

Satellite Compass



A Practical Guide to
GNSS Transmitting Heading Devices
For Marine Navigation

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NORTHROP GRUMMAN

Sperry Marine



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Where Are You Going?



It's often said that the most important revolution in marine navigation took place when the magnetic compass was invented. Its exact origins are forever shrouded in the mists of history, but historical references to magnetic compasses go back at least 1,000 years. With the magnetic compass, coupled with a rudimentary speed log, it became possible for mariners to leave the safety and security of the coastline and venture out onto the open ocean.

For centuries, dead reckoning with magnetic compass and speed log, updated with periodic observations of celestial bodies, defined the state of the art in marine navigation.

Then, in the last half of the 20th century, the electronics revolution swept through the marine industry, bringing with it hyperbolic radionavigation aids like Decca, Omega and Loran, followed by satellite navigation systems such as Transit, GPS and Glonass, which provided real-time position fixing, and eliminating much of the need for traditional dead reckoning.

But some things, it seems, never change. Determining the ship's heading and speed are still fundamental requirements in marine navigation. In fact, the proliferation of electronic systems, such as Electronic Chart

Display and Information Systems (ECDIS), Automatic Identification Systems (AIS), Automatic Radar Plotting Aids (ARPA) and Voyage Data Recorders (VDR), has created a need for heading reference data to function properly.

Hence the appearance of a new type of navigation systems – transmitting heading devices (THD).

In this booklet, we will explain how satellite-based technology can satisfy this requirement for stable, accurate and reasonably priced heading data. In this booklet, we will explain how Global Navigation Satellite Systems (GNSS) can satisfy this requirement.

Transmitting Heading Devices

Automatic Identification Systems (AIS), Voyage Data Recorders (VDR), Automatic Radar Plotting Aids (ARPA) and other modern ship electronic systems, which are mandated for ships under the Safety of Life at Sea (SOLAS) Convention, require accurate real-time inputs of the ship's heading to function properly.

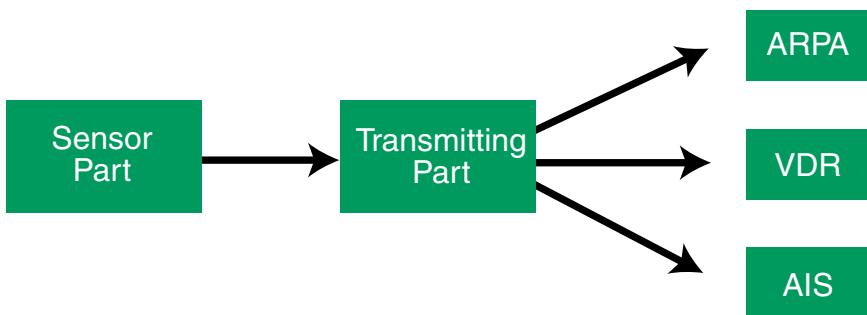
The International Maritime Organization (IMO) therefore has adopted regulations governing the new types of heading reference systems that provide these critical inputs.

A Transmitting Heading Device (THD) is defined by the IMO as “an electrical device that provides information about the ship’s true heading.” The ship’s heading data must be provided in a standard format that can be used by other equipment as specified in IMO regulations. (Note that the definition calls for true, not magnetic, heading.)

The THD consists of two basic parts: the sensing part (a device capable of detecting heading information) and the transmitting part (a device which receives heading information from the sensing part and converts it into the required accurate signal).

The IMO documents do not specify what sort of sensor must be used to measure the ship’s true heading. Thus, the THD heading sensor could be satisfied by a gyrocompass or an electronic magnetic compass, corrected for variation and deviation and capable of meeting the minimum standards for reliability and resolution. The advent of high-accuracy, real-time Global Navigation Satellite Systems (GNSS) such as

GPS opens a third possibility, and in the next chapter we will discuss how the satellite signals can be used to determine the ship's true heading – at a fraction of the cost of a gyrocompass.



