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Sensors

Orbital Navigation Systems

Present and Future Systems

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The Dynamic Positioning Centre

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1 Glossary

The following abbreviations are used in this paper:

BPS	Bits per second.
BOC	binary Offset Carrier
DARPS	Differential and GPS absolute and relative positioning
DGPS	Differential GPS
DP	Dynamic positioning
DVL	Doppler velocity log
EGNOS	European geo-stationary overlay service
FPSO	Floating storage production offshore
FOG	Fibre optic gyro
GIB	GPS intelligent beacon
GNSS	Global navigation satellite system
GPS	American Navstar global positioning system
IGEB	Interagency GPS executive board
INS	Inertial navigation system
IRC	Ionospheric Range Correction
ITU	International telecommunications union
KART	Kinematic application real time
LAAS	Local area augmentation service
LRK	Long range kinematic
LRTK	Long range real time kinematic
MSAS	MTSAT satellite based augmentation system (Japan)
NCORS	National continuously operating reference station
NDGPS	Nationwide DGPS
NOAA	National Oceanic and atmospheric administration
PRN	Pseudo Random Noise code
PRS	Position reference system
RCC	Rescue co-ordination centre
RCTM SC104	Radio technical commission for maritime services, special committee 104
RLG	Ring laser gyro
RTK	Real time Kinematic
SAR	Search and Rescue
SBAS	satellite based augmentation system
SV	Space Vehicle (satellite)
VBS	Virtual base station
WAAS	Wide area augmentation system (USA)
QZSS	Quasi zenith navigation satellite system (Japan)

2 Introduction

The intention of this paper is to discus orbital navigation systems as they relate to use in the civil offshore Industry, and specifically as they relate to its use as a Position Reference System (PRS) in the Dynamic Positioning (DP) Industry. It is not intended as a Technical discussion on the operation of satellite systems.

The paper commences with a brief history of orbital navigation systems, followed by a description of navigations systems in use at the time of writing. This will include methods of using basic signals, augmentation of basic signals and other uses of the navigation signals.

Some of the problems and shortfall of orbital navigation systems will be mentioned, followed by known planned improvements to operational systems, and proposed systems.

Finally, some thoughts on what the future could hold.

3 A Brief History of Orbital Navigation Systems.

The first artificial satellite, the now famous Sputnik was launched in 1957. Many types of satellite orbit the earth: communications, remote sensing, weather observation, and of course navigation systems. Although relatively few people are aware of it there have been quite a number of navigational systems. Of the latter there have been quite a few, most of them funded from Military budgets.

One of the first satellite systems was United States Army SECOR system, launched in 1964. The system consisted of 4 portable ground stations and orbital satellites. Three ground stations would be placed at known locations and the fourth at the location to be fixed, timing signals from the known locations fixed the satellite, and the range was calculated to the fourth location. Successive ranges would fix the fourth location. This technique was used extensively to fix the location of Pacific Islands.

Timation was a United States Navy system, with the first satellite being launched in 1967. This system allowed a passive user to get position from a 400 MHz ranging signal as well as precise time. The early satellites used quartz clocks whilst later satellites carried the first space borne atomic clocks. The great disadvantage of this system militarily was that it was easy to jam.

621B was a proposed United States Air Force system. Its great advantage was that it was three dimensional. In addition it used a jamming resistant Pseudo Random Noise code (PRN). It was tested from aircraft between 1968 and 1971. However, unlike Timation it required terrestrial based signals to function.

The first Transit Doppler system satellite (1A) was launched in 1959 but failed and Transit 1B was launched in 1960. The system eventually comprised six satellites (three operating and three spare) and three ground control stations. The satellites were of two types known as Oscar and Nova. Signals were broadcast on 150 MHz and 400 MHz. The satellites were in polar orbits and fixes were derived from tracking the Doppler shift of the signal to generate hyperbolic position lines. As too many satellites caused jamming, satellite numbers were restricted, also as polar orbits were used the interval between fixes was greater in lower latitudes. The system was operational between 1964 and 1996.

The most widely used system is the American Navstar GPS. It combines the accurate atomic clocks of the earlier Timation system and the jamming resistant PRN codes of the 621B system. The system is jointly operated by the Interagency GPS Executive board (IGEB) and the DOD as a national resource, and while it is a military system it is made available to all users free of charge.

A test bed system of 10 satellites (Block I) was used to prove the system. The first Navstar satellite was launched in 1978 with the system being declared operational in 1989 although the full satellite constellation was not completed until 1994. The system requires twenty-four satellites (twenty-one operating and three spare). At the present time there are twenty-nine satellites in the system.

There are 6 orbital planes that are offset by 55 degrees (see Figure 1), these orbital planes are fixed and arranged to ensure that reasonable satellite constellations are available world wide

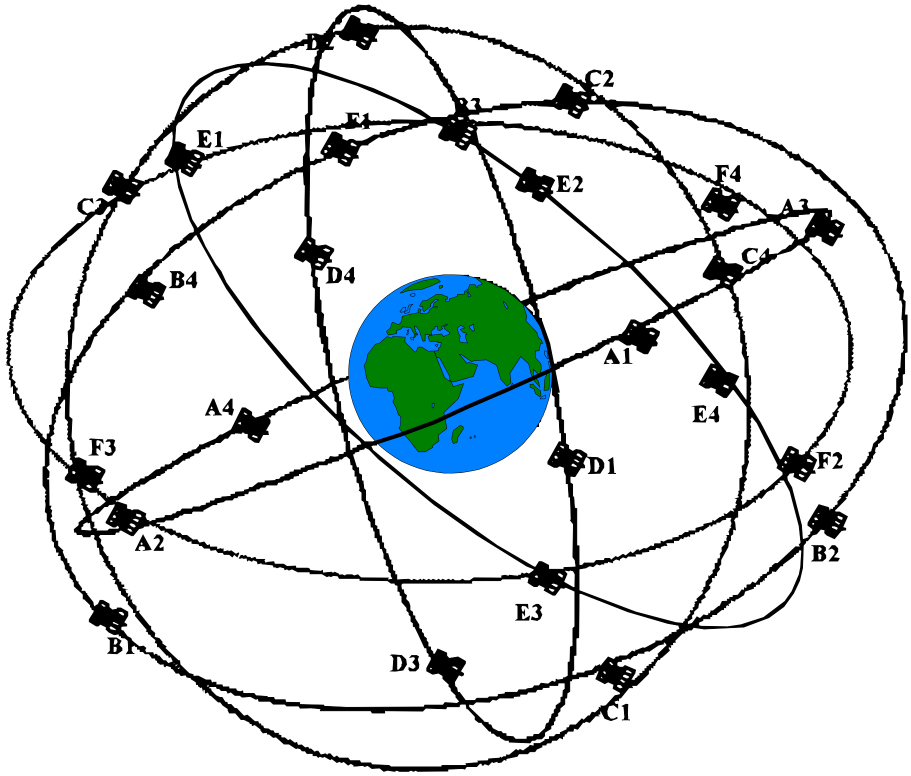

Figure 1 Satellite Orbital planes

When the system was commissioned the signals were degraded with a randomly varying error on the clocks. This was called dithering or, more commonly, Selective Availability. This error caused the GPS fixes to spread over an area of about 100m. The error was removed in 2000.

The system broadcasts on two frequencies L1 and L2, with various overlay signals, the Coarse Acquisition code (CA or "Civilian code) was initially only transmitted on L1. Military Precise codes (P codes) were transmitted on L1 and L2. There are additional security codes such as the Anti spoofing code (Y code).

The former Soviet Union developed several navigation satellite systems for both civilian and military use. One of the earliest systems developed is a Doppler system similar in operation to the American transit system. It is divided into two parts: Parus and Tiskada. Parus (also known as Tsikada M) is the military arm of the system. Parus consists of six satellites with orbital planes offset by 30 degrees. The civilian section, Tsikada, consists of four satellites with orbital planes offset by 45 degrees. Some of the Tsikada satellites are fitted with transponders for use with COSPAS-SARSAT (search and rescue system) these satellites are called Nadezha (hope). The first satellites were launched in 1974 with the military system becoming operational in 1976. Both systems appear to still be in use (last launch Tsikada – 1995, Parus - 2003).

