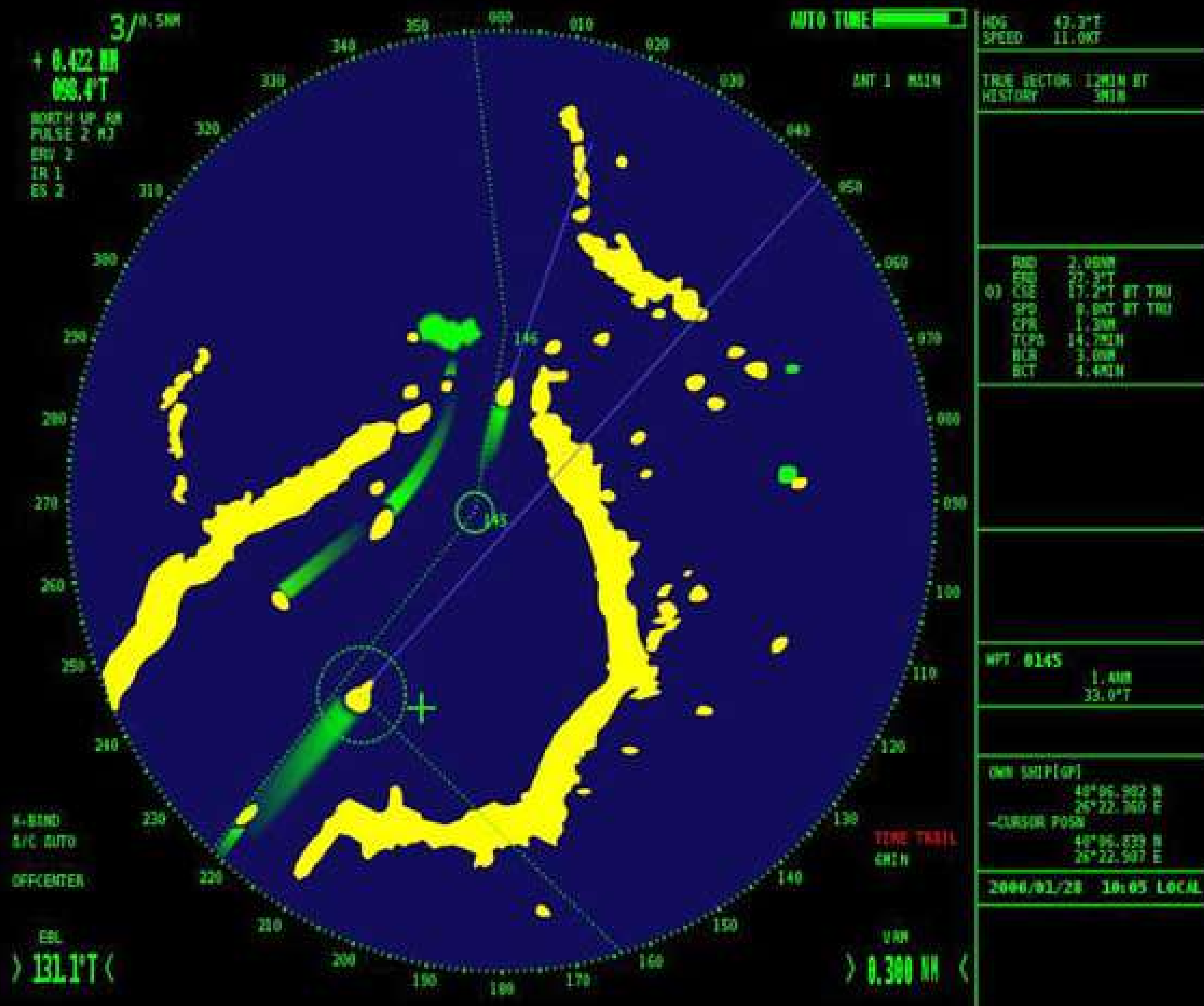
Marine Electronics

Yan Holland



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Chapter- 1

Marine Electronics

Marine electronics refers to electronics devices designed and classed for use in the marine environment where even small drops of salt water will destroy electronics devices. Therefore the majority of these types of devices are either water resistant or waterproof. A wide variety of marine electronics are available in the marketplace today. Reviews and reports on marine chartplotters, autopilots, VHF radios, network chartplotters, fish finders, and a wide range of handheld devices can be found at Marine Electronics Reviews

The term marine electronics is used for areas such as

- Ship
- Yacht

Ship

Italian full-rigged ship *Amerigo Vespucci* in New York Harbor, 1976

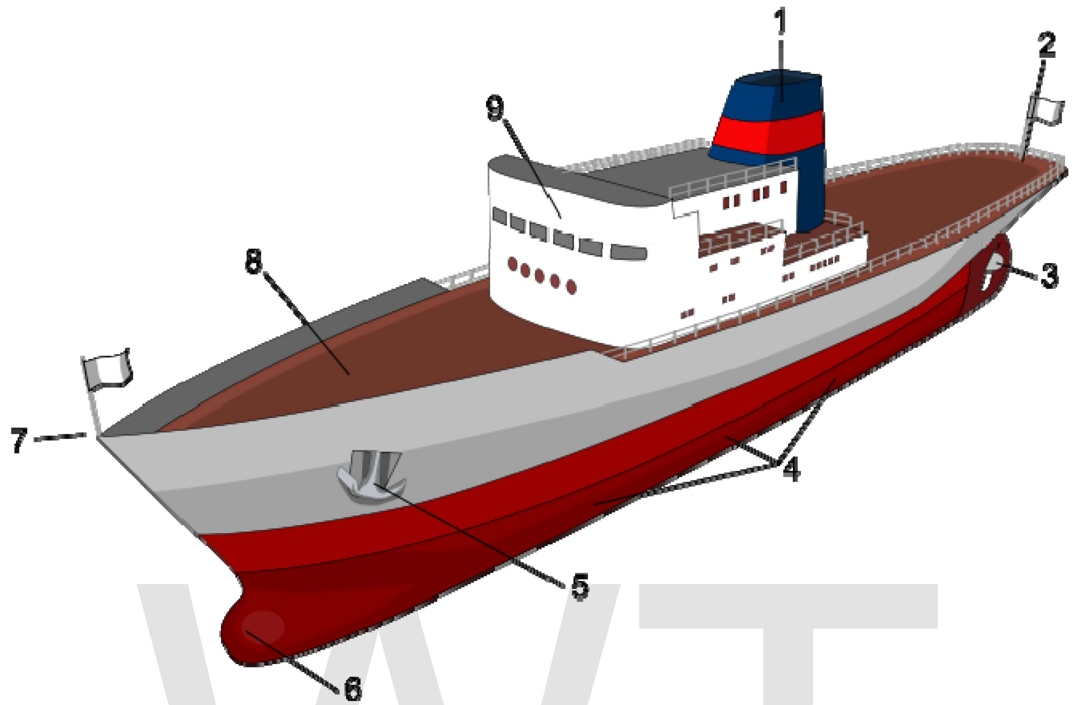
A **ship** is a large vessel that floats on water. Ships are generally distinguished from boats based on size and cargo or passenger capacity. Ships may be found on lakes, seas, and rivers and they allow for a variety of activities, such as the transport of people or goods, fishing, entertainment, public safety, and warfare. Historically, a ship referred to a vessel with sails rigged in a specific manner.

Ships and boats have developed alongside mankind. In major wars, and in day to day life, they have become an integral part of modern commercial and military systems. Fishing boats are used by millions of fishermen throughout the world. Military forces operate highly sophisticated vessels to transport and support forces ashore. Commercial vessels, nearly 35,000 in number, carried 7.4 billion tons of cargo in 2007.

These vessels were also key in history's great explorations and scientific and technological development. Navigators such as Zheng He spread such inventions as the compass and gunpowder. Ships have been used for such purposes as colonization and the slave trade, and have served scientific, cultural, and humanitarian needs. New crops that had come from the Americas via the European seafarers in the 16th century significantly contributed to the world's population growth.

As Thor Heyerdahl demonstrated with his tiny craft the *Kon-Tiki*, it is possible to navigate long distances upon a simple log raft. From Mesolithic canoes to today's powerful nuclear-powered aircraft carriers, ships tell the history of human technological development.

Nomenclature



Main parts of ship. **1**: Smokestack or Funnel; **2**: Stern; **3**: Propeller and Rudder; **4**: Portside (the right side is known as starboard); **5**: Anchor; **6**: Bulbous bow; **7**: Bow; **8**: Deck; **9**: Superstructure

Ships can usually be distinguished from boats based on size and the ship's ability to operate independently for extended periods. A commonly used rule of thumb is that if one vessel can carry another, the larger of the two is a ship. As dinghies are common on sailing yachts as small as 35 feet (10.67 m), this rule of thumb is not foolproof. In a more technical and now rare sense, the term ship refers to a sailing ship with at least 3 square-rigged masts and a full bowsprit, with lesser ships described by their sailplan (e.g. barque, brigantine, etc.).

A number of large vessels are traditionally referred to as boats. Submarines are a prime example. Other types of large vessels which are traditionally called boats are the Great Lakes freighter, the riverboat, and the ferryboat. Though large enough to carry their own boats and heavy cargoes, these vessels are designed for operation on inland or protected coastal waters.

In most maritime traditions, ships have an individual name, and modern ships may belong to a ship class often named after its first ship. In English, a ship is traditionally referred to as "she", even if named after a man, but as of the 2000s this figure of speech is in decline and journalistic style guides advise to use "it".

Types of ships

Ships are difficult to classify, mainly because there are so many criteria to base classification on. One classification is based on propulsion; with ships categorised as either a sailing ship a Steamship or a motorship. Sailing ships are ships which are propelled solely by means of sails. Steamships are ships which are propelled by steam engines. Motorships are ships which use internal combustion engines as a means to propel themselves. Motorships include ships that propel itself through the use of both sail and mechanical means.

Other classification systems exist that use criteria such as:

- The number of hulls, giving categories like monohull, catamaran, trimaran.
- The shape and size, giving categories like dinghy, keelboat, and icebreaker.
- The building materials used, giving steel, aluminum, wood, fiberglass, and plastic.
- The type of propulsion system used, giving human-propelled, mechanical, and sails.
- The epoch in which the vessel was used, triremes of Ancient Greece, men of war in the 18th century.
- The geographic origin of the vessel, many vessels are associated with a particular region, such as the pinnace of Northern Europe, the gondolas of Venice, and the junks of China.
- The manufacturer, series, or class.

Another way to categorize ships and boats is based on their use, as described by Paulet and Presles. This system includes military ships, commercial vessels, fishing boats, pleasure craft and competitive boats. In this section, ships are classified using the first four of those categories, and adding a section for lake and river boats, and one for vessels which fall outside these categories.

Yacht

Luxury sailing yacht

A **yacht** is a recreational boat. The term originated from the Dutch *Jacht* meaning "hunt". It was originally defined as a light, fast sailing vessel used by the Dutch navy to pursue pirates and other transgressors around and into the shallow waters of the Low Countries. After its selection by Charles II of England as the vessel of choice to return to Britain from Holland for his restoration, it came to be used to convey important persons.

In modern use the term designates two rather different classes of watercraft, sailing and power boats. Yachts are different from working ships mainly by their leisure purpose, and it was not until the rise of the steamboat and other types of powerboat that sailing vessels in general came to be perceived as luxury, or recreational vessels. Later the term came to encompass motor boats for primarily private pleasure purposes as well.

Yacht lengths generally range from 20 feet (6.1 m) up to hundreds of feet. A luxury craft smaller than 40 feet (12.19 m) is more commonly called a cabin cruiser or simply "cruisers." A mega yacht generally refers to any yacht (sail or power) above 100 ft (30.5 m) and a super yacht generally refers to any yacht over 200 ft (61 m). This size is small in relation to typical cruise liners and oil tankers.

Classifications

Day sailing yachts

Day sailing yachts are usually small, at under 20 ft (6 m) in length. Sometimes called dinghies, they often have a retractable keel, centerboard, or daggerboard. Most day sailing yachts do not have a cabin, as they are designed for hourly or daily use and not for overnight journeys. At best they may have a 'cubby', where the front part of the hull has a raised solid roof to provide a place to store equipment or to offer basic shelter from wind or spray.

Weekender yachts

Weekender yachts are slightly larger, at under 30 ft (9.5 m) in length. They often have twin keels or lifting keels such as in trailer sailers. This allows them to operate in shallow waters, and if needed "dry out"—become beached as the tide falls. The hull shape (or twin-keel layout) allows the boat to sit upright when there is no water. Such boats are designed to undertake short journeys, rarely lasting more than 2 or 3 days (hence their name). In coastal areas, long trips may be undertaken in a series of short hops. Weekenders usually have only a simple cabin, often consisting of a single "saloon" with bedspace for two to three people. Clever use of ergonomics allows space in the saloon for a galley (kitchen), seating, and navigation equipment. There is limited space for stores of water and food. Most are single-masted "Bermuda sloops" (not to be confused with the type of traditional Bermudian ship known as a Bermuda sloop), with a single foresail of the jib or genoa type and a single mainsail (one variation of the aforementioned Bermuda rig). Some are gaff rigged. The smallest of this type, generally called *pocket yachts* or *pocket cruisers*, and *trailer sailers* can be transported on special trailers.

Cruising yachts Cruising yachts are by the far the most common yacht in private use, making up most of the 25 to 45 ft (7 to 14 m) range. These vessels can be quite complex in design, as they need a balance between docile handling qualities, interior space, good light-wind performance and on-board comfort. The huge range of such craft, from dozens of builders worldwide, makes it hard to give a single illustrative description. However, most favour a teardrop-planform hull, with a wide, flat bottom and deep single-fin keel to give good stability. Most are single-masted Bermuda rigged sloops, with a single fore-sail of the jib or Genoa type and a single mainsail. Spinnaker sails, in various sizes, are often supplied for down-wind use. These types are often chosen as family vessels, especially those in the 26 to 40-foot (8 to 12 m) range. Such a vessel will usually have many cabins below deck. Typically there will be three double-berth cabins; a single large saloon with galley, seating and navigation equipment; and a "head" consisting of a toilet and shower-room.

Most large yachts, 50 ft (15 m) (15 m) and up, are also cruisers, but their design varies greatly as they are often "one off" designs tailored to the specific needs of the buyer.The interior is often finished in wood panelling, with plenty of storage space. Cruisers are quite capable of taking on long-range passages of many thousands of miles. Such boats have a cruising speed upwards of 6 knots. This basic design is typical of the standard types produced by the major yacht-builders.

Luxury sailing yachts

These yachts are generally 82 ft (25 m) or longer. In recent years, these yachts have evolved from fairly simple vessels with basic accommodation into sophisticated and luxurious boats. This is largely due to reduced hull-building costs brought about by the introduction of fibreglass hulls, and increased automation and "production line" techniques for yacht building, especially in Europe.

On the biggest, 130-foot-plus (40 m) luxury yachts, every modern convenience, from air conditioning to television, is found. Sailing yachts of this size are often highly automated with, for example, computer-controlled electric winches controlling the sails. Such complexity requires dedicated power-generation systems. In recent years the amount of electric equipment used on yachts has increased greatly. Even 20 years ago, it was not common for a 25-foot (7 m) yacht to have electric lighting. Now all but the smallest, most basic yachts have electric lighting, radio, and navigation aids such as Global Positioning Systems. Yachts around 33 ft (10 m) bring in comforts such as hot water, pressurised water systems, and refrigerators. Aids such as radar, echo-sounding and autopilot are common. This means that the auxiliary engine now also performs the vital function of powering an alternator to provide electrical power and to recharge the yacht's batteries. For yachts engaged on long-range cruising, wind-, water- and solar-powered generators can perform the same function.

Racing yachts

Inshore yacht racing in Sydney Harbour, Australia

Racing yachts try to reduce the wetted surface area, which creates drag, by keeping the hull light whilst having a deep and heavy bulb keel, allowing them to support a tall mast with a great sail area. Modern designs tend to have a very wide beam and a flat bottom, to provide buoyancy preventing an excessive heel angle. Speeds of up to 35 knots can be attained in extreme conditions. Dedicated offshore racing yachts sacrifice crew comfort for speed, having basic accommodation to reduce weight. Depending on the type of race, such a yacht may have a crew of 15 or more. Very large inshore racing yachts may have a crew of 30. At the other extreme are "single handed" races, where one person alone must control the yacht.

Yacht races may be over a simple course of only a few miles, as in the harbour racing of the International One Design; long-distance, open-ocean races, like the Bermuda Race; or epic trans-global contests such as the Global Challenge, Volvo Ocean Race, and Clipper Round the World Race.

Propulsion

The motive force being the wind, sailing is more economical and environmentally friendly than any other means of propulsion. A hybrid type of vessel is a motor sailing yacht that can use either sail or propulsion (or both) as conditions dictate.

Many "pure" sailing yachts are also equipped with a low-power internal-combustion engine for use in conditions of calm and when entering or leaving difficult anchorages. Vessels less than 25 ft (8 m) (7 m) in length generally carry a petrol outboard-motor of between 5 and 40 horsepower (3.5 and 30 kW). Larger vessels have in-board diesel engines of between 20 and 100 horsepower (15 and 75 kW) depending on size. In the common 25 to 45-foot (7 to 14 m) class, engines of 20 to 40 horsepower are the most common.

Hull types

Monohull yachts are typically fitted with a fixed keel or a centerboard (adjustable keel) below the waterline to counterbalance the overturning force of wind on the vessel's sails. Multihull yachts use two hulls (catamarans) or three (trimarans) widely separated from each other to provide a stable base that resists overturning and allows for sailing in shallower waters than most keeled monohulls.

Motor yachts

Motor yacht at Gdańsk Bay in Poland

Classification

Motor yachts generally fit into the following categories:

- Day cruiser yacht (no cabin, sparse amenities such as refrigerator and plumbing)

- Weekender yacht (one or two basic cabins, basic galley appliances and plumbing)
- Cruising yacht (sufficient amenities to allow for living aboard for extended periods)
- Sport fishing yacht (yacht with living amenities and sporting fishing equipment)
- Luxury yacht (similar to the last three types of yachts, with more luxurious finishings/amenities)

Propulsion

Yachts moored at Rowe's Wharf in Boston Harbor

Motor yachts typically have one or two internal combustion engines that burn diesel fuel. Depending on engine size, fuel costs may make motor yachts more expensive to operate than sailing yachts. Biodiesel for marine propulsion is in the experimental stage (e.g. Earthrace).

Hull types

The shape of a motor yacht's hull may be based on displacement, planing, or in between. Although monohulls have long been the standard in motor yachts, multihulls are gaining in popularity.

Chapter- 2

Chartplotter & Marine VHF Radio

Chartplotter

A **Chartplotter** is a device used in marine navigation that integrates GPS data with an electronic navigational chart (ENC). The chartplotter displays the ENC along with the position, heading and speed of the ship, and may display additional information from radar, automatic information systems (AIS) or other sensors. As appropriate to particular marine applications, chartplotters may also display data from other sensors, such as echolocators/sonar.

Electronic chartplotters always require a computer, or sometimes multiple computers. It is a feature of the implementation, and sometimes of regulatory requirements, whether the computer is a general-purpose one that can run other applications, or must be dedicated to the chartplotter application. Especially when the chartplotter generates three-dimensional displays, as used for fishing, considerable processing power and video memory can be needed.

Recreational marine chartplotters are used for displaying chart data. Normally a chartplotter is also fed GPS input to compute an accurate position of the vessel. These marine electronics devices are continuously evolving with larger screens, increased processing power, and multi-function capabilities that allow them to display data from a connected radar, fish finder, weather receiver, or be coupled to another marine chartplotter via a marine network.

