Mini RadaScan Microwave Radar Sensor for Dynamic Positioning Operations
The International Marine Contractors Association (IMCA) is the international trade association representing offshore, marine and underwater engineering companies.

IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means.

Members are self-regulating through the adoption of IMCA guidelines as appropriate. They commit to act as responsible members by following relevant guidelines and being willing to be audited against compliance with them by their clients.

There are two core activities that relate to all members:

- Competence & Training
- Safety, Environment & Legislation

The Association is organised through four distinct divisions, each covering a specific area of members’ interests: Diving, Marine, Offshore Survey, Remote Systems & ROV.

There are also five regional sections which facilitate work on issues affecting members in their local geographic area – Asia-Pacific, Central & North America, Europe & Africa, Middle East & India and South America.

**IMCA M 229**

This report has been prepared in order to give IMCA members an overview and review of the Mini RadaScan position reference sensor as used within dynamic positioning applications. Mini RadaScan is a microwave radar sensor system which has gained wide usage within marine offshore operations.

The major part of the document has been prepared by the manufacturers of this system, Guidance Marine Ltd. It covers the components of the system, sensor design, operation including advantages and disadvantages, servicing and maintenance, applications and technical specification.

**www.imca-int.com/marine**

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Mini RadaScan Microwave Radar Sensor for Dynamic Positioning Operations

IMCA M 229 – October 2015

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I Preface

Reliable and robust methods of positioning are required for safe vessel operations at offshore installations. The development of dynamic positioning (DP) systems has been gradual over the past 50 years and today, various manufacturers’ systems are available around the world.

Every measurement technology is bound by limitations (i.e. physics) and external factors (e.g. signal obstruction, solar activity, weather, sea conditions, range), which makes it difficult for one technology to cover all applications with uninterrupted service. Hence the growth in the use of DP has been accompanied by the development of internationally recognised rules, standards and guidelines against which DP vessels are designed, constructed and operated.1 2 3

The growth and development of DP systems has stimulated the development of DP position measurement sensors which have become more sophisticated as technology has allowed. Within the relative position measurement equipment range the DP market is familiar with the use of laser and microwave sensors.4 5 6 7 This document describes the Mini RadaScan product, which is part of the range of microwave relative positioning systems offered by Guidance Marine (see www.guidance.eu.com).

IMCA has published IMCA M 209 – RadaScan microwave radar sensor for dynamic positioning operations. This document provides an overview of the Mini RadaScan system.

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1 IMO MSC Circ. 645 – Guidelines for vessels with dynamic positioning systems
2 IMCA M 103 – Guidelines for the design and operation of dynamically positioned vessels
3 I82 MSF – International guidelines for the safe operation of dynamically positioned offshore supply vessels
4 IMCA M 170 – A review of marine laser positioning systems – Part 1: MK IV Fanbeam® and Part 2: CyScan
5 IMCA M 174 – A review of the Artemis Mark V positioning system
6 IMCA M 209 – RadaScan microwave radar sensor for dynamic positioning operations
7 IMCA M 224 – Guidance on RADius relative positioning system
## Glossary of Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ATEX</td>
<td>ATmospères EXplosibles</td>
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<tr>
<td>CE</td>
<td>Conformité Européenne. Mandatory marking for products sold in the European Economic Area (EEA)</td>
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<tr>
<td>Clutter</td>
<td>Radar signal that is echoed back towards the sensor</td>
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<tr>
<td>DAC</td>
<td>Digital to analogue converter</td>
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<tr>
<td>Dashboard</td>
<td>Graphical user interface used to control the sensor</td>
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<tr>
<td>DGNSS</td>
<td>Differential global navigation satellite system</td>
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<tr>
<td>DGPS</td>
<td>Differential Global Positioning System</td>
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<td>DP</td>
<td>Dynamic positioning</td>
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<tr>
<td>DSB</td>
<td>Dual side band</td>
</tr>
<tr>
<td>DSP</td>
<td>Digital signal processing</td>
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<tr>
<td>EMC</td>
<td>Electro-magnetic compatibility</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communications Commission. Among many of its functions it specifies the electromagnetic interference specification for products manufactured or sold in the United States</td>
</tr>
<tr>
<td>FMCW</td>
<td>Frequency-modulated continuous wave</td>
</tr>
<tr>
<td>FSK</td>
<td>Frequency shift key</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HPR</td>
<td>Hydroacoustic positioning reference system</td>
</tr>
<tr>
<td>I/O</td>
<td>Input/output</td>
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<tr>
<td>IMCA</td>
<td>International Marine Contractors Association</td>
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<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
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<tr>
<td>IP</td>
<td>Internet protocol</td>
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<tr>
<td>LAN</td>
<td>Local area network</td>
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<td>LED</td>
<td>Light emitting diode</td>
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<tr>
<td>mrad</td>
<td>milli-radians</td>
</tr>
<tr>
<td>OSV</td>
<td>Offshore supply vessel</td>
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<tr>
<td>PCI</td>
<td>Peripheral component interconnect</td>
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<tr>
<td>PSK</td>
<td>Phase shift key</td>
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<tr>
<td>PSV</td>
<td>Platform support vessel</td>
</tr>
<tr>
<td>RAS</td>
<td>Replenishment at sea</td>
</tr>
<tr>
<td>RCS</td>
<td>Radar cross section</td>
</tr>
<tr>
<td>Reflection</td>
<td>RF signal received by the sensor from the responder</td>
</tr>
<tr>
<td>Responder</td>
<td>Purpose built hardware unit mounted on a structure, which retransmits a modulated version of the signal it receives from a Mini RadaScan sensor</td>
</tr>
<tr>
<td>RF</td>
<td>Radio frequency</td>
</tr>
<tr>
<td>RX</td>
<td>Received RF signal</td>
</tr>
<tr>
<td>Series 1</td>
<td>miniResponders that implement FSK-DSB</td>
</tr>
<tr>
<td>Series 2</td>
<td>miniResponders that implement PSK-SSB</td>
</tr>
<tr>
<td>SSB</td>
<td>Single side band</td>
</tr>
<tr>
<td>Target</td>
<td>A processed and positively identified return from a responder</td>
</tr>
<tr>
<td>TX</td>
<td>Transmitted RF signal</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriters Laboratories Inc. The leading North American product safety certification organisation, whose certifications are recognised world-wide</td>
</tr>
<tr>
<td>UPS</td>
<td>Universal power supply</td>
</tr>
<tr>
<td>VFD</td>
<td>Vacuum fluorescent display</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation is a measure that is used to quantify the amount of variation of a set of data values</td>
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3 Overview