The other and more widely known, major Russian system is GLONASS, a system similar in operation to GPS. GLONASS was started in 1982 and declared operational in 1996, and initially for the civilian user, the repeatability (spread of fixes) was more precise than that of GPS as GLONASS was not degraded in any way. GLONASS uses L1 at 1602MHz, However, unlike GPS, each satellite broadcasts the same PRN, but on a unique frequency. This is the carrier offset by satellite modifier multiplied by 0.5265MHz.

The GLONASS system requires twenty four satellites to function accurately. However, due to funding problems, following the break up of the Soviet Union, the system was at one time reduced to about seven satellites. New funding appears to have been allocated and the launch program has been restarted.

There are other satellites that aid the satellites navigation systems such as ETALON, GEO 1K, and NOOAA systems that carry out geodetic surveys to establish spheroids such as WGS84 as used by GPS, and PZ90 as used by Glonass the operation of these systems is outside the scope of this paper and will not be dealt with at this time.

4 Systems Presently In Use

4.1 Time Delay Measurement with PRN Codes.

The major requirement for this system to operate is accurate timing; the satellites are fitted with atomic clocks of cesium and rubidium type. Errors in the satellite clocks are tracked and corrected from the ground segment, as although atomic clocks are very accurate it must be remembered that a nano second error can cause a 30cm error.

The terrestrial receivers are not fitted with atomic clocks, errors are calculated and corrected (this will be explained later).

To calculate the user's position we need two things, first the position of at least 4 satellites, second ranges from the user to the satellite. The first is calculated by ground tracking stations, the tracking stations plot a satellites historical path, this is then used to predict the satellites future path. This predicted path is uploaded to the satellite, as is the information on starting broadcasts all in the form of an almanac. When the user switches on the receiver, part of the initialisation is for the satellite to download the Almanac of all visible satellites to the receiver, other satellites almanacs are downloaded as they come into view.

So the satellites knows where it is and what time to start broadcasts, the user will have the same information once the Almanac is down loaded. Now we need the range, using its internal clock and the almanac the receiver generates the PRN codes from the satellites in view as they are due to start. A short while later the PRN signal is received from the satellite (see Figure 2). The receiver measures the time delay between internal, and actual signal, then calculates the range to the satellite with Range = Speed x time, propagation speed is constant, so we have the range to satellites. Position lines are generated and plotted from the satellite known position to give users position.

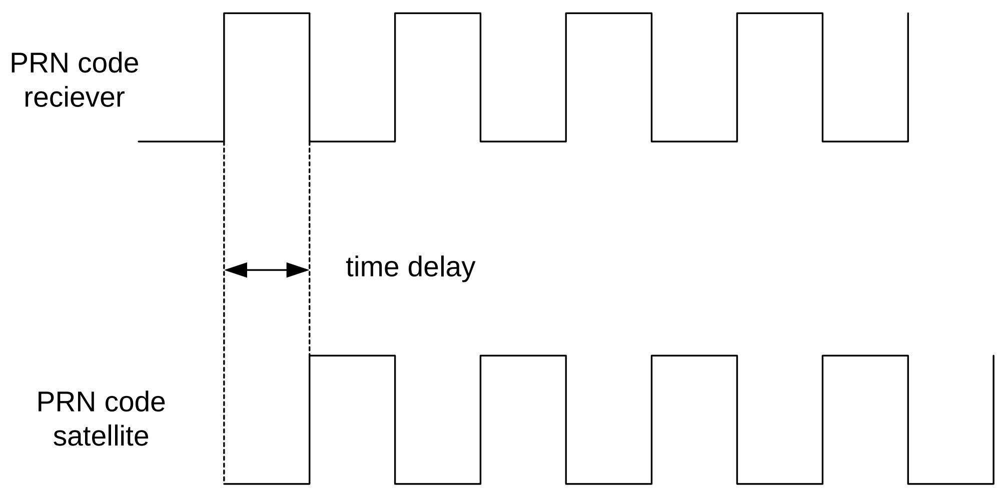

Figure 2 PRN Timing

4.2 DGPS

Differential GPS was initially required because of the degraded nature of GPS signals; which meant repeatability was in the order of 90 metres which was not acceptable. SA was set to zero in May 2000, giving the real possibility of using raw GPS for much offshore work. In many areas it is still required due to the safety critical nature of operations where DGPS can be more reliable and correct for sources of error other than SA.

There are many systems in operation, Government systems such as NDGPS, Commercial systems where corrections are provided via satellites such as Spot-beam, and Inmarsat The important thing is, it does not matter which route the corrections travel they essentially do the same job. A major difference will be cost ranging from free, to expensive.

The system consists of a network of reference stations in known locations, a central control station, and a link to a communications system.

When signals are received from satellites the pseudo ranges are calculated (Figure 3) and raw position lines are plotted, this plotted position will contain errors from various sources. Timing errors are calculated and applied to give corrected position lines that cross in the actual position of the reference station.

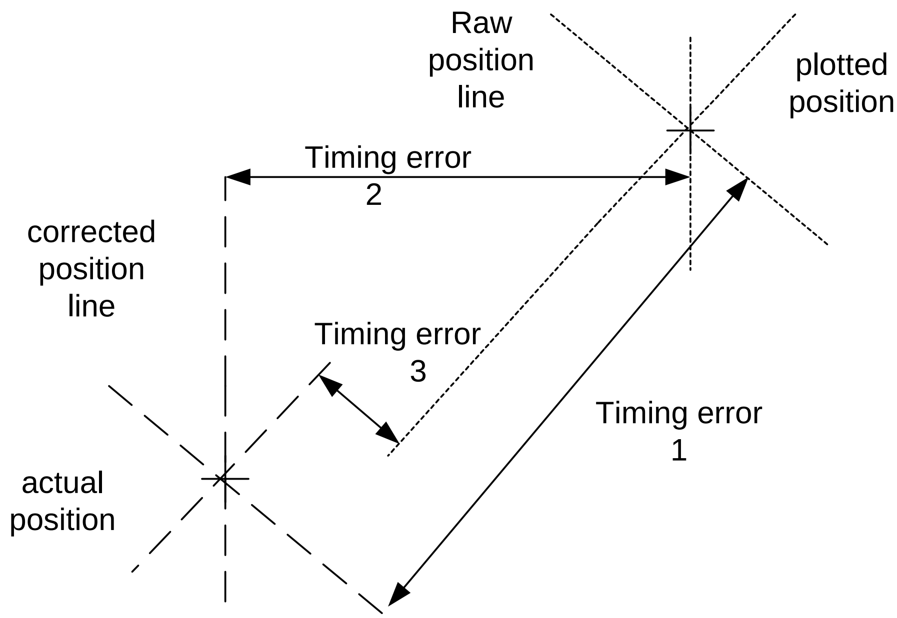

Figure 3 Calculation of Timing Errors

These timing errors will then be checked and may be coded, and then sent via the control hub where they are transmitted to the user via a communication system. These systems also usually also calculate the rate of change of error to allow interpolation at user end for the age of correction.

Signals that are to the standard RTCM SC104 (ITU-R M.823) are used in over 35 countries.

