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Novel developments within close proximity surface DP reference systems

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Abstract

The paper objective is to present the latest developments within DP reference systems for close proximity operations. The paper will also focus on some important topics frequently raised by users.

An overview of different types of operations given. Many of these operations will rely on relative GNSS. However, supplementary technologies are required of different reasons. The need for other solutions that GNSS will be justified.

Supplementary technologies to GNSS are usually microwave signals or lasers. The basic features of both microwaves and lasers are discussed and capacities and limitations compared.

Some driving requirements for close proximity DP reference systems are accuracy, range, reliability and integrity. The paper includes a discussion of these driving requirements and the respective trade-offs.

The paper includes a comparison between the features of reference systems based on practical implementations of a relative GNSS, a microwave and a laser system. The comparison is based on both theoretical analyses and real life experiences.

Different signal forms, improved signal detection and more powerful signal processing is improving the performance of microwave/laser technology development. The paper presents a discussion of these improvements based on the driving requirements including important risk aspects.

Introduction

The development of GNSS has for many years been driving the performance of surface based DP reference systems. From the early days of GPS when accuracy was degraded to tens of meters, to the current multi-constellation, global precise positioning solutions, game changing technologies have been presented to the market. During the nineties, someone thought that GNSS had the potential to become THE reference system, and the term sole-means-of-navigation was used. The sole-means-of-navigation concept does not seem very likely today. In spite of all the advantageous features of GNSS, there seems to be a rising awareness regarding complementary systems and these systems are continuously improved to match the performance of GNSS.

This paper gives a status update on the characteristics and latest development of surface based DP reference system technologies. In addition to GNSS, focus is on microwave and laser technologies.

Close Proximity DP Operations

A great variety of close proximity DP operations requires use of high performance surface DP reference systems. A characteristic development is that the size of the vessels involved increases together with the complexity of the operation.

Some relevant operations are:

- Offshore loading
- Gangway monitoring
- Heavy lift
- Platform support
- Anchor handling
- Offshore wind farm

Most of these operations typically involves safety critical aspects that impose strict requirements to the DP and the DP reference systems concerning:

- Accuracy
- Reliability
- Availability

Figure 1: Gangway-monitoring

The gangway-monitoring example illustrated in Figure 1 requires the relative vector between the vessels to be measured with just a few cm accuracy. The reliability of the measurements is expected to be very high since the consequences of undetected errors are potentially hazardous. The operation is preferably going on 24 hours a day, 365 days a year, and the availability of the measurements provided by the DP reference systems should be close to 100 %.

Close Proximity Surface DP Reference Systems

The different DP reference system technologies discussed in this paper are:

- Relative GNSS
- Microwaves
- L.A.S.E.R.

The list is not necessarily complete but these technologies seem to represent the majority of surface DP reference systems today.

During the late eighties and early nineties NAVSTAR GPS represented a real disruption of the different navigation systems available at the time. Even during the years with a limited satellite constellation and a deliberate degradation of accuracy, GPS was outperforming many of the other systems (e.g. Loran-C, Pulse-8, Argo, Hyperfix, Syledis, Geoloc). Later the success of GPS led to the development of other GNSS (Global Navigation Satellite System) like GLONASS, Galileo and Beidou.

GNSS can be used in two different modes, absolute or relative. In absolute mode, GNSS measures co-ordinated in an earth fixed reference system like latitude, longitude and height. The usual reference system is defined by WGS-84 (or any other datum). Accuracy of the GNSS provided co-ordinates can be expected to be at the meter level. By using a correction service (usually referred to as differential corrections) accuracy can be improved to 10-20 cm or better. By subtracting the absolute co-ordinates measured at two different points, the relative vector between the two points can be calculated. However, this is not always the most effective way of finding the relative vector between two GNSS antennas.

The alternative method is to apply a relative GNSS solution. By subtracting the GNSS measurements at two different GNSS antennas in near real-time it is possible to directly calculate the ΔX, ΔY, ΔZ between them with very high accuracy. This eliminates the need for using data from a correction service. The method is usually effective to measure the distance between two moving objects.

Figure 2: Motion Reference Unit

Both absolute and relative GNSS can be integrated with inertial measurements from e.g. an MRU (Motion Reference Unit). The method has been known from the beginning of the GPS era and is becoming more and more popular thanks to the development of navigation systems in automobiles and handheld devices. An integrated solution will enable calculation of a position even during periods with limited availability of GNSS signals and allow enhanced integrity checks of GNSS data.

Inertial measurements are also important to make accurate lever arm compensation of position and velocity from GNSS antenna points to the points of interest for the DP.