Electronic Charts

An individual electronic chart, or, more commonly, a database of charts, is the heart of a chartplotter. The chartplotter system can be no more accurate than its charts. While there are different formats for electronic charts, there are even more important quality and legal aspects.

Without charts that are accredited by appropriate governmental organizations, a chartplotter is an example of an Electronic Charting System (ECS). When the charts meet the technical requirements of the International Maritime Organization (IMO) and national hydrographic bodies, the chartplotter can qualify as an Electronic Chart Display and Information System(ECDIS). ECDIS legally can be substituted for paper charts while navigating in active waterways, but vessels are required to maintain paper charts if their chartplotter does not use ECDIS.

ECDIS will use IMO-standardized formats, but some chartplotters require specific data formats. A charter may use one or both types of ENC:

- Raster Charts: The chart plotter displays a "picture" of a paper chart or map which is referenced to geographic coordinates. A GPS position can be displayed upon the raster chart, but accuracy depends upon many factors including the type of projection (eg. conic or mercator) used in the original chart, and the reference system used (eg. NAD-27 or WGS-84).
- Vector Charts: The chart plotter constructs a facsimile of a chart using raw data from a data base. The major advantages are a reduction in the amount of data to be stored, and the ability of the chart plotter to identify certain features (such as water depth) and act upon them (eg. do not allow the ship to run aground)

Human Interfaces

A basic navigational display is common to all chartplotters. Depending on intended use and characteristics of the specific chartplotter, they may have options to present such displays as three-dimensional fish-finding and bottom characteristics useful in fishing. These optional displays can be presented by commands to a single screen, causing the main display to be replaced with the one requested. Alternatively, chartplotters may offer split-screen modes on a single physical screen, or may support multiple physical displays.

They may be programmable to generate audible and visual alarms for conditions such as a potential collision, deviating significantly from the planned course, etc.

Related Application

The principal function of a classic chartplotter is assisting a human pilot to plot and follow a course.

Safety-related Automatic identification systems (AIS), required on all passenger vessels and vessels of 300 tons and over, also assist in piloting, and can display on the chartplotter. AIS have collision avoidance, and avoidance of known hazards such as reefs, as their primary function. AIS depend on cooperative data communications among ships. Vessel traffic services (VTS) go even farther as safety systems, being analogous to the proactive function of air traffic control systems. VTS assist vessel traffic control in routing vessels in busy waters. Other vessel-based safety collision avoidance functions are Automatic Radar Plotting Aids (ARPA), usually a component of the radar system or an accessory to it, and coupled with the radar system input to the chartplotter.

Marine VHF radio

A standard handheld maritime VHF, mandatory on larger vessels under the GMDSS rules

A classical maritime VHF set

A portable VHF which is both ip67, GMDSS and ATEX approved.

A VHF set and a VHF channel 70 DSC set, the DSC on top, both produced by Sailor

Marine VHF radio is installed on all large ships and most seagoing small craft. It is used for a wide variety of purposes, including summoning rescue services and communicating with harbours, locks, bridges and marinas, and operates in the VHF frequency range, between 156 to 174 MHz. Although it is widely used for collision avoidance, its use for this purpose is contentious and is strongly discouraged by some countries, including the UK.

A marine VHF set is a combined transmitter and receiver and only operates on standard, international frequencies known as channels. **Channel 16** (156.8 MHz) is the international calling and distress channel. **Channel 9** can also be used in some places as a secondary call and distress channel. Transmission power ranges between 1 and 25 watts, giving a maximum range of up to about 60 nautical miles (111 km) between aerials mounted on tall ships and hills, and 5 nautical miles (9 km) between aerials mounted on small boats at sea-level. Frequency modulation is used, with vertical polarization, meaning that antennas have to be vertical in order to have good reception.

Modern day marine VHF radios not only offer basic transmit and receive capabilities, many package additional features that truly make these radios indispensable for the mariner. For the last several years all fixed mount marine VHF radios have required by certification some level of "Digital Selective Calling" (DSC) calling capability. Even the basic set has the ability to alert other boats, ships, and shore stations with a single button press. More expensive radios offer far more extensive DSC capabilities. These may include position polling or a variety of group calling options. Most mid-priced marine VHF radios integrate other features too. Many have the ability to connect to a remote microphone and act as an intership intercom system. Still others have a built-in hailer that when connected to an external hailer horn can act as a public address system and/or output required fog signals when conditions warrant. The most sophisticated marine VHF radios have an alphanumeric keypad for data entry, are able to connect to optional voice scramblers, and a few even have the ability to use a Bluetooth headset. The newest combination of features offered is the integration of a complete Class B AIS unit with a marine VHF radio.

Marine VHF mostly uses "simplex" transmission, where communication can only take place in one direction at a time. A transmit button on the set or microphone determines whether it is operating as a transmitter or a receiver. The majority of channels, however, are set aside for "duplex" transmissions channels where communication can take place in both directions simultaneously . Each duplex channel has two frequency assignments. This is mainly because, in the days before mobile phones and satcomms became widespread, the duplex channels could be used to place calls on the public telephone system for a fee via a marine operator. This facility is still available in some areas, though its use has largely died out. In US waters, Marine VHF radios can also receive weather radio broadcasts, where they are available, on receive-only channels wx1, wx2, etc.

Types of equipment

Sets can be fixed or portable. A fixed set generally has the advantages of a more reliable power source, higher transmit power, a larger and more effective aerial and a bigger display and buttons. A portable set (often essentially a waterproof, VHF walkie-talkie in design) can be carried on a kayak, or to a lifeboat in an emergency, has its own power source and is water-proof if GMDSS approved. A few portable VHFs are even approved to be used as emergency radios in environments requiring intrinsically safe equipment (e.g. gas tankers, oil rigs, etc.).

Marine radios can be "voice-only" or can include "Digital Selective Calling" (DSC).

Voice-only equipment is the traditional type, which relies totally on the human voice for calling and communicating.

Digital Selective Calling equipment, a part of the Global Maritime Distress Safety System (GMDSS), provides all the functionality of voice-only equipment and, additionally, allows several other features:

- a transmitter can automatically call a receiver equipped with Digital Selective Calling, using a telephone-type number known as a Maritime Mobile Service

Identity or MMSI. The DSC information is sent on the reserved Channel 70. When the receiver picks up the call, his active channel is automatically switched to the transmitter's channel and normal voice communication can proceed.
- a distress button, which automatically sends a digital distress signal identifying the calling vessel and the nature of the emergency
- a connection to a GPS receiver allowing the digital distress message to contain the distressed vessel's position

The MMSI is a nine digit number identifying a VHF set or group of sets. The left hand digits of MMSI indicate the country and type of station. For example, here are MMSI prefixes of four station types:

- Ship : 232, 233, 234 or 235 are the United Kingdom – e.g. a UK ship : 232003556
- Coast : 00 – e.g. Solent Coastguard : 002320011
- Group of stations : 0 – e.g. 023207823
- Portable DSC equipment : for UK 2359 - e.g. 235900498

Operating procedure

The accepted conventions for use of marine radio are collectively termed "proper operating procedure." These conventions include:

- Listening for 2 minutes before transmitting
- Using Channel 16 only to establish communication (if necessary) and then switch to a different channel
- using a set of international "calling" procedures such as the "Mayday" distress call, the "Pan-pan" urgency call and "Securité" navigational hazard call.
- using "pro-words" based on the English language such as *Acknowledge, All after, All before, All stations, Confirm, Correct, Correction, In figures, In letters, Over, Out, Radio check, Read back, Received, Repeat, Say again, Spell, Standby, Station calling, This is, Wait, Word after, Word before, Wrong*
- using the NATO phonetic alphabet: *Alpha, Bravo, Charlie, Delta, Echo, Foxtrot, Golf, Hotel, India, Juliet, Kilo, Lima, Mike, November, Oscar, Papa, Quebec, Romeo, Sierra, Tango, Uniform, Victor, Whiskey, X-ray, Yankee, Zulu*
- using a phonetic numbering system based on the English language: *Wun, Too, Tree, Fow-er, Fife, Six, Sev-en, Ait, Nin-er, Zero, Decimal*

Slightly adjusted regulations can apply for inland shipping, such as the Basle rules in Western Europe.

Marine VHF radio is sometimes illegally operated inland. Since enforcement is often the job of the local coast guard, enforcement away from the water is sometimes difficult.

Chapter- 3

Autopilot (Marine Electronic Device)

Autopilot panel of an older Boeing 747 aircraft

An **autopilot** is a mechanical, electrical, or hydraulic system used to guide a vehicle without assistance from a human being. An autopilot can refer specifically to aircraft, self-steering gear for boats, or auto guidance of space craft and missiles. The autopilot of an aircraft is sometimes referred to as "George".

First autopilots

In the early days of aviation, aircraft required the continuous attention of a pilot in order to fly safely. As aircraft range increased allowing flights of many hours, the constant attention led to serious fatigue. An autopilot is designed to perform some of the tasks of the pilot.

The first aircraft autopilot was developed by Sperry Corporation in 1912. The autopilot connected a gyroscopic Heading indicator and attitude indicator to hydraulically operated elevators and rudder (ailerons were not connected as wing dihedral was counted upon to produce the necessary roll stability.) It permitted the aircraft to fly straight and level on a compass course without a pilot's attention, greatly reducing the pilot's workload.

Lawrence Sperry (the son of famous inventor Elmer Sperry) demonstrated it two years later in 1914 at an aviation safety contest held in Paris. At the contest, Lawrence Sperry demonstrated the credibility of the invention were shown by flying the aircraft with his hands away from the controls and visible to onlookers of the contest. This autopilot system was also capable of performing take-off and landing, and the French military command showed immediate interest in the autopilot system. Wiley Post used a Sperry autopilot system to fly alone around the world in less than eight days in 1933.

Further development of the autopilot were performed, such as improved control algorithms and hydraulic servomechanisms. Also, inclusion of additional instrumentation such as the radio-navigation aids made it possible to fly during night and in bad weather. In 1947 a US Air Force C-53 made a transatlantic flight, including takeoff and landing, completely under the control of an autopilot.

In the early 1920s, the Standard Oil tanker *J.A Moffet* became the first ship to use an autopilot.

Modern autopilots

Not all of the passenger aircraft flying today have an autopilot system. Older and smaller general aviation aircraft especially are still hand-flown, while small airliners with fewer than twenty seats may also be without an autopilot as they are used on short-duration flights with two pilots. The installation of autopilots in aircraft with more than twenty seats is generally made mandatory by international aviation regulations. There are three levels of control in autopilots for smaller aircraft. A single-axis autopilot controls an aircraft in the roll axis only; such autopilots are also known colloquially as "wing levellers", reflecting their limitations. A two-axis autopilot controls an aircraft in the pitch axis as well as roll, and may be little more than a "wing leveller" with limited pitch-oscillation-correcting ability; or it may receive inputs from on-board radio navigation systems to provide true automatic flight guidance once the aircraft has taken off until shortly before landing; or its capabilities may lie somewhere between these two extremes. A three-axis autopilot adds control in the yaw axis and is not required in many small aircraft.

Autopilots in modern complex aircraft are three-axis and generally divide a flight into taxi, takeoff, ascent, level, descent, approach and landing phases. Autopilots exist that automate all of these flight phases except the taxiing. An autopilot-controlled landing on a runway and controlling the aircraft on rollout (i.e. keeping it on the centre of the runway) is known as a CAT IIIb landing or Autoland, available on many major airports' runways today, especially at airports subject to adverse weather phenomena such as fog. Landing, rollout and taxi control to the aircraft parking position is known as CAT IIIc. This is not used to date but may be used in the future. An autopilot is often an integral component of a Flight Management System.

Modern autopilots use computer software to control the aircraft. The software reads the aircraft's current position, and controls a Flight Control System to guide the aircraft. In such a system, besides classic flight controls, many autopilots incorporate thrust control capabilities that can control throttles to optimize the air-speed, and move fuel to different tanks to balance the aircraft in an optimal attitude in the air. Although autopilots handle new or dangerous situations inflexibly, they generally fly an aircraft with a lower fuel-consumption than a human pilot.

The autopilot in a modern large aircraft typically reads its position and the aircraft's attitude from an inertial guidance system. Inertial guidance systems accumulate errors over time. They will incorporate error reduction systems such as the carousel system that rotates once a minute so that any errors are dissipated in different directions and have an overall nulling effect. Error in gyroscopes is known as drift. This is due to physical properties within the system, be it mechanical or laser guided, that corrupt positional data. The disagreements between the two are resolved with digital signal processing, most often a six-dimensional Kalman filter. The six dimensions are usually roll, pitch, yaw, altitude, latitude and longitude. Aircraft may fly routes that have a required performance factor, therefore the amount of error or actual performance factor must be monitored in order to fly those particular routes. The longer the flight the more error accumulates within the system. Radio aids such as DME, DME updates and GPS may be used to correct the aircraft position.

Computer system details

The hardware of an autopilot varies from implementation to implementation, but is generally designed with redundancy and reliability as foremost considerations. For example, the Rockwell Collins AFDS-770 Autopilot Flight Director System used on the Boeing 777, uses triplicated FCP-2002 microprocessors which have been formally verified and are fabricated in a radiation resistant process.

Software and hardware in an autopilot is tightly controlled, and extensive test procedures are put in place.

Some autopilots also use design diversity. In this safety feature, critical software processes will not only run on separate computers and possibly even using different architectures, but each computer will run software created by different engineering teams, often being programmed in different programming languages. It is generally considered unlikely that different engineering teams will make the same mistakes. As the software becomes more expensive and complex, design diversity is becoming less common because fewer engineering companies can afford it. The flight control computers on the Space Shuttle uses this design: there are five computers, four of which redundantly run identical software, and a fifth backup running software that was developed independently. The software on the fifth system provides only the basic functions needed to fly the Shuttle, further reducing any possible commonality with the software running on the four primary systems.

Categories

Instrument-aided landings are defined in categories by the International Civil Aviation Organization. These are dependent upon the required visibility level and the degree to which the landing can be conducted automatically without input by the pilot.

CAT I - This category permits pilots to land with a decision height of 200 ft (61 m) and a forward visibility or Runway Visual Range (RVR) of 550 m. Simplex autopilots are sufficient.

CAT II - This category permits pilots to land with a decision height between 200 ft and 100 ft (≈ 30 m) and a RVR of 300 m. Autopilots have a fail passive requirement.

CAT IIIa -This category permits pilots to land with a decision height as low as 50 ft (15 m) and a RVR of 200 m. It needs a fail-passive autopilot. There must be only a 10^{-6} probability of landing outside the prescribed area.

CAT IIIb - As IIIa but with the addition of automatic roll out after touchdown incorporated with the pilot taking control some distance along the runway. This category permits pilots to land with a decision height less than 50 feet or no decision height and a forward visibility of 250 ft (76 m, compare this to aircraft size, some of which are now over 70 m long) or 300 ft (91 m) in the United States. For a landing-without-decision aid, a fail-operational autopilot is needed. For this category some form of runway guidance system is needed: at least fail-passive but it needs to be fail-operational for landing without decision height or for RVR below 100 m.

CAT IIIc - As IIIb but without decision height or visibility minimums, also known as "zero-zero".

Fail-passive autopilot: in case of failure, the aircraft stays in a controllable position and the pilot can take control of it to go around or finish landing. It is usually a dual-channel system.

Fail-operational autopilot: in case of a failure below alert height, the approach, flare and landing can still be completed automatically. It is usually a triple-channel system or dual-dual system.

Radio-controlled models

In radio-controlled modelling, and especially RC aircraft and helicopters, an autopilot is usually a set of extra hardware and software that deals with pre-programming the model's flight.

Chapter- 4

Self-Steering Gear

Self-steering gear is equipment used on ships and boats to maintain a chosen course without constant human action. It is also known by several other terms, such as **autopilot** (borrowed from aircraft and considered incorrect by some) and **autohelm** (technically a Raymarine trademark, but often used generically). Several forms of self-steering gear exist, divided into two categories: electronic and mechanical.

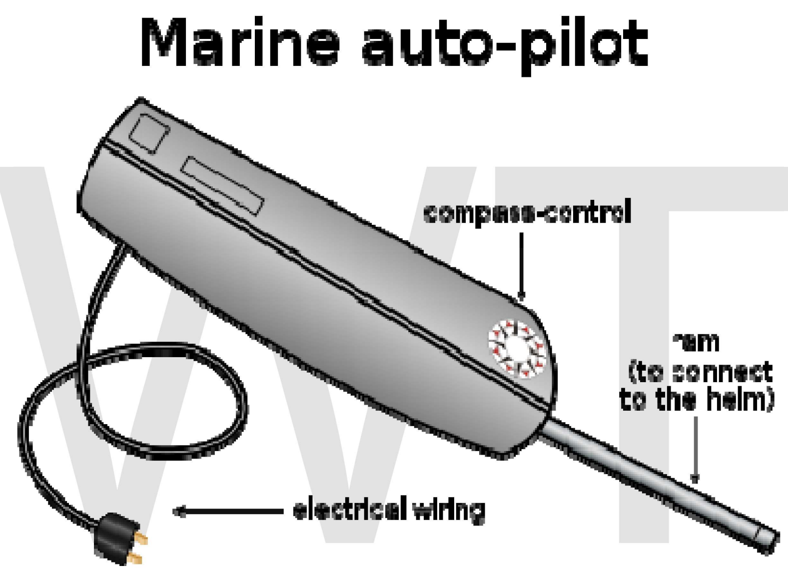
Electronic

A tiller-pilot on a sailing boat - simple electronic self-steering.

Electronic self-steering is controlled by electronics operating according to one or more input sensors, invariably at least a magnetic compass and sometimes wind direction or GPS position versus a chosen waypoint. The electronics module calculates the required steering movement and a drive mechanism (usually electrical, though possibly hydraulic in larger systems) causes the rudder to move accordingly.