4.3 Dual Frequency DGPS

This system came into being to counter the effects of localized signal refraction caused by sunspot activity. The effect of this localized refraction means that corrections calculated at the reference station are not valid at the user location (Figure 4)

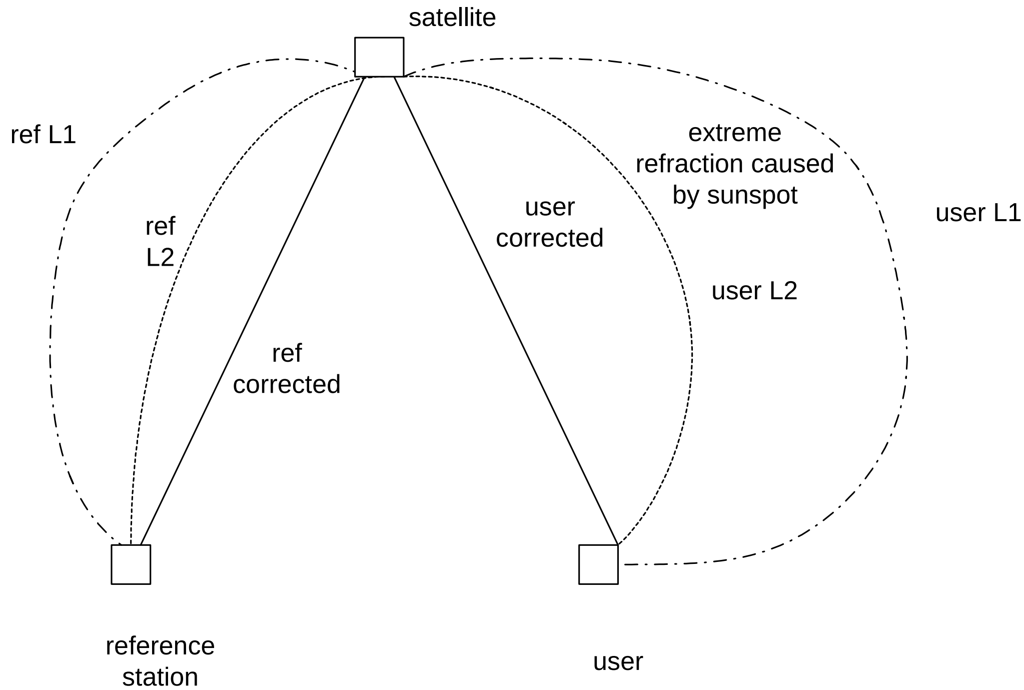

Figure 4 DGPS Refractive Errors

The system calculates atmospheric corrections at both the reference station and the user. The difference in refraction is measured between the 2 frequencies, the frequency of the 2 signals is known so the actual amount of refraction can be extrapolated. The reference station then generates correction messages for the atmospheric interference (IRC's). These come in several formats, which comply with RTCM standards.

These are then transmitted to the user end, the user calculates local IRC to correct own atmospheric interference, this interference free signal is then has the interference differential signals applied to it to give a fix that is free from atmospheric interference

4.4 Real Time Kinematic

This method is based on measuring phase difference in the carrier. The make up the CA code is such that a section of transmitted CA code covers about 300m, however the carrier wavelength is about 20cm, measurement of phase difference therefore permits calculation of refraction errors with centimetric accuracy. One of the major problems is resolving the ambiguity between one section of the carrier phase and the next (Figure 5) this ambiguity must be resolved at both the user and the reference and user station. There are several methods they all usually need high-speed data links of about 4800bps or better, to permit the fixes to be correctly calculated within a timeframe suitable for real time use.

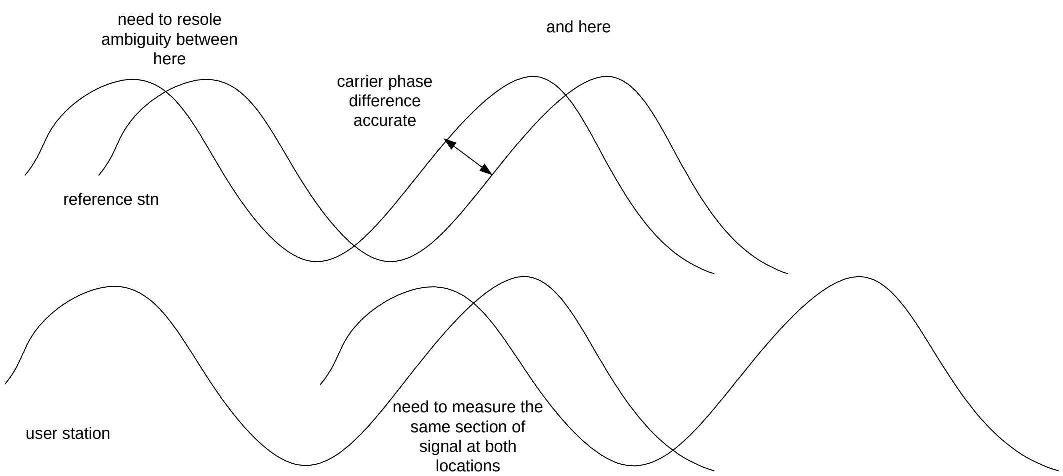

Figure 5 Real Time Kinematic Phase Errors

The first method corrects single frequency L1 GPS, a search area is set up based on statistical data, all solutions are calculated for that area, and the best solution is picked based on minimum variance. This is then validated against the next best solution.

A second method uses Dual Frequency; a wide lane is generated (86cm) to resolve ambiguity. The position can then be calculated by either working out a solution for the carrier phase difference of both L1 and L2, the final position will be the most accurate, but can be less reliable. Another way is to work out a solution based on the carrier phase difference between L1 and L2, this is more reliable but not as accurate as calculating solutions for each carrier. There are many combinations of the above methods.

The operation of these systems is limited to about 40 km so would require local reference stations setting up. A long range (500km) system was available in Europe but correction signals have been discontinued.

4.5 Optimised Solutions.

DGPS usually assume that the errors experienced at the user are the same or similar to the errors at the reference station, this may not always be so. There are optimized solutions that allow for the differing conditions between reference and user stations.

4.5.1 Virtual base station

One method used is that of a virtual base station, the user receives differential corrections from multiple references. The user DGPS will then apply weightings to the all the corrections and then pool them to generate a single set of corrections.

4.5.2 Local and wide area networks

Another method is to set up networks these can be local area, or wide area networks, these are used offshore, but also for aircraft landing systems such WAAS, MSAS, EGNOS, LAAS. It is also used in systems ashore in agriculture. Reference stations are set to report to a central hub, errors are then optimized for the coverage area and broadcast to users within the network area. The national continuously operating reference station (NCORS) is one system providing this data in America.

4.5.3 Error segmentation

One of the latest processing tools is to break the errors into different parts, these consist of:

- User independent errors such as satellite clock, satellite orbit, atmospheric errors
- User dependant, receiver errors, multi-path

The atmospheric errors can be corrected with dual frequency technology; clock errors and orbital errors can be measured and transmitted as a separate correction. Receiver errors can be calculated with carrier phase measurement. Multi-path can be minimized with improved models, and improved antenna design using choke rings for single and dual frequency systems.

4.6 GPS and INS combinations

Inertial Navigation System (INS) technology is not new and has been available since about 1950. It is based on the operation of fibre optic gyro (FOG), or ring laser gyro (RLG), where motion is detected measuring light travel. By setting up separate sensors, direction and magnitude of motion can be measured in horizontal, vertical, and heading planes. From a known start position an estimated position can be calculated.

There are two drawbacks: the first is that over time the accuracy of the estimated position decreases, so the INS needs to have position updated from an external PRS. The second drawback has historically been cost. INS systems used by the military while of the best quality and highly accurate are expensive. However recent technological developments have permitted the production of reasonably accurate INS units to be manufactured for the commercial market.

There are now systems available (Figure 6) that will accept an input from GPS and Doppler velocity log (DVL). GPS is output as a PRS, in the event that the GPS fails the unit will switch to INS navigation, with DVL connected drift in the region of 1m per hour is expected, without DVL drift rates in the region of 3m per minute can be expected.

Figure 6 Combined GPS INS Module

4.7 GPS intelligent buoys (GIB)

The system allows a vessel that has no acoustic systems fitted to track submerged vehicles (Figure 7). The system consists of a vehicle with a pinger (a beacon that transmits an acoustic signal at a fixed interval), three or four buoys fitted with acoustic receivers, GPS receivers, and a radio transmitter. The vessel is fitted with a radio receiver, and a data processing computer.