DP systems using relative position measurement equipment have been used in a wide range of industrial applications where operation typically requires vessels to perform either:

- ‘station keeping’; e.g. maintain their position against fixed or moving installations for loading and/or unloading;
- ‘track and follow’; e.g. maintain the same heading and speed relative to another vessel.

These operations often require sub-metre accurate local reference measurements to be supplied to the DP system. The Mini RadaScan sensor is a microwave based reference system that has been developed to offer an accuracy that is comparable to a laser system combined with the capability to work in all weather conditions where the presence of heavy fog, heavy rain, snow, dust or steam could affect the performance of laser systems.

A typical vessel will utilise a number of sensors simultaneously. Therefore each sensor needs to be capable of operating without interfering with or suffering interference from other sensors.8

The Mini RadaScan system builds on the success of RadaScan and is one of the latest developments in local reference sensor technology. The Mini RadaScan is smaller and lighter than the RadaScan, thus making installation easier and quicker, whilst providing crucial all-weather operation without compromising on accuracy. Mini RadaScan has the same friendly and familiar user interface as RadaScan.

In the rest of the document, the term sensor will be used to refer to the Mini RadaScan unit unless stated otherwise.
4 Components

A Mini RadaScan system consists of three main components:

- a sensor unit for the detection and processing of reflections;
- a responder(s) unit, which reflects the signal from the sensor;
- a marine computer used to configure and control the sensor using the dashboard software.

System components are shown in Figure 1.

![Figure 1 – Mini RadaScan system components](image-url)
5 Features

The sensor is a low power (1 watt) all-weather FMCW radar unit operating over a 100 MHz bandwidth in the licence-free 9.25 GHz maritime radiolocation band. A 360° rotating antenna which is spun at a continuous rate of 1 Hz provides unrestricted vessel manoeuvrability when tracking targets, unlike a fixed antenna design.

The sensor works by detecting reflections from one or more ATEX certified responders mounted on a structure such as an oil rig. The sensor calculates a relative target position which is sent to the DP system and the dashboard.

A maximum of four responders can be detected by each sensor. They operate in four distinct frequency channels specifically designed for the sensor and introduce a unique identifying code into the reflection to allow unambiguous target identification and robust tracking. Each responder can also be used simultaneously by multiple sensors which allows several vessels to obtain position information at the same time from one set of responders.

There are two main modes of operation:

- Single-target tracking provides target range and bearing measurements. It is mainly used in fixed structure applications such as drilling rigs and production platforms;
- Multi-targets tracking provides target range and bearing measurements and is also capable of calculating vessel heading. It is mainly used in mobile structure applications such as vessel track and follow.

Once a valid relative position has been calculated, the sensor generates a standard DP telegram every second, which is compatible with all modern DP systems.

5.1 System Advantages

- All-weather operations;
- uniquely coded responders ensure reliable tracking;
- single or multiple responder capability;
- automatic target detection;
- full 360° scanning providing an unobstructed field of view;
- uses coded responders making the system immune to false reflections;
- responders are ATEX certified and intrinsically safe;
- compatible with all leading DP systems;
- versatile choice of responders to suit all applications (power cell pack powered, mains powered, or rechargeable battery);
- compact and lightweight design for easy transport and installation;
- modular design to simplify servicing and maintenance.

5.2 System Disadvantages

- Responder location must be selected to ensure line of sight is maintained throughout the operation;
- requires the use of manufacturer’s own responders;
- like all microwave based sensors, sea reflections can cause problems in still conditions if the installation instructions are not followed carefully.
6  Installation

6.1  Sensor Wiring Diagram

The Mini RadaScan installation cable routing is shown in Figure 2.

![Sensor Wiring Diagram](image)

Figure 2 – Mini RadaScan components cable routing

6.2  Sensor Placement

Sensor placement varies with each application therefore the information hereafter is provided as a general guideline.

On a platform supply vessel (PSV), the typical mounting position for the sensor is above the wheelhouse, with a clear view over the aft deck area or whichever operating area is required.

![Sensor Placement](image)

Figure 3 – Typical sensor mounting position covering deck area
Ideally the sensor should be mounted:

- with the inspection hatch facing towards the bow (opposite the operating area), parallel to the vessel's fore and aft centre-line. Any deviation from the centre-line alignment can be corrected in the dashboard software (see section 6.4);
- with an unobstructed view in the expected direction of the target;
- above sea-level to prevent swamping or immersion;
- on a different vertical level to any radar systems operating in the X-band (see section 11.1);
- on a flat, rigid, horizontal surface able to support the sensor weight and receive four M12 fixing bolts;
- allowing for easy access to the connection panel and sensor information display;
- high enough to be level with the responder.