An alternative to relative GNSS is to measure the distance and bearing between two points by using microwaves. Microwaves are electromagnetic radiation in the frequency band between 300 MHz and 300 GHz. The usual frequency bands used for DP reference systems are either 5.6 GHz or 9.3 GHz. The bandwidth of the emitted microwaves is typically about 100 MHz. The signal might be emitted from a fixed or a rotating unit. The emitted signal will be reflected by any object in the proximity of the active unit, but to be able to identify where the reflected signal is coming from, a transponder/responder is used to give the reflected signal some kind of ID.

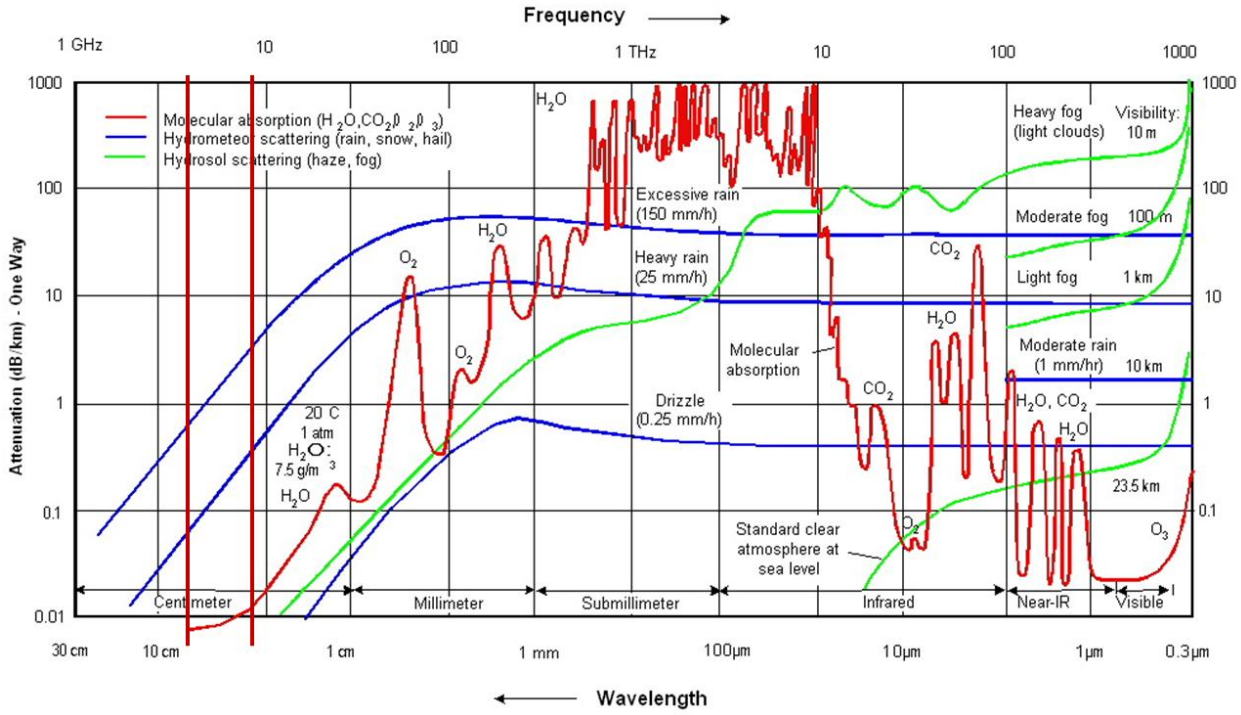

Figure 3: Atmospheric scattering/absorption of microwaves

All electromagnetic signals will partly be scattered/absorbed by the atmosphere. Figure 3 shows different effects of atmospheric scattering/absorption as a function of frequency. Red, vertical lines indicate the actual microwave frequencies. These frequencies are almost ideal since the scattering/absorption effects are very low in these bands (< 1 - 10 dB).

In addition to scattering/absorption, there are a few other effects affecting microwave systems which are to be considered:

- multipath interference
- in-band interference

Multipath interference can be caused by reflections from the sea surface (calm sea, no heave) leading to destructive fading of the emitted/reflected signal. Another multipath source can be reflections from metallic structures close to the transmitter/transponder.

In-band interference in the 5.6 GHz band is rare in a maritime environment, but X-band radar can occasionally cause interference in the 9.3 GHz band. To avoid in-band interference vertical separation between antennas can be necessary.