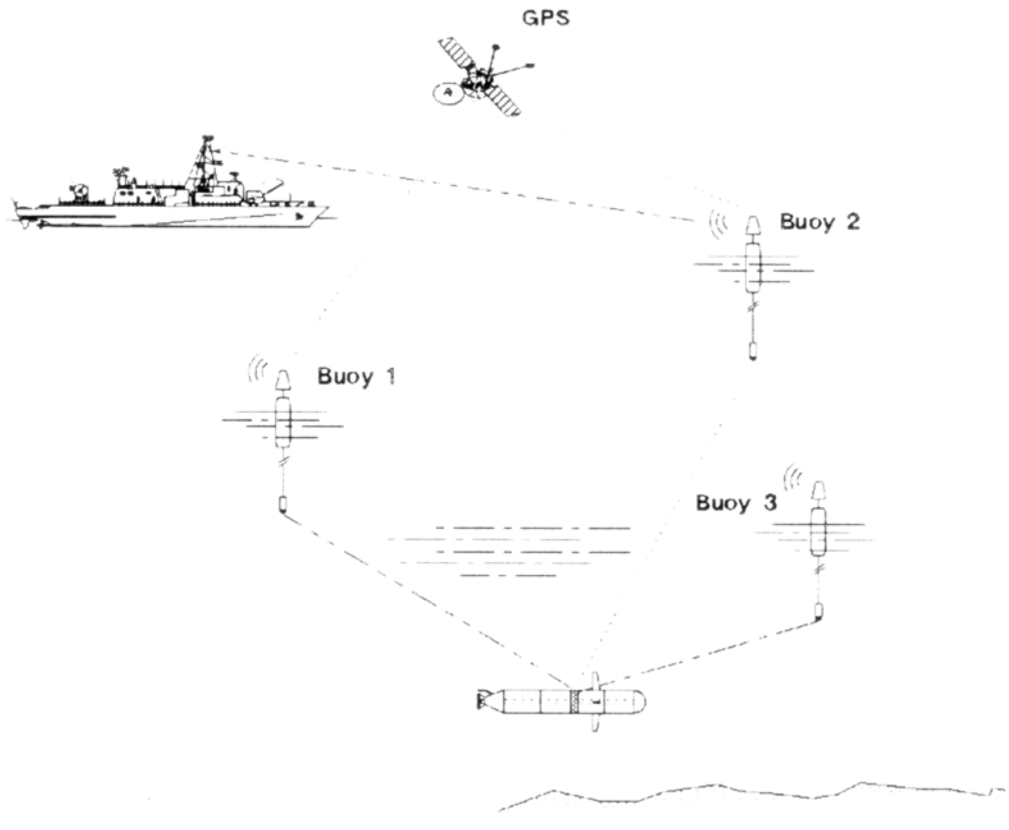

Figure 7 GPS Intelligent Buoys

The submarine transmits acoustic signals which are received at the buoys at different times depending on the range. The buoys then transmit the time of reception, and buoy position to the vessel supervising the operation. The buoys positions are then plotted and the range to the vehicle is calculated using the time delay between signals, and the speed of sound in water. The position of the vehicle is then calculated from the range data.

The buoys can be moored if water depth allows so that the array is maintained, or free floating if water depth is too great. In the latter case the buoys must be manually repositioned or fitted with some form of controllable propulsion in order to remotely maintain the array.

4.8 Differential (GPS) absolute and relative positioning (DARPS).

This is mainly used by shuttle tankers to obtain a correct relative position to Floating storage facility of some kind e.g. FPSO. The system will work with raw GPS, each vessel has a GPS receiver and a radio transmitter, the shuttle tanker also has a processing unit.

When the shuttle tanker is in range radio contact is established, the storage tanker transmits its fix to the shuttle tanker, the shuttle tanker plots its own and the FPSO fix. The relative range and bearing is then calculated, if there are errors in the GPS fixes it is likely they will be similar due to the proximity of the two stations so that the relative range and bearing should still be correct (see figure 8)

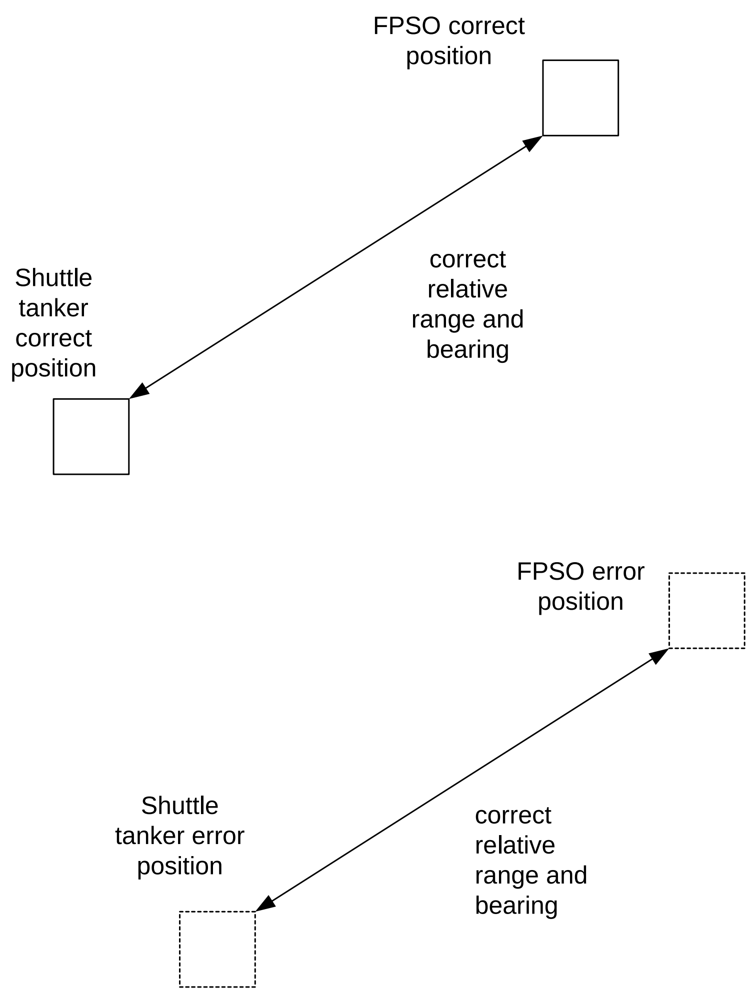

Figure 8 DARPS

The system will work with raw GPS, however systems are now made that will operate with DGPS, dual frequency DGPS. The demand for this system is such that now extra time slots have had to be inserted in the timing so that a second is divided into 13 parts permitting more than one station to operate on the communication frequency. Extra frequencies permitting further system extension have also been assigned.

4.9 GPS Compass.

While not a position reference it is an offshoot of GPS technology and can be used offshore. The Norwegian government will accept a GPS compass as the third heading reference required for a class II DP vessel.

There are several examples available, the unit consists of 2 GPS receivers that are aligned either fore and aft, or port and starboard. The unit will need to go through a calibration procedure upon installation, this will be the only one needed provided the unit is not moved or modified. The unit is also relatively maintenance free.

The system uses carrier phase difference measurement at the two receivers is used to derive heading information, including, rate of turn. The quality and reliability of the information can be improved by providing the unit with differential information either in the form of DGPS, or RTK inputs. These units usually also provide positioning and velocity information.

If GPS signals are lost the heading output is also lost, some units are fitted with a back up system in the form of an inertial gyro that will sense heading change and update the heading until GPS signals are restored.

5 Problems

5.1 Atmospheric interference

Satellite signals are refracted or bent as they travel through the earth's atmosphere; the two areas of the earth's atmosphere where refraction is caused are the Ionosphere, and the Troposphere. In the Ionosphere refraction is a result of ionisation caused by solar radiation. The amount of ionisation varies with night and day, time of year and solar activity. There is sunspot activity that occurs on an 11 year cycle, the height of the last cycle was 2001, and at times this caused extreme localised ionisation called Scintillation.

In the Troposphere the refraction is caused by temperature, pressure, and humidity of the atmosphere.

The standard way to deal with this was modelling where the refraction was modelled for large areas, and refraction calculated and allowances made for the refraction. This was satisfactory provided that conditions at the user location were the same or similar to the modelled conditions, if they were not the errors could be caused, or losses of signals result. When Differential corrections are being used it is also necessary that the conditions at both the user and the reference station are similar, or the correction calculated at the reference station would not be valid at the user station.