### 6.3 Responder Placement

To ensure highest performance of the system and quality of the relative position data sent to the DP system, the location, range and orientation of the responders must be optimised.

Ideally responders should be mounted:

- within the recommended height difference limits;
- within the tilt limits;
- facing the sensor directly;
- in a permanent location.

Additionally the sensor blanking zone should be configured in the Dashboard software. Following these guidelines should prevent the sensor detecting any 'ghost' reflections from metallic surfaces which may occur from any microwave-based system.

### 6.4 Calibration

#### 6.4.1 Calibrating the Sensor Range Measurement

The sensor range measurement is factory calibrated and does not require any further steps during installation or operation.

#### 6.4.2 Calibrating the Sensor Bearing Measurement

Once installed on the vessel, the mounting of the sensor unit may have introduced a bearing offset between the sensor and the vessel centre-line or heading axis. The dashboard user interface allows the installation team to enter a fixed offset to the bearing to compensate for it.

This change requires service access and should be carried out by trained personnel during installation.

In multi-target tracking mode, the DP system may require that the reported heading is aligned with the on-board gyro(s). This must be done through the Mini RadaScan user interface and repeated prior to commencing any DP operation.

#### 6.4.3 Responders

The responders do not require any calibration steps and are ready for use out-of-the-box once switched on. However the operator should pay great attention to installation guidelines to maximise responder visibility from the sensor point of view.
7 System Design

7.1 Sensor Properties

Figure 4 shows the internal components of the Mini RadaScan sensor.

![Mini RadaScan sensor components](image)

Figure 4 – Mini RadaScan dome (left); base (centre); rotor and base (right)

There are three main modules in the sensor.

The rotor includes:
- receive (Rx) and transmit (Tx) antenna arrays;
- transceiver connected to the antenna arrays;
- main DSP circuit board which analyses the output from the transceiver.

The chassis includes:
- belt drive, motor and encoder;
- bearing, heating element and slipring;
- hinge to facilitate access to the elements in the base.

The base and dome assembly includes:
- gasket protecting internal elements;
- small observation hatch (which includes its own seal);
- power supply;
- vacuum fluorescent display (VFD);
- mounting holes and pressure vent;
- I/O for the DP system and the dashboard.

The radar dome is attached to the base by fixing screws while the gasket ensures a tight seal. The assembly and disassembly of the dome should only be carried out by trained personnel as it may compromise the seal and cause damage to the sensor electronics.

The antenna arrays have been designed specifically to optimise the radar beam shape for most applications; specifically the elevation pattern is wider than the azimuth pattern to allow the system to cope with the pitch and roll of a vessel, and to ensure good bearing accuracy.

7.1.1 VFD – Status Display

The sensor is equipped with a display for diagnostics and fault finding purposes. In particular, it offers a convenient way for the installer to read the network IP address and the current fault conditions when the dashboard is unable to initiate a connection to the sensor.
7.2 Measurement Principles

7.2.1 Range

The range measurement is the most important function of traditional radars and it is achieved by measuring the time $T_R$ taken by a signal to travel to the target and return (i.e. time of travel). The more accurate the time measurement, the more accurate the range measurement $R$ will be.

$$R = \frac{cT_R}{2}$$

The Mini RadaScan sensor operates using the well-known principles of FMCW radars,\(^9\) where the difference in frequency between the transmitted (Tx) and the echoed signal (Rx) – $f_b$ (beat frequency) – is proportional to the transit time and $c$ is the speed of light.

![Diagram of FMCW beat frequency illustration (no Doppler shift)](image)

While DP operations are usually executed at low-speed, the vessel movements are still significant enough to introduce a non-negligible Doppler frequency shift.

If the frequency is modulated at a rate $f_m$ over a range $\Delta f$ (Figure 5), the beat frequency can be expressed as a function of the range:

$$f_b = \frac{4Rf_m\Delta f}{c}$$

By measuring the beat frequency within a few Hz and compensating for the Doppler shift, the Mini RadaScan sensor is able to measure the range with great accuracy. However it should be noted that the sensor only reports the range from the sensor to the responder and not the horizontal distance to the structure (see Figure 6).

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7.2.2 Bearing

The bearing measurement is derived from the energy peak of the reflection as detected by the 360º rotating antenna.

The combination of the angular position of the rotor (measured by the encoder disc) and the reflection data (sensed by the antenna) allows for an accurate and consistent bearing measurement.

The (Tx-Rx) FMCW signal generated by the transceiver is sampled and processed so that the energy peak can accurately be measured by a sample position \( i \) (Figure 7), which is then converted to a bearing measurement using the corresponding encoder count \( I \).

The encoder also provides a fixed marker position, which is indicated by the direction of the connection panel on the sensor. It represents a fixed reference point (reference bearing) used to provide a consistent relative bearing measurement. The convention is that the bearing reported by the sensor shows 0º when the antenna is facing the connection panel and increases in a clockwise direction.
The reported result is the calculated bearing compensated by any other bearing offset to align the result with the vessel's gyro (if required).

\[ b_{vessel} = \frac{360I}{N} + b_{offset} \]

### 7.2.3 Target Detection and Tracking

The range and bearing are the main measurements used to form the telegram provided by the sensor to the DP system. However, there are important internal algorithms that evaluate the quality of each reflection in order to decide if a target is acquired (i.e. acceptable for tracking) or lost.

