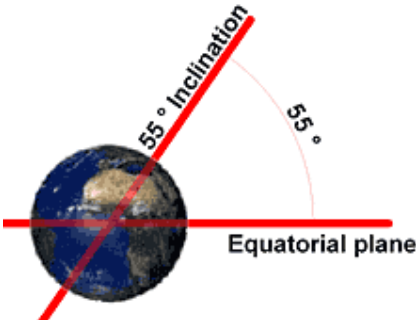
(Current as of August 2006)

Satellite Orbits

Orbits of the GPS-Satellites

The satellites orbit the earth with a speed of 3.9 km per second and have a circulation time of 12 h sidereal time, corresponding to 11 h 58 min earth time. This means that the same satellite reaches a certain position about 4 minutes earlier each day. The mean distance from the middle of the earth is 26560 km. With a mean earth radius of 6360 km, the height of the orbits is then about 20200 km. Orbits in this height are referred to as MEO – medium earth orbit. In comparison, geostationary satellites like Inmarsat – satellites orbit the earth at 42300 km, which is about twice the distance of GPS satellites.

The satellites are arranged on 6 planes, each of them containing at least 4 slots where satellites can be arranged equidistantly. Today, typically more than 24 satellites orbit the earth, improving the availability of the system.



Inclination of the orbital planes

The inclination angle of the planes towards the equator is 55°, the planes are rotated in the equatorial plane by 60° against each other. This means that the orbits range from 55° north to 55° degrees south. (Block I satellites had an inclination of 63° against the equator.)

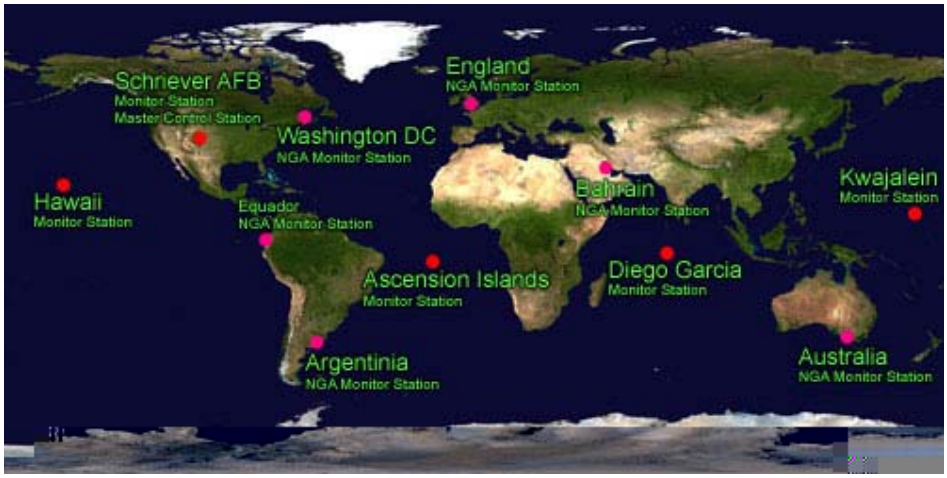
By this arrangement of the orbits it is avoided that too many satellites are to often over the north and south pole (like it was the case in the TRANSIT system, where the satellites ran on polar orbits).
However the orbits run far enough to the north and south to guarantee GPS availability in Polar Regions. Furthermore this arrangement leads to a rather stable constellation, as orbit disturbing factors like solar winds and gravitation fields have about the same influence on all of the satellites.

The number and constellation of satellites guarantees that the signals of at least four satellites can be received at any time all over the world.
The closer you get to the poles, the lower over the horizon the satellites are located. They can still be received very well, but in no case they are directly above. This may lead to a - typically insignificant - loss of the precision of the position determination. This effect, caused by the geometry of the satellite arrangement, happens from time to time on any spot of the earth surface and can be forecasted.

Control Segment (Monitor Stations)

The GPS-System is controlled by the US Army. The “master control station” (Schriever Air Force Base) and five additional monitoring stations (on Hawaii, Cape Canaveral, Ascension Islands, Diego Garcia and Kawajalein) are set up for monitoring the satellites.

During August and September 2005, six more monitor stations of the NGA (National Geospatial-Intelligence Agency) were added to the grid. Now, every satellite can be seen from at least two monitor stations. This allows calculating more precise orbits and ephemeris’s data. For the end user, a better position precision can be expected from this. In the near future, five more NGA station will be added so that every satellite can be seen by at least three monitor stations. This improves integrity monitoring of the satellites and thus the whole system.



Position of the monitor stations and the master control (Note Cape Canaveral not shown)

The passive monitor stations are GPS receivers which track all satellites in their range and collect data of the satellite signals. The raw data are then sent to the mater control station where the data are processed. The stations on Ascension Islands, Diego Garcia and Kwajalein are also transmitting stations for correction data.

Schriever AFB, Colorado

Satellite-tracking-station on Hawaii

error is corrected and the receiver clock is synchronized with the atomic clocks in the satellites.
The GPS receiver can now be regarded as an atomic clock itself. The distances to the satellites, formerly regarded as pseudo ranges, now correspond to the actual distances and the determined position is accurate.

In case of the example – a two dimensional disc world – we therefore need three satellites for an unequivocal determination of our position. In the real world which has one additional dimension (the height), we would need a fourth satellite.

Well, then why is it always said that three satellites are enough? In practice you get a two-dimensional position determination (2D-fix) with three satellites. The position is bound to be located on the earth's surface. The fourth satellite is the geocenter; the distance to the "fourth satellite" corresponds to 6360 km (the radius of the globe). Therewith the fourth satellite necessary for the calculation is given, but the calculation is restricted to locations on the earth surface. However the earth is not a perfect sphere. The surface of the earth in this case means the earth geoid, corresponding to sea level. If the receiver is located on a mountain, the determined position again is afflicted with an inaccuracy, as the runtime of the satellite signals is wrong.

Conclusion:

3 satellites solution = 2D position,
Solution: Latitude, longitude and time

4 (or more) satellites solution = 3D position –
Solution: Latitude, longitude, height and time

Carrier Phase

Carrier phase is another processing technique that gathers data via a carrier phase receiver, which uses the radio signal (carrier signal) to calculate positions. The carrier signal, which has a much higher frequency than the pseudo-random code, is more accurate than using the pseudo-random code alone. The pseudo-random code narrows the reference then the carrier code narrows the reference even more. After differential correction, this processing technique results in sub-meter accuracy.

Carrier phase follows the same general concept as described earlier, but uses the satellite's carrier as its signal, not the messages contained within. The improvement possible using

this signal is potentially very high if one assume a 1% accuracy in locking.
For instance, the GPS C/A signal broadcast in the L1 signal changes phase at 1.023 MHz, but the L1 carrier itself is 1575.42 MHz, over a thousand times faster. This corresponds to a 1% accuracy of 19 cm using the L1 signal, and 24 cm using the lower frequency L2 signal.

The difficulty in making a carrier phase system is properly aligning the signals. The navigation signals are deliberately encoded in order to allow them to be aligned easily, whereas every cycle of the carrier is similar to every other. This makes it extremely difficult to know if you have properly aligned the signals, or are "off by one" and thus introducing an error of 20 cm or a larger multiple of 20 cm. This integer ambiguity problem can be addressed to some degree with sophisticated statistical methods that compare the measurements from the C/A signals and by comparing the resulting ranges between multiple satellites. Generally this means that the receivers lock on to the code in order to find the correct.

Glonass

Glonass (Global'naya Navigatsionnaya Sputnikovaya Sistema or in english: GLObal NAvigation Satellite System) is a radio-based satellite navigation system, developed by the former Soviet Union and now operated for the Russian government by the Russian Space Forces. Its United States' counterpart is the Global Positioning System (GPS).

History

Development on the GLONASS began in 1976, with a goal of global coverage by 1991. From 1982 through April 1991, the Soviet Union successfully launched a total of 43 GLONASS-related satellites plus five test satellites. In 1991, twelve functional GLONASS satellites in two planes were available; enough to allow limited usage of the system.

Following the disintegration of the Soviet Union in 1991, continued development of GLONASS was undertaken by the Russian Federation. It was declared operational on September 24, 1993 by then president Boris Yeltsin, however the constellation was not completed until December 1995.