The situation can be improved by several ways some of which have already been introduced, the first is network systems where corrections are corrected for the area covered by the network, and the user being in the network receives valid corrections. Of course you be in the network area for the corrections to be valid.

The second is dual frequency DGPS, where separate corrections for atmospheric interference are calculated for both the reference, and user station. To be able to use this facility the user must be in range of a dual frequency reference station and also be fitted with dual frequency equipment.

There effects can some time be reduced by the vessel picking reference stations that are outside the area affected as reference station are often affected more than offshore users , to be able to do this the user must have a differential that operates over a long distance.

Lastly as SA has been removed it is some time possible that the vessel can switch to raw GPS and have a reference that will operate, but with a greater spread of fixes.

5.2 Multi Path

Multi-path is caused by satellite signals bouncing off nearby objects and being reflected onto the satellite antenna. These nearby objects can be onboard own vessel on other nearby vessels or platforms This sometimes called “long-path” interference as the signals follow a longer path (Figure 9).

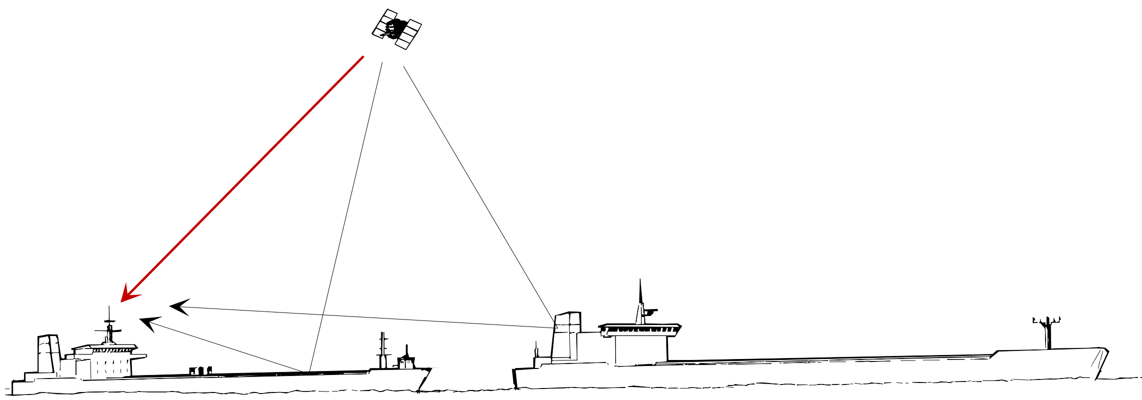

Figure 9 Multi-path effect.

The signals have the correct frequency codes, etc so are accepted by the satellite receiver causing interference, and in extreme cases signal drop out.

There are several methods to try and combat this effect, some are based on signal processing, and others are based on improved antenna design. One signal processing method works by detecting the fact that the indirect signals lagging, are at a slightly different phase and can be differentiated. However if the difference between the direct and indirect signals is small the processing will remove some of the direct line signals and increase the level of noise.

Improved antennas such as choke rings have been designed (Figure 10)

Figure 10 A Choke ring antenna with radome

The Choke ring suppresses multi-path signals from below, the choke ring sets up secondary reflected signals that has opposite phase to the GPS signals that cancel out the indirect signals, the frequency and phase the frequency and phase of this “anti signal” depends on the depth of the choke ring, this means that Choke rings are only really effective for one frequency (L1 or L2). The choke is only completely effective signals at the zenith at least effective with horizontal signal.

There are dual frequency choke ring antennas; these have a baffle that gives the rings a dual depth. Some designs are more effective than others but dual frequency antennas are generally less effective than single frequency counterparts.

5.3 Poor Constellations

Affect the reliability of the fix, the best cross is if position lines cross at right angles, then if there are any errors it will have the least amount of error (area of uncertainty). If position lines cross at shallow angles and there is any error, the shallower the angle of cross the greater the amount of error (area of uncertainty) it will cause (Figure 11)

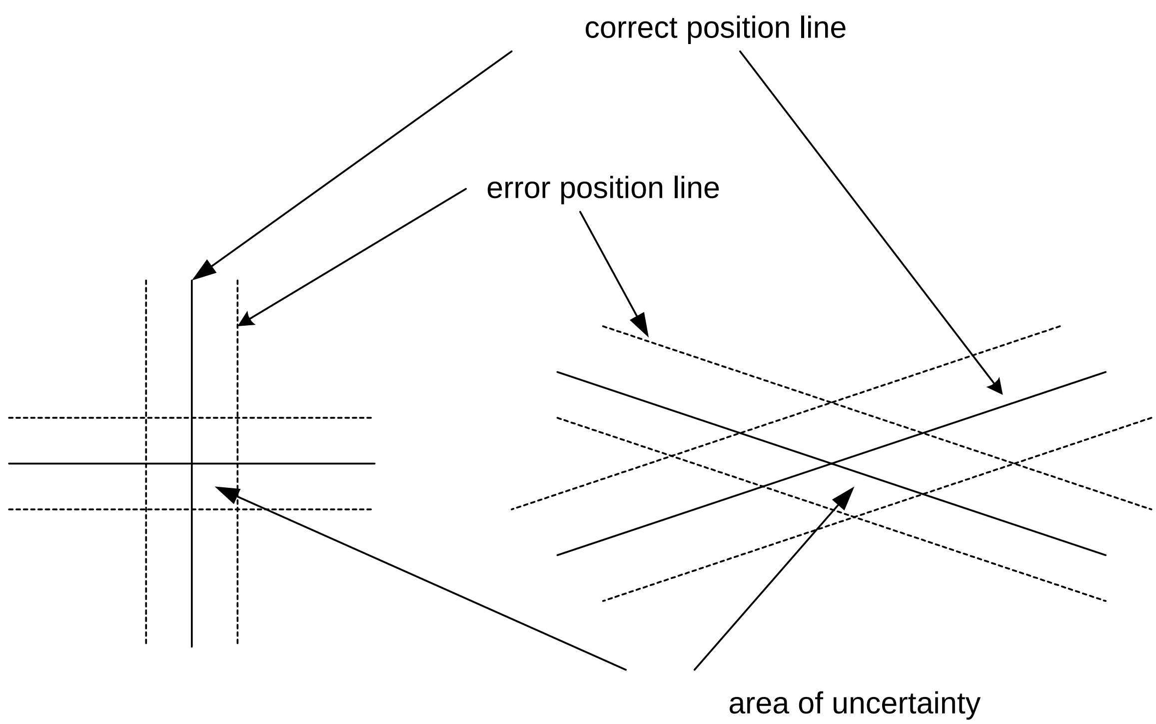

Figure 11 Area of uncertainty

This is usually caused by too few satellites, this may be because the system in use has a reduced number of satellites, GLONASS for example had recently as few as 6 or 7 satellites available. A second cause may be that an external structure such as a large platform or vessel is blocking the line of sight to satellites. Another scenario is when the line of sight to DGPS corrections is blocked.

Planning the use of satellites can reduce this effect, there are satellite planning programs that allow the user to check satellite availability. There are extreme cases where the shadowing is caused by users own vessel; a satellite antenna array can help to reduce this problem.

5.4 Old Satellites

GLONASS has been particularly troubled, between January 1989 and December 1995 44 satellites were launched to keep the constellations topped up. There were then no more launches until December 1998 when 3 satellites were launched, then in December 2000 an annual top up launch program was started with 3 new satellites launched each year. In December 2000 there were only 14 GLONASS satellites and only 9 were operating. This reduced at its lowest to about 7 operational satellites. This meant that the system could not provide 24-hour 7-day per week worldwide coverage, and horizontal accuracy when available was in the region of 70 metres. In 2000 the Russians entered into talks with the Chinese to secure funding for the new launch program, at present there are 11 GLONASS satellites with 10 operational.

The GPS system has not had problems to the same extent as GLONASS; the GPs system requires 24 operational satellites, 21 operating with 3 spare. GPS Block I satellites were the test bed satellites and are not covered here.