There are several possibilities for the interface between the drive mechanism and the conventional steering system. On yachts, the three most common systems are:

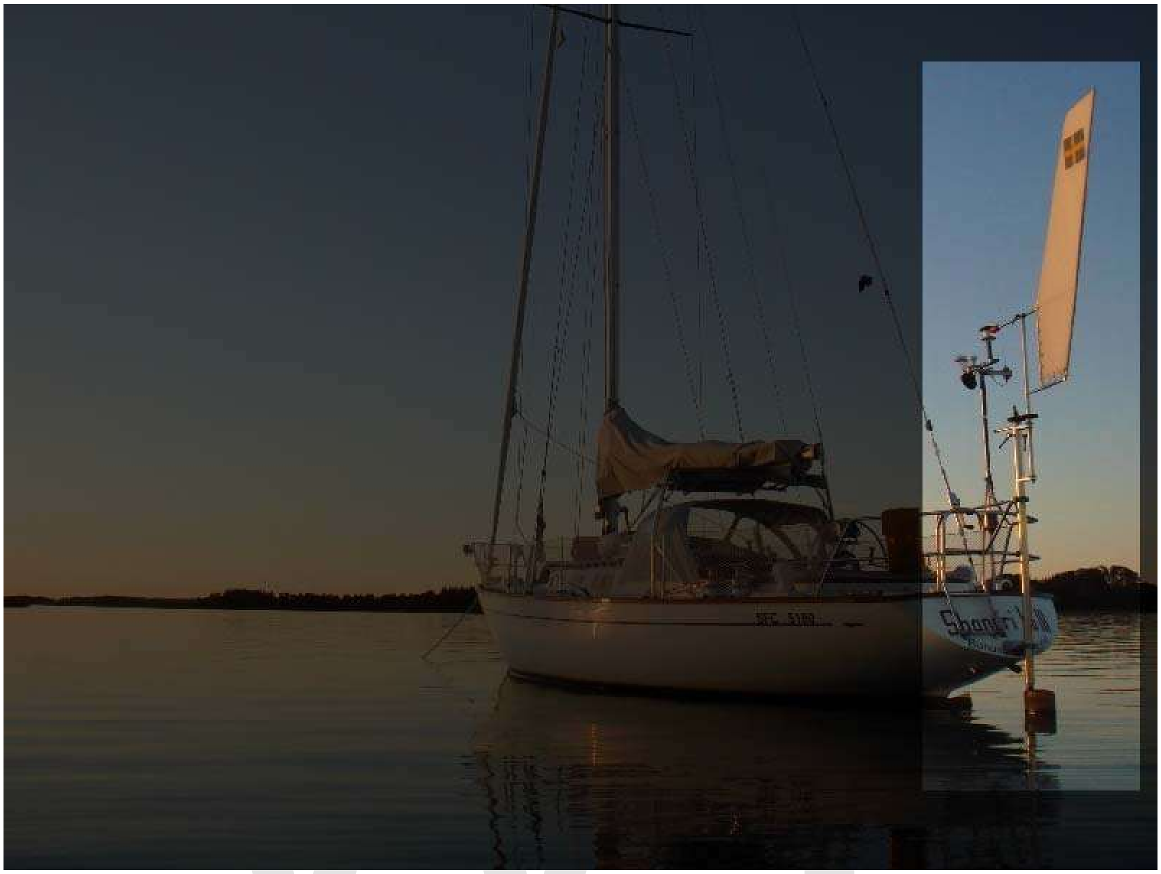
- Direct drive, in which an actuator is attached to the steering quadrant, at the top of the rudder stock inside the boat. This is the least intrusive method of installation.
- Wheel mounting, in which a motor is mounted near the steering wheel, and can be engaged with it when in use. This typically involves either a belt drive or a toothed gear-ring attached to the wheel itself, and is a common option for retro-fitted installations on yachts with a wheel.
- Tiller-pilots are usually the only option on smaller vessels steered with a tiller. They consist of an electrically driven ram which is mounted between the tiller and a fitting on the side of the cockpit. Some are entirely self-contained, needing only a power supply, while others have the control unit separate from the actuator. These are quite popular, as they are maintenance-free and easy to install.



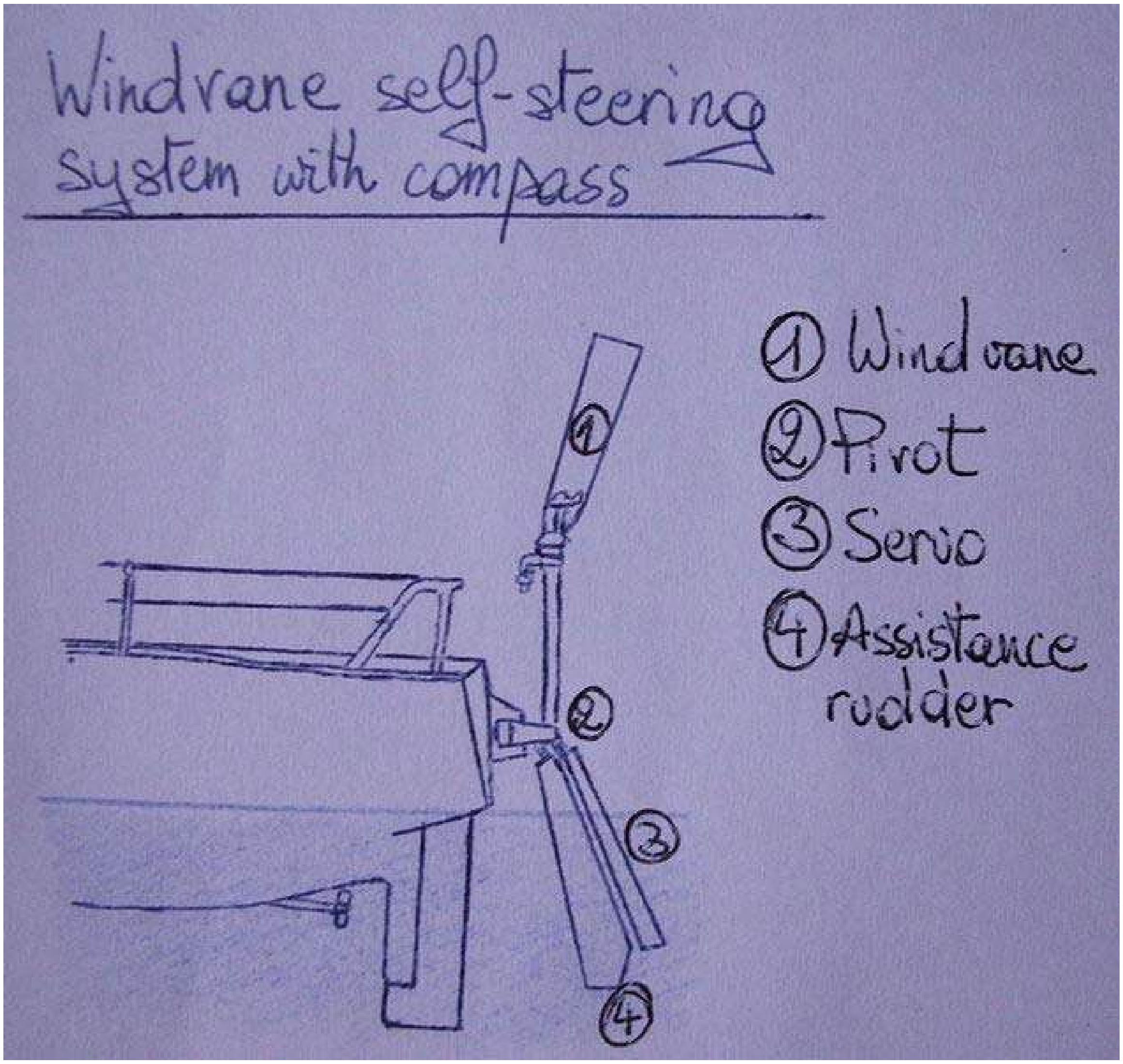
Workings of a marine tiller-pilot

Depending on the sophistication of the control unit (e.g. tiller pilot, steering wheel attached Chartplotter, ...), electronic self-steering gear can be programmed to hold a certain compass course, to maintain a certain angle to the wind (so that sailing boats need not change their sail trim), to steer towards a certain position, or any other function which can reasonably be defined. However, the amount of power required by electrical actuators, especially if constantly in action because of sea and weather conditions, is a serious consideration. Long-distance cruisers, which have no external source of electricity and often do not run their engines for propulsion, typically have relatively strict power budgets and do not use electrical steering for any length of time. As the electronic autopilot systems require electricity to operate, many vessels also make use of PV solar panels or small wind turbines on the boat. This eliminates extra pollution and cuts costs.

Mechanical



Yacht with highlighted self-steering device



A windvane self-steering system

Mechanical or "wind vane" self-steering started out as a way to keep model sail boats on course. The first time that it was used to cross an ocean was on a motorboat. The most widespread form of self steering, the servo pendulum principle (introduced by Herbert "Blondie" Hasler) uses power derived from the motion of the boat through the water to hold a constant angle to the wind with the use of the boat's main rudder. Offshore, the wind direction is relatively stable, so over a number of hours this results in a reasonably constant compass course, and also means that the sails need not be adjusted. Mechanical self-steering can be complicated to set up, so it is typically used only for long-distance sailing where the same course is maintained for long periods. Many boats fitted with mechanical self-steering also carry an electrical autohelm for use over shorter periods where it is not worth setting up the wind vane.

Mechanical self-steering gear is made by a number of manufacturers, but most share the same principle. A narrow upright board, the wind vane, is rotated so that with the boat traveling in the desired direction it is edge-on to the wind. The wind vane is held upright by a small weight below the pivot, but if the boat turns so that the board is no longer edge-on to the wind it will be blown over to one side as the extra surface area is revealed. This movement is transmitted by a series of linkages to a second blade in the water. In the simplest devices for very small boats, this blade acts directly as a secondary rudder, and steers the boat back onto the proper course. The force provided by the wind vane, however, is not sufficient to make this system work with larger loads, and hence a so-called servo pendulum system is used:

As the blade described above turns, the pressure of water moving past it causes it to swing out sideways on the end of a pivoted rod. The length of this rod and the speed of the water means that a considerable force is available at the top end of it, sufficient to change the course of much larger boats. This is achieved either by a connection to the main wheel or tiller (typically involving a complex arrangement of lines and blocks rigged around the stern of the boat) or by fixing the main steering in place and equipping the self-steering gear with its own rudder. Once the boat has moved back to its correct course, the wind vane stands up again as it is no longer blown over by the wind.

If the sails are trimmed correctly and the device is properly set up, wind vane self-steering is very effective. Some experimentation and judgement is usually needed, however, to determine the proper settings for a given vessel and steering mechanism. In addition, wind vanes perform poorly in very light winds, as the forces needed to operate them are much reduced. The same applies when travelling downwind, as the apparent wind speed is reduced by the speed of the boat.

As well as their requirement for power, many long-distance cruisers observe that electronic self-steering machinery is complex and unlikely to be repairable without spare parts in remote areas. By contrast, the often agricultural-looking mechanism of a wind vane gear offers at least the possibility of an improvised repair at sea, and can usually be rebuilt on land using non-specific parts (sometimes plumbing parts) by a local welder or machinist.

Another version of wind vane self steering on sail boats is known as the vertical axis vane and usually, because of the inferior power it has to its Servo Pendulum cousins it makes use of a trim tab hung off the rudder to control the course of the boat. The vane spins at right angles to the ground and can lock to the trim tab in any desired position, as the boat falls off the wind the vane will be turned by the wind and will take the trim tab with it which in turn causes the rudder to move in the opposite direction and thus corrects course. Generally self steering like this, with a trim tab can only be used on boats with transom (or aft hung double enders) rudders as the trim tab needs to be mounted directly to and aft of the rudder to produce the desired effect, and of course has to be controlled even as the rudder swings side to side. This is typically accomplished by use of a slotted bar in which the connection to the vane assembly can slide in as the rudder turns. These self steering systems are generally simpler and are thus easier to set and adjust course as they don't make use of lines controlling the rudder but control it more directly through solid linkages.

A related device has been used on some windmills, the fantail, a small windmill mounted at right angles to the main sails which automatically turns the heavy cap and main sails into the wind, (invented in England in 1745). (When the wind is already directly into the main vanes, the fantail remains essentially motionless.)

A popular source on contemporary windvane technology is *The Windvane Self-Steering Handbook*. One particularly valuable contribution of Morris's book is his coverage of the variety of alloys used in vane gear manufacturing. Morris admits to his practice of setting a kitchen timer for a half hour at a time and sleeping while the windvane steering device controls the helm, even in head winds of 25 to 35 knots. In a recent interview, he said he once narrowly missed being hit by a huge freighter while sleeping on his sail up the Red Sea. Morris points out, "An autopilot wouldn't have made any difference in this case. If I had been using an electronic autopilot, that freighter still would have been there. I made a choice to sail two-thirds of my circumnavigation single-handed, and I accepted the risks that came with that decision. I guess fate was on my side."

Developments

For quite a long time there was little development in the self steering systems that were available commercially. Most new developments came in the form of self-build systems. Crucial roles were played by Walt Murray, an American who published his designs on his website and Dutchman Jan Alkema who developed a new windvane, the so called Up Side Down windvane (USD for short, commercially available from only one brand) and a new kind of servo pendulum system that could be fitted to boats with a transom hung rudder. For this last invention Jan Alkema was rewarded the John Hogg-Price from the AYRS (Amateur Yacht Research Society) in 2005. Jan Alkema published a lot of his inventions on Walt Murray's website.

Famous self-steering boats

Some of the most famous self-steering boats include:

- *Maltese Falcon*
- *Shin Aitoku Maru*
- *Son of Town Hall*, self-steering junk raft which made a transatlantic crossing in 1998

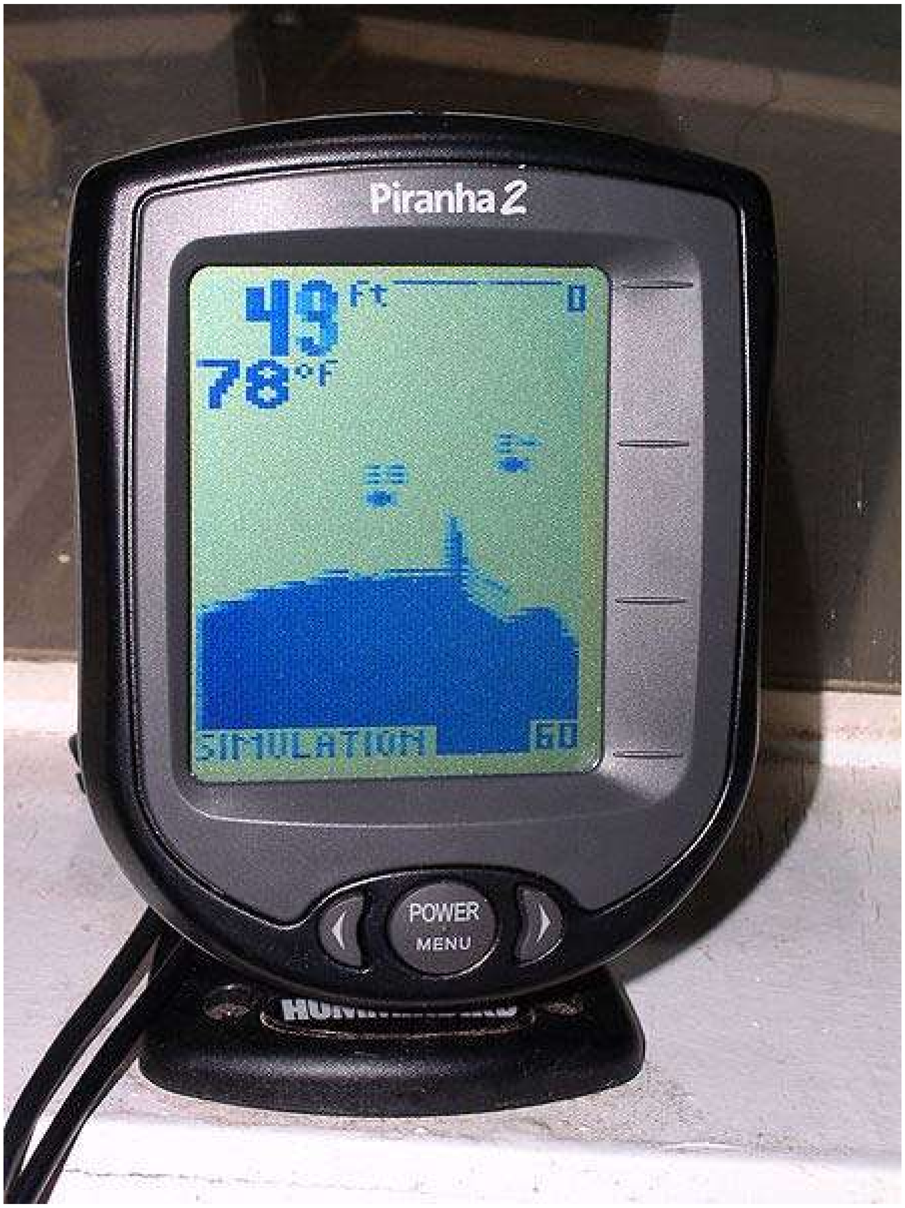
Chapter- 5

Fishfinder

Cabin display of a commercial or oceanographic fathometer sonar

A **fishfinder** is a type of **fathometer**, both being specialized types of echo sounding systems, a type of Active SONAR. ('Sounding' is the measurement of water depth, a historical nautical term of very long usage.) The fishfinder uses active sonar to detect fish and 'the bottom' and displays them on a graphical display device, generally a LCD or CRT screen. In contrast, the modern fathometer (from fathom plus meter, as in 'to measure') is designed specifically to show depth, so may use only a digital display (useless for fish finding) instead of a graphical display, and frequently will have some means of making a permanent recording of soundings (which are merely shown and subsequently electronically discarded in common sporting fishfinder technology) and are always principally **instruments of navigation and safety**. The distinction is in their main purpose and hence in the features given the system. Both work the same way, and use similar frequencies, and, display type permitting, both can show fish and the bottom. Thus today, both have merged, especially with the advent of computer interfaced multipurpose fishfinders combining GPS technology, digital chart-plotting, perhaps radar and electronic compass displays in the same affordable sporting unit.

Operating theory



Display of a consumer type fishfinder

In a generalized sense, an electrical impulse from a transmitter is converted into a sound wave by the transducer, called a hydrophone, and sent into the water. When the wave strikes something such as a fish, it is reflected back and displays size, composition, and shape of the object. The exact extent of what can be discerned depends on the frequency and power of the pulse transmitted. The signal is quickly amplified and sent to the display. Knowing that the speed of the wave in the water is 4921 ft/s (1500 m/s) in seawater, 4800 ft/s (1463 m/s) in freshwater (typical values used by commercial fish finders), the distance to the object that reflected the wave can be determined. The process can be repeated up to 40 times per second and eventually results in the bottom of the ocean being displayed versus time (the fathometer function that eventually spawned the sporting use of fishfinding.) **Note:** This discussion of the propagation of sound in water is simplified, speed of sound in water depends on the temperature, salinity and ambient pressure (depth). This follows approximately this formula (del Grosso, 1974):

$c = 1448.6 + 4.618T - 0.0523T^2 + 1.25 * (S - 35) + 0.017D$

where

c = sound speed (m/s)

T = temperature (degrees Celsius)

S = salinity (pro mille)

D = depth

This will give variations in speed through the water column

General interpretation

The image above, at right, clearly shows the bottom structure -- plants, sediments and hard bottom are descernible on sonar plots of sufficiently high power and appropriate frequency. Slightly more than halfway up from the bottom to the left of the screen center and about a third away from the left side, **this image is also displaying a fish** -- *a light spot* just to the right of a 'glare' splash from the camera's flashbulb. The **X-axis** of the image represents time, oldest (and behind the soundhead) to the left, most recent bottom (and current location) on the right; thus the fish is now well behind the transducer, and the vessel is now passing over a dip in the ocean floor or has just left it behind. The resulting distortion depends on both the speed of the vessel and how often the image is updated by the echo sounder.

Fish symbols in the screen of the fishfinder

Fishfinders usually have a "Fish Symbol" feature, which will display a FISH symbol for almost any echo not connected to the bottom or the surface. More specialized units use a detection of a special fingerprint in echosignals. With those you can find living fish and fish that have recently died. With these units also in some cases fish spawn will be shown as a large fish. Some kinds of seafish will be not marked as fish, but you will see an echo.

Fish Arches

With the Fish Symbol feature disabled, an angler can learn to distinguish between fish, vegetation, schools of baitfish or forage fish, debris, etc. Fish will usually appear on the screen as an arch. This is because the distance between the fish and the transducer changes as the boat passes over the fish (or the fish swims under the boat). When the fish enters the leading edge of the sonar beam, a display pixel is turned on. As the fish swims toward the center of the beam, the distance to the fish decreases, turning on pixels at shallower depths. When the fish swims directly under the transducer, it is closer to the boat so the stronger signal shows a thicker line. As the fish swims away from the transducer, the distance increases, which shows as progressively deeper pixels.