In the six years following completion, Russia was unable to maintain the system. By April of 2002, this resulted in only eight satellites remaining in operation, which rendered the system almost useless as a global navigation aid.

With GLONASS falling rapidly into disrepair, a special-purpose federal program named "Global Navigation System" was undertaken by the Russian government. According to it, the GLONASS system was to be restored to fully deployed status (i.e. with 24 satellites in orbit and the global continuous coverage) by 2011.

The New York Times reported that Russia had committed to accelerated launches, with eight satellites scheduled to be orbited in 2007 and a goal of reaching global coverage in 2009. As of April 2007, the number of operational satellite had increased to twelve, in addition to one new satellite in its commissioning phase.

Cooperation with the Indian government

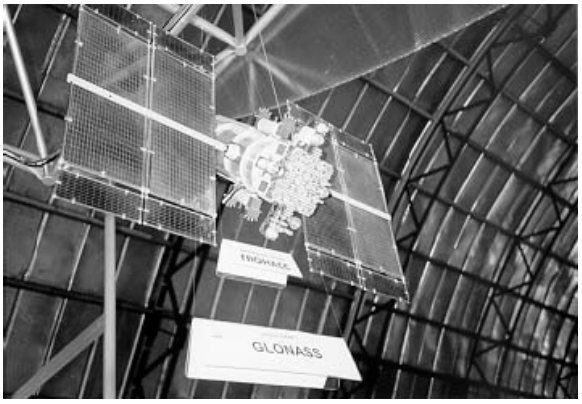
In January, 2004 the Russian Space Agency (RSA) announced a joint venture deal with India's space agency, the Indian Space Research Organization, where-in the two government agencies would collaborate to restore the system to constant coverage of Russian and Indian territory by 2008 with 18 satellites, and be fully operational with all 24 satellites by 2010.

Discussions with United States government

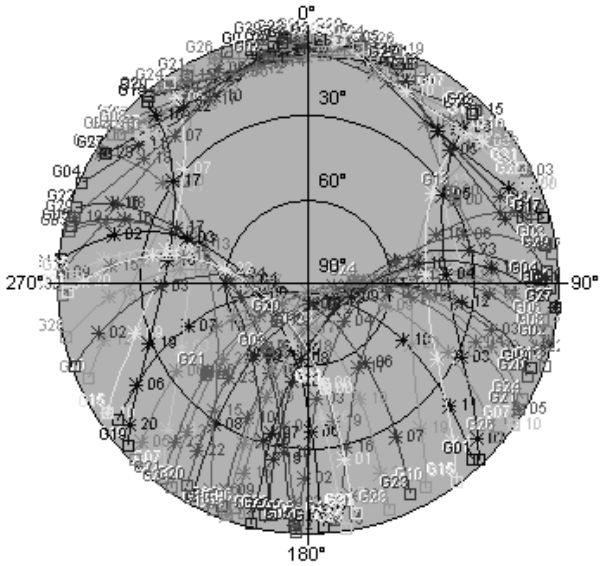
Following the December 2006 meeting in Moscow of the GPS-GLONASS Interoperability and Compatibility Working Group (WG-1), an announcement appeared on both US and Russian government websites stating both sides had made significant progress in understanding the benefit to the user community of changing GLONASS to a signal pattern that is in common with GPS and Galileo.

On May 18th 2007, Russian president Vladimir Putin signed a decree officially providing open access to the civilian navigation signals of the GLONASS system, to Russian and foreign consumers, free of charge and without limitations.

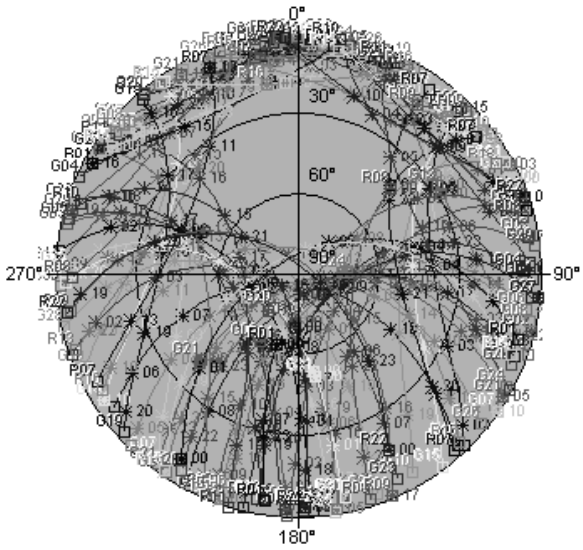
Space segment



Fully deployed the GLONASS system would consist of 24 operating satellites within three orbital planes spaced longitudinally by 120 degrees. Each satellite plane is nominally inclined to the equator by 64.8° a somewhat higher inclination compared to GPS thus making the coverage better for higher latitude sites. An illustration of this effect can be found in the below figures, where the GLONASS satellites help to reduce the gap in the sky.



Polar plot of GPS satellite sky tracks as seen from latitude 57.4°N for a period of 24 hours The midpoint of the plot is equivalent to the zenith direction with the elevation decreasing to zero at the outer edges of the figure. Due north is upwards in the figure.



Polar plot of GLONASS+GPS satellite sky tracks as seen from latitude 57.4°N , for a period of 24 hours

Number of Satellites	24 + spares
Number of orbital planes	3
Satellites pr. Plane	8
Orbital inclination	64.8 deg.
Orbital Radius	19.130 km
Orbital Period	11 h 15m
Repeat ground track	8 days*

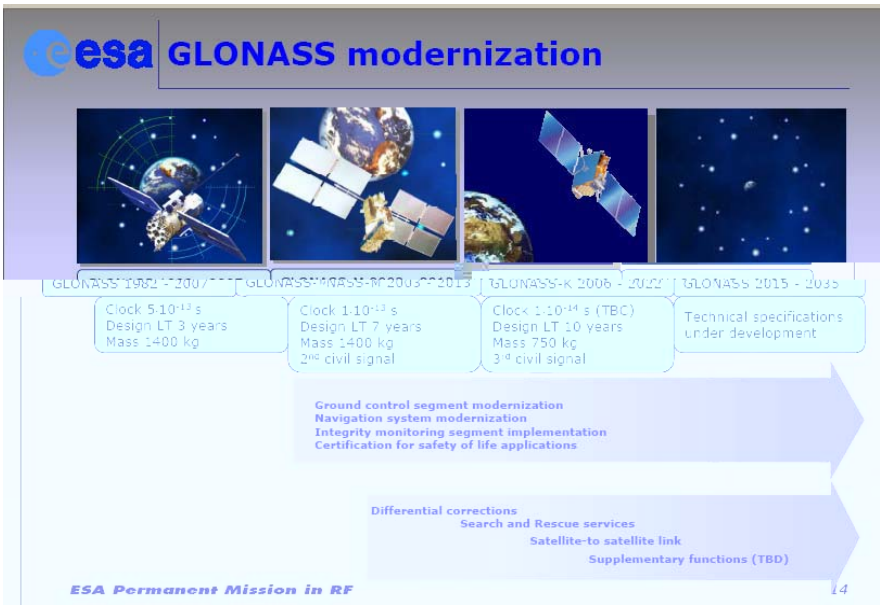
* Due to the constellation, a fully operational Glonass system will (on same location) show a satellite in the same direction and altitude every 24h.

Each satellite is identified by its slot number, which defines the orbital plane and its location within the plane. The 1st orbital plane has slot numbers 1…8, the 2nd orbital plane - slots 9…16, and the 3rd orbital plane - slots 17…24.

None of the first launched Glonass satellites are in use today. Since the decision to focus on the repair of the Glonass system, there have been sent up several new generation Glonass satellites have been launched:

December 2004: 3 satellites, December 2005: 3 satellites, December 2006: 3 satellites.
The 2nd generation Glonass satellites (Glonass-M) satellite have better signal characteristics, a 2nd civilian signal, as well as a longer design life (7-8 years instead of the current 3 years).

Presently (2007) Glonass-K satellites is the 3rd generation Glonass satellites that will be put into service. These satellites will have increased characteristics, a 3rd civilian signal and improved lifespan (10-12 years).