The operational GPS system is made up of Block II satellites, the Block I were a test bed system and their use was discontinued after the successful trial.

Nine Block II satellites were launched, 2 are still in service, 19 block IIA satellites were launched, 16 are still in service, 12 Block IIR satellites have been launched 11 are in use, as the first satellite failed to become operational. It is planned that 8 IIR satellites will have M-code overlays, and broadcast on an improved L2C frequency, this will be dealt with later.

This means there are 29 satellites available in the GPS system, however some of these satellites have faults, and some have exceeded their planned life cycle. At present, 7 satellites have a failure in one of the onboard navigation systems, 1 satellite has had a failure in one onboard computer bus, and 4 satellites have a failure in both an onboard navigation system and a computer bus.

The planned lifecycle of GPS satellites was about 7.5 years, IGEB are allowing a 10-year lifecycle for all satellites. This means both block II satellites exceeding the 10-year lifecycle. Of the Block IIA satellite only 4 of the 16 satellites have not exceeded the 10-year lifecycle. The Block IIR do not start going out of date until December 2007.

The GPS system has an excess of satellites, but with 8 satellites on single onboard failures, 4 satellites with failures in 2 separate onboard systems, and 14 of the 29 satellites having exceeded an extended lifecycle, there is potential for a decrease in availability.

5.5 Clock errors

When range is calculated by measuring the time delay between transmission and receipt of a signal, it follows that you have to know the time the signal was sent from the satellite, and the time it was received at the user end. If there are clocks errors at either the satellite or user range, and position errors will result.

The Satellites are fitted with atomic clocks, they are accurate, but they are not perfect. The satellite signals travel at about 186,000 miles per second so 1 millionth of a second error would have a noticeable effect. The ground controllers monitor the satellite clocks, and clock errors can be corrected. As an example a Block IIA satellite usually needs correcting twice a year, this will result in about 18 hours downtime.

At the user end the situation is different, it is not at present possible to achieve atomic clock accuracy so when there are receiver clock errors position errors will result (Figure 12).

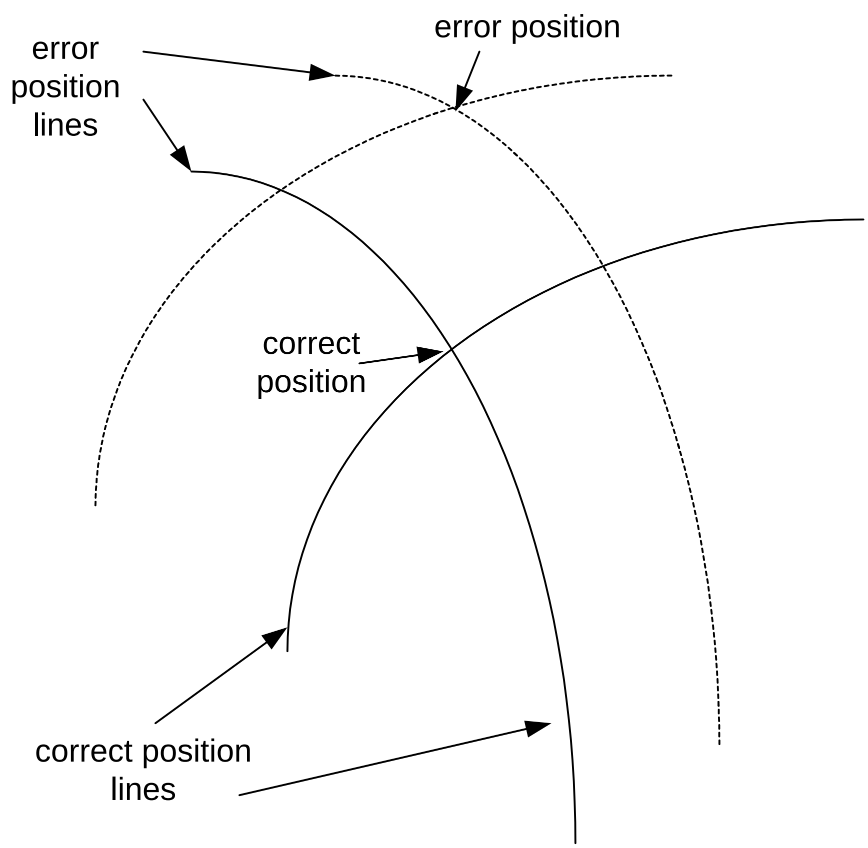

Figure 12 Error caused by receiver clock errors

A method has been found to minimise this using a minimum of 3 satellites, Figure 13 shows a cross from 3 correct position lines, and a “cocked hat” from three error position lines. The error in the position lines is assumed to be similar as the measurements are taken at the same time. As shown in Figure 13 all three position lines cannot cross in the same place, a program is run that systematically applies errors to the position lines until an optimised cross is achieved. The receiver clock error is now known.

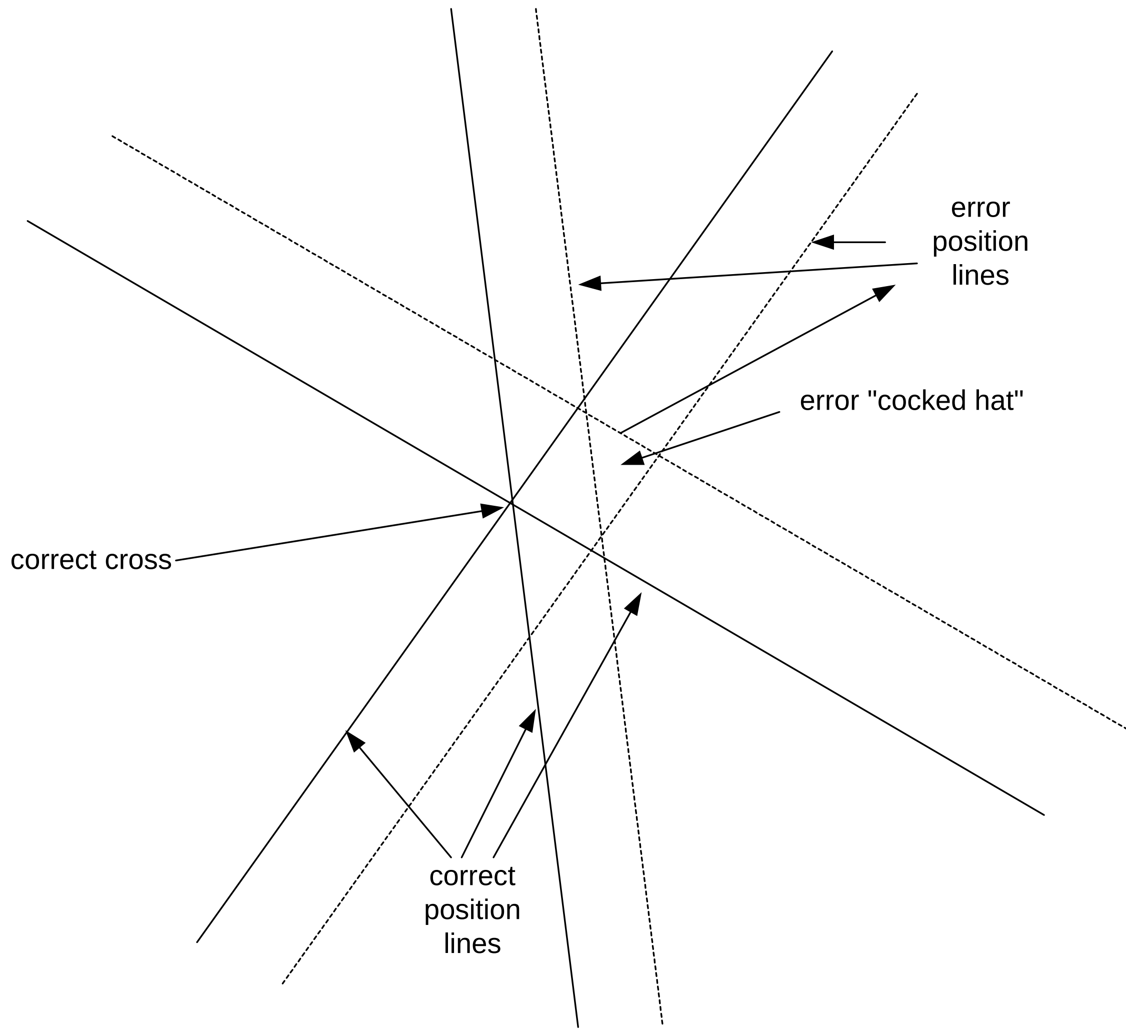

Figure 13 Cocked hat caused by multiple position lines with timing errors.