Sonar image of a white bass feeding frenzy

The image to the right shows a school of white bass aggressively feeding on a school of threadfin shad. Note the school of baitfish near the bottom. When threatened, baitfish form a tightly packed school, as the individuals seek safety in the center of the school. This typically looks like an irregularly shaped ball or thumbprint on the fishfinder screen. When no predators are nearby, a school of baitfish frequently appears as a thin horizontal line across the screen, at the depth where the temperature and oxygen levels are optimal. The nearly-vertical lines near the right edge of the screen show the path of fishing lures falling to the bottom.

General history in sporting and fishing

Early sporting fathometers for recreational boating used a rotating light at the edge of a circle which flashed in sync with the received echo, which in turn corresponded to depth. These also gave a small flickering flash for echos off of fish. Like today's low-end digital fathometers, they kept no record of the depth over time and provided no information about bottom structure. They had poor accuracy, especially in rough water, and were hard to read in bright light. Despite the limitations, they were still usable for rough estimates of depth, such as for verifying that the boat had not drifted into an unsafe area.

Commercial and naval units

Commercial and naval fathometers of yesteryear used a Strip Chart Recorder where an advancing roll of paper was marked by a stylus to make a permanent copy of the depth, usually with some means of also recording time (Each mark or time 'tic' is proportional to distance traveled) so that the strip charts could be readily compared to navigation charts and maneuvering logs (speed changes). Much of the world's ocean depths have been mapped using such recording strips. Fathometers of this type usually offered multiple (chart advance) speed settings, and sometimes, multiple frequencies as well. (Deep Ocean -- Low Frequency carries better, Shallows -- high frequency shows smaller structures (like fish, submerged reefs, wrecks, or other bottom composition features of interest.) At high frequency settings, high chart speeds, such fathometers give a picture of the bottom (and any intervening large or schooling fish) relatable to navigation position data. Fathometers of this constant recording type are still mandated for all large vessels (100+ tons displacement) in restricted waters (i.e. generally, within 15 miles (24 km) of land).

Birth of the fishfinder

Eventually, CRTs were married with a fathometer for commercial fishing and the fishfinder was born. With the advent of large LCD arrays, the high power requirements of a CRT gave way to the LCD in the early 1990s and fishfinding fathometers reached the sporting markets at prices nearly anyone of modest means could afford. Today, sporting fishfinders lack only the permanent record of the big ship navigational fathometer, and that is available in high end units that can use the ubiquitous computer to store that record as well.

Chapter- 6

Sonar

French F70 type frigates (here, *La Motte-Picquet*) are fitted with VDS (Variable Depth Sonar) type DUBV43 or DUBV43C towed sonars

Sonar (originally an acronym for **SO**und **N**avigation **A**nd **R**anging) is a technique that uses sound propagation (usually underwater, as in Submarine navigation) to navigate, communicate with or detect other vessels. Two types of technology share the name "sonar": *passive* sonar is essentially listening for the sound made by vessels; *active* sonar is emitting pulses of sounds and listening for echoes. Sonar may be used as a means of acoustic location and of measurement of the echo characteristics of "targets" in the water. Acoustic location in air was used before the introduction of radar. Sonar may also be used in air for robot navigation, and SODAR (an upward looking in-air sonar) is used for atmospheric investigations. The term *sonar* is also used for the equipment used to generate and receive the sound. The acoustic frequencies used in sonar systems vary from very low (infrasonic) to extremely high (ultrasonic). The study of underwater sound is known as underwater acoustics or hydroacoustics.

History

Although some animals (dolphins and bats) have used sound for communication and object detection for millions of years, use by humans in the water is initially recorded by Leonardo Da Vinci in 1490: a tube inserted into the water was said to be used to detect vessels by placing an ear to the tube.

In the 19th century an underwater bell was used as an ancillary to lighthouses to provide warning of hazards.

The use of sound to 'echo locate' underwater in the same way as bats use sound for aerial navigation seems to have been prompted by the *Titanic* disaster of 1912. The world's first patent for an underwater echo ranging device was filed at the British Patent Office by English meteorologist Lewis Richardson a month after the sinking of the Titanic, and a German physicist Alexander Behm obtained a patent for an echo sounder in 1913.

The Canadian engineer Reginald Fessenden, while working for the Submarine Signal Company in Boston, built an experimental system beginning in 1912, a system later tested in Boston Harbor, and finally in 1914 from the U.S. Revenue (now Coast Guard) Cutter Miami on the Grand Banks off Newfoundland Canada. In that test, Fessenden demonstrated depth sounding, underwater communications (Morse Code) and echo ranging (detecting an iceberg at two miles (3 km) range). The so-called Fessenden oscillator, at ca. 500 Hz frequency, was unable to determine the bearing of the berg due to the 3 metre wavelength and the small dimension of the transducer's radiating face (less than 1 metre in diameter). The ten Montreal-built British H class submarines launched in 1915 were equipped with a Fessenden oscillator.

During World War I the need to detect submarines prompted more research into the use of sound. The British made early use of underwater hydrophones, while the French physicist Paul Langevin, working with a Russian immigrant electrical engineer, Constantin Chilowski, worked on the development of active sound devices for detecting submarines in 1915 using quartz. Although piezoelectric and magnetostrictive transducers later superseded the electrostatic transducers they used, this work influenced future designs. Lightweight sound-sensitive plastic film and fibre optics have been used for hydrophones (acousto-electric transducers for in-water use), while Terfenol-D and PMN (lead magnesium niobate) have been developed for projectors.

ASDIC

In 1916, under the British Board of Invention and Research, Canadian physicist Robert William Boyle took on the active sound detection project with A B Wood, producing a prototype for testing in mid 1917. This work, for the Anti-Submarine Division of the British Naval Staff, was undertaken in utmost secrecy, and used quartz piezoelectric crystals to produce the world's first practical underwater active sound detection apparatus. To maintain secrecy no mention of sound experimentation or quartz was made - the word used to describe the early work ('supersonics') was changed to 'ASD'ics, and the quartz material to 'ASD'ivite: hence the British acronym *ASDIC*. In 1939, in response to a question from the Oxford English Dictionary, the Admiralty made up the story that it stood for 'Allied Submarine Detection Investigation Committee', and this is still widely believed, though no committee bearing this name has been found in the Admiralty archives.

By 1918, both France and Britain had built prototype active systems. The British tested their ASDIC on HMS *Antrim* in 1920, and started production in 1922. The 6th Destroyer Flotilla had ASDIC-equipped vessels in 1923. An anti-submarine school, HMS *Osprey*, and a training flotilla of four vessels were established on Portland in 1924. The US Sonar QB set arrived in 1931.

By the outbreak of World War II, the Royal Navy had five sets for different surface ship classes, and others for submarines, incorporated into a complete anti-submarine attack system. The effectiveness of early ASDIC was hamstrung by the use of the depth charge as an anti-submarine weapon. This required an attacking vessel to pass over a submerged contact before dropping charges over the stern, resulting in a loss of ASDIC contact in the moments leading up to attack. The hunter was effectively firing blind, during which time a submarine commander could take evasive action. This situation was remedied by using several ships cooperating and by the adoption of "ahead throwing weapons", such as Hedgehog and later Squid, which projected warheads at a target ahead of the attacker and thus still in ASDIC contact. Developments during the war resulted in British ASDIC sets which used several different shapes of beam, continuously covering blind spots. Later, acoustic torpedoes were used.

At the start of World War II, British ASDIC technology was transferred for free to the United States. Research on ASDIC and underwater sound was expanded in the UK and in the US. Many new types of military sound detection were developed. These included sonobuoys, first developed by the British in 1944 under the codename *High Tea*, dipping/dunking sonar and mine detection sonar. This work formed the basis for post war developments related to countering the nuclear submarine. Work on sonar had also been carried out in the Axis countries, notably in Germany, which included countermeasures. At the end of World War II this German work was assimilated by Britain and the US. Sonars have continued to be developed by many countries, including Russia, for both military and civil uses. In recent years the major military development has been the increasing interest in low frequency active systems.

SONAR

During the 1930s American engineers developed their own underwater sound detection technology and important discoveries were made, such as thermoclines, that would help future development. After technical information was exchanged between the two countries during the Second World War, Americans began to use the term *SONAR* for their systems, coined as the equivalent of RADAR.

Performance factors

The detection, classification and localisation performance of a sonar depends on the environment and the receiving equipment, as well as the transmitting equipment in an active sonar or the target radiated noise in a passive sonar.

Sound propagation

Sonar operation is affected by variations in sound speed, particularly in the vertical plane. Sound travels more slowly in fresh water than in sea water, though the difference is small. The speed is determined by the water's bulk modulus and mass density. The bulk modulus is affected by temperature, dissolved impurities (usually salinity), and pressure. The density effect is small. The speed of sound (in feet per second) is approximately:

> 4388 + (11.25 × temperature (in °F)) + (0.0182 × depth (in feet)) + salinity (in parts-per-thousand).

This empirically derived approximation equation is reasonably accurate for normal temperatures, concentrations of salinity and the range of most ocean depths. Ocean temperature varies with depth, but at between 30 and 100 meters there is often a marked change, called the thermocline, dividing the warmer surface water from the cold, still waters that make up the rest of the ocean. This can frustrate sonar, because a sound originating on one side of the thermocline tends to be bent, or refracted, through the thermocline. The thermocline may be present in shallower coastal waters. However, wave action will often mix the water column and eliminate the thermocline. Water pressure also affects sound propagation: higher pressure increases the sound speed, which causes the sound waves to refract away from the area of higher sound speed. The mathematical model of refraction is called Snell's law.

If the sound source is deep and the conditions are right, propagation may occur in the 'deep sound channel'. This provides extremely low propagation loss to a receiver in the channel. This is because of sound trapping in the channel with no losses at the boundaries. Similar propagation can occur in the 'surface duct' under suitable conditions. However in this case there are reflection losses at the surface.

In shallow water propagation is generally by repeated reflection at the surface and bottom, where considerable losses can occur.

Sound propagation is affected by absorption in the water itself as well as at the surface and bottom. This absorption depends upon frequency, with several different mechanisms in sea water. Long-range sonar uses low frequencies to minimise absorption effects.

The sea contains many sources of noise that interfere with the desired target echo or signature. The main noise sources are waves and shipping. The motion of the receiver through the water can also cause speed-dependent low frequency noise.

Scattering

When active sonar is used, scattering occurs from small objects in the sea as well as from the bottom and surface. This can be a major source of interference. This acoustic scattering is analogous to the scattering of the light from a car's headlights in fog: a high-intensity pencil beam will penetrate the fog to some extent, but broader-beam headlights emit much light in unwanted directions, much of which is scattered back to the observer, overwhelming that reflected from the target ("white-out"). For analogous reasons active sonar needs to transmit in a narrow beam to minimise scattering.

Target characteristics

The sound *reflection* characteristics of the target of an active sonar, such as a submarine, are known as its target strength. A complication is that echoes are also obtained from other objects in the sea such as whales, wakes, schools of fish and rocks.

Passive sonar detects the target's *radiated* noise characteristics. The radiated spectrum comprises a continuous spectrum of noise with peaks at certain frequencies which can be used for classification.

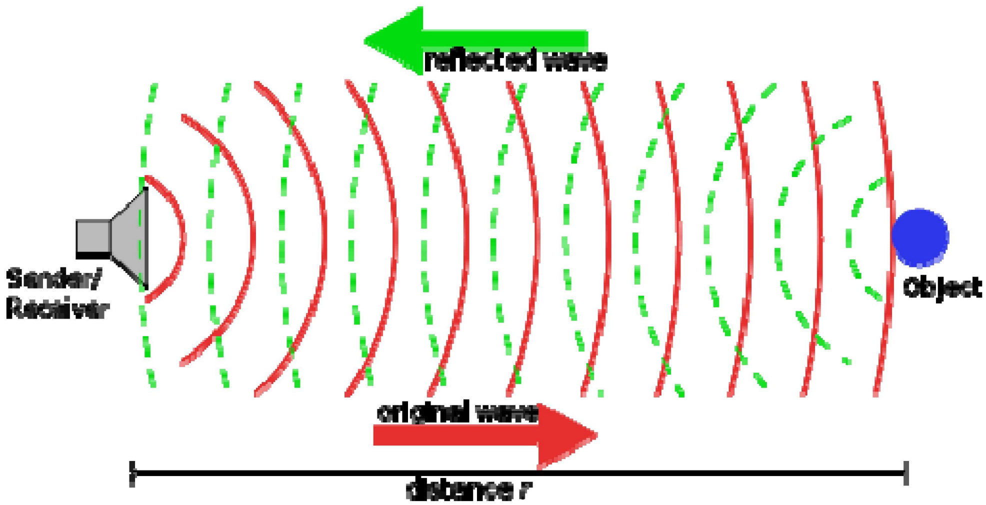
Countermeasures

Active (powered) countermeasures may be launched by a submarine under attack to raise the noise level, provide a large false target, and obscure the signature of the submarine itself.

Passive (i.e., non-powered) countermeasures include:

- Mounting noise-generating devices on isolating devices.
- Sound-absorbent coatings on the hulls of submarines, for example anechoic tiles.

Active sonar



Principle of an active sonar

Active sonar uses a sound transmitter and a receiver. When the two are in the same place it is monostatic operation. When the transmitter and receiver are separated it is bistatic operation. When more transmitters (or more receivers) are used, again spatially separated, it is multistatic operation. Most sonars are used monostatically with the same array often being used for transmission and reception. Active sonobuoy fields may be operated multistatically.

Active sonar creates a pulse of sound, often called a "ping", and then listens for reflections (echo) of the pulse. This pulse of sound is generally created electronically using a sonar Projector consisting of a signal generator, power amplifier and electro-acoustic transducer/array. A beamformer is usually employed to concentrate the acoustic power into a beam, which may be swept to cover the required search angles. Generally, the electro-acoustic transducers are of the Tonpilz type and their design may be optimised to achieve maximum efficiency over the widest bandwidth, in order to optimise performance of the overall system. Occasionally, the acoustic pulse may be created by other means, e.g. (1) chemically using explosives, or (2) airguns or (3) plasma sound sources.

To measure the distance to an object, the time from transmission of a pulse to reception is measured and converted into a range by knowing the speed of sound. To measure the bearing, several hydrophones are used, and the set measures the relative arrival time to each, or with an array of hydrophones, by measuring the relative amplitude in beams formed through a process called beamforming. Use of an array reduces the spatial response so that to provide wide cover multibeam systems are used. The target signal (if present) together with noise is then passed through various forms of signal processing, which for simple sonars may be just energy measurement. It is then presented to some form of decision device that calls the output either the required signal or noise. This decision device may be an operator with headphones or a display, or in more sophisticated sonars this function may be carried out by software. Further processes may be carried out to classify the target and localise it, as well as measuring its velocity.

The pulse may be at constant frequency or a chirp of changing frequency (to allow pulse compression on reception). Simple sonars generally use the former with a filter wide enough to cover possible Doppler changes due to target movement, while more complex ones generally include the latter technique. Since digital processing became available pulse compression has usually been implemented using digital correlation techniques. Military sonars often have multiple beams to provide all-round cover while simple ones only cover a narrow arc, although the beam may be rotated, relatively slowly, by mechanical scanning.

Particularly when single frequency transmissions are used, the Doppler effect can be used to measure the radial speed of a target. The difference in frequency between the transmitted and received signal is measured and converted into a velocity. Since Doppler shifts can be introduced by either receiver or target motion, allowance has to be made for the radial speed of the searching platform.

One useful small sonar is similar in appearance to a waterproof flashlight. The head is pointed into the water, a button is pressed, and the device displays the distance to the target. Another variant is a "fishfinder" that shows a small display with shoals of fish. Some civilian sonars (which are not designed for stealth) approach active military sonars in capability, with quite exotic three-dimensional displays of the area near the boat.

When active sonar is used to measure the distance from the transducer to the bottom, it is known as echo sounding. Similar methods may be used looking upward for wave measurement.

Active sonar is also used to measure distance through water between two sonar transducers or a combination of a hydrophone (underwater acoustic microphone) and projector (underwater acoustic speaker). A transducer is a device that can transmit and receive acoustic signals ("pings"). When a hydrophone/transducer receives a specific interrogation signal it responds by transmitting a specific reply signal. To measure distance, one transducer/projector transmits an interrogation signal and measures the time between this transmission and the receipt of the other transducer/hydrophone reply. The time difference, scaled by the speed of sound through water and divided by two, is the distance between the two platforms. This technique, when used with multiple transducers/hydrophones/projectors, can calculate the relative positions of static and moving objects in water.

In combat situations, an active pulse can be detected by an opponent and will reveal a submarine's position.

A very directional, but low-efficiency, type of sonar (used by fisheries, military, and for port security) makes use of a complex nonlinear feature of water known as non-linear sonar, the virtual transducer being known as a *parametric array*.

Project ARTEMIS

Project ARTEMIS was a one-of-a-kind low-frequency sonar for surveillance that was deployed off Bermuda for several years in the early 1960s. The active portion was deployed from a World War II tanker, and the receiving array was a built into a fixed position on an offshore bank.

Transponder

This is an active sonar device that receives a stimulus and immediately (or with a delay) retransmits the received signal or a predetermined one.

Performance prediction

A sonar target is small relative to the sphere, centred around the emitter, on which it is located. Therefore, the power of the reflected signal is very low, several orders of magnitude less than the original signal. Even if the reflected signal was of the same power, the following example (using hypothetical values) shows the problem: Suppose a sonar system is capable of emitting a 10,000 W/m² signal at 1 m, and detecting a 0.001 W/m² signal. At 100 m the signal will be 1 W/m² (due to the inverse-square law). If the entire signal is reflected from a 10 m² target, it will be at 0.001 W/m² when it reaches the emitter, i.e. just detectable. However, the original signal will remain above 0.001 W/m² until 300 m. Any 10 m² target between 100 and 300 m using a similar or better system would be able to detect the pulse but would not be detected by the emitter. The detectors must be very sensitive to pick up the echoes. Since the original signal is much more powerful, it can be detected many times further than twice the range of the sonar (as in the example).

In active sonar there are two performance limitations, due to noise and reverberation. In general one or other of these will dominate so that the two effects can be initially considered separately.

In noise limited conditions at initial detection:

$$SL - 2TL + TS - (NL - DI) = DT$$

where SL is the source level, TL is the transmission loss (or propagation loss), TS is the target strength, NL is the noise level, DI is the directivity index of the array (an approximation to the array gain) and DT is the detection threshold.

In reverberation limited conditions at initial detection (neglecting array gain):

$$SL - 2TL + TS = RL + DT$$

where RL is the reverberation level and the other factors are as before.

Marine mammals

A Humpback whale

Active sonar may harm marine animals, although the precise mechanisms for this are not well understood. Some marine animals, such as whales and dolphins, use echolocation systems, sometimes called *biosonar* to locate predators and prey. It is conjectured that active sonar transmitters could confuse these animals and interfere with basic biological functions such as feeding and mating.