Notice Advisory to GLONASS (13-06-2007):

1.STATUS Information Group

GLONASS Constellation Status
(August 18, 2008)

GLONASS number	Cosmos number	Plane/ slot	Frequ. chann.	Launch date	Intro date	Status	Outage date
796	2411	1/01	07	26.12.2004	06.02.2005	unusable	04.05.2008
		1/02					
		1/03					
795	2403	1/04	06	10.12.2003	30.01.2004	operating	.....
		1/05					
701	2404	1/06	01	10.12.2003	09.12.2004	operating	.....
712	2413	1/07	05	26.12.2004	22.12.2005	unusable	06.04.2008
797	2412	1/08	06	26.12.2004	06.02.2005	unusable	16.06.2008
722	2435	2/09	-2	25.12.2007	25.01.2008	operating	.....
717	2426	2/10	04	25.12.2006	03.04.2007	operating	.....
723	2436	2/11	00	25.12.2007	22.01.2008	operating	.....
721	2434	2/13	-2	25.12.2007	08.02.2008	operating	.....
715	2424	2/14	04	25.12.2006	03.04.2007	operating	.....
716	2425	2/15	00	25.12.2006	12.10.2007	operating	.....
718	2431	3/17	-1	26.10.2007	04.12.2007	operating	.....
720	2433	3/19	03	26.10.2007	25.11.2007	operating	.....
719	2432	3/20	02	26.10.2007	27.11.2007	operating	.....
		3/21					
		3/22					
714	2419	3/23	03	25.12.2005	31.08.2006	operating	.....
713	2418	3/24	02	25.12.2005	31.08.2006	operating	.....

Note: All the dates (DD.MM.YY) are given at Moscow Time (UTC+0300)

2.SUMMARY Information Group

SUBJ:GLONASS STATUS 13 June 2007

1.SATELLITES, PLANES, SLOTS AND CHANNELS

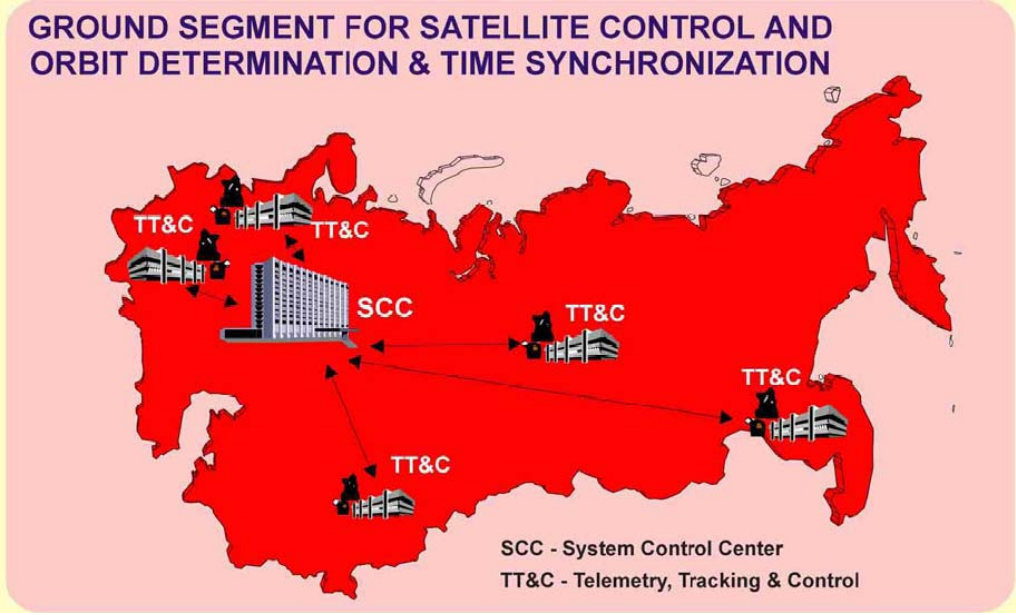
Plane 1/ slot	01	02	03	04	05	06	07	08
Channel	07	--	12	06	--	01	05	06
Plane 2/ slot	09	10	11	12	13	14	15	16
Channel	--	04	--	--	--	04	--	--
Plane 3/ slot	17	18	19	20	21	22	23	24
Channel	--	--	03	--	08	--	03	02

Timing

Just as the GPS system, timing is essential for the system to work. GLONASS time is based on an atomic time scale similar to GPS and Glonass satellites carries atomic clocks. This time scale is UTC as maintained by Russia (UTC (SU)). There is a difference in the time tags of GPS and Glonass satellites.

Ground Segment

The ground control segment of GLONASS is entirely located within former Soviet Union territory. The Ground Control Center and Time Standards is located in Moscow and the telemetry and tracking stations are in St. Petersburg, Ternopol, Eniseisk, Komsomolsk-na-Amure. The fact that all ground stations are within the former Sovjet Union can lead to update of satellites being “old” when not in sight from a ground station. This problem will be less and less, with new generation satellites, being able to autonomous operations without being in contact with a ground station.



User Segment (Glonass-Receiver)

The user segment consists of the Glonass receiver situated at the user.

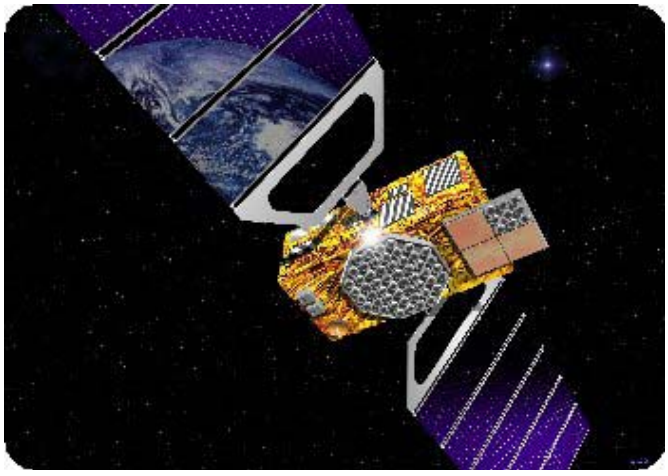
Seatex DPS 700
(DPS200 only)

Transmitted Glonass Signals and position determination

Just as the GPS signal, the Glonass transmits signals on 2 frequencies, called L1 and L2. There is a difference in the frequencies from the GPS. As the GPS, several signals are transmitted on the frequencies: The SPS, standard positioning service and the PPS, precise positioning service together with navigation signals. There is a difference in the way the satellites are recognized by the receiver. Glonass uses so called FDMA - Frequency Division Multiple Access – system. This means that the codes of the satellites are the same for each satellite, but the frequency is different for each satellite, giving the receiver the information of which satellite is sending the signal. For GPS the military P-code is encrypted to a so called Y-code a method known as AS or antispoofing. This is not done for GLONASS although the Russian authorities advise not to use the military code for navigational purposes due to military reasons.

The determination of the position is working on the same principles as the GPS system.

Galileo



Galileo will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. It will be inter-operable with GPS and GLONASS, the two other global satellite navigation systems.

History

The European Union and European Space Agency agreed on March 2002 to introduce their own alternative to GPS, called the Galileo positioning system. The total cost of the system was expected to be about GBP £2.4 billion. The first experimental satellite was launched on 28 December 2005. Galileo is expected to be compatible with the modernized GPS system that will be operational by after 2012. The receivers will be able to combine the signals from both Galileo, Glonass and GPS satellites to greatly increase the accuracy. At present (2007) there is some uncertainty regarding the future funding of the project. The time span of a fully operational system goes beyond 2010 and maybe even later.

Space segment

The Galileo space segment will comprise thirty satellites in a Walker constellation with three orbital planes at 56° nominal inclination. Each plane will contain nine operational satellites, equally spaced, 40° apart plus one inactive spare satellite to replace any of the operational satellites in case of failures. The spare, non-operational satellite in each orbit plane, ensures that in case of failure the constellation can be repaired quickly by moving the spare to replace the failed satellite. This could be done in a matter of days, rather than waiting for a new launch to be arranged which could take many months.

The orbit altitude of 23 222 km results in a repeat a constellation repeat cycle of 9 days 23 hours 20 min. during which each satellite has completed seventeen revolutions.