The target detection process has been illustrated in Figure 8. Note that the same target detection algorithm is used during tracking when a target is lost and needs to be automatically reacquired.

![Figure 8 – Sensor processing states](image)

For a DP operation to be initiated, the operator needs to select a reflection or a number of reflections among all the detected responders and then start tracking using the dashboard interface.

Once a responder has been detected, motion tracking is achieved using both range and bearing predictor algorithms. These predictors are used to optimise the observation window position (Figure 7) to provide the best possible observation of the target during each antenna revolution. The algorithms use gating and validation functions and do not alter the data transmitted to the DP system. It is important for the Mini RadaScan to provide unfiltered measurements to avoid adding any unnecessary lag or delay in the DP control loop. Any filtering/smoothing on the data should be carried out by the vessel DP system if required.

The prediction algorithms are optimised to track responders in an environment with the velocity and acceleration characteristics of a typical DP equipped vessel.

### 7.3 Responders

Figure 9 shows the components of the responder. Responders are typically permanently mounted on platforms and are available in a number of varieties with various mounting bracket options depending on the installation requirement.
7.3.1 Responder Antenna

The responder has been uniquely developed in conjunction with the radar sensor to ensure that the system as a whole is easy to set up and resilient to other microwave emissions in the operating frequency band. The responder allocated channel frequency (identifiable by the colour) allows the sensor signal processing software to effectively reject the background clutter normally encountered by any traditional radar system. This includes the signature of nearby structures, such as other vessels.

Although the antenna is designed to have a wide acceptance angle (see section 12) to facilitate target detection in a wide range of DP operations, it is strongly recommended to follow the installation procedure (see section 6.3) to optimise the signal quality and achieve the maximum range specified.

7.3.2 Power Source

The system offers three different types of power sources for the responders:

- rechargeable battery pack;
- mains power;
- non-rechargeable battery primary cell pack.

The responders feature one or more status LEDs offering a convenient indication of the state and charge level. The battery powered responder will switch itself off when it reaches critical battery level to avoid unreliable performance.

There is no indicator to advise nearby personnel that the responder is in DP operation and being tracked by a sensor. It is therefore important for personnel not to alter the position of the responder once installed and it is recommended that a notice to this effect is posted next to the responder.
8 Operation

The operator uses the dashboard to automatically find and identify all available responders. Upon detection these are displayed on the screen for the operator to select. Once selected and confirmed the system is switched into tracking mode by the operator.

The Mini RadaScan blanking zone is configured once during the installation and determined by the field of view where responders can be observed by the sensor (i.e. not obstructed by the vessel structure or any other metallic surface).

Once installed and configured the sensor can typically be brought online using the user interface in three easy steps:
- sensor start-up and target detection;
- target selection;
- initiate tracking.

8.1 Dashboard

The dashboard is the graphical user interface needed to operate the Mini RadaScan. It can be controlled using a mouse/keyboard or a touch screen display.

During normal operation the sensor updates the dashboard scanner display (Figure 10).

![Figure 10 – Mini RadaScan dashboard](image)

When a target has been detected, the display shows the relative position of the vessel to the responder(s) together with any selected blanking zone. Real-time numerical values of range, bearing and, where appropriate, heading are shown. A health bar shows the quality of the overall position measurement.

The health is an indicator to help the operator assess the quality of the signal received by the sensor, i.e. precursor to address any poor responder placement or vessel angle of approach.

The dashboard can be operated using two different levels of credentials:
- user access level – this provides enough credentials for the user to perform most DP operations using an already installed/configured sensor;
- service access level – this offers the same credentials as the user access level but also allows the operator to change configuration settings related to the sensor installation and the DP configuration.
Multiple client dashboards can be connected to the same sensor in a master/slave configuration. This feature provides redundancy around the vessel bridge where it is often important for multiple crew members to have access to the Mini RadaScan data. In order to enhance safety during operations, slave consoles are only able to view the current status of the sensor and are unable to gain service access, start tracking or change the blanking zone. Any slave can request to be the master.

When the console is connected to a sensor and navigating, it autonomously collects detailed logs. These logs offer valuable information to the support team to quickly diagnose any issues reported by customers.

8.2 Multiple Sensor/Multiple Target Operation

The Mini RadaScan sensor automatically detects and identifies responders within the maximum range and where a line of sight exists between the sensor and a responder. Each responder has a unique ID and will respond to multiple sensors simultaneously allowing multiple vessels to operate in the same region independently (Figure 11).

As illustrated in Figure 11, a DP operator can track more than one responder at the same time, whilst another DP operator can track one or more of the same responders. Both operators can track the same responders simultaneously.

The DP operator should refer to the Mini RadaScan documentation or contact the service team for details to make sure the DP telegram data matches expectations of their DP system.

8.3 Mini RadaScan Interoperability and Compatibility

The performance of the Mini RadaScan is determined by the target choice. There are two formats of target currently in field, a transponder and a responder as shown in Figure 12. The transponder is an older generation target and its modulation type differs from the currently manufactured responder. The modulation type of the transponder is referred to as series 1, the modulation type currently used is referred to as series 2.

The responders are the latest generation of target and are capable of being programmed as series 1 or series 2 or series 3. Responders are much smaller, lighter and give better performance than the earlier transponders. The older generation transponders may not provide the maximum range performance of the Mini RadaScan sensor.
When using multiple targets, because of the differing modulation types, certain rules must be adhered to. A comprehensive guide to the differences between these targets is available.\textsuperscript{10}
9 Servicing and Maintenance

The Mini RadaScan moving mechanical parts such as bearings, belt and motor should provide service free operation for the typical DP operation usage over a period of up to 10 years. To further enhance the product life expectancy the software will automatically initiate a suspend command and stop rotating the sensor if the DP operator has not initiated tracking after a certain period of time.