Determining Heading From Satellite Signals

The basic premise behind a satellite THD is simple. If you can determine the exact location of two discrete points relative to the earth, you can measure the “attitude” of the axis between them relative to the earth. To accomplish this you have to be able to locate the two points with a great deal of precision, especially if the baseline between them is relatively short. In addition, if one or both of the points are moving, the attitude of the axis between them is also changing, so you will need to update the positions of the two points frequently.

Thus, if we align two position determining devices along the fore-and-aft line of a ship, we can extract the ship’s heading and pitch. The tricky part is doing it with sufficient precision and frequency, so as to provide an accurate, stable and reliable real-time solution.

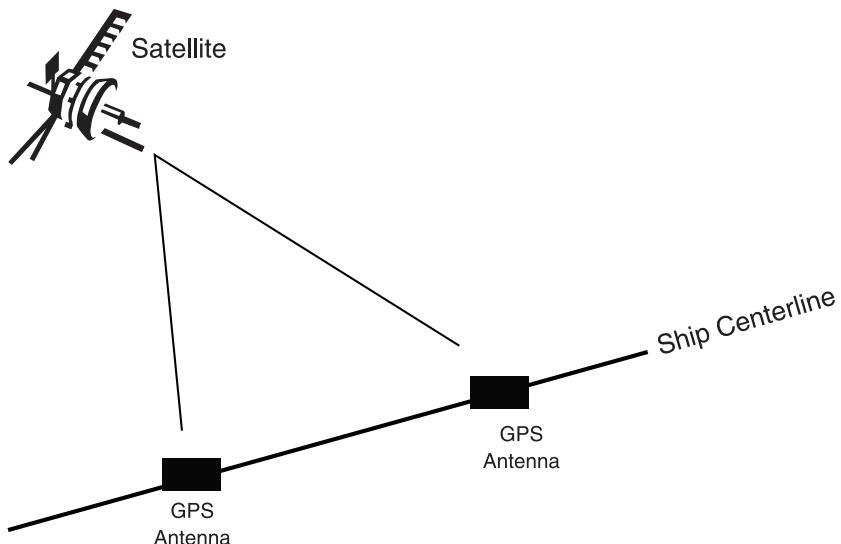
Modern Global Navigation Satellite Systems (GNSS), such as GPS, Glonass and Galileo, offer the capability to measure geographic position in real time using signals from several orbiting satellites. But the raw pseudorange measurements, even when corrected with conventional differential techniques, do not yield a position with sufficient accuracy in themselves. Sophisticated real-time kinematic (RTK) techniques have therefore been developed to refine the positioning accuracy by making phase comparisons on the signal’s carrier waves. The phase comparisons of the GPS signals received by the two antennas can yield a highly accurate measurement of the axis between them.

A second problem with satellite-based systems is that the signals from one or more of the satellites may be

temporarily out of service or corrupted by influences such as multipath propagation (the tendency of signals to bounce from reflective surfaces such as a ship's superstructure), signal blockage or attenuation, interference from space-based sources (e.g., sunspots or ionospheric effects) or man-made radio-frequency interference. It is therefore necessary to provide some level of redundancy with built-in backup systems for occasions when the satellite signals are unreliable or unavailable.

A third problem is update rate. While GPS satellite receivers typically provide 1 Hz (one per second) data outputs, this is insufficient for modern shipboard systems. The heading update rate requirement is 10 Hz for steering systems and 50 Hz for radar stabilization.

A GNSS transmitting heading device typically uses an aerial array consisting of two or three satellite antennas connected to a single processor unit that performs the calculations necessary to determine the ship's heading. It also contains some form of backup system to enable the THD to continue operation when the satellite solution does not meet the required levels of accuracy and frequency of update.



Carriage Requirements

THD carriage requirements are defined in IMO Resolution A.694 (17) and other documents (see complete reference list on page 19).

New ships 300 gross tons and higher, and passenger ships irrespective of size, constructed on or after July 1, 2002, must be fitted with a properly adjusted transmitting heading device, or other means to transmit heading information for input to the ship's radar, VDR and AIS.