Hand-held sonar for use by a diver

Scuba diver using INSS hand-held sonar

- The LIMIS (= Limpet Mine Imaging Sonar) is a hand-held or ROV-mounted imaging sonar for use by a diver. Its name is because it was designed for patrol divers (combat frogmen or Clearance Divers) to look for limpet mines in low visibility water. Links:
    - Abstract of article by the International Society for Optical Engineering

- Used to find debris from the Space Shuttle Columbia crash
  - Used in fish passage research at hydropower facilities
- The LUIS (= Lensing Underwater Imaging System) is another imaging sonar for use by a diver. Links:
  - Used for counting salmon in a river
- There is or was a small flashlight-shaped handheld sonar for divers, that merely displays range.
- For the INSS = Integrated Navigation Sonar System see:
  - an image.
  - short description
  - description

Passive sonar

Passive sonar listens without transmitting. It is often employed in military settings, although it is also used in science applications, *e.g.*, detecting fish for presence/absence studies in various aquatic environments. In the very broadest usage, this term can encompass virtually any analytical technique involving remotely generated sound, though it is usually restricted to techniques applied in an aquatic environment.

Identifying sound sources

Passive sonar has a wide variety of techniques for identifying the source of a detected sound. For example, U.S. vessels usually operate 60 Hz alternating current power systems. If transformers or generators are mounted without proper vibration insulation from the hull or become flooded, the 60 Hz sound from the windings can be emitted from the submarine or ship. This can help to identify its nationality, as most European submarines have 50 Hz power systems. Intermittent sound sources (such as a wrench being dropped) may also be detectable to passive sonar. Until fairly recently, an experienced trained operator identified signals, but now computers may do this.

Passive sonar systems may have large sonic databases, but the sonar operator usually finally classifies the signals manually. A computer system frequently uses these databases to identify classes of ships, actions (i.e. the speed of a ship, or the type of weapon released), and even particular ships. Publications for classification of sounds are provided by and continually updated by the US Office of Naval Intelligence.

Noise limitations

Passive sonar on vehicles is usually severely limited because of noise generated by the vehicle. For this reason, many submarines operate nuclear reactors that can be cooled without pumps, using silent convection, or fuel cells or batteries, which can also run silently. Vehicles' propellers are also designed and precisely machined to emit minimal noise. High-speed propellers often create tiny bubbles in the water, and this cavitation has a distinct sound.

The sonar hydrophones may be towed behind the ship or submarine in order to reduce the effect of noise generated by the watercraft itself. Towed units also combat the thermocline, as the unit may be towed above or below the thermocline.

The display of most passive sonars used to be a two-dimensional waterfall display. The horizontal direction of the display is bearing. The vertical is frequency, or sometimes time. Another display technique is to color-code frequency-time information for bearing. More recent displays are generated by the computers, and mimic radar-type plan position indicator displays.

Performance prediction

Unlike active sonar, only one way propagation is involved. Because of the different signal processing used, the minimum detectable signal to noise ratio will be different. The equation for determining the performance of a passive sonar is:

$$SL - TL = NL - DI + DT$$

where SL is the source level, TL is the transmission loss, NL is the noise level, DI is the directivity index of the array (an approximation to the array gain) and DT is the detection threshold. The figure of merit of a passive sonar is:

$$FOM = SL + DI - (NL + DT).$$

Warfare

Modern naval warfare makes extensive use of both passive and active sonar from water-borne vessels, aircraft and fixed installations. The relative usefulness of active versus passive sonar depends on the radiated noise characteristics of the target, generally a submarine. Although in WW II active sonar was used by surface craft—submarines avoided emitting pings which revealed their presence and position—with the advent of modern signal-processing passive sonar became preferred for initial detection. Submarines were then designed for quieter operation, and active sonar is now more used. In 1987 a division of Japanese company Toshiba reportedly sold machinery to the Soviet Union that allowed it to mill submarine propeller blades so that they became radically quieter, creating a huge security issue with their newer generation of submarines.

Active sonar gives the exact bearing to a target, and sometimes the range. Active sonar works the same way as radar: a signal is emitted. The sound wave then travels in many directions from the emitting object. When it hits an object, the sound wave is then reflected in many other directions. Some of the energy will travel back to the emitting source. The echo will enable the sonar system or technician to calculate, with many factors such as the frequency, the energy of the received signal, the depth, the water temperature, the position of the reflecting object, etc. Active sonar is used when the platform commander determines that it is more important to determine the position of a possible threat submarine than it is to conceal his own position. With surface ships it might be assumed that the threat is already tracking the ship with satellite data. Any vessel around the emitting sonar will detect the emission. Having heard the signal, it is easy to identify the sonar equipment used (usually with its frequency) and its position (with the sound wave's energy). Active sonar is similar to radar in that, while it allows detection of targets at a certain range, it also enables the emitter to be detected at a far greater range, which is undesirable.

Since active sonar reveals the presence and position of the operator, and does not allow exact classification of targets, it is used by fast (planes, helicopters) and by noisy platforms (most surface ships) but rarely by submarines. When active sonar is used by surface ships or submarines, it is typically activated very briefly at intermittent periods to minimise the risk of detection. Consequently active sonar is normally considered a backup to passive sonar. In aircraft, active sonar is used in the form of disposable sonobuoys that are dropped in the aircraft's patrol area or in the vicinity of possible enemy sonar contacts.

Passive sonar has several advantages. Most importantly, it is silent. If the target radiated noise level is high enough, it can have a greater range than active sonar, and allows the target to be identified. Since any motorized object makes some noise, it may in principle be detected, depending on the level of noise emitted and the ambient noise level in the area, as well as the technology used. To simplify, passive sonar "sees" around the ship using it. On a submarine, nose-mounted passive sonar detects in directions of about 270°, centered on the ship's alignment, the hull-mounted array of about 160° on each side, and the towed array of a full 360°. The invisible areas are due to the ship's own interference. Once a signal is detected in a certain direction (which means that something makes sound in that direction, this is called broadband detection) it is possible to zoom in and analyze the signal received (narrowband analysis). This is generally done using a Fourier transform to show the different frequencies making up the sound. Since every engine makes a specific sound, it is straightforward to identify the object. Databases of unique engine sounds are part of what is known as *acoustic intelligence* or ACINT.

Another use of passive sonar is to determine the target's trajectory. This process is called Target Motion Analysis (TMA), and the resultant "solution" is the target's range, course, and speed. TMA is done by marking from which direction the sound comes at different times, and comparing the motion with that of the operator's own ship. Changes in relative motion are analyzed using standard geometrical techniques along with some assumptions about limiting cases.

Passive sonar is stealthy and very useful. However, it requires high-tech electronic components and is costly. It is generally deployed on expensive ships in the form of arrays to enhance detection. Surface ships use it to good effect; it is even better used by submarines, and it is also used by airplanes and helicopters, mostly to a "surprise effect", since submarines can hide under thermal layers. If a submarine's commander believes he is alone, he may bring his boat closer to the surface and be easier to detect, or go deeper and faster, and thus make more sound.

Examples of sonar applications in military use are given below. Many of the civil uses given in the following section may also be applicable to naval use.

Anti-submarine warfare

Variable Depth Sonar and its winch

Until recently, ship sonars were usually with hull mounted arrays, either amidships or at the bow. It was soon found after their initial use that a means of reducing flow noise was required. The first were made of canvas on a framework, then steel ones were used. Now domes are usually made of reinforced plastic or pressurised rubber. Such sonars are primarily active in operation. An example of a conventional hull mounted sonar is the SQS-56.

Because of the problems of ship noise, towed sonars are also used. These also have the advantage of being able to be placed deeper in the water. However, there are limitations on their use in shallow water. These are called towed arrays (linear) or variable depth sonars (VDS) with 2/3D arrays. A problem is that the winches required to deploy/recover these are large and expensive. VDS sets are primarily active in operation while towed arrays are passive.

An example of a modern active/passive ship towed sonar is Sonar 2087 made by Thales Underwater Systems.

Torpedoes

Modern torpedoes are generally fitted with an active/passive sonar. This may be used to home directly on the target, but wake following torpedoes are also used. An early example of an acoustic homer was the Mark 37 torpedo.

Torpedo countermeasures can be towed or free. An early example was the German Sieglinde device while the Pillenwerfer was a chemical device. A widely used US device was the towed Nixie while MOSS submarine simulator was a free device. A modern alternative to the Nixie system is the UK Royal Navy S2170 Surface Ship Torpedo Defence system.

Mines

Mines may be fitted with a sonar to detect, localize and recognize the required target.

Mine countermeasures

Mine Countermeasure (MCM) Sonar, sometimes called "Mine and Obstacle Avoidance Sonar (MOAS)", is a specialised type of sonar used for detecting small objects. Most MCM sonars are hull mounted but a few types are VDS design. An example of a hull mounted MCM sonar is the Type 2193 while the SQQ-32 Mine-hunting sonar and Type 2093 systems are VDS designs.

Submarine navigation

Submarine navigation underwater requires special skills and technologies not needed by surface ships. The challenges of underwater navigation have become more important as submarines spend more time underwater, travelling greater distances and at higher speed. Military submarines travel underwater in an environment of total darkness with neither windows nor lights. Operating in stealth mode, they cannot use their active sonar systems to ping ahead for underwater hazards such as undersea mountains, drilling rigs or other submarines. Surfacing to obtain navigational fixes is precluded by pervasive anti-submarine warfare detection systems such as radar and satellite surveillance. Antenna masts and antenna-equipped periscopes can be raised to obtain navigational signals but in areas of heavy surveillance, only for a few seconds or minutes; current radar technology can detect even a slender periscope while submarine shadows may be plainly visible from the air.

The USS San Francisco (SSN-711) suffered substantial damage after colliding at high-speed with an undersea mountain.


A submarine at periscope depth risks visual or radar detection

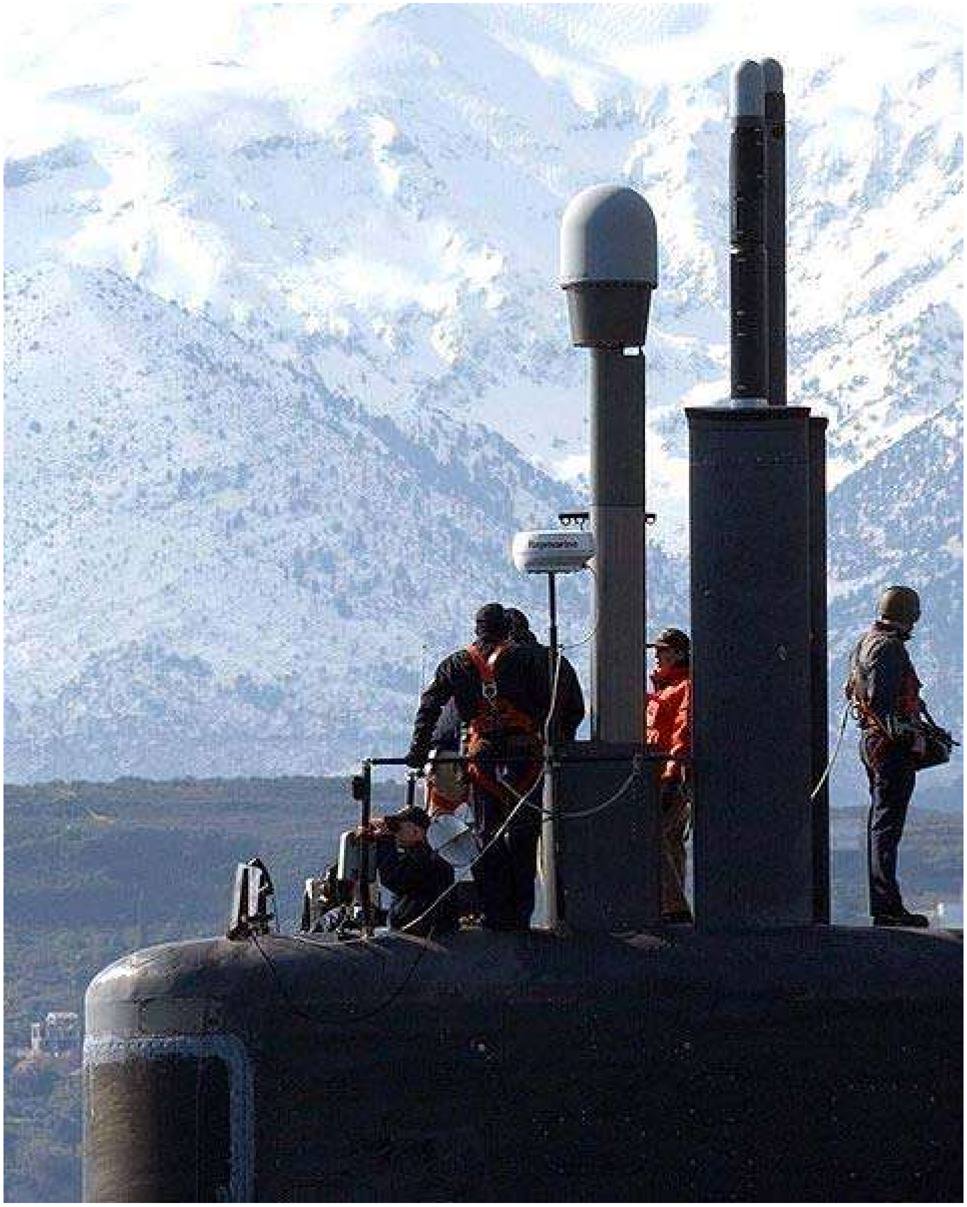
Surfaced submarines entering and leaving port navigate similarly to traditional ships but with a few extra considerations because most of the ship rides below the waterline, making them hard for other ships to see and identify.

Navigational technologies

Surface and near-surface navigation

On the surface or at periscope depth, submarines have used these methods to fix their position:

- Satellite navigation:
    - Global positioning system (GPS) - - by entering waypoints internally, able to navigate at a more precise level.
    - NAVSAT
- Terrestrial radio-based navigation systems; largely superseded by satellite systems
    - LORAN -- seldom if rarely used anymore.
    - CHAYKA, the Russian counterpart of LORAN
    - OMEGA, the Western counterpart of the Alpha Navigation System, no longer in use
    - Alpha, the Russian counterpart of the Omega Navigation System



Submarines can raise various antenna masts, radar masts and periscopes to facilitate communications and navigation

- Celestial navigation using the periscope, or sextant—seldom used anymore due to advancement in technology
- Radar navigation; radar signals are easily detected so radar is normally only used in friendly waters entering and exiting ports. With the implementation a more advanced radar system, many new techniques have been implemented in this process.
- Active sonar; like radar, active sonar systems are readily detected, so active sonar is usually used only entering and exiting ports.
- Pilotage -- in coastal and internal waters, surfaced submarines rely on the standard system of navigational aids (buoys, navigational markers, lighthouses, etc.), utilizing the periscopes for obtaining lines of position to plot a triangulation fix.

- Voyage Management System -- referred to as the VMS, utilizes digital charts with other external sources fed in, to establish the ship's position. Other information may also be entered in manually in establishing a high quality fix or position.

Deep water navigation

At depths below periscope depth submarines determine their position using:

- Dead reckoning course information obtained from the ship's gyrocompass, measured speed and estimates of local ocean currents, this could also be considered an estimated position as long as the ocean current is computed in.
- Inertial navigation system -- this is an estimated position source, utilizes acceleration, deceleration, and pitch and roll in computing.
- Bottom contour navigation may be used in areas where detailed hydrographic data has been charted and there is adequate variation in sea floor topography. Fathometer depth measurements are compared to charted depth patterns.

Submarines rely on sonar to a greater extent than surface ships as they cannot use radar at depth. The sonar arrays may be hull mounted or towed. Information fitted on typical fits is given in Oyashio class submarine and Swiftsure class submarine.

Aircraft

Helicopters can be used for antisubmarine warfare by deploying fields of active/passive sonobuoys or can operate dipping sonar, such as the AQS-13. Fixed wing aircraft can also deploy sonobuoys and have greater endurance and capacity to deploy them. Processing from the sonobuoys or dipping sonar can be on the aircraft or on ship. Helicopters have also been used for mine countermeasure missions using towed sonars such as the AQS-20A

AN/AQS-13 Dipping sonar deployed from an H-3 Sea King.

Underwater communications

Dedicated sonars can be fitted to ships and submarines for underwater communication.

Ocean surveillance

For many years, the United States operated a large set of passive sonar arrays at various points in the world's oceans, collectively called Sound Surveillance System (SOSUS) and later Integrated Undersea Surveillance System (IUSS). A similar system is believed to have been operated by the Soviet Union. As permanently mounted arrays in the deep ocean were utilised, they were in very quiet conditions so long ranges could be achieved. Signal processing was carried out using powerful computers ashore. With the ending of the Cold War a SOSUS array has been turned over to scientific use.

In the United States Navy, a special badge known as the Integrated Undersea Surveillance System Badge is awarded to those who have been trained and qualified in its operation.

Underwater security

Sonar can be used to detect frogmen and other scuba divers. This can be applicable around ships or at entrances to ports. Active sonar can also be used as a deterrent and/or disablement mechanism. One such device is the Cerberus system.

Hand-held sonar

Limpet Mine Imaging Sonar (LIMIS) is a hand-held or ROV-mounted imaging sonar designed for patrol divers (combat frogmen or clearance divers) to look for limpet mines in low visibility water.

The LUIS is another imaging sonar for use by a diver.

Integrated Navigation Sonar System (INSS) is a small flashlight-shaped handheld sonar for divers that displays range.

Intercept sonar

This is a sonar designed to detect and locate the transmissions from hostile active sonars. An example of this is the Type 2082 fitted on the British Vanguard class submarines.

Civilian applications

Fisheries

Fishing is an important industry that is seeing growing demand, but world catch tonnage is falling as a result of serious resource problems. The industry faces a future of continuing worldwide consolidation until a point of sustainability can be reached. However, the consolidation of the fishing fleets are driving increased demands for sophisticated fish finding electronics such as sensors, sounders and sonars. Historically, fishermen have used many different techniques to find and harvest fish. However, acoustic technology has been one of the most important driving forces behind the development of the modern commercial fisheries.

Sound waves travel differently through fish than through water because a fish's air-filled swim bladder has a different density than seawater. This density difference allows the detection of schools of fish by using reflected sound. Acoustic technology is especially well suited for underwater applications since sound travels farther and faster underwater than in air. Today, commercial fishing vessels rely almost completely on acoustic sonar and sounders to detect fish. Fishermen also use active sonar and echo sounder technology to determine water depth, bottom contour, and bottom composition.

Cabin display of a fish finder sonar

Companies such as Raymarine UK, Marport Canada, Wesmar, Furuno, Krupp, and Simrad make a variety of sonar and acoustic instruments for the deep sea commercial fishing industry. For example, net sensors take various underwater measurements and transmit the information back to a receiver onboard a vessel. Each sensor is equipped with one or more acoustic transducers depending on its specific function. Data is transmitted from the sensors using wireless acoustic telemetry and is received by a hull mounted hydrophone. The analog signals are decoded and converted by a digital acoustic receiver into data which is transmitted to a bridge computer for graphical display on a high resolution monitor.

Echo sounding

An echo-sounder sends an acoustic pulse directly downwards to the seabed and records the returned echo. The sound pulse is generated by a transducer that emits an acoustic pulse and then “listens” for the return signal. The time for the signal to return is recorded and converted to a depth measurement by calculating the speed of sound in water. As the speed of sound in water is around 1,500 metres per second, the time interval, measured in milliseconds, between the pulse being transmitted and the echo being received, allows bottom depth and targets to be measured.

The value of underwater acoustics to the fishing industry has led to the development of other acoustic instruments that operate in a similar fashion to echo-sounders but, because their function is slightly different from the initial model of the echo-sounder, have been given different terms.