Once installed, the sensor and responder units do not require cleaning under normal conditions. However, it is recommended that the vessel owner carries out regular visual inspection for damage that may compromise the integrity.

9.1 Software Upgrades

Mini RadaScan owners have access to the latest Guidance Marine software release through a web interface or by contacting the Guidance Marine customer support team (customerservices@guidance.eu.com).

Both the Mini RadaScan sensor firmware and the dashboard can be upgraded in the field using a USB memory stick or by transferring release files on the local network (e.g. marine computer). The two-step procedure involves:

♦ Remote installation of the sensor software on the sensor unit. This requires a LAN connection to the sensor and the IP address of the sensor unit. The upgrade process is fully automated except for the first time installation, which requires user configuration input. The installation software can be executed using the installer user interface or a Windows command line.

♦ Local installation of the dashboard on the marine computer. The dashboard installation works like any standard Windows software using the supplied executable.

9.2 Recycling and Disposal

Guidance Marine employs the philosophy that supplied products do not contain hazardous substances. A record of Mini RadaScan unit material content is available upon request.

When disposing of a Mini RadaScan sensor or responder, Guidance Marine recommends that Mini RadaScan owners contact an electronics recycler that follows environmentally sound recycling practices in accordance with the local rules.
10 Applications

The Mini RadaScan sensor is built on the success of the larger RadaScan sensor. Although both products are in operation across a number of marine applications (Figure 13), the smaller footprint and mounting requirements of the Mini RadaScan has expanded the range of applications to smaller vessels.

Figure 13 – Suitable vessel applications
11 Operational Experience

11.1 Co-location/Sensor Placement

The sensor operates in a narrow frequency band between 9.2 GHz and 9.3 GHz, which is part of the X-band frequency spectrum. This licence-free spectrum is shared with other marine systems such as marine navigation radars or Artemis. The high transmit power (typically kW) usually associated with X-band radars means that it is important for the Mini RadaScan sensor to be located in a position or shielded so that other radar signals cannot interfere with it.

The sensor design includes interference protection, which prevents any damage to the sensitive electronics. However it is possible to encounter a loss of performance, which can be mitigated by positioning the sensor and the interfering system on different horizontal planes (Figure 14) with as much vertical separation as possible between the Mini RadaScan Sensor and any X-band radar.

If vertical separation of the two systems is impossible, they must be shielded from one another with a metal screen. The screen must be large enough to physically shield the Mini RadaScan sensor from the whole width of the X-band antenna.

The Mini RadaScan sensor does not need to be shielded from radar-based systems mounted on other vessels or structures.

11.2 Performance

The performance of any measurement system can be characterised in terms of accuracy, availability, continuity and integrity.

In the case of a local position reference sensor, availability, continuity and integrity depend on local operational factors, e.g. how well maintained are the reflectors? What obstructs the view from sensor to reflector? These statistics vary factors widely across all installations.

For dynamic positioning accuracy a relatively small constant offset error in a local position reference is of little concern. For station keeping performance we require:

♦ local accuracy – once the vessel is in position and holding station, the measurement of displacement within a small area is accurate;
♦ repeatability – if the vessel returns to the same actual position, the same position is reported as before.

The measure of accuracy is determined for the Mini RadaScan by the error model.
11.2.1 Error Model

The error in a position fix obtained from a GPS receiver is said to be circular. The easting and the northing have approximately the same accuracy, making the confidence region around a point estimate circular.

With a range-bearing local position reference sensor that is not the case. When the range-bearing measurement is interpreted as a position fix, the error in the radial direction may be of quite a different size to the error in the tangential direction. Radial error is more or less constant over a wide operating range. For a given bearing error, tangential position error is proportional to the distance from the sensor to the responder.

To illustrate this, imagine that across the normal range of operating circumstances that the typical range error is 0.25 m and that the typical bearing error is 2.5 mrad. At 50 m the tangential position will be accurate to 0.125 m. At 200 m the tangential position will be accurate to 0.5 m.

![Figure 15 – Error mode](image-url)
When blending measurements from a local position reference sensor with those from GPS, it
is best to calculate the weight for the range and bearing components of the measurement
separately. This applies whether weights are assigned on the strength of an \textit{a priori}
measurement noise model or in response to the observed variation of measurements.

11.3 Responder Angle of Incidence

We get the maximum signal power at the sensor when the responder is facing directly towards the
sensor. The signal level falls off as the responder is pointed away from the sensor. This is illustrated in
the following plot:

![Azimuth antenna pattern](image)

The responder is at the origin. The contour shows the positions at which the signal power received by
the sensor is equal to that received at bore sight at 500 m.

The natural tendency for any measurement system is for the errors to increase as the signal power
decreases and Mini RadaScan is no exception. The Mini RadaScan sensor monitors the signal to noise
ratio of the reflection. When this falls below a threshold, the measurement is suppressed and the fix is
not supplied to the DP system. This threshold is set so that measurements cut out before the errors
grow much above the level seen at high signal power.

It also illustrates that when using the responder in a constant wide angle configuration (e.g. Figure 11)
the maximum range (at bore sight) may not be achieved. Nevertheless, the sensor should still deliver
good performance in close range operation.