A third alternative to relative GNSS is to measure the distance and bearing between two points by using lasers. Albert Einstein made the theoretical foundation for LASER (Light Amplification by Stimulated Emission of Radiation) in 1917, but the practical development started in the fifties. Today there are many implementations, but the usual type used for DP reference system is based on 905 nm wavelength (infra-red) and a repetition rate of 7.5 – 30 kHz. Systems in use seem to use a vertical beam divergence of 10 – 20 degrees, and a horizontal beam divergence of 2- 4 mrad. Note that a beam divergence of 2 mrad represents a beam-width of 2 m at a 1 000 m distance. Since the human eye is sensitive to light and potentially can be hurt by laser light, equipment is expected to be so-called Class I. Laser based DP reference systems are based on transponders (reflectors) such as prisms, prism clusters or reflective tape. Usually, the reflectors do not provide any ID as the case is for microwave-based systems.

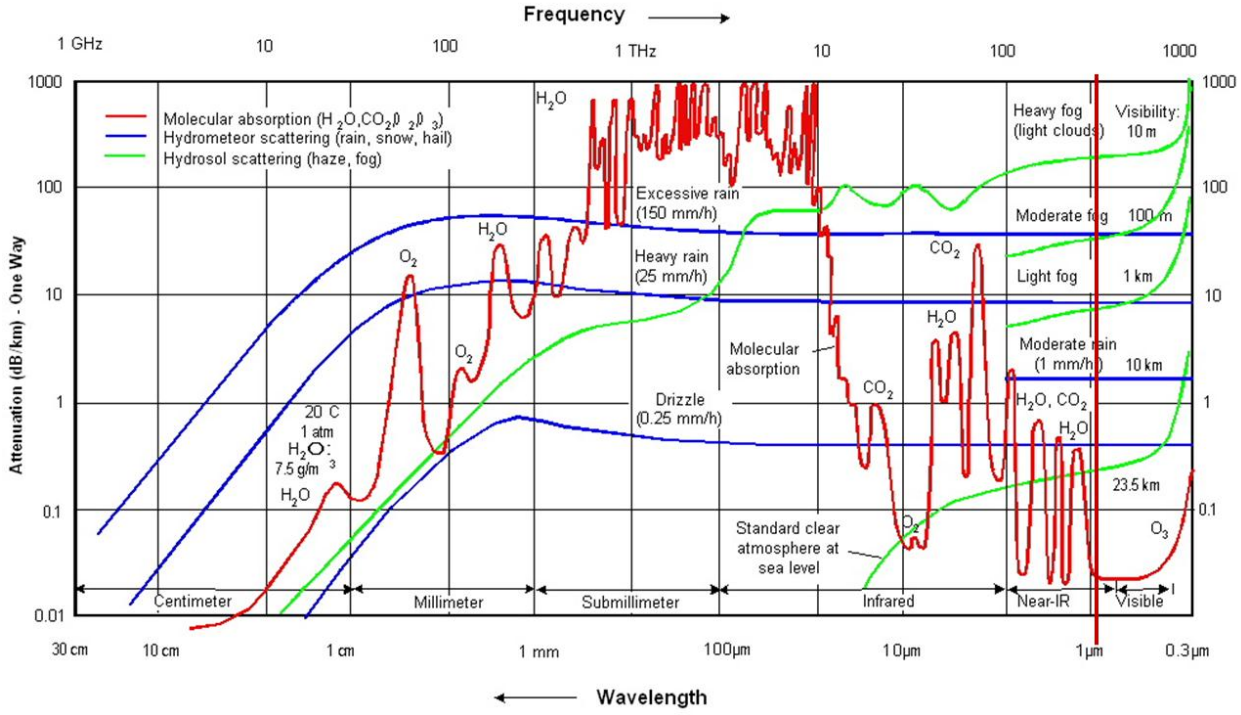

Figure 4: Atmospheric scattering/absorption of laser

Figure 4 shows different effects of atmospheric scattering/absorption where the red, vertical lines indicate the actual laser frequency. The figure shows that the 905 nm wavelength is ideal to avoid molecular absorption, while significant scattering due to humidity (e.g. rain) is significant (> 10 – 100 dB signal loss).

A qualitative comparison between the three technologies for surface DP reference systems is presented in Figure 5. A plus sign indicates an advantages, and minus sign a limitation. The figure is indicative, and there might be differences between different systems based on the actual implementation and trade-offs made by the vendor. However, the complementary characteristics of the different technologies are quite striking.

	GNSS	MW	LASER
Heavy rain	+	+	−
Fog	+	+	−
Snow/ice	+	+	−
Ionosphere	−	+	+
Sunlight	+	+	−
Interference	−	−	+
Multipath	−	−	+
Integrity	+	+	+ −
Heavy sea conditions	+	+	+ −
Complexity	−	+	+
Range	+	−	+

Figure 5: Comparison between DP reference system technologies

Driving Requirements

Unfortunately, there is a lack of consistency in the requirements to DP reference systems. It seems like the requirements have been driven more from the capabilities of the different solutions than from operational needs. This has to be expected in a technology push scenario but it is time to consider a more consistent approach.