Number of Satellites	27 + 3 spares
Number of orbital planes	3
Satellites pr. Plane	9 (10 with spares)
Orbital inclination	56 deg.
Orbital Radius	23.222 km
Orbital Period	14 h 05m
Repeat ground track	9 days 23 hours 20 min.

Presently (2007) 2 satellites are planned for in orbit validation. The GIOVE A (launched Dec. 2005) and B (Plan. For Dec. 2007) (GIOVE= Galileo In Orbit Validation Element).

Control segment

The core of the Galileo ground segment will be the two control centres. Each control centre will manage “control” functions supported by a dedicated Ground Control Segment (GCS) and “mission” functions, supported by a dedicated Ground Mission Segment (GMS). The GCS will handle spacecraft housekeeping and constellation maintenance while the GMS will handle navigation system control.

The GCS will use a global network of nominally five TTC stations to communicate with each satellite on a scheme combining regular, scheduled contacts, long-term test campaigns and contingency contacts.

The TTC Stations will be large, with 13-metre antennas operating in the 2 GHz Space Operations frequency bands. During normal operations, spread-spectrum modulation (similar to that used for TDRSS and ARTEMIS data relay applications) will be used, to provide robust, interference free operation. However, when the navigation system of a satellite is not in operation (during launch and early orbit operations or during a contingency) use of the common standard TTC modulation will allow non-ESA TTC stations to be used.

Mission control segment

The Galileo Mission Segment (GMS) will use a global network of nominally thirty Galileo Sensor Stations (GSS) to monitor the navigation signals of all satellites on a continuous basis, through a comprehensive communications network using commercial satellites as well as cable connections in which each link will be duplicated for redundancy. The prime element of the GSS is the Reference Receiver.

The GMS communicates with the Galileo satellites through a global network of Mission Up-Link Stations (ULS), installed at five sites, each of which will host a number of 3-metre antennas. ULSs will operate in the 5 GHz Radionavigation Satellite (Earth-to-space) band.

The GMS will use the GSS network in two independent ways. The first is the Orbitography Determination and Time Synchronisation (OD&TS) function, which will provide batch processing every ten minutes of all the observations of all satellites over an extended period and calculates the precise orbit and clock offset of each satellite, including a forecast of predicted variations ("SISA", Signal-in-Space Accuracy) valid for the next hours. The results of these computations for each satellite will be up-loaded into that satellite nominally every 100 minutes using a scheduled contact via a Mission Up-link Station.

User Segment (Receiver)

The user segment consists of the receiver situated at the user.

Transmitted Signals and position determination

Galileo receivers receive the signals broadcast by the Galileo satellites and process them to compute position. Through this processing, the receivers extract measurements giving an indication of the distance from the user to the satellite.

They also decode the Galileo navigation data, which contain fundamental pieces of information for computing the user position such as the position of the satellites or the satellite clock errors as determined by the Galileo ground segment and up-linked regularly to the Galileo constellation.

The frequencies used by the satellites are within the 1.1 to 1.6 GHz band; a range of frequencies particularly well suited for mobile navigation and communication services.

Each Galileo satellite will broadcast 10 different navigation signals making it possible for Galileo to offer the open (OS), safety-of-life (SOL), commercial (CS) and public regulated services (PRS).

A distinction is made between signals containing navigation data (the data channels) and signals carrying no data (pilot channels). In the diagram this is highlighted by plotting the data channels and the pilot channels in orthogonal planes, a means of indicating that the signals of the data and pilot channels are shifted by 90 degrees in phase, which allows for their separation in the receivers.

Galileo signals have codes

All the satellites transmit at the same frequency, that is, the Galileo signal at L1 is broadcast at 1575.42 MHz from any satellite. To allow the receivers to distinguish which satellites the signals are coming from and to allow the receivers to measure the time it took the signal to travel from the satellite to the receiver (the basic measurements used for position determination), a code is added to the signal. This code is different for each satellite and its design is one of the many arts involved in making a good satellite navigation system.

A long code would allow tracking of very faint signals, such as those received inside a building, but it would be very difficult to acquire because a receiver acquires the signal by searching for the delay of the received code and for a long code there are more possibilities than for a shorter code.

Shorter codes are good for achieving fast acquisition but may lead to false acquisitions of satellites when a receiver confuses the signal between two satellites. This is because the capability of a receiver to distinguish between two different codes is inversely proportional to the length of the codes.

The code is like a key. When a receiver attempts to acquire a satellite signal, it compares the code of the received signal with a local replica stored on the receiver. When the two codes match, the receiver channel is open, otherwise the receiver tries with another code corresponding to another satellite till it succeeds.

However, not all the elements of the code need to match precisely and it is sufficient if the two codes are close enough. This means that the more complex the keys are, that is, the longer the codes, the more difficult it is to confuse keys, and therefore to mix up satellites.

Why so many different Galileo signals?

In the end, a good engineering compromise has been found, but since those compromises may not satisfy all type of users (an indoor, static user may like long codes, while outdoor, fast-moving users would prefer short codes), the solution has been to provide alternative codes with different characteristics on the various Galileo signals. This is one of the reasons why there are so many signals.

In GPS only one signal is available, which does not allow the kind of optimization performed for Galileo. This will be overcome with the GPS modernization program where more GPS signals will be made available.

Another reason for having so many signals in Galileo is to allow the receiver to estimate the ionospheric delay error. This error is due to the delay that the navigation signals suffer when they travel through the ionosphere. This delay, makes the distance from the satellite to the user, as measured by the receiver, appear longer than it actually is and if not corrected would lead to large positioning errors. Fortunately, this delay is proportional to the frequency of the signal, with lower frequency signals experiencing a longer delay than higher frequency signals. Therefore, by combining measurements to the same satellite at two different frequencies it is possible to produce another measurement where the ionospheric error has been cancelled out. This cancellation becomes more effective as the separation between the two frequencies increases. This is the reason why Galileo services are generally realized using pairs of signals.

The open services are realized by using the signals at L1, E5a and E5b, whether data or pilot. Several combinations are also possible, such as a dual frequency service based on using L1 and E5a (for best ionospheric error cancellation) or single frequency

services (at L1, E5a, E5b or E5a and E5b together) in which case the ionospheric error is removed using a model, and even triple frequency services using all the signal together (L1, E5a and E5b), which can be exploited for very precise centimetric applications.

The safety of life services are based on the measurements obtained from the open signal and use the integrity data carried in special messages designated for this purposed within the open signals. The safety of life service is like a data channel within the open signals.

The Commercial service is realized with two additional signals in the 1278.75 MHz band plus also the capability to include commercial data within the open signals.

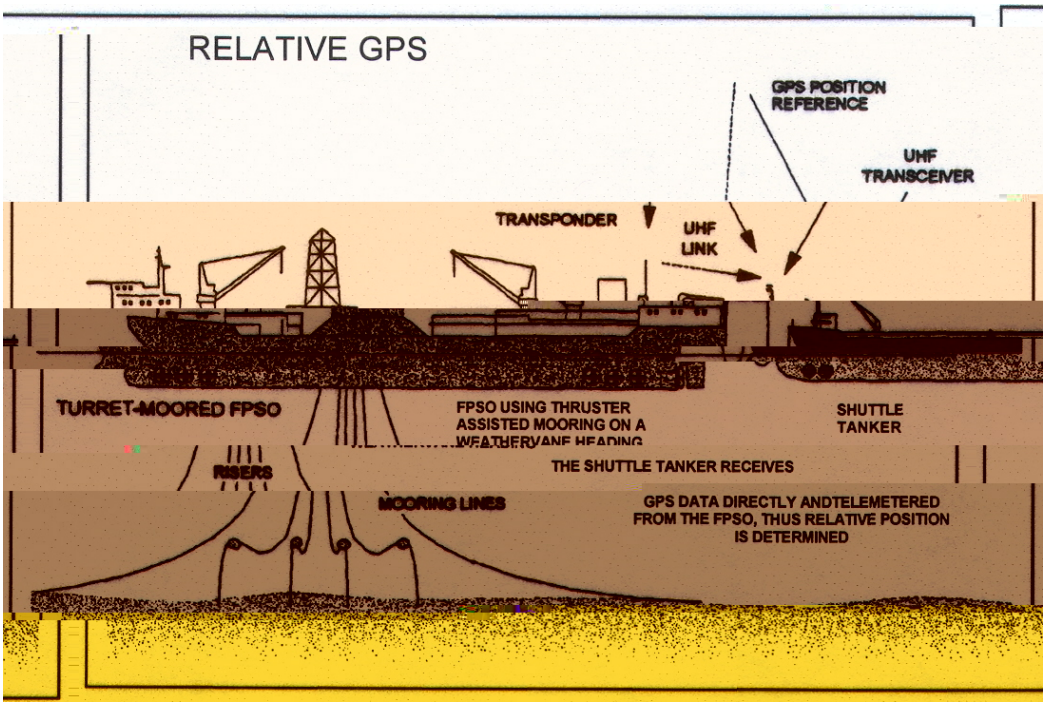
The Public Regulated Service is realized by two signals in the 1575.42 MHz and the 1278.75 MHz band. The signals are encrypted allowing the implementation of an effective access control scheme.