5.6 Operator error

There are two major concerns here, human error at the user end, and human error in the control system. In these two scenarios user error is known to occur. This can be caused in several ways, incorrect initialisation, such as incorrect trial points, and height aiding. Lack of awareness of failure modes, such as having separate units set to the same hubs, reference stations etc. Poor set up by having separate systems in the same space or connected to the same power supply. Poor bridge design can contribute, such as having the (D)GPS unit at a remote location so the operator cannot here alarms or note that units have changed to DR navigation. This should properly be the subject of a separate paper.

While the control segments would be a much easier section to quantify errors on, it has not been possible to obtain such figures. There are mentions of such failures but as they have not been verified they are not included. However should such human errors occur they should be rectified.

As an example on July 28th 2001 SV22 had a positioning error of 300Km that lasted for 2 hours. On May 25th SV 27 had an error that increased until by 1733 UTC may 26th it was 38m and the satellite was shut down. These were due to satellite failures (I believe) but they were detected and dealt with.

The GPS satellites are monitored by the US Air force, NASA (JPL (Jet Propulsion Laboratory)), and National Imagery, and Mapping Agency (NIMA). Once faults or problems arise there are 4 levels of reaction from the control segment:

1. Remove the carrier to make the SV unusable
2. Make the PRN code untrackable (also called SATZAP)
3. Set the SV status to unhealthy, so that it is not used.
4. Issue a separate warning to the user

IGEB are involved in a Integrity failure modes effect analysis (IFMEA) of the GPS system

5.7 Security concerns

The major satellite systems that are in use at present have some military function, to ensure the integrity of the satellite system they need to be protected from jamming, and may well include a system to degrade the signals so that users that do not have military grade receivers will operate at a decreased accuracy.

GLONASS has historically not been degraded; though this does not mean the facility does not exist. GPS used a random timing error called dithering or more commonly Selective Availability this however was set to zero in May 2000, and IGEB have said it is not intended to re-instate it.

Satellite navigation jamming systems are available on the Internet, a 1 watt jammer can be built that is the size of a coke can, and will cause interference over an area of about 2km. To counter this it will be necessary to make the satellite signals more powerful. Unfortunately if signals are jammed for military reasons civil users will suffer.

There are other signals or overlays that are available to the Military that allow them to obtain more precise fixes, and reject false signals; existing overlays are not included in this paper, but the latest GPS overlay will be mentioned in Section 6.

6 Planned Improvements.

6.1 Galileo.

Galileo is a satellite navigation system, not under military command, being provided by the European Union (EU). The system will compose 30 satellites (27 operating and 3 spare), in three medium earth orbital planes offset by 56 degrees, orbiting at about 23000km. They are expected to operate in L1, L2, E1, E2, E6 bands; it expected that 4 navigation carriers will be broadcast. The satellites will have two clocks, one a Rubidium atomic clock, and a Passive Hydrogen Maser.

Apart from navigation signals, the satellites are expected to broadcast system integrity data, search and rescue services to the COSPAS SARSAT system, and commercial information.

The ground system will comprise a Navigation control system and a Satellite control system. Navigation control will be responsible for collecting and collating the orbital and synchronization information from tracking stations. This will be passed to Satellite control which will use a system of uplink stations to load information onto satellites, and carry out corrective control, of orbit, status, timing, and message broadcast.

The system has had some serious difficulties to overcome, not the least political; one of the first was internal disagreement between member states over items such as construction and running contracts. At the time of writing, resolution to these issues appears to be in hand and the project is moving forward. The second issue was potentially the greater of the difficulties; part of the frequency band which had initially been assigned to Galileo would going to overlap the part of the GPS signal intended to be used for the new security M code overlays. The United States DOD was adamant that they would allow nothing to impinge on the security of the GPS system; it seemed for quite some time that there was no common ground. Various Committees were set up and technical discussions held, and in June 2004, reduction in the size of bandwidths, effectively removing the potential interference, was agreed upon.

The project has gathered investment and co-operation from the Russian federation, China, India, and Canada. The investment has taken various forms: financial investment, shared launch facilities, and co-operation over frequency sharing.

Galileo is expected to be operational by 2008, it is planned there will be experimental satellites launched by 2005, with the next series of satellites performing the In Orbit Validation (IOV). It is planned that some of the IOV satellites will be launched in co-operation with GLONASS. The French Ariane rocket will also be used as a launch vehicle, it is planned that multiple satellites will be deployed during each Ariane mission.

The system will be capable of positioning using single frequency tracking, dual frequency operation. At the time of writing, there is discussion of a precise positioning service but details are not available.

In addition to the services described Galileo will also be able to transmit data, for navigation, commercial, and safety purposes. The messages will have a packet data structure so that safety related messages would not be delayed. The system will also be capable of transmitting system integrity messages that will give user warning of systems failures within 6 seconds, it is not known if this will be acceptable for safety related uses. However, integrity messages could be broadcast on differential links that would give warnings within 1 second but that would not be an integral part of the Galileo system.

6.2 GLONASS.

As previously mentioned, the system has suffered from funding problems. Since he original Uragan satellites had an expected lifecycle of about three years frequent launches were needed. Consequently when funding was cut back the system became degraded until the number of operational satellites dropped to around seven units. Twenty four hour coverage was consequently not assured, and accuracy dropped to the region of seventy metres.

To remedy this situation two actions have been taken; firstly funding has been negotiated with China, this has enabled replenishment of the constellation with annual launches, there are now 11 satellites in orbit 10 of these are in operation, the status of onboard systems is not known. Secondly agreement has been made with India over launching satellites, India could launch between eight and nine satellites for the GLONASS system. It remains possible that the eighteen operational satellites planned for 2007 could become a reality.

It is also intended that new satellites would be of the Uragan type M or type K (with planned life cycles of seven and ten years respectively), reducing the requirement for frequent satellite replacement.

Upgraded signal structure for the system has been considered but no definitive information for the public domain is currently available.

6.3 GPS

GPS remains the most widely used Satellite based navigation system, however as the system has become adopted in more diverse applications a number of previously unforeseen problems have come to light in each area of use.

In the offshore industry the following issues have affected the reliability of GPS positioning:

- Poor constellations caused by too few satellites
- Atmospheric interference, especially scintillation, the localized signal bending was particularly problematic during the peak of the 11 year cycle in 2000
- The effect of deliberate military degradation of the system, coupled with the fact that SA could be varied at any time, and indeed was on several occasions
- The build up of faults on the satellites, and the fact that the age of many satellites is greater than the planned lifecycle.

Many of these issues have been dealt with using both software and hardware solutions, for example augmentation systems and improved modeling. Additionally setting Selective Availability to zero, with no known plans for re-instatement has also made it possible to get a true assessment of GPS capabilities.

There are several additional improvements, which are in hand or in the planning stage. The launch program of Block IIR (replenishment) satellites has already commenced with 12 launches of which 11 are in service, one having failed. It is planned that eleven more will be launched and eight of these will be the Block IIR-M type, whose improvements include, higher power signals to improve jamming resistance. It is intended to provide a new civilian signal on L2, to be designated L2C (S); this will have an improved signal structure improving tracking reliability. In this latter instance, the concern to the user will be that it will not be interoperable with present equipment, It has been suggested that the new satellites will broadcast old style signals to provide an overlap until the system is fully operational.