One opportunity is to base the requirements on the performance pyramid used in aviation. The foundation is an accuracy requirement representing a 95 % confidence level. The next level is integrity based on the concept of defining protection levels and alarm limits. If the expected protection level is exceeding the alarm limit, the user (DP) will be warned within a certain amount of time (time to alarm) and there is a limited risk of misleading information. The third level is continuity, representing the risk that accuracy and integrity will be maintained for a certain time into

Figure 6: Performance pyramid

the future. Finally, availability is the proportion of time where accuracy, integrity and continuity is maintained. Such an approach will enable the DP to make a more optimal selection between reference systems based on operational requirements.

Comparisons and Test Results

For close proximity operations going on within the usual safety zone of typically 500 m, relative GNSS will have no degradation of accuracy as a function of distance. A 10 - 20 cm accuracy is achievable more or less at any distance, even hundreds of km.

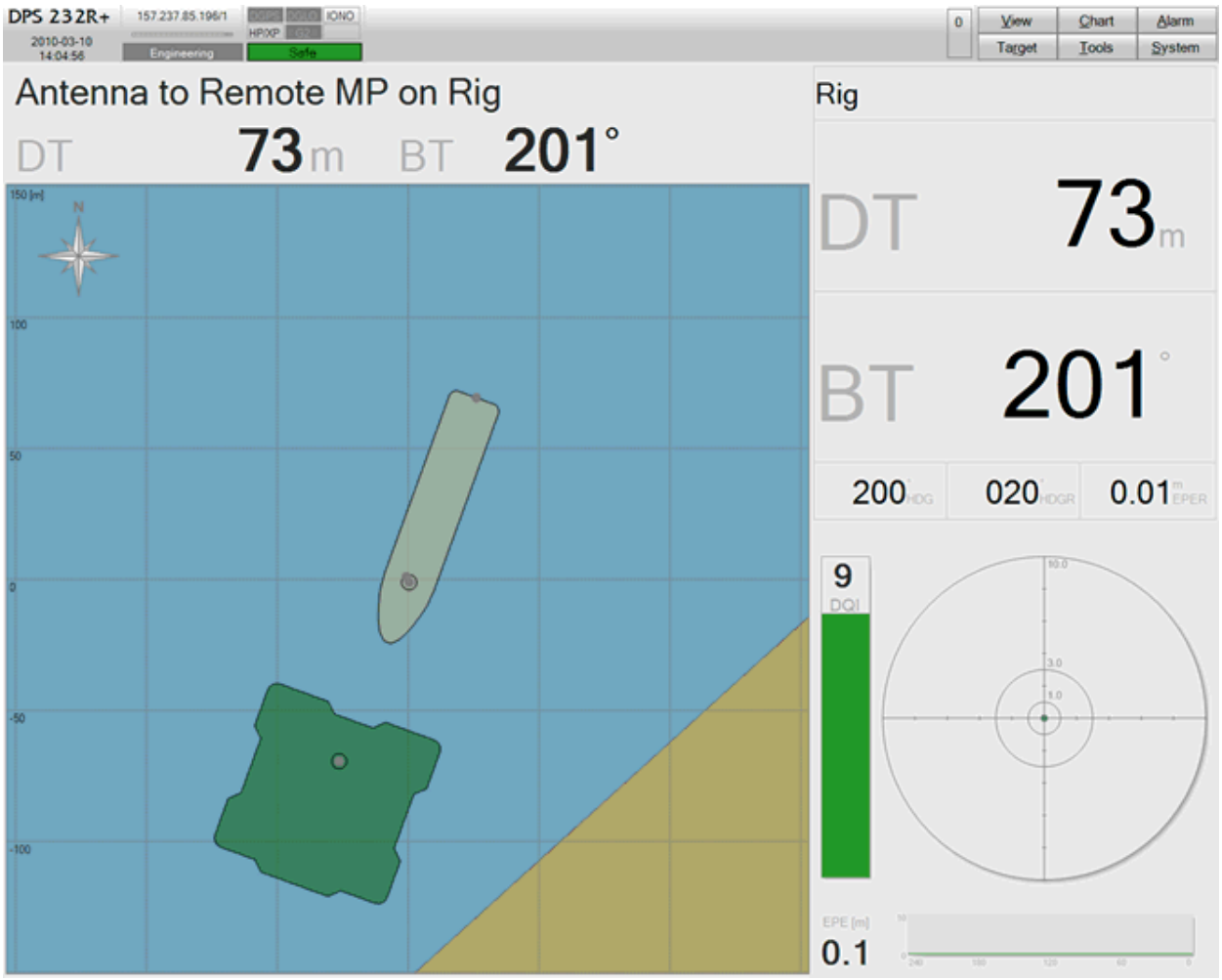

Figure 7: GNSS integrity represented by an error ellipse (95 % confidence)