11.4 Multi-path Accuracy

It is well known in the field of microwave radar that ground or sea reflection at very low elevation angles
produces deep nulls where the radar target disappears at particular combinations of height and
distance.\textsuperscript{11} The direct signal from the target interferes with the signal reflected from the water to
produce 'Lloyd's mirror' interference fringes. This phenomenon affects all microwave radars (see IMCA
M 224). An arrangement of antennas at different heights can mitigate the effect and give a signal which
is adequate throughout the operating range.\textsuperscript{12}

\textsuperscript{11} Simon Kingsley and Shaun Quegan, Multipath, Understanding radar systems, section 7.4, Feb 1999, SciTech Publishing
\textsuperscript{12} Active Target With Height Diversity, Patent application EP 2369366, published Sept 2011
**Longer ranges:** Multi-path nulls are seldom a practical problem for DP vessels in any case. The effect is most prominent at long distance and low height. A radar position reference sensor is typically mounted at least 15 m above the surface of the water. At this height we can rely on the frequency diversity of the FMCW radar to deliver a usable signal at least as far as 1000m. Height diversity measures are not required for ordinary work boat operations, at least, not with Mini RadaScan.

![Figure 17 – Multi-path illustration](image)

**Medium ranges:** At more modest ranges (200 m to 300 m), sea reflections can have a significant effect on accuracy. Here the direct image and the reflected image are not so close that they cancel each other out in destructive interference. But they are closer than the range resolution capability of the radar. That means that the two images interfere with each other and the range measured to either of them is distorted. Resulting range errors can be up to a few decimetres. Again, this phenomenon from the underlying physics affects all microwave radar systems. The effect is a function of bandwidth rather than of radio frequency. Various mitigating measures are taken within Mini RadaScan, but it remains the fact that operation in this range is the most challenging in terms of range accuracy. And in this range, sea reflection is by far the most important source of measurement error.

**Shorter ranges:** At shorter ranges, sea reflection is less of a problem. First of all the difference in distance between the direct image and the reflected image becomes great enough for the two images to be separated, allowing accurate measurement of both ranges. Secondly the reflected image becomes much fainter. As the grazing angle increases, the reflectivity of the water decreases. Also the reflection moves to the edge of the main lobe of the radar antennas.

The geometry and environment are key to understanding the performance of a microwave radar system such as Mini RadaScan so tests done on land at about 2 m above the ground are not a good indication of the accuracy which is achievable in typical operations at sea.

Sea reflection is at its most troublesome when the sea is calm because waves tend to break up the reflection. So conditions in the harbour approach represent the worst case.

**11.4.1 Sea Reflection – Harbour Case Study**

The sensor and responder were relatively low (average height above the water of 15 m), which brings the onset of measurement errors due to sea reflection closer.
Both range and bearing errors are quite a lot larger than in the most normal operating cases. This is nearly all due to sea reflection.
The impact of sea reflection on accuracy depends on the region of operation:

<table>
<thead>
<tr>
<th>Region of Operation</th>
<th>Short Range</th>
<th>Medium Range</th>
<th>Long Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>less than 125m</td>
<td>125m to 250m</td>
<td>250m to 1000m</td>
</tr>
<tr>
<td></td>
<td>Very little radiation reaches the sea surface. Reflected image is a few metres further away than the direct image and can easily be rejected</td>
<td>Reflected image is a metre or two further away than the direct image. It can usually be rejected, but it can distort the direct image</td>
<td>Reflected image is only a fraction of a metre further away than the direct image. The images can’t be separated</td>
</tr>
<tr>
<td></td>
<td>No Errors</td>
<td>Occasional Errors</td>
<td>Frequent Small Errors</td>
</tr>
</tbody>
</table>

Table 1 – Sea reflection accuracy summary

11.4.2 Sea Reflection – Typical Operating Conditions

Here are some range and bearing measurements typical of station keeping operations in the North Sea:

![Range and bearing plots at 70 m – Standard deviation: ≤ 0.085 m](image1)

**Figure 21** – Range and bearing plots at 70 m – Standard deviation: ≤ 0.085 m

![Range and bearing plots at 70 m – Standard deviation: ≤ 2.41 mrad](image2)

**Figure 22** – Range and bearing plots at 70 m – Standard deviation: ≤ 2.41 mrad

The wave motion is fairly strong, making it more difficult to quantify the accuracy performance. In a comparison with an alternative sensor (e.g. GPS), timing and other registration errors dominate over Mini RadaScan measurement errors. We can apply a high-pass filter which has unity gain for white noise while attenuating the wave motion. This gives us an upper bound on the standard deviation of the range and bearing measurements.
Here are some further examples of Mini RadaScan performance in North Sea operating conditions:

![Figure 23 – Range and bearing plots at 160 m – Standard deviation: ≤ 0.095 m](image)

![Figure 24 – Range and bearing plots at 160 m – Standard deviation: ≤ 2.09 mrad](image)

Under typical operating conditions Mini RadaScan can be expected to provide 1-σ accuracy of 0.25 m in range and 2.5 mrad in bearing out to a range of 500 m. At greater distances errors grow roughly in proportion to distance.

As the distance decreases below 250 m, the effect of sea reflection diminishes and accuracy improves. Sea reflection has no significant effect at less than 125 m and 1-σ accuracy of 0.1 m in range and 1 mrad in bearing are commonly achieved.

11.5 Frequently Asked Questions

1. **Does Mini RadaScan operate on the same principles as X-band radars?**

   No. Although Mini RadaScan operates at 9.25 GHz, it uses frequency-modulated continuous wave (FMCW) emission rather than the pulsed emission of conventional radar. (FMCW is the technology found in the vehicle speed radar guns used by law enforcement agencies around the world.)