Net location

The net sounder is an echo sounder with a transducer mounted on the headline of the net rather than on the bottom of the vessel. Nevertheless, to accommodate the distance from the transducer to the display unit, which is much greater than in a normal echo-sounder, several refinements have to be made. Two main types are available. The first is the cable type in which the signals are sent along a cable. In this case there has to be the provision of a cable drum on which to haul, shoot and stow the cable during the different phases of the operation. The second type is the cable less net-sounder – such as Marport's Trawl Explorer - in which the signals are sent acoustically between the net and hull mounted receiver/hydrophone on the vessel. In this case no cable drum is required but sophisticated electronics are needed at the transducer and receiver.

The display on a net sounder shows the distance of the net from the bottom (or the surface), rather than the depth of water as with the echo-sounder's hull-mounted transducer. Fixed to the headline of the net, the footrope can usually be seen which gives an indication of the net performance. Any fish passing into the net can also be seen, allowing fine adjustments to be made to catch the most fish possible. In other fisheries, where the amount of fish in the net is important, catch sensor transducers are mounted at various positions on the cod-end of the net. As the cod-end fills up these catch sensor transducers are triggered one by one and this information is transmitted acoustically to display monitors on the bridge of the vessel. The skipper can then decide when to haul the net.

Modern versions of the net sounder, using multiple element transducers, function more like a sonar than an echo sounder and show slices of the area in front of the net and not merely the vertical view that the initial net sounders used.

The sonar is an echo-sounder with a directional capability that can show fish or other objects around the vessel.good

Ship velocity measurement

Sonars have been developed for measuring a ship's velocity either relative to the water or to the bottom.

ROV and UUV

Small sonars have been fitted to Remotely Operated Vehicles (ROV) and Unmanned Underwater Vehicles (UUV) to allow their operation in murky conditions. These sonars are used for looking ahead of the vehicle. The Long-Term Mine Reconnaissance System is an UUV for MCM purposes.

Vehicle location

Sonars which act as beacons are fitted to aircraft to allow their location in the event of a crash in the sea. Short and Long Baseline sonars may be used for caring out the location, such as LBL.

Scientific applications

Biomass estimation

Detection of fish, and other marine and aquatic life, and estimation their individual sizes or total biomass using active sonar techniques. As the sound pulse travels through water it encounters objects that are of different density or acoustic characteristics than the surrounding medium, such as fish, that reflect sound back toward the sound source. These echoes provide information on fish size, location, abundance and behavior. Data is usually processed and analysed using a variety of software such as Echoview.

Wave measurement

An upward looking echo sounder mounted on the bottom or on a platform may be used to make measurements of wave height and period. From this statistics of the surface conditions at a location can be derived.

Water velocity measurement

Special short range sonars have been developed to allow measurements of water velocity.

Bottom type assessment

Sonars have been developed that can be used to characterise the sea bottom into, for example, mud, sand, and gravel. Relatively simple sonars such as echo sounders can be promoted to seafloor classification systems via add-on modules, converting echo parameters into sediment type. Different algorithms exist, but they are all based on changes in the energy or shape of the reflected sounder pings. Advanced substrate classification analysis can be achieved using calibrated (scientific) echosounders and parametric or fuzzy-logic analysis of the acoustic data (See: Acoustic Seabed Classification)

Bottom topography measurement

Side-scan sonars can be used to derive maps of the topography of an area by moving the sonar across it just above the bottom. Low frequency sonars such as GLORIA have been used for continental shelf wide surveys while high frequency sonars are used for more detailed surveys of smaller areas.

Sub-bottom profiling

Powerful low frequency echo-sounders have been developed for providing profiles of the upper layers of the ocean bottom.

Synthetic aperture sonar

Various synthetic aperture sonars have been built in the laboratory and some have entered use in mine-hunting and search systems. An explanation of their operation is given in synthetic aperture sonar.

Parametric sonar

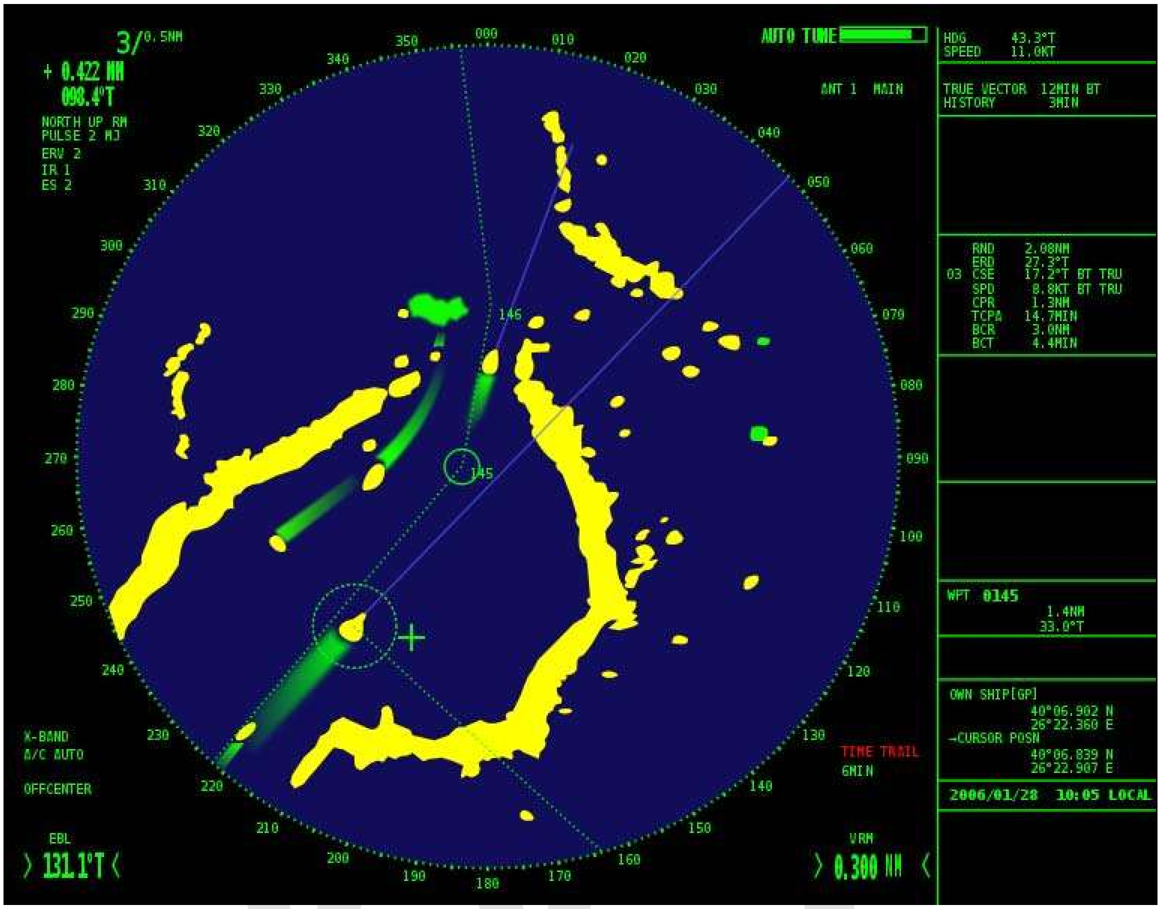
Parametric sources use the non-linearity of water to generate the difference frequency between two high frequencies. A virtual end-fire array is formed. Such a projector has advantages of broad bandwidth, narrow beamwidth, and when fully developed and carefully measured it has no obvious sidelobes. Its major disadvantage is very low efficiency of only a few percent.. P.J. Westervelt's seminal 1963 JASA paper summarizes the trends involved.

Chapter- 7

Marine Radar & GPS Navigation Device

Marine radar

Marine Radar Display



New colour Marine Radar Display

Marine Radars are x-band or s-band radar to provide bearing and distance of ships and land targets in vicinity from own ship (radar scanner) for collision avoidance and navigation at sea.

In port or in harbour, Vessel traffic service radar systems are used to monitor and regulate ship movements in busy waters. Police forces use radar guns to monitor vehicle speeds on the roads.

Collision avoidance

As required by COLREGS, all ships shall maintained a proper radar lookout if it is available onboard to obtain early warning of risk of collision. Radar plotting or ARPA should be used to get the information of movement and the risk of collision (bearing, distance, CPA, TCPA) of other ships in vicinity.

Navigation

Marine radar systems can provide very useful radar navigation information for navigators onboard ships. Ship position could be fixed by the bearing and distance information of land target on radar screen.

Radar Controls

Marine radar has performance adjustment controls for brightness and contrast, gain, tuning, sea clutter and rain clutter suppression, and other interference reduction. Other common controls consist of range scale, bearing cursor, fix/variable range marker or bearing/distance cursor.

Tuning - This control should be adjusted to get maximum returns of small targets and reduce slightly when you see little noise (speckles) in the background on the radar screen.

Gain - This control is to adjust the sensitivity of the receiver. To get the picture, adjust this control until noise of the pictures just picked up on screen.

Anti Rain Clutter (also FTC) - Radar can detect returns of heavy rain at some distance, but slight rain, snow or fog may not be detected and display on screen but the effect of rain could mask or weaken returns from nearby targets, especially small boats (yachts or fishing boats). Increase Anti-clutter control is to filter or suppress rain clutters on radar in order to identify the targets beyond the leading edge of rain region. However, the turn up this control also mask or diminish the radar returns (echoes) of other targets, so it should be set carefully just enough to filter clutters but without over suppress other targets. The clutters should not be suppressed by this control, if they are far away or the area is not causing concern, to avoid mask the important small targets in vicinity of your vessel. This control should be adjusted every time you watch the radar as the rain condition is changingall the time. Some auto FTC may over suppress the noise and also the real weak echoes.

Anti Sea Clutter (also STC) - Radar can detect returns of seas or breaking waves near the vicinity of your vessel, this result clutters around the center of the screen from all direction. This sea clutters could mask small targets in the close vicinity of your vessel (usually from1 to 2 n.m. depends on the height of waves, the higher the wave the stronger the sea clutters). The sea clutter is different with other real targets as the clutters returns is not constantly remaining in the same position on each sweep as real targets. Simply increase is setting until the seas speckles of waves are reduced to the level just able to identify or see other small targets in vicinity. It is important not to over suppress sea clutters as small target may be masked too. Never suppress sea clutters completely, as this is dangerous especially when visibility is poor. This control should be adjusted every time you watch the radar as the sea condition is changingall the time. Some auto STC may over suppress the noise and also the real weak echoes.

Operation procedures

1. before turning on the radar, ensure no person standing near by the radar scanner and then switch the radar (OFF/STANDY/ON) to STANDBY (wait up to 4 minutes for the radars magnetron to warm up)

2. turn the radar to ON

3. turn the range scale to 3 or 6 n.m. depend on the coastal or open sea

3. adjust the brightness to rotation trace just dimly appeared

4. adjust the gain and tuning until background noise just dimly visible

5. adjust the anti-clutter sea/rain slightly if the sea clutters/rain clutters obstructs the area at sea (never over suppress the clutters completely as it reduce the target signal too)

GPS navigation device

A **GPS navigation device** is any device that receives Global Positioning System (GPS) signals for the purpose of determining the device's current location on Earth. GPS devices provide latitude and longitude information, and some may also calculate altitude, although this is not considered sufficiently accurate or continuously available enough (due to the possibility of signal blockage and other factors) to rely on exclusively to pilot aircraft. GPS devices are used in military, aviation, marine and consumer product applications.

GPS devices may also have additional capabilities such as:

- containing maps, which may be displayed in human readable format via text or in a graphical format
- providing suggested directions to a human in charge of a vehicle or vessel via text or speech
- providing directions directly to an autonomous vehicle such as a robotic probe
- providing information on traffic conditions (either via historical or real time data) and suggesting alternative directions
- providing information on nearby amenities such as restaurants, fueling stations, etc.

In other words, all GPS devices can answer the question "Where am I?", and may also be able to answer:

- which roads or paths are available to me now?
- which roads or paths should I take in order to get my desired destination?

- if some roads are usually busy at this time or are busy right now, what would be a better route to take?
- where can I get something to eat nearby or where can I get fuel for my vehicle?

Consumer applications

Consumer GPS navigation devices include:

- Dedicated GPS navigation devices
- GPS modules that need to be connected to a computer to be used
- GPS loggers that record trip information for download. Such GPS tracking is useful for trailblazing, mapping by hikers and cyclists, and the production of geocoded photographs.
- Converged devices, including GPS Phones and GPS cameras, in which GPS is a feature rather than the main purpose of the device. Those devices may be assisted GPS or standalone (not network dependent) or both.

Dedicated GPS navigation devices

A variety of hand-held receivers

A taxi equipped with GPS navigation system

Dedicated devices have various degrees of mobility. *Hand-held*, *outdoor*, or *sport* receivers have replaceable batteries that can run them for several hours, making them suitable for hiking, bicycle touring and other activities far from an electric power source. Their screens are small, and some do not show color, in part to save power. Cases are rugged and some are water resistant.

Other receivers, often called *mobile* are intended primarily for use in a car, but have a small rechargeable internal battery that can power them for an hour or two away from the car. Special purpose devices for use in a car may be permanently installed and depend entirely on the automotive electrical system.

The pre-installed embedded software of early receivers did not display maps; 21st century ones commonly show interactive street maps (of certain regions) that may also show points of interest, route information and step-by-step routing directions, often in spoken form with a feature called "text to speech".

Manufacturers include:

- Navman products
- TomTom products
- Garmin products
- Mio products

- Navigon products
- Magellan Navigation consumer products
- TeleType products

Mobile phones with GPS capability

Due in part to regulations encouraging mobile phone tracking, including E911, the majority of GPS receivers are built into mobile telephones, with varying degrees of coverage and user accessibility. Commercial navigation software is available for most 21st century smartphones as well as some Java-enabled phones that allows them to use an internal or external GPS receiver (in the latter case, connecting via serial or Bluetooth). Some phones with GPS capability work by assisted GPS (A-GPS) only, and do not function when out of range of their carrier's cell towers. Others can navigate worldwide with satellite GPS signals as a dedicated portable GPS receiver does, upgrading their operation to A-GPS mode when in range. Still others have a hybrid positioning system that can use other signals when GPS signals are inadequate.

More bespoke solutions also exist for smartphones with inbuilt GPS capabilities. Some such phones can use tethering to double as a wireless modem for a laptop, while allowing GPS-navigation/localisation as well. One such example is marketed by Verizon Wireless in the United States, and is called VZ Navigator. The system uses gpsOne technology to determine the location, and then uses the mobile phone's data connection to download maps and calculate navigational routes. Other products including iPhone are used to provide similar services. Nokia gives Ovi Maps free on its smartphones and maps can be preloaded. According to market research from the independent analyst firm Berg Insight, the sales of GPS-enabled GSM/WCDMA handsets was 150 million units in 2009. while only 40 million separate GPS receivers were sold.

GPS navigation applications for mobile phones include Waze.

Laptop PC GPS

Various software companies have made available GPS road navigation software programs for in-vehicle use on laptop computers. Benefits of GPS on a laptop include larger map overview, ability to use the keyboard to control GPS functions, and some GPS software for laptops offers advanced trip-planning features not available on other platforms. Laptop computers allow for other uses beside GPS.

GPS modules

A modern SiRFstarIII chip based 20-channel GPS receiver with WAAS/EGNOS support.

Other GPS devices need to be connected to a computer in order to work. This computer can be a home computer, laptop or even a PDAs, or smartphones. Depending on the type of computer and available connectors, connections can be made through a serial or USB cable, as well as Bluetooth, CompactFlash, SD, PCMCIA and the newer ExpressCard. Some PCMCIA/ExpressCard GPS units also include a wireless modem. Devices usually do not come with preinstalled GPS navigation software, thus once purchased the user must install or write their own navigation software. As the user can choose which navigation software to use, it can be better matched to their personal taste. It is very common for a PC-based GPS receiver to come bundled with a navigation software suite. Also, GPS modules are significantly cheaper than complete stand-alone systems (around 50-100 €). The software may include maps only for a particular region, or the entire world (if software such as Google Maps, Networks in Motion's AtlasBook mobile navigation platform, etc. is used).

Examples of Bluetooth GPS devices are:

- Holux GPSlim236

For examples of USB GPS devices:

- Globalsat BU-303 GPS
- Holux ?
- DeLorme Earthmate LT-40 with Street Atlas USA 2009
- Haicom HI-204 III USB GPS
- Canmore GT-730F USB GPS
- Navman GPS e Series
- PlayStation Portable PSP-290

Examples of CF GPS devices are:

- Globalsat BC-337 SiRF Star III Compact Flash)
- Gophers SiRF Atlas V 500MHz Compact Flash
- Holux GR-271 Slim Compact Flash
- Haicom Hi-303III CompactFlash

Examples of ExpressCard GPS devices with embedded modem are:

- Sony Ericsson ec400g

Some hobbyists have also made some GPS devices and open-sourced the plans. An example is the Elektor GPS units. These are based around a SirFStar 3 chip and are comparable to their commercial counterparts.

Commercial aviation

Commercial aviation applications include GPS devices that calculate location and feed that information to large multi-input navigational computers for autopilot, course information and correction displays to the pilots, and course tracking and recording devices.

Military

Military applications include devices similar to consumer sport products for foot soldiers (commanders and regular soldiers), small vehicles and ships, and devices similar to commercial aviation applications for aircraft and missiles. Examples are the US military's **Commander's Digital Assistant** and the **Soldier Digital Assistant**.

Chapter- 8

Satellite Television & its Application in Marine Electronics

Satellite television is television delivered by the means of communications satellite and received by a satellite dish and set-top box. In many areas of the world it provides a wide range of channels and services, often to areas that are not serviced by terrestrial or cable providers.

History

The first satellite television signal was relayed from Europe to the Telstar satellite over North America in 1962. The first geosynchronous communication satellite, Syncom 2, was launched in 1963. The world's first commercial communication satellite, called Intelsat I (nicknamed Early Bird), was launched into synchronous orbit on April 6, 1965. The first national network of satellite television, called Orbita, was created in Soviet Union in 1967, and was based on the principle of using the highly elliptical Molniya satellite for re-broadcasting and delivering of TV signal to ground downlink stations. The first domestic North American satellite to carry television was Canada's geostationary Anik 1, which was launched in 1972. ATS-6, the world's first experimental educational and Direct Broadcast Satellite, was launched in 1974. The first Soviet geostationary satellite to carry Direct-To-Home television, called Ekran, was launched in 1976.

Technology

Satellites used for television signals are generally in either naturally highly elliptical (with inclination of +/-63.4 degrees and orbital period of about 12 hours, also known as Molniya orbit) or geostationary orbit 37,000 km (22,300 miles) above the earth's equator.

Satellite television, like other communications relayed by satellite, starts with a transmitting antenna located at an uplink facility. Uplink satellite dishes are very large, as much as 9 to 12 meters (30 to 40 feet) in diameter. The increased diameter results in more accurate aiming and increased signal strength at the satellite. The uplink dish is pointed toward a specific satellite and the uplinked signals are transmitted within a specific frequency range, so as to be received by one of the transponders tuned to that frequency range aboard that satellite. The transponder 'retransmits' the signals back to Earth but at a different frequency band (a process known as translation, used to avoid interference with the uplink signal), typically in the C-band (4–8 GHz) or K_u-band (12–18 GHz) or both. The leg of the signal path from the satellite to the receiving Earth station is called the downlink.

A typical satellite has up to 32 transponders for Ku-band and up to 24 for a C-band only satellite, or more for hybrid satellites. Typical transponders each have a bandwidth between 27 MHz and 50 MHz. Each geo-stationary C-band satellite needs to be spaced 2 degrees from the next satellite (to avoid interference). For K_u the spacing can be 1 degree. This means that there is an upper limit of 360/2 = 180 geostationary C-band satellites and 360/1 = 360 geostationary K_u-band satellites. C-band transmission is susceptible to terrestrial interference while K_u-band transmission is affected by rain (as water is an excellent absorber of microwaves at this particular frequency).