New ships over 500 gross tons constructed since July 1, 2002, must be equipped with a gyrocompass or other means to determine and display heading by shipborne non-magnetic means and to transmit heading information for input to radar, AIS and VDR.

Existing ships constructed before July 1, 2002, may continue to comply with the regulations in force prior to that date. When any systems are replaced or added to existing ships, however, they must comply with the new carriage requirements insofar as is reasonable and practical.

Note that in some cases, the regulations allow for "other means" to be used to comply with the functional requirements of the equipment item. When "other means" are permitted, such means must be approved by the national administration.

The SOLAS V High Speed Craft (HSC) Code establishes special additional carriage requirements. It states that new passenger craft constructed since July 1, 2002, certified to carry 100 passengers or less,

must be fitted with a properly adjusted transmitting heading device suitable for the speed and motion characteristics and area of operation of the craft, capable of transmitting a true heading reference to other equipment. Larger passenger vessels (over 100 passengers) must be fitted with a gyrocompass.

From January 1, 2003, existing passenger ships certified to carry 100 passengers or less must be fitted with an instrument providing a heading reference of accuracy superior to that provided by a magnetic compass.

IMO CARRIAGE REQUIREMENTS

Ship Type	Requirement
New ships of 500 grt and upwards constructed after July 1, 2002	Gyrocompass or other means to determine and display heading by non-magnetic means and transmit to designated devices
New ships of 300 grt and upwards and passenger ships irrespective of size constructed after July 1, 2002	Properly adjusted transmitting heading device (THD) or other means to transmit heading to designated devices
Existing ships constructed prior to July 1, 2002	Comply with regulations in force prior to July 1, 2002. When systems are upgraded or replaced, must comply with new regulations

HIGH SPEED CRAFT CODE

Ship Type	Requirement
New passenger ships carrying 100 passengers or less, constructed after July 1, 2002	Properly adjusted transmitting heading device (THD) capable of transmitting true heading reference to other equipment
Passenger vessels carrying more than 100 passengers	Gyrocompass

Performance Standards

Detailed performance standards for marine GNSS transmitting heading devices are contained in IMO Resolution MSC.116 (73) and ISO International Standard 22090-3. The following is a brief summary of relevant provisions. Users should refer to the source documents (see References, page 17) for complete information.

- The THD must be capable of continuous operation under conditions of vibration, humidity and temperature spelled out in detail in ISO 22090-3.
- All displays, with the exception of the sensor, and all outputs of heading must indicate true heading.
- The THD must have means to align the sensing direction to the ship's fore and aft line.
- The THD must be able to maintain the heading accuracy within $\pm 1.5^\circ$ for at least 60 seconds if the satellite signal is interrupted.
- Settling time must be less than 10 minutes under static conditions.
- The THD must output a new heading at least once every 50 ms.
- At least one digital serial output must comply with IEC 61162.
- The THD must be equipped with an alarm to indicate THD malfunction, failure of power supply and continuous GNSS signal interruption over 60 seconds at least.
- The transmission error, including the resolution error, must be less than $\pm 2^\circ$.
- The static error (settle point error) at any heading must be within 1.0° , 95%.

- The dynamic error must be within 1.5° , 95%.
- The follow-up error for different rates of turn must be:
 - Less than $\pm 0.5^\circ$ up to a rate of 10° per second
 - Less than $\pm 1.5^\circ$ up to a rate of between 10 and 20° per second

DEFINITIONS

Transmission and resolution error. Error which is caused by the method used to transmit the original information to a receiving device. This error is caused by the method used inside the THD and at its output to code the information.

Static Error. Error which is caused by any reason and which stays unchanged in value during the operation of the system. This error should be measured under static conditions.

Dynamic Error. Error which is caused by dynamic influences acting on the system, such as vibration, roll, pitch or linear acceleration. This error may have an amplitude and usually a frequency related to the environmental influences and the parameters of the system itself.

Follow-up Error. Error which is caused by the delay between the existence of a value to be sensed and the availability of the corresponding signal or data stream at the output of the system – for instance, the difference between the real heading of turning vessel and the available information at the output of the system. The follow-up error disappears when the system is static.