2. **Mini RadaScan operates at a similar frequency to conventional X-band radar. Do the systems interfere with one another?**

   No, not if the installation is carried out as instructed. Care must be taken to ensure that Mini RadaScan is not installed at the same horizontal level as the X-band radar. The recommended level separation distance is at least 3 m.
3. Is the mounting position of the responders important to the performance of Mini RadaScan?

Yes. Mini RadaScan requires a clear view of a responder in order to operate successfully. Responders are best mounted with the active face directly facing the sensor. The viewing angle is more important than the distance between the responder and the sensor. Responder mounting brackets that swivel are available to ensure optimum responder location and direction.

4. What sea states can Mini RadaScan operate in?

Experience in the North Sea has shown Mini RadaScan working satisfactorily to produce stable DP position data for prolonged periods in 3 m sea states. Such challenging conditions require optimum responder placement in relation to the Mini RadaScan sensor.

5. Can multiple vessels use a single Mini RadaScan responder at the same time?

Yes. The characteristics of the responder allow multiple sensors to use it simultaneously.

6. What is the advantage of using coded responder for Mini RadaScan?

The coded responders add their unique identity codes to the reflections that they send back to the sensor. The codes are used in the sensor's location measurement and tracking algorithms to ensure good stability, even in the cluttered radar environments found offshore.

7. Can Mini RadaScan be used in the proximity of personnel? Is it safe?

Yes. Mini RadaScan is a local position reference sensor and only outputs low power transmission of the order of a few watts. The minimum safe distance is contained within the radome. There is no safety risk to personnel working on the Mini RadaScan equipped vessel or on the target installation.

8. What type of DP systems can Mini RadaScan be connected to?

The Mini RadaScan was designed specifically as a generic DP position reference sensor. It supports all the major DP systems and is supplied with numerous selectable DP message formats for configuration at installation. Refer to technical specification.

9. Can responders be used in hazardous areas?

Yes. All responders are ATEX certified and intrinsically safe for use in hazardous atmospheres.

10. The responders are battery powered. What is the lifetime of the batteries and how are they replaced?

The responder should only be serviced by a certified technician according to ATEX guidelines in a dry and non-hazardous area. Battery powered responders should provide 30 days of operation before requiring a charge whilst the power cell pack (PCP) responders provide one year of operation after which the PCP needs replacing.

11. Are battery responders suitable for temporary deployment?

Yes. Responders are self-contained and powered by internal batteries. They are available in a robust transit case for easy transfer to, and rapid deployment in, the required target location. However, if they are temporarily handed over to the platform by the vessel to support a DP operation, care must be taken to mount and orientate the responder according to the recommended instructions. Carelessly mounted responders can result in poor performance of the vessel's DP system. For this reason, we recommend permanent installation of the responders on the fixed platform to provide optimum performance and DP setup.

12. Can Mini RadaScan be installed semi-permanently? What is needed for installation?

The sensor installation is usually considered as permanent and would require a procedure to be moved around the vessel on a regular basis. Contact Guidance Marine for further details.
11.6 Operational Experience

IMCA has received from its members favourable feedback on this system with accuracy down to 0.5m being reported. It has been described as flexible, reliable, accurate and easy to set up. Particularly noted were the good vertical angle and the acquisition range from 400 up to 1000m making it suitable for setting up on DP outside the 500m zone. Furthermore it continues to perform well in heavy rain, snow and fog. It was also noted that although the unit has a number of moving parts this has caused no issues over a prolonged period of years.

Members have stated that the need to set up a target responder can be a disadvantage. Vertical separation between responder and transceiver at close range can become critical therefore pre-site planning for positioning of the responders can be essential. The requirement to recharge standalone responders is also seen as a possible issue. The use of permanently installed and powered responders will alleviate this problem, however this can only be achieved with the co-operation of the platform operator.
12 Specifications

12.1 Computer Specifications

<table>
<thead>
<tr>
<th>Marine Computer Technical Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Fan less design</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Marine Computer Interfaces</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power adapter</strong></td>
<td>Input 220V/110V, 1.5A, 50-60Hz; Output 12V, 5A max</td>
</tr>
<tr>
<td><strong>Sensor</strong></td>
<td>TCP/IP over Ethernet 100Base-T</td>
</tr>
<tr>
<td><strong>Display</strong></td>
<td>VGA</td>
</tr>
<tr>
<td><strong>USB</strong></td>
<td>2 USB ports</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Marine Computer Environmental Conditions</th>
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<tbody>
<tr>
<td><strong>Temperature range</strong></td>
<td>-25ºC to +55ºC</td>
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<tr>
<td><strong>Atmospheric conditions</strong></td>
<td>Operates in fog, heavy rain, snow and ice conditions</td>
</tr>
<tr>
<td><strong>Water and dust protection</strong></td>
<td>IP66 certified</td>
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</table>

<table>
<thead>
<tr>
<th>Marine Computer Dimensions</th>
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<tbody>
<tr>
<td><strong>Dimension</strong></td>
<td>260 x 132 x 71 mm</td>
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<tr>
<td><strong>Weight</strong></td>
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12.2 Sensor Specifications