The downlinked satellite signal, quite weak after traveling the great distance, is collected by a parabolic receiving dish, which reflects the weak signal to the dish's focal point. Mounted on brackets at the dish's focal point is a device called a feedhorn. This feedhorn is essentially the flared front-end of a section of waveguide that gathers the signals at or near the focal point and 'conducts' them to a probe or pickup connected to a low-noise block downconverter or LNB. The LNB amplifies the relatively weak signals, filters the block of frequencies in which the satellite TV signals are transmitted, and converts the block of frequencies to a lower frequency range in the L-band range. The evolution of LNBs was one of necessity and invention.

The original C-Band satellite TV systems used a Low Noise Amplifier connected to the feedhorn at the focal point of the dish. The amplified signal was then fed via very expensive and sometimes 50 ohm impedance gas filled hardline coaxial cable to an indoor receiver or, in other designs, fed to a downconverter (a mixer and a voltage tuned oscillator with some filter circuitry) for downconversion to an intermediate frequency. The channel selection was controlled, typically by a voltage tuned oscillator with the tuning voltage being fed via a separate cable to the headend. But this design evolved.

Designs for microstrip based converters for Amateur Radio frequencies were adapted for the 4 GHz C-Band. Central to these designs was concept of block downconversion of a range of frequencies to a lower, and technologically more easily handled block of frequencies (intermediate frequency).

The advantages of using an LNB are that cheaper cable could be used to connect the indoor receiver with the satellite TV dish and LNB, and that the technology for handling the signal at L-Band and UHF was far cheaper than that for handling the signal at C-Band frequencies. The shift to cheaper technology from the 50 Ohm impedance cable and N-Connectors of the early C-Band systems to the cheaper 75 Ohm technology and F-Connectors allowed the early satellite TV receivers to use, what were in reality, modified UHF TV tuners which selected the satellite television channel for down conversion to another lower intermediate frequency centered on 70 MHz where it was demodulated. This shift allowed the satellite television DTH industry to change from being a largely hobbyist one where receivers were built in low numbers and complete systems were expensive (costing thousands of Dollars) to a far more commercial one of mass production.

Direct broadcast satellite dishes are fitted with an LNBF, which integrates the feedhorn with the LNB.

In the United States, service providers use the intermediate frequency ranges of 950-2150 MHz to carry the signal to the receiver. This allows for transmission of UHF band signals along the same span of coaxial wire at the same time. In some applications, (DirecTV AU9-S and AT-9) ranges the lower B-Band and upper 2250-3000 MHz, are used. Newer LNBFs in use by DirecTV referred to as SWM, use a more limited frequency range of 950-1800 MHz.

The satellite receiver or [Set-top box] demodulates and converts the signals to the desired form (outputs for television, audio, data, etc.). Sometimes, the receiver includes the capability to unscramble or decrypt the received signal; the receiver is then called an Integrated receiver/decoder or IRD. The cable connecting the receiver to the LNBF or LNB should be of the low loss type RG-6, quad shield RG-6 or RG-11, etc. RG-59 is not recommended for this application as it is not technically designed to carry frequencies above 950 MHz, but will work in many circumstances, depending on the quality of the coaxial wire.

Standards

Analog television distributed via satellite is usually sent scrambled or unscrambled in NTSC, PAL, or SECAM television broadcast standards. The analog signal is frequency modulated and is converted from an FM signal to what is referred to as baseband. This baseband comprises the video signal and the audio subcarrier(s). The audio subcarrier is further demodulated to provide a raw audio signal.

If the signal is a digitized television signal or multiplex of signals, it is typically QPSK.

In general, digital television, including that transmitted via satellites, are generally based on open standards such as MPEG and DVB-S or ISDB-S.

The conditional access encryption/scrambling methods include BISS, Conax, Digicipher, Irdeto, Nagravision, PowerVu, Viaccess, Videocipher, and VideoGuard. Many conditional access systems have been compromised.

Categories of usage

There are three primary types of satellite television usage: reception direct by the viewer, reception by local television affiliates, or reception by headends for distribution across terrestrial cable systems.

Direct to the viewer reception includes direct broadcast satellite or DBS and television receive-only or TVRO, both used for homes and businesses including hotels, etc.

Direct broadcast via satellite

Direct broadcast satellite, (DBS) also known as "Direct-To-Home" can either refer to the communications satellites themselves that deliver DBS service or the actual television service. DBS systems are commonly referred to as "mini-dish" systems. DBS uses the upper portion of the K_u band, as well as portions of the K_a band.

Modified DBS systems can also run on C-band satellites and have been used by some networks in the past to get around legislation by some countries against reception of K_u-band transmissions.

Most of the DBS systems use the DVB-S standard for transmission. With Pay-TV services, the datastream is encrypted and requires proprietary reception equipment. While the underlying reception technology is similar, the Pay-TV technology is proprietary, often consisting of a Conditional Access Module and smart card.

This measure assures satellite television providers that only authorised, paying subscribers have access to Pay TV content but at the same time can allow free-to-air (FTA) channels to be viewed even by the people with standard equipment (DBS receivers without the Conditional Access Modules) available in the market.

Television receive-only

The term Television receive-only, or TVRO, arose during the early days of satellite television reception to differentiate it from commercial satellite television uplink and downlink operations (transmit and receive). This was before there was a DTH satellite television broadcast industry. Satellite television channels at that time were intended to be used by cable television networks rather than received by home viewers. Satellite TV receiver systems were largely constructed by hobbyists and engineers. These TVRO systems operated mainly on the C band frequencies and the dishes required were large; typically over 3 meters (10 ft) in diameter. Consequently TVRO is often referred to as "big dish" or "Big Ugly Dish" (BUD) satellite television.

TVRO systems are designed to receive analog and digital satellite feeds of both television or audio from both C-band and K_u-band transponders on FSS-type satellites. The higher frequency K_u-band systems tend to be Direct To Home systems and can use a smaller dish antenna because of the higher power transmissions and greater antenna gain.

TVRO systems tend to use larger rather than smaller satellite dish antennas, since it is more likely that the owner of a TVRO system would have a C-band-only setup rather than a K_u band-only setup. Additional receiver boxes allow for different types of digital satellite signal reception, such as DVB/MPEG-2 and 4DTV.

The narrow beam width of a normal parabolic satellite antenna means it can only receive signals from a single satellite at a time. Simulsat or the Vertex-RSI TORUS, is a quasi-parabolic satellite earthstation antenna that is capable of receiving satellite transmissions from 35 or more C- and K_u-band satellites simultaneously.

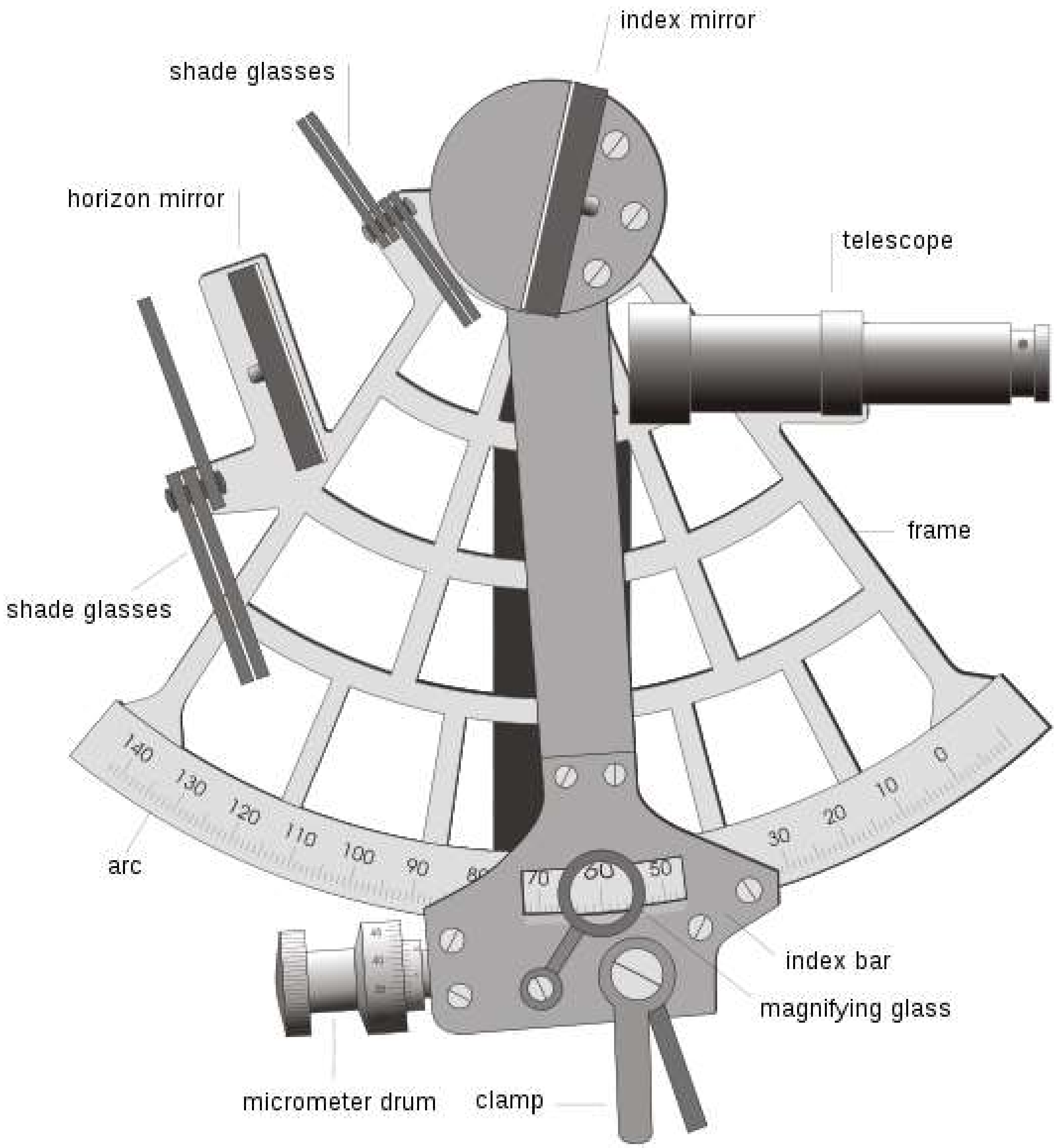
Direct to Home television

Many satellite TV customers in developed television markets get their programming through a direct broadcast satellite (DBS) provider. The provider selects programs and broadcasts them to subscribers as a set package. Basically, the provider's goal is to bring dozens or even hundreds of channels to the customers television in a form that approximates the competition from Cable TV. Unlike earlier programming, the provider's broadcast is completely digital, which means it has high picture and stereo sound quality. Early satellite television services broadcast in C-band - radio in the 3.7 GigaHertz (GHz) to 4.2 GHz frequency range. Digital broadcast satellite transmits programming in the K_u frequency range (10 GHz to 14 GHz).

Programming sources are simply the channels that provide programming for broadcast. The provider (the DTH platform) doesn't create original programming itself. The broadcast center is the central hub of the system. At the broadcast center, the television provider receives signals from various programming sources, compresses these signals using digital compression (encryption if necessary), and sends a broadcast signal to the proper satellite.

Chapter- 9

Celestial Navigation



A Sextant

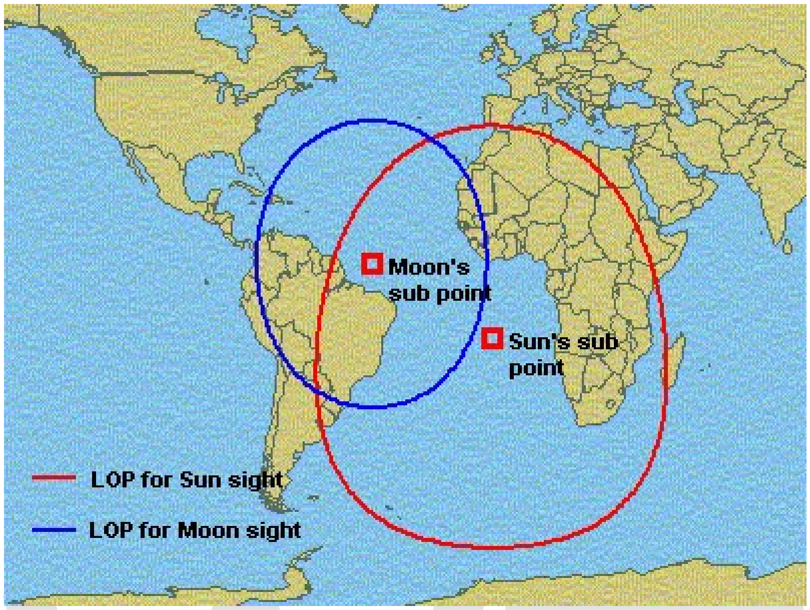
Celestial navigation, also known as **astronavigation**, is a position fixing technique that has evolved over several thousand years to help sailors cross oceans without having to rely on estimated calculations, or dead reckoning, to know their position. Celestial navigation uses "sights," or angular measurements taken between a celestial body (the sun, the moon, a planet or a star) and the visible horizon. The sun is most commonly used, but navigators can also use the moon, a planet or one of 57 navigational stars whose coordinates are tabulated in the Nautical Almanac and Air Almanacs.

Celestial navigation is the use of angular measurements (sights) between celestial bodies and the visible horizon to locate one's position on the globe, on land as well as at sea. At a given time, any celestial body is located directly over one point on the Earth's surface. The latitude and longitude of that point is known as the celestial body's geographic position (GP), the location of which can be determined from tables in the Nautical or Air Almanac for that year.

The measured angle between the celestial body and the visible horizon is directly related to the distance between the celestial body's GP, and the observer's position. After some computations, referred to as "sight reduction," this measurement is used to plot a line of position (LOP) on a navigational chart or plotting work sheet, the observer's position being somewhere on that line. (The LOP is actually a short segment of a very large circle on the earth which surrounds the GP of the observed celestial body. An observer located anywhere on the circumference of this circle on the earth, measuring the angle of the same celestial body above the horizon at that instant of time, would observe that body to be at the same angle above the horizon.) Sights on two celestial bodies give two such lines on the chart, intersecting at the observer's position. That premise is the basis for the most commonly used method of celestial navigation, and is referred to as the "Altitude-Intercept Method."

There are several other methods of celestial navigation which will also provide position finding using sextant observations, such as the "Noon Sight", and the more archaic "Lunar Distance" method. Joshua Slocum used the Lunar Distance method during the first ever recorded single-handed circumnavigation of the world. Unlike the Altitude-Intercept Method, the noon sight and lunar distance methods do not require accurate knowledge of time. The altitude-intercept method of celestial navigation requires that the observer know exact Greenwich Mean Time (GMT) at the moment of his observation of the celestial body, to the second.

Example

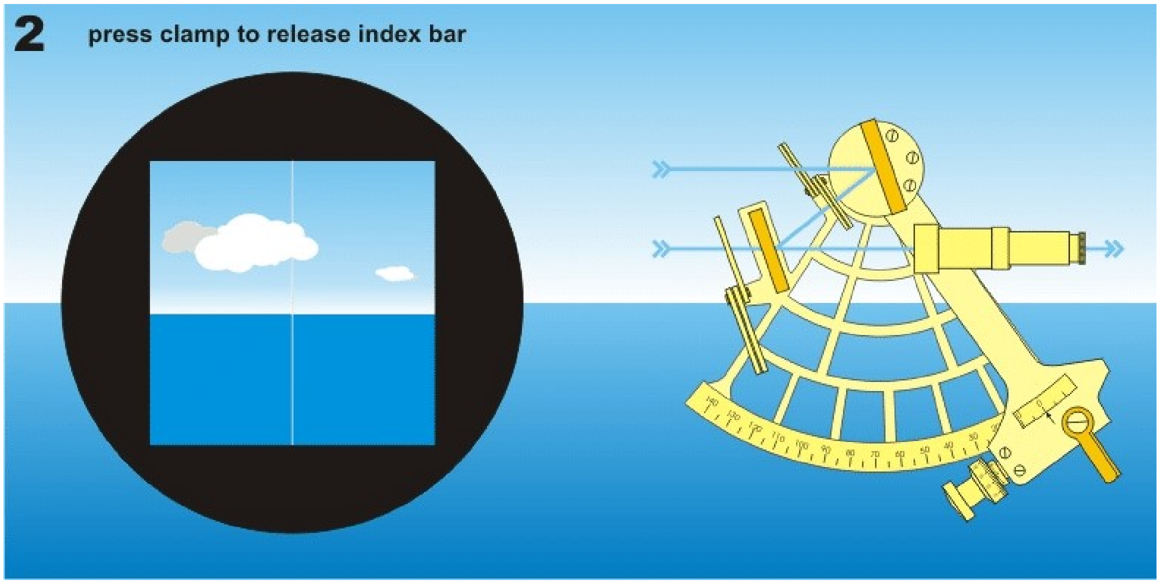


An example illustrating the concept behind the intercept method for determining one's position is shown to the right. (Two other common methods for determining one's position using celestial navigation are the longitude by chronometer and ex-meridian methods.) In the image to the right, the two circles on the map represent lines of position for the Sun and Moon at 1200 GMT on October 29, 2005. At this time, a navigator on a ship at sea measured the Moon to be 56 degrees above the horizon using a sextant. Ten minutes later, the Sun was observed to be 40 degrees above the horizon. Lines of position were then calculated and plotted for each of these observations. Since both the Sun and Moon were observed at their respective angles from the same location, the navigator would have to be located at one of the two locations where the circles cross.

In this case the navigator is either located on the Atlantic Ocean, about 350 nautical miles (650 km) west of Madeira, or in South America, about 90 nautical miles (170 km) southwest of Asunción, Paraguay. In most cases, determining which of the two intersections is the correct one is obvious to the observer because they are often thousands of miles apart. As it is unlikely that the ship is sailing across the Chaco, the position in the Atlantic is the correct one. Note that the lines of position in the figure are distorted because of the map's projection; they would be circular if plotted on a globe.

Note also that an observer in the Chaco point would see the Moon at the left of the Sun, and an observer in the Madeira point would see the Moon at the right of the Sun, and that whoever measured the two heights was likely to observe also this one bit of information.

Angular measurement



Using a marine sextant to measure the altitude of the sun above the horizon

Accurate angle measurement evolved over the years. One simple method is to hold the hand above the horizon with your arm stretched out. The width of the little finger is an angle just over 1.5 degrees elevation at extended arms length and can be used to estimate the elevation of the sun from the horizon plane and therefore estimate the time till sunset. The need for more accurate measurements led to the development of a number of increasingly accurate instruments, including the kamal, astrolabe, octant and sextant. The sextant and octant are most accurate because they measure angles from the horizon, eliminating errors caused by the placement of an instrument's pointers, and because their dual mirror system cancels relative motions of the instrument, showing a steady view of the object and horizon.

Navigators measure distance on the globe in degrees, arcminutes and arcseconds. A nautical mile is defined as 1852 meters, but is also (not accidentally) one minute of angle along a meridian on the Earth. Sextants can be read accurately to within 0.2 arcminutes. So the observer's position can be determined within (theoretically) 0.2 miles, about 400 yards (370 m). Most ocean navigators, shooting from a moving platform, can achieve a practical accuracy of 1.5 miles (2.8 km), enough to navigate safely when out of sight of land.