Relative GNSS does not require line of sight between observation points. Another GNSS advantage is the fact that a large number of satellites usually is available, enabling a high degree of over determination in the position fix. Hence, residual measurements can be used to achieve better accuracy and to get an indication of the integrity of the position by e.g. an error ellipse.

The GNSS drawback is that reliable and accurate lever arm compensation is necessary to achieve e.g. steel-to-steel measurements.

Laser system range accuracy is more or less maintained at any distance as long as the reflected laser beam is tracked. It can be assumed that the angular accuracy is more or less independent of distance, meaning that the cross-track error will scale linearly with distance (e.g. 1 mrad at 1 000 m will mean a cross-track error of 1 m). Line of sight between laser and reflector is crucial but the focused beam gives a large S/N ratio margin. Dependent on the implementation, laser systems will also provide vertical measurements with a certain accuracy. This can be important for converting slant range to horizontal measurements (usually the primary interest of the DP). Vertical accuracy will be affected by the detector implementation. Today, it is possible to use multiple detectors arranged in a vertical array to provide a vertical resolution of the reflected signal.

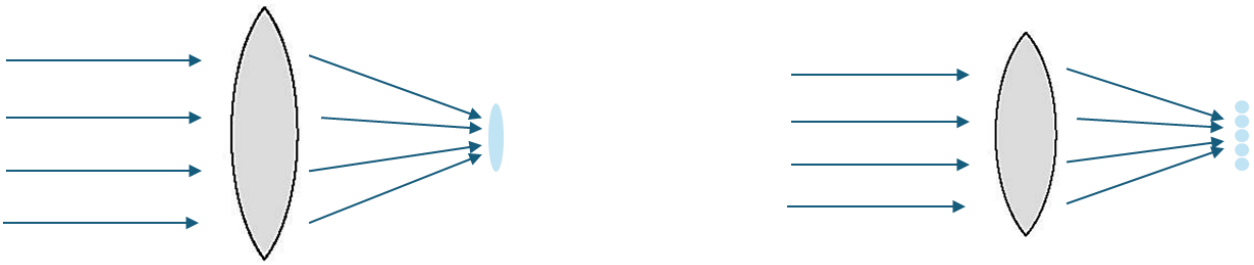

Figure 8: Single vs. multiple laser beam detectors

An detector array, rather than a conventional single detector, will also have advantages such as redundancy and more stable tracking under roll/pitch exposure.

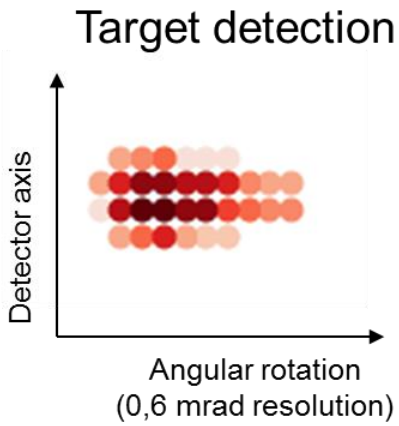

Figure 9: Target detection by multiple detectors

Microwave system range and angle accuracy will tend to degrade as a function of distance caused by e.g. noise and multipath effects. This will cause an un-linear degradation of cross-track error as a function of distance.