<table>
<thead>
<tr>
<th>Sensor Technical Details</th>
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</thead>
<tbody>
<tr>
<td><strong>Sensor type</strong></td>
<td>FMCW</td>
</tr>
<tr>
<td><strong>Emission frequency</strong></td>
<td>9.2-9.3 GHz</td>
</tr>
<tr>
<td><strong>Maximum output power</strong></td>
<td>1 W</td>
</tr>
<tr>
<td><strong>Operating range</strong></td>
<td>10 m to 600 m</td>
</tr>
<tr>
<td><strong>Range accuracy</strong></td>
<td>0.25 m (1σ)</td>
</tr>
<tr>
<td><strong>Bearing accuracy</strong></td>
<td>0.2º (1σ)</td>
</tr>
<tr>
<td><strong>Scanning angle</strong></td>
<td>360º</td>
</tr>
<tr>
<td><strong>Rotational frequency</strong></td>
<td>1 Hz</td>
</tr>
<tr>
<td><strong>Antenna type</strong></td>
<td>Unidirectional array</td>
</tr>
<tr>
<td><strong>Elevation angle</strong></td>
<td>Up to +50º/-25º</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Sensor Interfaces</th>
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<tbody>
<tr>
<td><strong>Cable connectors</strong></td>
<td>3 way R/A socket w/strain</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>85 to 264V AC 45-65 Hz 5A</td>
</tr>
<tr>
<td><strong>Marine computer</strong></td>
<td>TCP/IP over ethernet 100 Base-T</td>
</tr>
<tr>
<td><strong>DP system</strong></td>
<td>Serial over RS422</td>
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<table>
<thead>
<tr>
<th>Supported DP manufacturers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kongsberg</td>
<td></td>
</tr>
<tr>
<td>GE Energy (Converteam)</td>
<td></td>
</tr>
<tr>
<td>L-3</td>
<td></td>
</tr>
<tr>
<td>Marine Technologies</td>
<td></td>
</tr>
<tr>
<td>Rolls-Royce</td>
<td></td>
</tr>
<tr>
<td>Navis</td>
<td></td>
</tr>
<tr>
<td>Beier Radio</td>
<td></td>
</tr>
<tr>
<td>Praxis</td>
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</table>

<table>
<thead>
<tr>
<th>Supported DP telegrams formats</th>
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<tbody>
<tr>
<td>NMEA0183R (IEC 61162-1)</td>
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<tr>
<td>NMEA0183P (IEC 61162-1)</td>
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<td>MDL standard and multi-target</td>
<td>Kongsberg BCD</td>
</tr>
<tr>
<td>Kongsberg BCD</td>
<td>Marine Technologies custom strings</td>
</tr>
<tr>
<td>Rolls-Royce custom strings</td>
<td></td>
</tr>
<tr>
<td><strong>Sensor Environmental conditions</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature range</strong></td>
<td>-25°C to +55°C</td>
</tr>
<tr>
<td><strong>Atmospheric conditions</strong></td>
<td>All-weather</td>
</tr>
<tr>
<td><strong>Water and Dust protection</strong></td>
<td>Sealed, water-tight radome meets IP66</td>
</tr>
<tr>
<td><strong>Sensor Dimensions</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>500mm</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>400mm</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>21kg</td>
</tr>
<tr>
<td><strong>Dimensions (boxed)</strong></td>
<td>620x620x730 mm</td>
</tr>
<tr>
<td><strong>Weight (boxed)</strong></td>
<td>63 kg</td>
</tr>
<tr>
<td><strong>Mounting</strong></td>
<td>4 bolts in base</td>
</tr>
<tr>
<td><strong>Sensor Compliance</strong></td>
<td></td>
</tr>
<tr>
<td>EN 60945 &amp; EN301 843-1 (EMC)</td>
<td></td>
</tr>
<tr>
<td>EN 62388:2002, Annex B</td>
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</tr>
<tr>
<td>ITU-R Recommendation RM. 1177 European Directive</td>
<td></td>
</tr>
<tr>
<td>2004/108/EC EMC: CE Certified</td>
<td></td>
</tr>
<tr>
<td>FCC Approved</td>
<td></td>
</tr>
</tbody>
</table>

### 12.3 Responder Specifications

| **Responder Technical details** |  |
| **Emission frequency** | 9.2-9.3 GHz |
| **Power** |  |
| ✦ 220V/110V mains adapter |  |
| ✦ Rechargeable battery (30 days) |  |
| ✦ Non-rechargeable power cell pack (12 months) |  |
| **Antenna type** | Unidirectional array |
| **Azimuth angle** | Up to 170° |
| **Elevation angle** | Up to +/-35° |
| **Responder Environmental conditions** |  |
| **Temperature range** | -25°C to +55°C (-40°C option) |
| **Atmospheric conditions** | All-weather, explosive atmosphere |
| **Water and dust protection** | Sealed, water tight connector cap |
| **Buoyancy** | Floating design and tested for immersion up to 1m |
| **Responder Dimensions** |  |
| **Dimension** | 170 x 305 x 128 mm |
| **Weight** | 5 kg |
| **Dimension (boxed)** | 480 x 380 x 210 mm |
| **Weight (boxed)** | 11 kg |
| **Mounting** | Brackets |
| **Responder Compliance** |  |
| ATEX, UL certified |  |
13 References

1. IMO MSC Circ. 645 – Guidelines for vessels with dynamic positioning systems
2. IMCA M 103 – Guidelines for the design and operation of dynamically positioned vessels
3. 182 MSF – International guidelines for the safe operation of dynamically positioned offshore supply vessels
5. IMCA M 174 – A review of the Artemis Mark V positioning system
6. IMCA M 209 – RadaScan microwave radar sensor for dynamic positioning operations
7. IMCA M 224 – Guidance on RADius relative positioning system
8. IMCA M 199 – Guidelines on installation and maintenance of DGNSS-based positioning systems
12. 94-0271-4-A RadaScan Series 2 Responder Buying Guide