Practical navigation

Practical celestial navigation usually requires a marine chronometer to measure time, a sextant to measure the angles, an almanac giving schedules of the coordinates of celestial objects, a set of sight reduction tables to help perform the height and azimuth computations, and a chart of the region. With sight reduction tables, the only maths required is addition and subtraction. Small handheld computers, laptops and even scientific calculators enable modern navigators to "reduce" sextant sights in minutes, by automating all the calculation and/or data lookup steps. Most people can master simpler celestial navigation procedures after a day or two of instruction and practice, even using manual calculation methods.

Modern practical navigators usually use celestial navigation in combination with satellite navigation to correct a dead reckoning track, that is, a course estimated from a vessel's position, angle and speed. Using multiple methods helps the navigator detect errors, and simplifies procedures. When used this way, a navigator will from time to time measure the sun's altitude with a sextant, then compare that with a precalculated altitude based on the exact time and estimated position of the observation. On the chart, one will use the straight edge of a plotter to mark each position line. If the position line shows one to be more than a few miles from the estimated position, one may take more observations to restart the dead-reckoning track.

In the event of equipment or electrical failure, one can get to a port by simply taking sun lines a few times a day and advancing them by dead reckoning to get a crude running fix.

Latitude

Latitude was measured in the past either at noon (the "noon sight") or from Polaris, the north star (assuming it is sufficiently visible above the horizon, which it may not be in the Southern Hemisphere). Polaris always stays within 1 degree of the celestial north pole. If a navigator measures the angle to Polaris and finds it to be 10 degrees from the horizon, then he is about 10 degrees north of the equator. Angles are measured from the horizon because locating the point directly overhead, the zenith, is difficult. When haze obscures the horizon, navigators use artificial horizons, which are bubble levels reflected into a sextant.

Latitude can also be determined by the direction in which the stars travel over time. If the stars rise out of the east and travel straight up you are at the equator, but if they drift south you are to the north of the equator. The same is true of the day-to-day drift of the stars due to the movement of the Earth in orbit around the Sun; each day a star will drift approximately one degree. In either case if the drift can be measured accurately, simple trigonometry will reveal the latitude.

Longitude

Longitude can be measured in the same way. If one can accurately measure the angle to Polaris, a similar measurement to a star near the eastern or western horizons will provide the longitude. The problem is that the Earth turns about 15 degrees per hour, making such measurements dependent on time. A measure only a few minutes before or after the same measure the day before creates serious navigation errors. Before good chronometers were available, longitude measurements were based on the transit of the moon, or the positions of the moons of Jupiter. For the most part, these were too difficult to be used by anyone except professional astronomers.

The longitude problem took centuries to solve. Two useful methods evolved during the 18th century and are still practised today: lunar distance, which does not involve the use of a chronometer, and use of an accurate timepiece or chronometer.

Lunar distance

The older method, called "**lunar distances**", was refined in the 18th century. It is only used today by sextant hobbyists and historians, but the method is theoretically sound, and can be used when a timepiece is not available or its accuracy is suspect during a long sea voyage. The navigator precisely measures the angle between the moon and the sun, or between the moon and one of several stars near the ecliptic. The angle naturally will depend on the navigator's position (which he doesn't know) but he can still hope to correct the angle well enough to use the tables that give the corresponding angle as viewed from the center of the earth at a given Greenwich time. The navigator would thumb through the almanac to find the angle he measured, and thus know the time at Greenwich. Modern handheld and laptop calculators can perform the calculation in minutes, allowing the navigator to use other celestial bodies than the old nine. Knowing Greenwich time, the navigator can work out his longitude.

Use of time

The considerably more popular method was (and still is) to use an accurate timepiece to directly measure the time of a sextant sight. The need for accurate navigation led to the development of progressively more accurate chronometers in the 18th century. Today, time is measured with a chronometer, a quartz watch, a shortwave radio time signal broadcast from an atomic clock, or the time displayed on a GPS. A quartz wristwatch normally keeps time within a half-second per day. If it is worn constantly, keeping it near body heat, its rate of drift can be measured with the radio, and by compensating for this drift, a navigator can keep time to better than a second per month. Traditionally, a navigator checked his chronometer from his sextant, at a geographic marker surveyed by a professional astronomer. This is now a rare skill, and most harbour masters cannot locate their harbour's marker.

Traditionally, three chronometers were kept in gimbals in a dry room near the centre of the ship. They were used to set a watch for the actual sight, so that no chronometers were ever risked to the wind and salt water on deck. Winding and comparing the chronometers was a crucial duty of the navigator. Even today, it is still logged daily in the ship's deck log and reported to the Captain prior to *eight bells* on the forenoon watch (shipboard noon). Navigators also set the ship's clocks and calendar.

Modern celestial navigation

The celestial line of position concept was discovered in 1837 by Thomas Hubbard Sumner when, after one observation he computed and plotted his longitude at more than one trial latitude in his vicinity – and noticed that the positions lay along a line. Using this method with two bodies, navigators were finally able to cross two position lines and obtain their position – in effect determining both latitude and longitude. Later in the 19th century came the development of the modern (Marcq St. Hilaire) intercept method; with this method the body height and azimuth are calculated for a convenient trial position, and compared with the observed height. The difference in arcminutes is the nautical mile "intercept" distance that the position line needs to be shifted toward or away from the direction of the body's subpoint. (The intercept method uses the concept illustrated in the example in the “How it works” section above.) Two other methods of reducing sights are the longitude by chronometer and the ex-meridian method.

While celestial navigation is becoming increasingly redundant with the advent of inexpensive and highly accurate satellite navigation receivers (GPS), it was used extensively in aviation until 1960s, and marine navigation until quite recently. But since a prudent mariner never relies on any sole means of fixing his position, many national maritime authorities still require deck officers to show knowledge of celestial navigation in examinations, primarily as a back-up for electronic navigation. One of the most common current usages of celestial navigation aboard large merchant vessels is for compass calibration and error checking at sea when no terrestrial references are available.

The U.S. Air Force and U.S. Navy continued instructing military aviators on its use until 1997, because:

- it can be used independently of ground aids
- has global coverage
- cannot be jammed (although it can be obscured by clouds)
- does not give off any signals that could be detected by an enemy

The US Naval Academy announced that it was discontinuing its course on celestial navigation, considered to be one of its most demanding courses, from the formal curriculum in the spring of 1998 stating that a sextant is accurate to a three-mile (5 km) radius, while a satellite-linked computer can pinpoint a ship within 60 feet (18 m). Presently, midshipmen continue to learn to use the sextant, but instead of performing a tedious 22-step mathematical calculation to plot a ship's course, midshipmen feed the raw data into a computer. At another federal service academy, the US Merchant Marine Academy, students are still taught courses in celestial navigation, as it is required to pass the US Coast Guard License Exam.

Likewise, celestial navigation was used in commercial aviation up until the early part of the jet age; it was only phased out in the 1960s with the advent of inertial navigation systems.

Celestial navigation continues to be taught to cadets during their training in the British Merchant Navy and remains as a requirement for their certificate of competency.

A variation on terrestrial celestial navigation was used to help orient the Apollo spacecraft enroute to and from the Moon. To this day, space missions, such as the Mars Exploration Rover use star trackers to determine the attitude of the spacecraft.

As early as the mid-1960s, advanced electronic and computer systems had evolved enabling navigators to obtain automated celestial sight fixes. These systems were used aboard both ships as well as US Air Force aircraft, and were highly accurate, able to lock onto up to 11 stars (even in daytime) and resolve the craft's position to less than 300 feet (91 m). The SR-71 high-speed reconnaissance aircraft was one example of an aircraft that used automated celestial navigation. These rare systems were expensive, however, and the few that remain in use today are regarded as backups to more reliable satellite positioning systems.

Celestial navigation continues to be used by private yachtsmen, and particularly by long-distance cruising yachts around the world. For small cruising boat crews, celestial navigation is generally considered an essential skill when venturing beyond visual range of land. Although GPS (Global Positioning System) technology is reliable, offshore yachtsmen use celestial navigation as either a primary navigational tool or as a backup.

Celestial navigation trainer

Celestial navigation trainers combine a simple flight simulator with a planetarium in order to train aircraft crews in celestial navigation.

An early example is the Link Celestial Navigation Trainer, used of the Second World War. Housed in a 45 feet (14 m) high building, it featured a cockpit which accommodated a whole bomber crew (pilot, navigator and bomber). The cockpit offered a full array of instruments which the pilot used to fly the simulated aeroplane. Fixed to a dome above the cockpit was an arrangement of lights, some collimated, simulating constellations from which the navigator determined the plane's position. The dome's movement simulated the changing positions of the stars with the passage of time and the movement of the plane around the earth. The navigator also received simulated radio signals from various positions on the ground.

Below the cockpit moved "terrain plates" – large, movable aerial photographs of the land below, which gave the crew the impression of flight and enabled the bomber to practise lining up bombing targets.

A team of operators sat at a control booth on the ground below the machine, from which they could simulate weather conditions such as wind or cloud. This team also tracked the aeroplane's position by moving a "crab" (a marker) on a paper map.

The Link Celestial Navigation Trainer was developed in response to a request made by the British Royal Air Force (RAF) in 1939. The RAF ordered 60 of these machines, and the first one was built in 1941. The RAF used only a few of these, leasing the rest back to the U.S., where eventually hundreds were in use.

Chapter- 10

Marine Electronics Devices used for Communication

NMEA 0183

NMEA 0183 (or **NMEA** for short) is a combined electrical and data specification for communication between marine electronic devices such as echo sounder, sonars, anemometer, gyrocompass, autopilot, GPS receivers and many other types of instruments. It has been defined by, and is controlled by, the U.S.-based National Marine Electronics Association.

The NMEA 0183 standard uses a simple ASCII, serial communications protocol that defines how data is transmitted in a "sentence" from one "talker" to multiple "listeners" at a time. Through the use of intermediate expanders, a talker can have a unidirectional conversation with a nearly unlimited number of listeners, and using multiplexers, multiple sensors can talk to a single computer port.

At the application layer, the standard also defines the contents of each sentence (message) type so that all listeners can parse messages accurately.

Serial configuration (data link layer)

Typical Bit rate	4,800
Data bits	8
Parity	None
Stop bits	1
Handshake	None

AIS units use a default baud rate of 38,400.

Application layer protocol rules

- Each message's starting character is a dollar sign.
- The next five characters identify the talker (two characters) and the type of message (three characters).
- All data fields that follow are comma-delimited.
- Where data is unavailable, the corresponding field contains *NUL* bytes (e.g., in "123,,456", the second field's data is unavailable).
- The first character that immediately follows the last data field character is an asterisk, but it is only included if a checksum is supplied.
- The asterisk is immediately followed by a two-digit checksum representing a hexadecimal number. The checksum is the exclusive OR of all characters between the *$* and *. According to the official specification, the checksum is optional for most data sentences, but is compulsory for RMA, RMB, and RMC (among others).
- <CR><LF> ends the message.

As an example, a waypoint arrival alarm has the form:

*$GPAAM,A,A,0.10,N,WPTNME*32*

where:

GP	Talker ID (*GP* for a GPS unit, *GL* for a GLONASS)
AAM	Arrival alarm
A	Arrival circle entered
A	Perpendicular passed
0.10	Circle radius
N	Nautical miles
WPTNME	Waypoint name
*32	Checksum data

The new standard, NMEA 2000, accommodates several *talkers* at a higher baud rate, without using a central hub.

The NMEA standard is proprietary and sells for at least US$ 325 as of June 2010. However, much of it has been reverse-engineered from public sources and is available in references like gpsd and Dale DePriest's.

Vendor extensions

Most GPS manufacturers include special messages in addition to the standard NMEA set in their products for maintenance and diagnostics purposes. These extended messages are not standardized at all and are normally different from vendor to vendor.

Software compatibility

NMEA 0183 GPS compliant software

- Telogis GeoBase
- NetStumbler
- Rand McNally StreetFinder
- Magic e-Map
- NemaTalker NMEA instrument simulation
- Microsoft Streets & Trips
- Microsoft MapPoint
- Serotonin Mango M2M (suitable for NMEA compliant weather stations)
- MapKing
- gpsd - Unix GPS Daemon
- GPSy X for Mac OS X
- Turbo GPS PC/PPC/Android
- GRLevelX Weather Suite
- Google Maps Mobile Edition
- JOSM - OpenStreetMap Map Editor
- PolarCOM - a set of digital and analog NMEA instruments
- Avia Sail - PC instruments for both NMEA 0183 and NMEA 2000
- VisualGPS - A free NMEA Monitoring utility for NMEA 0183 GPS devices
- DeLorme Street Atlas

NMEA 2000

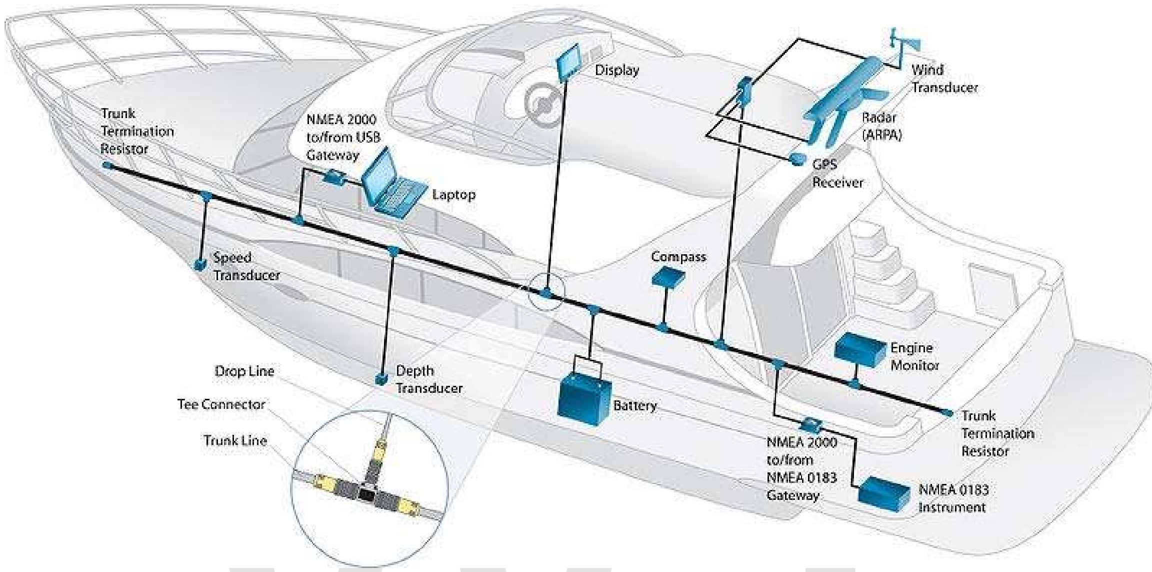
NMEA 2000 is a combined electrical and data specification for a marine data network for communication between marine electronic devices such as depth finders, nautical chart plotters, navigation instruments, engines, tank level sensors, and GPS receivers. It has been defined by, and is controlled by, the US based National Marine Electronics Association (NMEA).

NMEA 2000 connects devices using Controller Area Network (CAN) technology originally developed for the auto industry. NMEA 2000 is based on the SAE J1939 high-level protocol, but defines its own messages. NMEA 2000 devices and J1939 devices can be made to co-exist on the same physical network.

NMEA 2000 (IEC 61162-3) can be considered a successor to the NMEA 0183 (IEC 61162-1) serial data bus standard. It has a significantly higher data rate (250k bits/second vs. 4800 bits/second for NMEA 0183). It uses a compact binary message format as opposed to the ASCII serial communications protocol used by NMEA 0183. Another improvement is that NMEA 2000 supports a disciplined multiple-talker, multiple-listener data network whereas NMEA 0183 requires a single-talker, multiple-listener (simplex) serial communications protocol.

Network Construction

The NMEA 2000 network, like the SAE J1939 network on which it is based, is organized around a bus topology, and requires a single 120Ω termination resistor at each end of the bus (The resistors are in parallel. A properly terminated bus should have a total resistance of 60 ohms). The maximum distance for any device from the bus is six metres.



Typical NMEA 2000 Network Installation

Cabling and Interconnect

The only cabling standard approved by the NMEA for use with NMEA 2000 networks is the DeviceNet cabling standard, which is controlled by the Open DeviceNet Vendors Association. Such cabling systems are permitted to be labeled "NMEA 2000 Approved". The DeviceNet standard defines levels of shielding, conductor size, weather resistance, and flexibility which are not necessarily met by other cabling solutions marketed as "NMEA 2000" compatible.

There are two sizes of cabling defined by the DeviceNet/NMEA 2000 standard. The larger of the two sizes is unfortunately denoted as "Mini" (or alternatively, "Thick") cable, and is rated to carry up to 8 Amperes of power supply current. The smaller of the two sizes is denoted as "Micro" (or alternatively, "Thin") cable, and is rated to carry up to 3 Amperes of power supply current.

Mini cable is primarily used as a "backbone" (or "trunk") for networks of larger vessels (typically with lengths of 20 m and above), with Micro cable used for connections between the network backbone and the individual components. Networks on smaller vessels often are constructed entirely of Micro cable and connectors.

An NMEA 2000 network is not electrically compatible with an NMEA 0183 network, and so an interface device is required to send messages between devices on the different types of network. Examples include the Maretron USB-100, Simrad AT10 and Actisense's NGW-1. These devices vary in which messages they will translate between the two networks. An adapter such as the Actisense NGT-1-USB, Airmar U200 or Maretron USB100 is also required if NMEA 2000 messages are to be received by or transmitted from a PC.

Message Format and PGNs

In accordance with the SAE J1939 protocol, NMEA 2000 messages are sent as packets that consist of a header followed by (typically) 8 bytes of data. The header for a message specifies the transmitting device, the device to which the message was sent (which may be all devices), the message priority, and the PGN. The PGN indicates which message is being sent, and thus how the data bytes should be interpreted to determine the values of the data fields that the message contains. The NMEA sells the standard that describes how to decode each message given its PGN, and so this information is not publicly available. However, enthusiasts are slowly making progress in discovering these PGN definitions.

Device Certification

Devices go through a rigorous certification process overseen by the NMEA, and are permitted to display the "NMEA 2000 Certified" logo once they have completed the certification process. The certification process does not guarantee data content, that is the responsibility of the manufacturers. However, the certification process does assure that products from different manufacturers exchange data in a compatible way and that they can coexist on a network.

NMEA 2000 and proprietary networks

Several manufacturers, including Raymarine, Furuno, Garmin, Stowe, and the Brunswick Corporation, have their own proprietary networks. Raymarine's is called *SeaTalk*. Furuno's is *NavNet*. Garmin's is called *Garmin Marine Network*. Stowe's is called *Dataline 2000*. Brunswick's is called *SmartCraft*.

The SmartCraft protocol was developed by Brunswick, and is used by its Mercury Marine subsidiary and some Cummins engines (many Cummins engines also support the J1939 data protocol). While SmartCraft is a closed proprietary CAN network technology. NMEA 2000 is based on an open protocol CAN technology. The benefits of SmartCraft being a "closed" network allows for the Mercury engines to have and display Mercury specific features (such as Smart Tow, Troll Control, Zeus, and Axius technologies).

Most SmartCraft messages can be converted to NMEA 2000 by use of a gateway manufactured by Mercury Marine. NMEA 2000 certification for the gateway is currently pending.

Trademarks

The term "NMEA 2000" is a registered trademark of the National Marine Electronics Association. Devices which are not "NMEA 2000 Certified" may not legally use the NMEA 2000 trademark in their advertising.