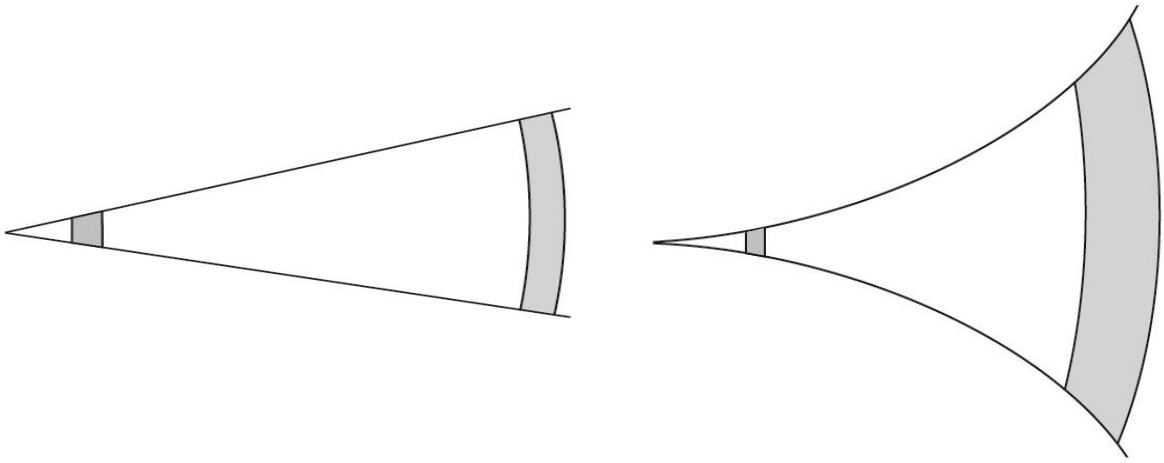

Figure 10: Laser and microwave accuracy respectively as function of distance (illustration)

Microwave systems also require line of sight between interrogator and transponders. The S/N marking will be less than for laser systems, meaning that the signal is much closer to the noise floor giving a limitation of range caused by free space loss. The level of vertical accuracy is dependent on implementation.

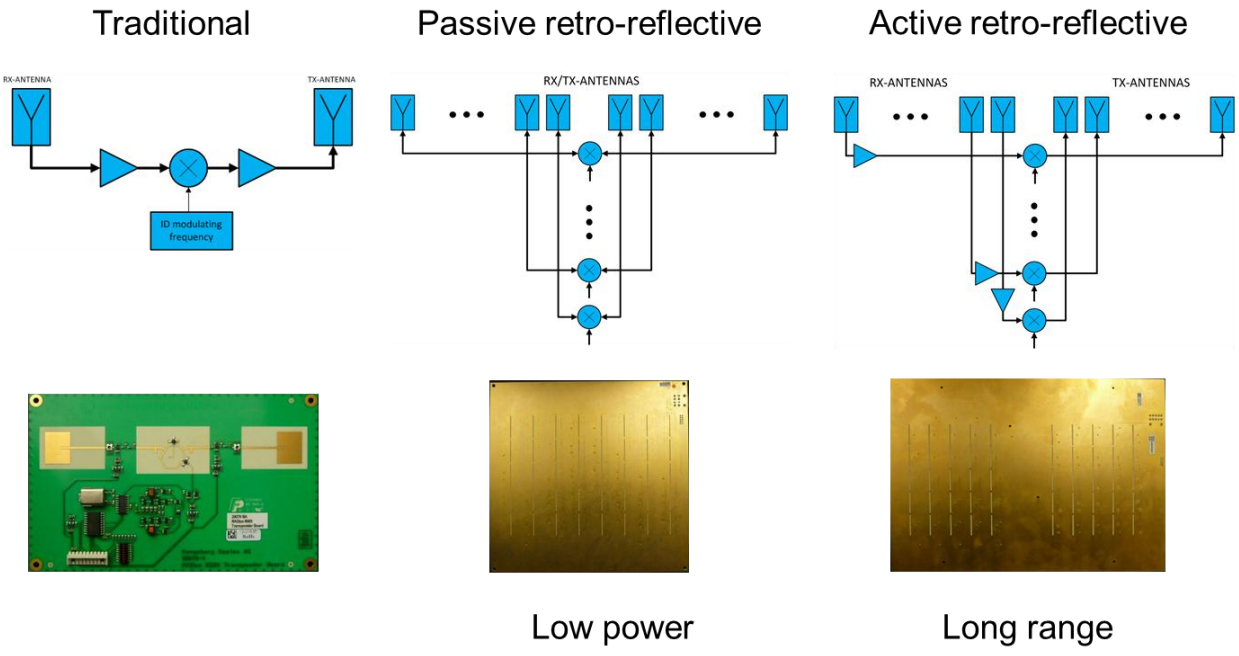

Figure 11: Microwave transponder designs

For microwave systems there are many different transponder designs meeting different requirements or trade-offs (Figure 11). The first priority is to maximize the energy reflected in the direction of the transmitter but another priority is to minimize the size of the transponder and the power consumption.

Further improvements of especially the angular accuracy of microwave systems is to implement individual calibration to each transmitter/detector system (interrogator).