The Block IIR-M satellites will also broadcast the M code; these will replace the Y code, which is an encrypted P code. The M codes overlays are a binary offset carrier 10.23, 5.115 (BOC10.5) that is a sub carrier at 10.23 MHz, with a spreading rate of 5.115 bps. This should resist jamming better than the Y codes, and allow the operation of selective deniability, where a specific region can be denied to users without affecting the whole system which would be the case if SA were to be re-instated. It was this frequency band that contained the overlays that would have been interfered with by the proposed Galileo signals.

It is expected the first IIR-M will be launched in 2004.

The next planned generation of Block II satellites is Block IIF. Contracts have been awarded to Boeing and satellites 1 to 3 are under construction with additional contracts in place for satellites 4 to 9. It is envisaged that there will twelve Block IIF satellites; each will have a planned 10-year lifecycle and three atomic clocks. It is intended that they will broadcast civilian signals on L1 and L2 these should be of the newer type, and, as noted above, interoperability with older satellites will need to be taken into account. P and M codes will also be broadcast on L1 and L2. A new signal will be broadcast on L5 which will be a high power precision navigation signal open to all users, it will also allow dual frequency operation for aircraft, and the calculation of corrections for atmospheric interference. In addition it will offer the possibility of improved continuity if L1 or L2 is lost.

The system should be jam resistant, having an extra 20db of power, the P and M codes will also have "flex power" to defeat low level jamming. Block IIF is planned to commence in 2005.

It is also planned to upgrade the ground control segment. Boeing has also been awarded the contract for this work. Following the improvements in the satellites it is expected that satellite control functions will be upgraded. An extra tracking station in the ground control section is planned.

A further system, GPSIII, this is still in the research phase. Contracts have been awarded to Boeing and Lockheed Martin to commence the System Architecture Research and development (SARD).

The following improvements for civilian use are under consideration:

1. Significant increase in system accuracy
2. Assured and improved level of standalone integrity
3. Improved availability of accuracy with integrity
4. Backward compatibility with existing receivers
5. IOC for L5 (in combination with IIF satellites)
6. Smooth transition from GPS Block II to Block III
7. Flexibility to respond to evolving requirements with limited programmatic impacts following the preliminary design stage an in depth risk assessment to reduce risk in the final engineering – manufacturing – design phase (EMD).

The system will have a planned lifecycle of 30 years. The only specific details to have been published to date are that the system will have three orbital planes not six, that to ensure coverage the orbits will be non-reoccurring, and that the open signals will have the same structure as the Galileo system.

6.4 Chinese Satellite systems.

The Chinese system is known as Beidou (Big/Northern Dipper), it is regional, and operates with 2 geo-stationary satellites launched in October and December 2000. Beidou 1A is at 80E, Beidou 1B is at 140E, both orbit at an altitude of 36000km. A third spare satellite was launched in 2003.

The system is believed to operate in a similar manner to the discontinued American private sector Geo-star system, in that signals are sent between the user and the ground sector, which calculates position and sends the position back to the user. The system is two-dimensional only and has a separate communications function.

The system is designed for both military and commercial use with the commercial being utilized for infrastructure control and navigation in the Pacific. As the system is not global it cannot be compared to the likes of GPS, GLONASS, and Galileo.

The Chinese have expressed the intention to build a worldwide GPS type satellite navigation system, and likely have the will and the resources to carry out the project when the technical knowledge is available. If this was an open signals it could make the improvements possible in 6.5 of greater value.

6.5 Combined Systems

The co-operation between, Galileo GPS, and GLONASS sees all of the major worldwide GNSS systems co-operating to some greater or lesser extent. At present the majority of satellite navigators use the GPS system and, to the general public, GPS is the term used to describe all satellite navigation systems.

In the mid 1990's several GPS/GLONASS receivers were available, but with the decline of the GLONASS system these have become relatively rare. A simple web search will now show that combined systems are again becoming readily available and there are some twenty four dual channel system satellite navigation receivers on the market already.

One academic foundation has already put forth a proposal to construct a combined GPS/GLONASS/Galileo receiver. Such a device could give the user access to twenty one GPS, twenty seven Galileo, and seventeen GLONASS satellites: a total of sixty five satellites. With this degree of flexibility, poor constellations could be avoided by choice of optimal satellites and system failure would not be the major concern it is now, due to the availability of system level back up. At this point GNSS systems could be classed as a truly redundant positioning service. In additions there would be the opportunity to minimize multi-path effects by choice of optimum constellation selection.

In using multiple systems satellites could be selected not only on position in the constellation but by age, health status, and integrity information, if available.

Of the sources of interference scintillation is probably one of the largest concerns and though sunspot activity is in decline at the moment, the next peak is due in 2012; studies are already underway to investigate how atmospheric interference can be assessed and corrected using triple frequency monitoring.

7 Conclusions.

The use of satellite navigation systems is rapidly increasing. This use is not restricted to military and offshore operations; these are in fact percentage wise amongst the lowest users of GPS signals. GPS is used in many diverse applications; agriculture, aviation, surveying, construction, geology, construction, leisure, and vehicle tracking for personal use or transport systems, these are the largest users of GPS services. Each area of use has its own concerns. Offshore users are not concerned with getting the smallest GPS package, or skyscrapers blocking out signals, their concerns are with achieving accurate and reliable signals and fixes.

Operation without augmentation of GNSS signals is possible depending on how safety critical the operation is. However, there are problems such as interference caused by multi-path, sunspot activity and atmospheric delays, errors such as receiver and satellite clock errors, orbital errors, deliberate degradation by military users, and poor fixes due to lack of satellites, caused by blocking by platforms or other vessels Whilst these problems are being reduced by augmentation, they can still be the cause of loss of fixes. With Selective availability removed, the user is now aware of the true causes of positioning error, and manufacturers can work towards minimizing them.

To the offshore user this means that the GNSS is a useful tool and the most widely used position reference. It is to be expected that its use will probably become more widespread and less costly.

GNSS can however have severe limitations, particularly when operating close to platforms or large vessels. These are the situations that GPS is most depended upon, and also the time when satellite systems are least reliable. Multiple satellite receivers do not make the system truly redundant; if one receiver fails due to signal loss it is likely that all the remaining receivers will fail in the same manner. This means that for safety critical operation, especially with Dynamic Positioning it is necessary to use more than one type of position reference system; this situation will exist for the foreseeable future.

Multi-path propagation is also a problem when operating close to structures. Differential systems can detect reflected signals allowing the user the chance to change the system configuration and reduce the effect. Choke rings are available that can reduce this problem. In critical situations multiple receiver arrays can be installed and the optimal GPS solution selected.

The above solutions only partially resolve the issue of multi-path propagation and signals from above remain problematic. An effective way of accurately detecting and rejecting all multi-path signals is still required. One suggested solution is a system where remote station is set up on the platform in a clear location that could send GPS signals by telemetry, assuring the integrity of that link would be vital.

Improved models, optimised solutions and dual frequency DGPS can reduce the effects of atmospheric interference, modeling alone is not fully effective. Dual frequency technology and corrections are relatively expensive. In addition, this method of operation is limited to areas where dual frequency signals are available. To use optimised solutions it is necessary to be within the network area. The simplest solution would be to measure atmospheric interference on a global basis and provide corrections in an RTCM format. Whether this will ever become feasible remains a matter of debate. Improvements in technology may lead to the development of automatic detection as well as making such systems more available and cheaper.

It should be noted that satellite systems are not redundant and that there are single points of failure within the system. Examples are that there is only one set of satellites, correction systems often depend on a single hub, and sometimes corrections are sent via a single communications link. Operator error may also be a factor, it is reported that one DGPS user had the DGPS corrections to all their vessels suspended due to an accounting error.

As more GNSS systems become available GNSS can become truly redundant systems, with operators having real choice of GNSS systems, and the satellites used. This choice of multiple systems may offer solutions to some of the other issues.

Finally, one item, which does not appear to be addressed by the GPS system, or plans for the future, is integrity monitoring Systems status is verified externally by monitoring, and checking, however, there are no systems status messages built into the satellite messages. Galileo is expected to include this, but it is not known if the planned 6 second warning will be satisfactory, nonetheless this could go a long way to removing concern regarding operator error in the control system.

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