A Hybrid Solution

The Sperry Marine NAVISTAR system has been designed to meet the IMO requirement for transmitting heading devices on new ships 300-500 gross tons, and as a viable low-cost alternative to spinning-mass and fiber-optic gyrocompasses for workboats, fishing boats, pleasure yachts, naval patrol boats and other smaller vessels not required to carry a gyrocompass.

NAVISTAR incorporates a unique “hybrid” design, using advanced attitude algorithms to process phase data from two GPS carrier frequencies, together with data from three gyro rate sensors and three accelerometers to provide a stable and reliable geographic-north oriented heading reference. In addition to true heading, the system also outputs rate of turn, speed over ground and GPS position in standard maritime message formats.

NAVISTAR provides a very high dynamic accuracy and rapid start-up times. The very high update rate makes the NAVISTAR an ideal heading reference for modern adaptive autopilots.

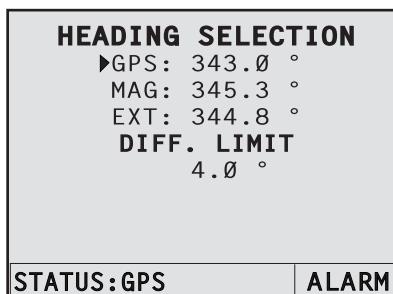
The system provides eight selectable heading output ports. All output data is provided in industry-standard IEC 61162-1 formats suitable for integration into repeaters, radars, autopilots, chart plotters, scanning sonars, AIS, VDR and steerable antenna arrays.

The system also contains a three-axis magnetic field sensor for redundancy and backup. The magnetic field sensor is automatically corrected for deviation and variation to provide true heading. An internal compass monitor constantly compares the GPS solution against the magnetic heading sensor. In case of degradation or loss of GPS data, an audible alarm sounds, and the system automati-

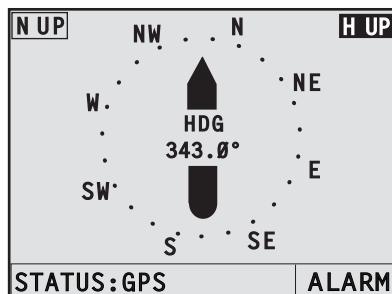
cally defaults to the internal magnetic compass for uninterrupted navigation.



The NAVISTAR system consists of three primary components: the dual GPS antenna array, the processor unit and the control/display unit with large, high-resolution LCD screen, plus connecting cables. The system runs on 12-24 VDC power supply and is designed for easy installation on new or existing vessels. It has no moving parts and is virtually maintenance free. The three rate gyros and accelerometers provide angular rate and acceleration data in three planes with a very high update rate of 100 times per second. They can supply heading for up to 3 minutes with no reset from the GPS or