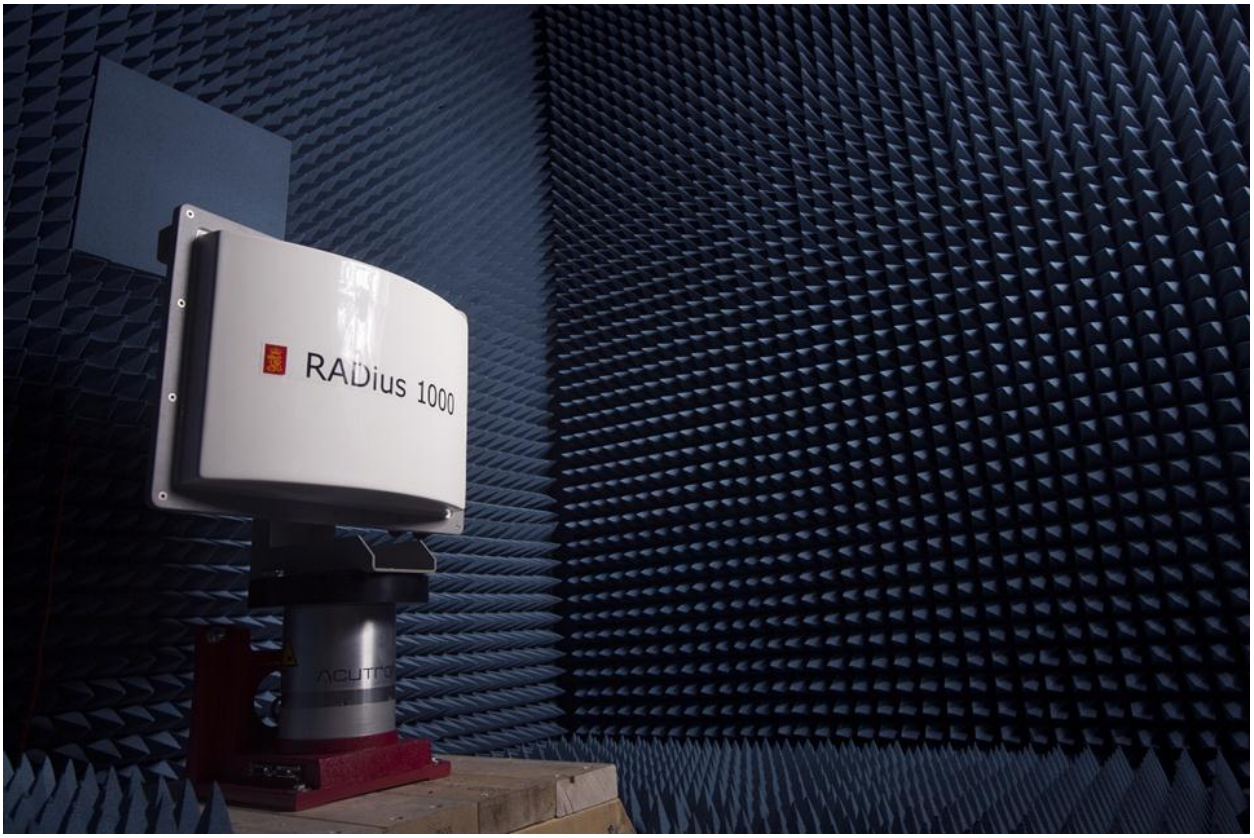

Figure 12: Calibration in echo-free chamber

An important part of the design and development of DP reference systems is the endless loop of testing, learning and tweaking. Theory and lab experiments are necessary, but the final phase of meeting the real world can never be under-estimated.

Figure 13: Real life testing of surface DP reference systems

Technology Evolution

The technology evolution is expected to continue. Future improvements will contribute to improve safety, operational efficiency and reduce energy consumption.

Within GNSS, the development is characterized by:

- Multi-frequency satellite systems
- Improved signal tracking capabilities
- Improved accuracy

Current solutions rely on GPS and GLONASS, but both Galileo and Beidou are on their way. This means that more than 100 GNSS satellites will be in service within a few years' time. Satellites are also continuously replaced and modernized. Thereby, the performance is gradually improved, as demonstrated in Figure 14.

Within microwave technology, new generations of low power FMCW transmitters become available. One driver is to reduce potential radiation hazards to a minimum, and another is to make systems smaller and more installation-friendly. Development of integrated multi-interrogator systems and extended multi-transponder tracking can be assumed. It is also possible to foresee transponders with even lower power consumption and high effective radar cross sections. More flexible FMCW patterns will enable dynamic optimizing between e.g. fast or slow movements. A driving requirement will be the need for better accuracy and integrity.