Finally, the distinctive shape of the spectrum of the signals is due to the special modulation adopted for Galileo. This modulation has been adopted to avoid interference with other satellite navigation systems within the same band, which is indeed the case of GPS at L1. The modulation adopted is the so called BOC(1,1), meaning Binary Offset Carrier of rate (1,1). This kind of modulation allows GPS and Galileo signals to occupy the same frequency while avoiding mutual interference. This makes building receivers that use both GPS and Galileo simpler because GPS and Galileo use the same frequency.

DARPS (Differential Absolute and Relative Positioning System)

Some DP functions require the positioning of a vessel relative to a moving, rather than fixed, position. An example of this is the operation of a DP shuttle tanker tandem loading via a bow loading hose from the stern of a floating production vessel (FPSO). The FPSO may be turretmoored and in a continuous weathervane mode. As well as the FPSO having a certain amount of positional wander, the stern of the FPSO describes the arc of a circle providing a complex positioning problem for the shuttle tanker.
The Seatex DARPS system (Differential Absolute and Relative Positioning System) is configured to handle this problem. The storage tanker or FPSO uses DGPS to monitor its absolute

position using the Network DGPS. This enables the shuttle tanker to determine both its Absolute and its Relative position. For the measurement of relative position differential corrections are not used, as the errors are the same for the shuttle tanker as they are for the FPSO. A DARPS transponder is placed on the point of reference (FPSO) and telemeters received GPS data to the UHF transceiver aboard the shuttle tanker. A computer aboard the shuttle tanker then makes a comparison between the GPS position of the transponder and the GPS position of the tanker, deriving a range/bearing vector which may be input to the DP system as position reference.
When the shuttle tanker is in the approach mode it will initiate the UHF comms with its transceiver, activating the FPSO DARPS transponder. This link has a range of some 2 - 3 km. and remains active until loading completes and the tanker moves off, when the system can be switched off.



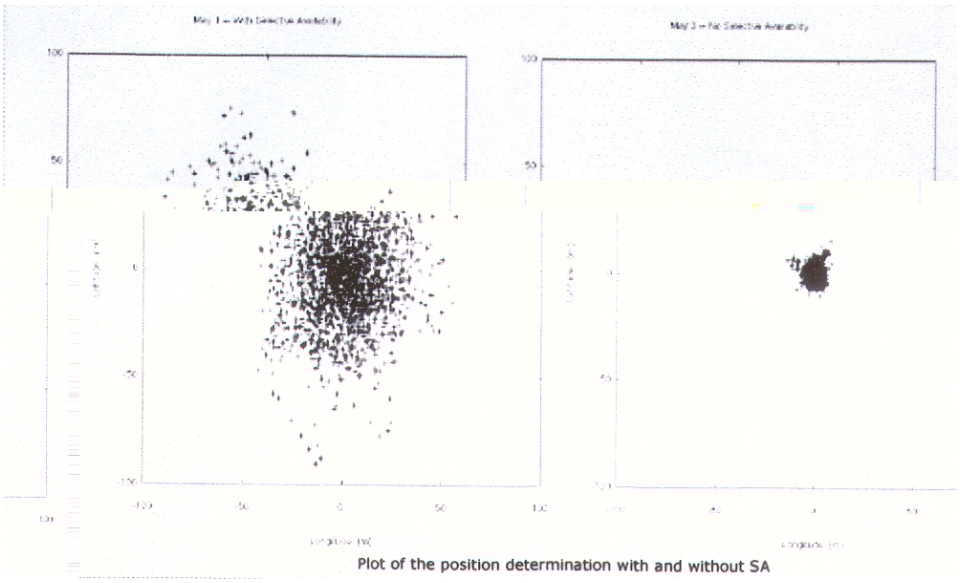
Sources of Errors in GNSS systems

Selective Availability

The most relevant factor for the inaccuracy of the GPS system is no longer an issue. On May 2, 2000 5:05 am (MEZ) the so-called selective availability (SA) was turned off. Selective availability is an artificial falsification of the time in the L1 signal transmitted by the satellite. For civil GPS receivers that leads to a less accurate position determination (fluctuation of about 50 m during a few minutes). Additionally the ephemeris

data are transmitted with lower accuracy, meaning that the transmitted satellite positions do not for several hours. While in times of selective availability the position determination with civil receivers had an accuracy of approximately 100 m, nowadays 20 m or even less is usual. Especially the determination of heights has improved considerably from the deactivation of SA (having been more or less useless before). The reasons for SA were safety concerns. For example terrorists should not be provided with the possibility of locating important buildings with homemade remote control weapons. Paradoxically, during the first gulf war in 1990, SA had to be deactivated partially, as not enough military receivers were available for the American troops. 10000 civil receivers were acquired (Magellan and Trimble instruments), making a very precise orientation possible in a desert with no landmarks. Meanwhile SA is permanently deactivated due to the broad distribution and world wide use of the GPS system.

The following two graphs show the improvement of position determination after deactivation of SA. The edge length of the diagrams is 200 m, the data were collected on May 1, 2000 and May 3, 2000 over a period of 24 h each. While with SA 95 % of all points are located within a radius of 45 m, without SA 95 % of all points are within a radius of 6.3 m.



Plot of the position determination with and without SA

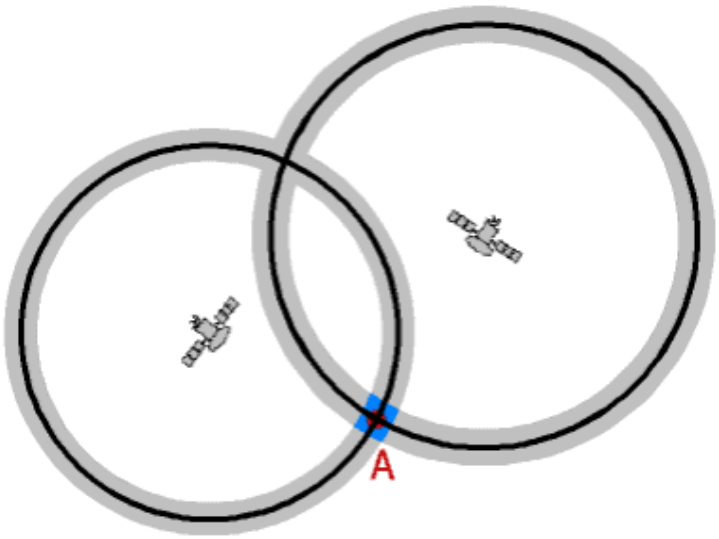
"Satellite geometry"

Another factor influencing the accuracy of the position determination is the "satellite geometry". Simplified, satellite

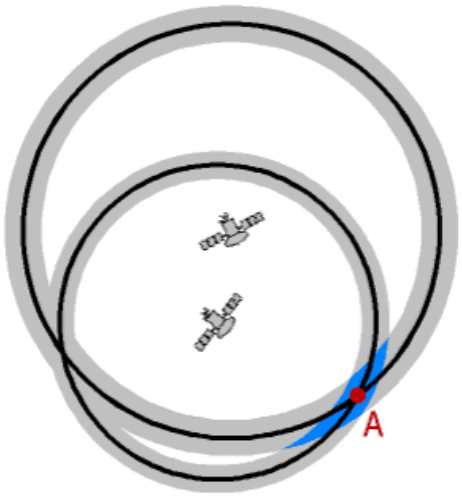
geometry describes the position of the satellites to each other from the view of the receiver.