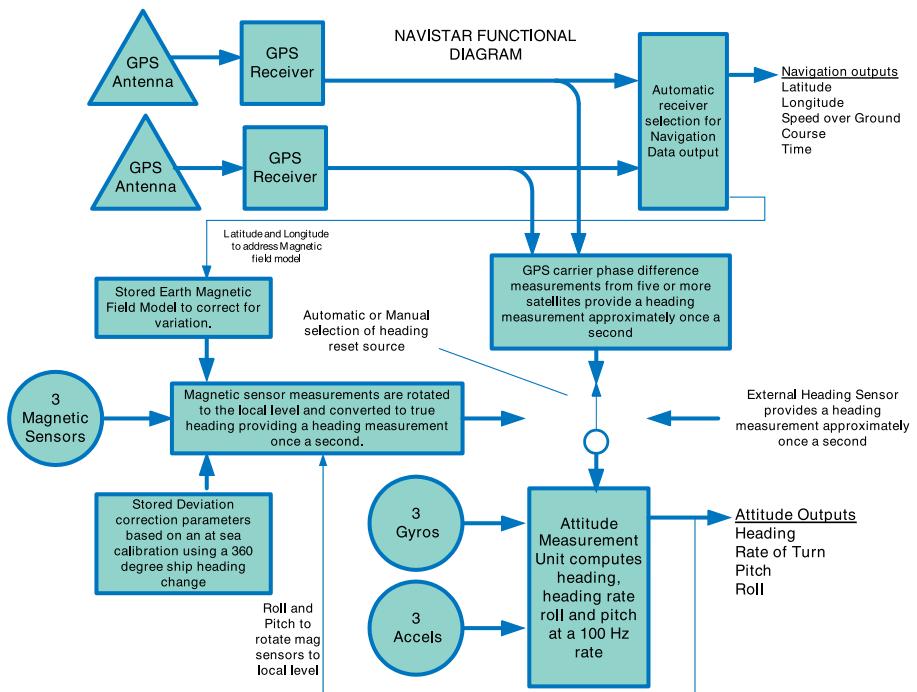
Heading Selector & Compass Monitor



Head-Up Compass Card

magnetic sensor. The two GPS receivers provide heading updates approximately once per second. The three-axis magnetic sensor, compensated for deviation and variation, supplies low-frequency heading for comparison and backup. The computer uses advanced attitude algorithms to process the data from all sources and produce outputs of heading, roll, pitch, speed and course over ground, latitude and longitude and a GPS time reference.

The NAVISTAR system computes attitude from the rate gyros and accelerometers, with resets typically every second from the GPS receivers.



REFERENCES

The following source documents provide detailed information on carriage requirements and performance standards for transmitting heading devices.

- *IMO Resolution A.694 (17) – Recommendations on General Requirements for Shipborne Radio Equipment Forming Part of the Global Maritime Distress and Safety System (GMDSS) and for Electronic Navigational Aids.*
- *MSC.116 (73) – Recommendations on Performance Standards for Marine Transmitting Heading Devices (THDs).*
- *ISO international Standard ISO/DIS 22090-3 – Ships and Marine Technology – Transmitting Heading Devices (THDs) – Part 3: GNSS Principles.*
- *IEC 60945 – Maritime Navigation and Radiocommunication Equipment and Systems – General Requirements – Methods of Testing and Required Test Results.*
- *IEC 61162 – Maritime Navigation and Radiocommunication Equipment and Systems – Digital Interfaces*
- *SOLAS V Regulation 19 – Carriage Requirements for Shipborne Navigational Systems and Equipment.*
- *SOLAS V Regulation 18 – Approvals, Surveys and Performance Standards of Navigational Systems and Equipment and Voyage Data Recorders.*
- *SOLAS V Annex 11 – Navigational Equipment – New Ships*
- *SOLAS V Annex 12 – Navigational Equipment – Existing Ships*
- *SOLAS V Annex 19 – High Speed Craft Code, Chapter 13 – Shipborne Navigational Systems and Equipment and Voyage Data Recorder.*
- *IMO Resolution A.813 (19) – General Requirements for Electromagnetic Compatibility (EMC) for All Electrical and Electronic Ship's Equipment.*

ABBREVIATIONS AND ACRONYMS

- AIS Automatic Identification System
ARPA Automatic Radar Plotting Aid
COG Course over Ground
DGPS Differential GPS
ECDIS Electronic Chart Display and Information System
EPA Electronic Plotting Aid
GNSS Global Navigation Satellite System
GPS Global Positioning System
IEC International Electrotechnical Commission
IMO International Maritime Organization
ISO International Standards Organization
ROT Rate of Turn
RTCM Radio Technical Commission for Maritime Services
SOG Speed over Ground
SOLAS V ... Safety of Life at Sea Convention, Chapter V
THD Transmitting Heading Device
VDR Voyage Data Recorder

USEFUL LINKS

www.sperrymarine.northopgrumman.com – Sperry Marine

www.navcen.uscg.gov – U.S. Coast Guard Navigation Center

www.imo.org – International Maritime Organization

www.iec.ch – International Electrotechnical Commission

www.mcagency.org.uk – Marine and Coastguard Agency

www.seamanship.co.uk – Seamanship International



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www.sperrymarine.northropgrumman.com