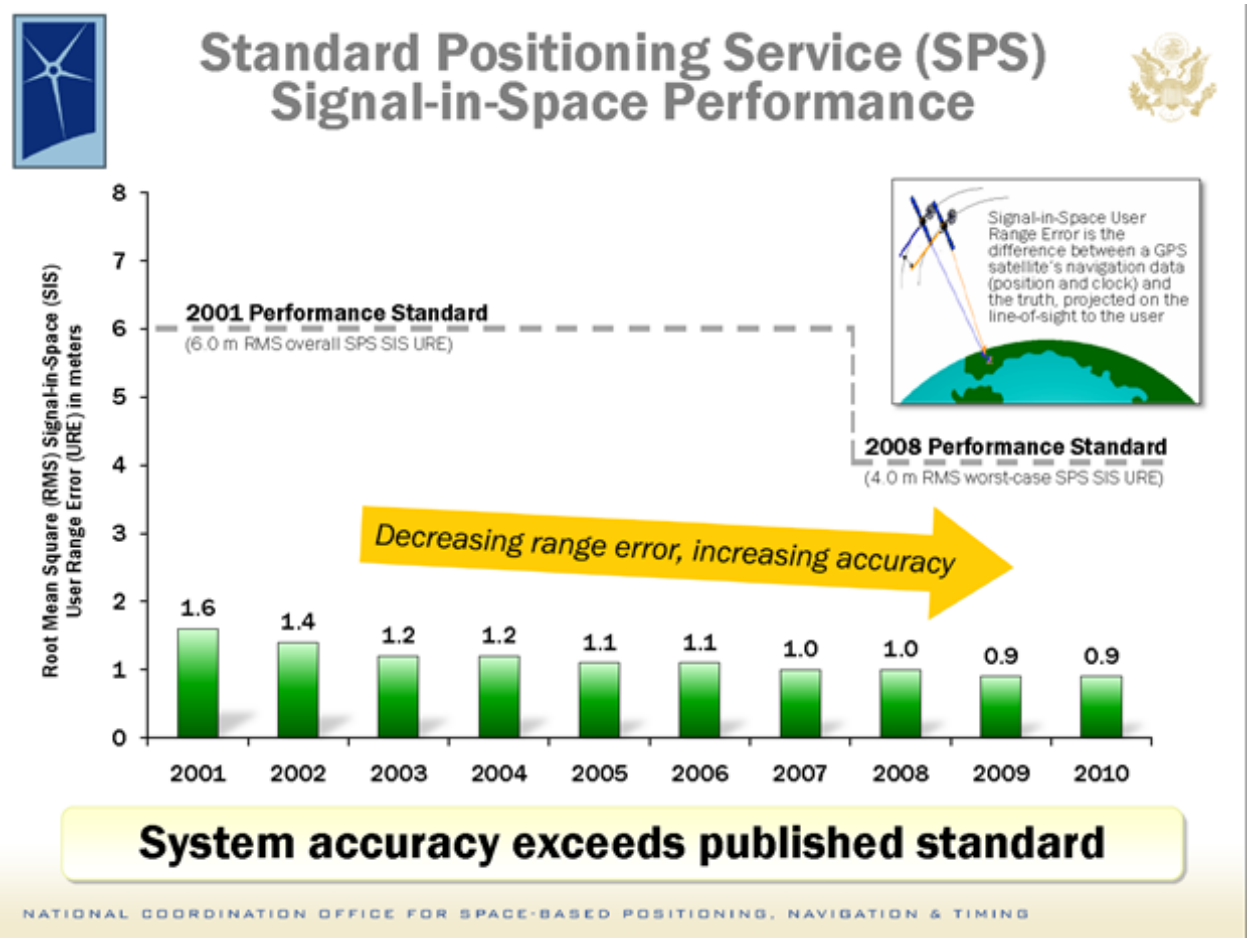

Figure 14: Continuous GPS accuracy improvement

Within laser technology the development will enable smaller and more installation-friendly sensors with a minimum of moveable parts. Current photo diode arrays are already available to improve/simplify tracking during rough sea, and this development is expected to continue. Improvements to reduce the risk of false target detection is also expected. Another interesting development is the use of new laser frequency bands potentially opening up for increased transmission power since these are frequency bands with less eye sensitivity.

Conclusion

Even as GNSS has been a driver for new close proximity surface DP reference systems, it is not likely that GNSS will be a sole-mean solution. Different technologies will still offer complementary properties and different systems will be advantageous to fulfil the operational requirements of close proximity DP operations.

The vigorous development of automotive and communication technologies is expected to benefit solutions also for professional markets such as advanced offshore operations. This evolution will not only benefit GNSS based solutions, but also microwave and laser based solutions.

The evolution of DP reference system capabilities will also challenge the use of data from such systems in the DP.