If a receiver sees 4 satellites and all are arranged for example in the north-west, this leads to a “bad” geometry. In the worst case, no position determination is possible at all, when all distance determinations point to the same direction. Even if a position is determined, the error of the positions may be up to 100 – 150 m. If, on the other hand, the 4 satellites are well distributed over the whole firmament the determined position will be much more accurate. Let’s assume the satellites are positioned in the north, east, south and west in 90° steps. Distances can then be measured in four different directions, reflecting a “good“ satellite geometry.

The following graph shows this for the two-dimensional case.



If the two satellites are in an advantageous position, from the view of the receiver they can be seen in an angle of approximately 90° to each other. The possible positions are marked by the grey circles (Errors on position). The point of intersection A of the two circles is a rather small, more or less quadratic field (blue), the determined position will be rather accurate.



If the satellites are more or less positioned in one line from the view of the receiver, the plane of intersection of possible positions is considerably larger and elongated- The determination of the position is less accurate.

DOP – Dilution of Precision

To indicate the quality of the satellite geometry, the DOP values (dilution of precision) are used.

Based on which factors are used for the calculation of the DOP values, different variants are distinguished:
GDOP (Geometric Dilution Of Precision); Overall-accuracy; 3D-coordinates and time
PDOP (Positional Dilution Of Precision) ; Position accuracy; 3D-coordinates
HDOP (Horizontal Dilution Of Precision); horizontal accuracy; 2D-coordinates
VDOP (Vertical Dilution Of Precision); vertical accuracy; height
TDOP (Time Dilution Of Precision); time accuracy; time

HDOP-values below 4 are good, above 8 bad. HDOP values become worse if the received satellites are high on the firmament. VDOP values on the other hand become worse the closer the satellites are to the horizon and PDOP values are best if one satellite is positions vertically above and three are evenly distributed close to the horizon.

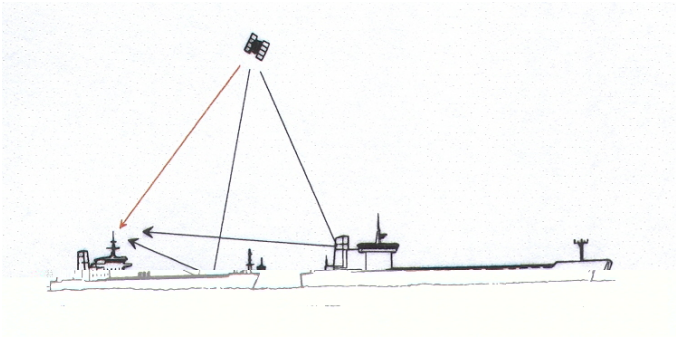
Satellite Orbits

Although the satellites are positioned in very precise orbits, slight shifts of the orbits are possible due to gravitation forces.

Sun and moon have a weak influence on the orbits. The orbit data are controlled and corrected regularly and are sent to the receivers in the package of ephemeris data. Therefore the influence on the correctness of the position determination is rather low, the resulting error being not more than 2 m.

Multipath effect

The multipath effect is caused by reflection of satellite signals (radio waves) on objects. It was the same effect that causes ghost images on television using antennae on the roof.
For GPS signals this effect mainly appears close to platforms (reflections) or with low satellites reflecting signal onboard the vessel. The reflected signal takes more time to reach the receiver than the direct signal. The resulting error typically lies in the range of a few meters. . If the reflected signal is very strong, the GPS receiver might lose lock on the satellite.



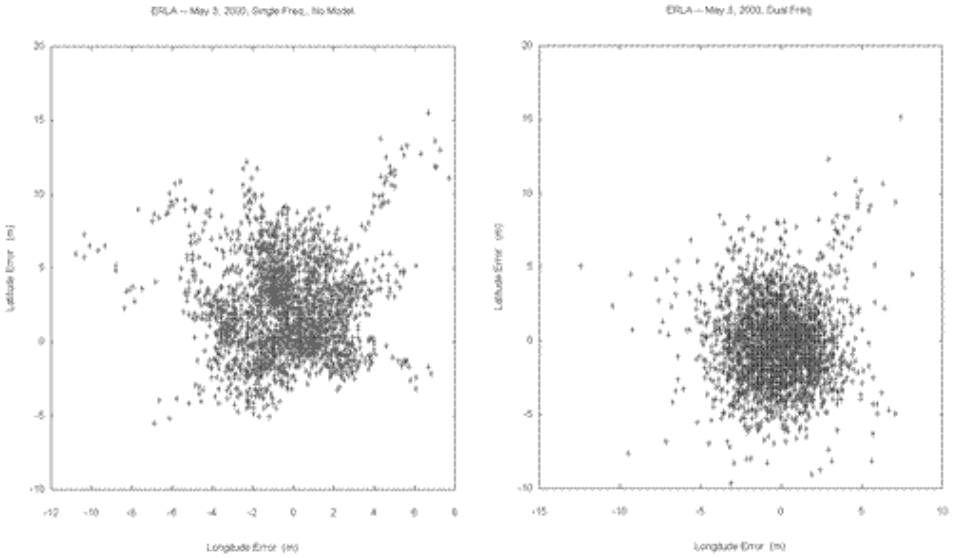
Multipath is difficult to detect and sometime hard to avoid.

Atmospheric effects

One of the biggest sources of inaccuracy is the reduced speed of the signal in the troposphere and ionosphere. While radio signals travel with the velocity of light in the outer space, the speed in the ionosphere and troposphere is slower.
In the ionosphere in a height of 80 – 400 km a large number of electrons and positive charged ions are formed by the ionizing force of the sun. The layers of electrons and ions in the ionosphere refract the electromagnetic waves from the satellites, resulting in an elongated runtime of the signals.
These errors are mostly corrected by the receiver by calculations. The receivers have a build in model of the standard ionospheric conditions, giving possibility to calculate the delay of the radio signal for standard conditions. Theses variations are taken into account for all calculations of positions. However single frequency receivers are not capable of correcting unforeseen runtime changes, for example by strong solar winds.

caused that way is smaller than the ionospheric error, but can not be eliminated by calculation. It can only be approximated by a general calculation model.

The following two graphs visualize the ionospheric error. The left data were collected with a one-frequency receiver without ionospheric correction, the right data were collected with a two-frequency receiver with ionospheric correction. Both diagrams have approximately the same scale (Left: latitude -15 m to +10 m, longitude -10 m to +20 m, Right: latitude -12 m to +8 m, longitude -10 m to +20 m). The right graph clearly shows less outliers.



Clock inaccuracies and rounding errors

Despite the synchronization of the receiver clock with the satellite time during the position determination, the remaining inaccuracy of the time still leads to an error of about 2 m in the position determination. Rounding and calculation errors of the receiver sum up approximately to 1 m.

Relativistic effects

The following section shall not provide a comprehensive explanation of the theory of relativity. In the normal life we are quite unaware of the omnipresence of the theory of relativity. However it has an influence on many processes, among them is the proper functioning of the GPS system. This influence will be explained shortly in the following.
As we already learned, the time is a relevant factor in GPS navigation and must be accurate to 20 – 30 nanoseconds to ensure the necessary accuracy. Therefore the fast movement of

the satellites themselves (nearly 12000 km/h) must be considered.
Whoever already dealt with the theory of relativity knows that time runs slower during very fast movements. For satellites moving with a speed of 3874 m/s, clocks run slower when viewed from earth. This relativistic time dilation leads to an inaccuracy of time of approximately 7,2 microseconds per day (1 microsecond = 10-6 seconds).
The theory of relativity also says that time moves the slower the stronger the field of gravitation is. For an observer on the earth surface the clock on board of a satellite is running faster (as the satellite in 20000 km height is exposed to a much weaker field of gravitation than the observer). And this second effect is six times stronger than the time dilation explained above.
Altogether, the clocks of the satellites seem to run a little faster. The shift of time to the observer on earth would be about 38 milliseconds per day and would make up for a total error of approximately 10 km per day. In order that those errors do not have to be corrected constantly, the clocks of the satellites were set to 10.229999995453 Mhz instead of 10.23 Mhz but they are operated as if they had 10.23 MHz. By this trick the relativistic effects are compensated once and for all.

There is another relativistic effect, which is not considered for normal position determinations by GPS. It is called Sagnac-Effect and is caused by the movement of the observer on the earth surface, who also moves with a velocity of up to 500 m/s (at the equator) due to the rotation of the globe. The influence of this effect is very small and complicate to calculate as it depends on the directions of the movement. Therefore it is only considered in special cases.

Sum of errors

The errors of the GPS system are summarized in the following table. The individual values are no constant values, but are subject to variances. All numbers are approximate values.

Ionospheric effects	± 5 meter
Shifts in the satellite orbits	± 2.5 meter
Clock errors of the satellites' clocks	± 2 meter
Multipath effect	± 1 meter
Tropospheric effects	± 0.5 meter
Calculation- und rounding errors	± 1 meter

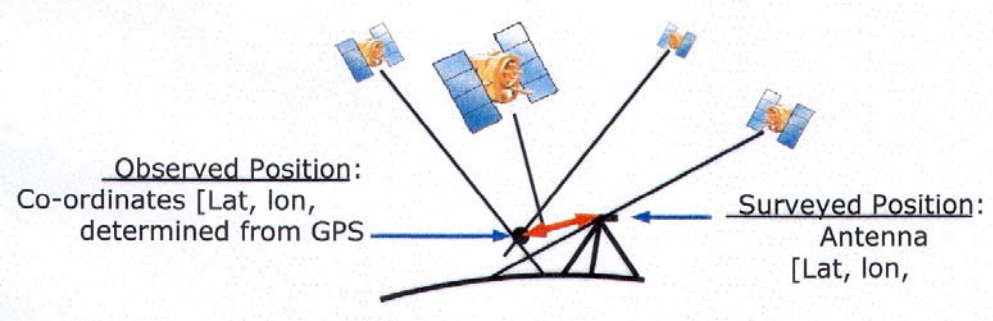
Altogether this sums up to an error of ± 15 meters. With the SA still activated, the error was in the range of ± 100 Meter.

Differential GNSS

Differential GPS (DGPS) or Glonass (DGlonass) systems are a way of correcting the received signal of the GNSS satellite in order to improve accuracy.

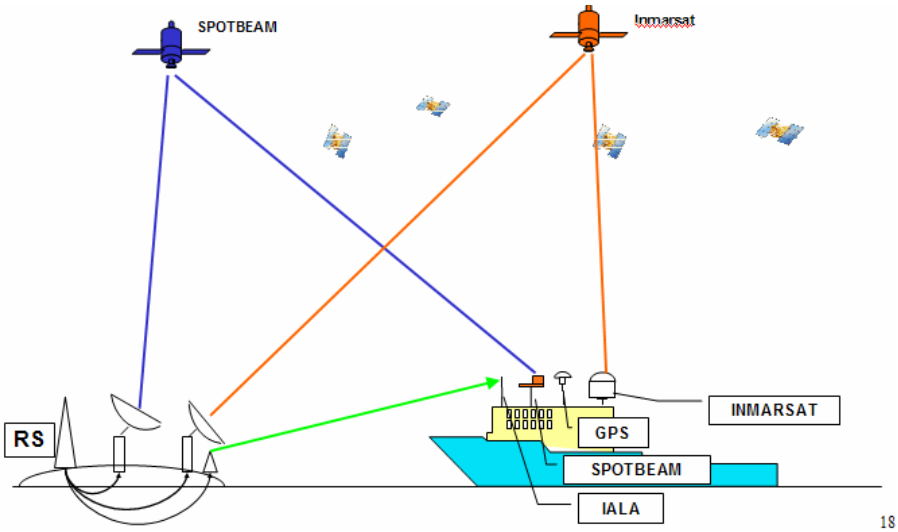
The way it works includes 2 receivers, namely the one we have at the user end and one placed at a known point, normally a shore.

As the receiver ashore - known as the reference station - have information of its own position and are receiving signals from a number of satellites, the position error at the reference station can be determined. This is calculated in to a *correction for each satellite.*



This correction is then sent to the user by various means:

- Maritime radio beacons (the IALA beacons)
- HF, UHF or VHF radio systems
- Satellite-based systems (Geo stationary Inmarsat & Spotbeam satellites)



GPS sats. Providing positions to the Reference station (RS) AND User (vessel)Calculated correction for EACH satellite is transmitted by various means to the user and processed at the user end, optimizing the position.

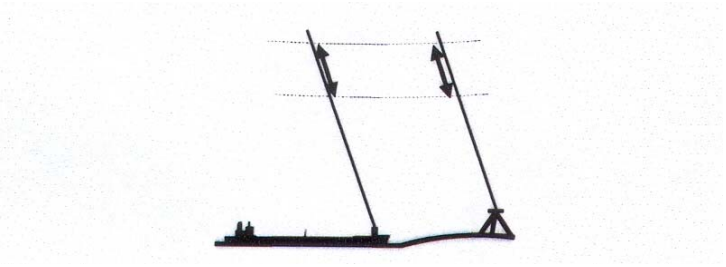
It is of utmost importance to understand, that the satellites used to send the corrections to the user are *NOT* GNSS satellites, but geostationary satellites in much higher orbits.

On board the vessel (user end), the corrections are processed and used on the same satellite and in that way optimizing the position. It is only possible to correct satellites which are visible to both the reference station and the user.

Errors introduced to the GPS signals are often similar over large geographical areas. The DGPS principle therefore assumes that major errors like:

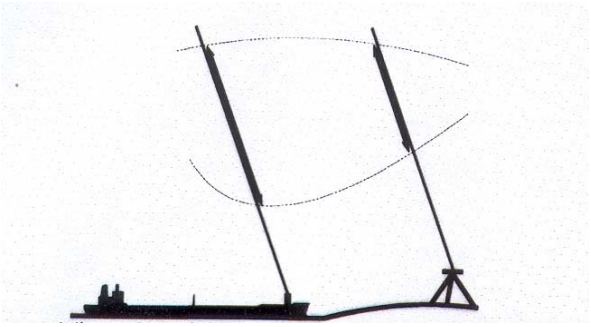
- Satellite clock and ephemeris errors
- Disturbances in the ionosphere and troposphere

are of the same *magnitude* at both the reference station and the mobile station. The corrections, when processed and incorporated into measurements in the user GPS receiver, virtually eliminate errors common to both the DGPS reference station and the on-board GPS receiver. This is normally the case when the distance between user and reference station is relatively small.



Distance between Reference station and user is small. Effected by same errors

If the distance between user and reference station increases, the errors at the reference station and the user end is not the same. This is referred to as “spatial decorrelation” Spatial decorrelation can be described as a gradual increase in error as User/reference station distance increases. This error is due to differences in the path of the radio signal from the satellite to the reference station and user receivers. When the signal paths to reference station and user are not identical, the resulting differences show up as position errors that cannot be removed by differential correction (because this error is not common to base and rover). Usually such differences are the result of variation in the Earth's ionosphere and troposphere.



Distance between Reference station and user is big. Effected by different ionosphere and having different errors

Due to the phenomenon known as *Ionospheric scintillations*, the effect of the ionosphere can vary locally. Irregularly sturctured ionospheric regions can cause diffraction and scattering of trans-ionospheric radio signals. When received at an antenna, these signals present random temporal fluctuations in both amplitude and phase. This is known as *ionospheric scintillation.*

Some reference stations around the equator have a dual receiver and are transmitting the error due to ionosphere to the user. When the user has a dual receiver, this error can be calculated

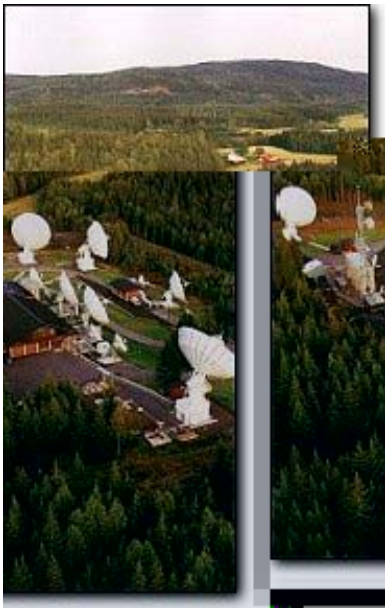
onboard and the information from the reference station used to improve accuracy even more. Dual receivers and dual corrections improves accuracy, but does not totally removes the effects of scintillations.

FUGRO

On board DP vessels these corrections are bought from companies specialized in obtaining and distributing corrections. One of these companies are Fugro Seastar.

Fugro Seastar AS is situated in Oslo, Norway and is part of Fugro Norway AS.
Fugro Norway AS is owned by Fugro N.V in The Netherlands, a multi-national group with approx. 7000 employees and over 250 offices in about 60 countries.

DGNSS Infrastructure Management and Support



Fugro operates a global DGNSS network.
The network includes:

100 reference stations,
an extensive data communication network and
3 manned network control centres (NCC)

The reference stations are fitted with high quality GNSS (GPS/GLONASS) receivers and a data communications link.

reference stations and linking these to the US WAAS master control stations.
The first international Wide Area Reference Station (WRS) was installed in Gander, New Foundland, Canada in June 2005.

India's SBAS, GAGAN (GPS and GEO Augmented Navigation), is being co-ordinated by the Indian Space Research Organisation and the Airports Authority of India. They are planning for an initial operational capability in 2006/7.

The People's Republic of China is deploying its Satellite Navigation Augmentation System (SNAS). There is also a high level of interest in Brazil and the African continent. There are currently (2006) 10 test stations in Africa – with two more planned for South Africa and Madagascar.

More international installations will be installed in Mexico City, Merida, and Puerto Vallarta, Mexico; and at Goose Bay, Canada.

How does SBAS work

In principle all SBAS systems are working the same way. The following is based on the WAAS system, but other systems have the same specifications.

Similar to a beacon transmitter the WAAS system collects data from strategically placed and well characterized ground locations. However, unlike the standard DGPS a WAAS system cannot directly send corrections to the pseudorange data.

This is because the unit has no idea where you are. Instead it attacks the problem by addressing the individual sources of error and sending corrections for each one of them. The biggest component of error is due to ionospheric delays followed by clock errors and ephemeris errors. In addition another significant error source was troposphere errors.

To attack these error sources the WAAS system sends clock corrections, ephemeris corrections, and ionospheric corrections. It cannot compute tropospheric corrections due to the localized nature of this error but it does remove the tropospheric error component from the data it computes so that the local receiver can apply its own corrections based on an atmospheric model that is based on the current sky location of the SV.

The ground stations do not send the data directly to a WAAS satellite for re-transmission but rather to a master ground station

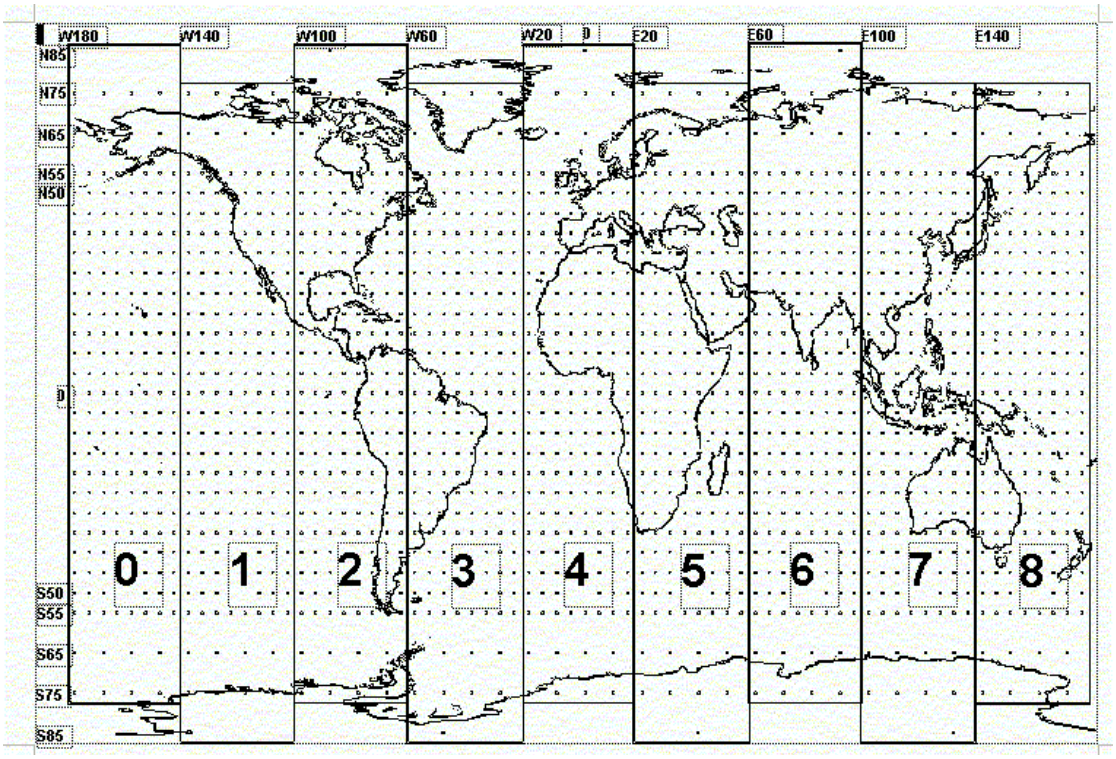
that analyzes the input and computes the full detailed error information.

This fully correct data is then sent to the GEO satellite to be sent to the GPS receiver. Note that there is no correction done by the GEO satellite; the master ground station will even correct for errors produced by the GEO satellite itself. There are redundant master stations as well for system wide integrity.

Clock errors can change rapidly so this data is update every minute if required, ephemeris errors and ionosphere errors don't change nearly so fast so they are only updated every 2 minutes and can be generally be considered valid for up to 3 times that period of time.

Even this time is very conservative in practice. Clock and ephemeris data is specific to a satellite but ionospheric errors are specific to your location therefore they must be sent separately. After receiving raw data from each of the ground station the master station divides the country into a grid and then builds ionospheric correction information on a per grid location basis from the data received from each reporting station. It is this grid location that is used by the GPS receiver to determine the applicable ionospheric corrections. In addition the master station determines the validity of the data it receives and can indicate invalid data within 6 seconds to the GPS receiver.

Of the forms of error correction supported by WAAS only the ionospheric data requires knowledge of the receiver position. Clock and ephemeris data is available for any receiver even if it is currently located outside the area covered by ionospheric correction data. In addition system integrity data can be used outside theis area. The designers of WAAS developed a grid system of correction data that permits a receiver to use the data it needs for this correction. Below is what the grid system looks like.



The master ground station computes a correction for ionospheric data for each of the points on the grid based on field data it gets from the other ground units. Of course it is very unlikely that there will be data for all of the points on the grid over the entire earth so the GPS receiver downloads a grid mask that is part of the almanac data that tells it where to expect corrections.

The mask is divided into bands as shown on the drawing and each band contains 201 grid points (except the last one which has 200). A single bit is used to represent the availability of data on each grid point so the entire band can be contained in a single packet of data. Each geo satellite can have data for up to a maximum of three or four bands but may have less.

The master station will generate correction data or each of the grid points tagged in the mask. A receiver will locate its position relative to 4 grid points and interpolate the data from those 4 points based on their relative distance. If only 3 points have data then the receiver will compute a triangle of the 3 points and if it is inside the triangle it will use the 3 points to interpolate its correction. Otherwise, the use of any of the grid points for correction is undefined. It seems however that most GPS implementations will use the data from even a single point if it is "close" to the current location.

In addition to correction data the WAAS system places a high degree of importance to system integrity. Each ground station and the master station has independent sources of critical data and can determine if an SV is out of calibration. Bad data can be identified and relayed to the receiver within about 6 seconds. The geosynchronus satellites that retransmit the data can even be used as regular GPS satellites as part of the regular GPS solution since they also relay regular satellite ephemeris data for themselves. This data like all of the other data, is generated at the master station and can be turned off independent from the regular WAAS corrections if the satellite drifts too far.

All of the data for a region is loaded into the WAAS SV, so only one is required to receive everything. A second provides redundancy.

The geostationary satellites do provide a signal very similar to that of the GPS-satellites and on the same frequency. Therefore these satellites may be used for position calculation and additionally, the correction data sent out can be used to improve accuracy for position calculation with all GPS satellites.