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# Search and Rescue Location and Identification: Experience with SARTs

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This paper summarizes the current situation on maritime navigation transponders, including those used in the Global Maritime Distress and Safety System (GMDSS) and those installed in Rescue Co-ordination Centres (RCCs) and on board Search and Rescue boats, and discusses the possible future trends. The paper then describes the methods used and conclusions reached during a variety of tests carried out in Tenerife Roads, RCC Tenerife and on board Sociedad Estatal de Salvamento vessels, in order to determine the accuracy and efficiency of various ships' identification, positioning, location, tracking and homing systems in normal and distress situations. The systems tested included Radar/Automatic Radar Plotting Aids (ARPAs), Search and Rescue Transponders (SARTs), Target Enhancers and Radar Reflectors.

KEY WORDS

1. Search and Rescue. 2. Radio. 3. Radar. 4. GMDSS.

1. INTRODUCTION. It is well known that, during the last 20 years, the accuracy of positioning systems has developed very rapidly, particularly in coastal waters and in zones of dense maritime traffic. The main reason has been the multiple installations of IALA Differential Global Positioning System (DGPS) stations using old, but updated, MF radiobeacons. By October 1997, there were 161 radiobeacons in 24 countries transmitting differential signals, with a further 49 new stations scheduled for installation, so producing an extensive coastal network for the transmission of differential signals (Ward, 1998). There are also some commercial organisations offering DGPS services via geostationary satellites, whereby monitoring stations on shore transmit the differential messages to geostationary satellites and these retransmit differential corrections to users.

From February 1999, it became mandatory for SOLAS ships over 300 gt on international voyages to be fitted with Global Maritime Distress and Safety System (GMDSS) and transmit distress, urgency and safety calls using Digital Selective Calling (DSC). Since 1st of July 1999, the European Union has also established compulsory installation of GMDSS for all passenger ships on international voyages, new fishing vessels of length over 24 metres and existing fishing vessels of length over 45 metres (De la Torre, 1999).

If these GMDSS units are connected to DGPS receivers, they can transmit a very precise position in the coded message (IMO, 1992), with the ability to make routine calls with this system. The position will be very precise in waters near to the differential station and less precise when the GPS position cannot be corrected. This may occur when the vessel is far from the coast, sailing outside DGPS coverage or when the ship does not have a DGPS receiver fitted.

It can thus be assumed that a ship in a distress situation will be able to transmit a DSC call and be identified and located from a Coast Earth Station (CES). This will permit the initiation of a quick and precise search and rescue operation co-ordinated by a Rescue Control Centre (RCC). However, many people think that this could be dangerous because the GMDSS relies on the GPS for positioning. To avoid such problems, the use of other systems is needed, like those also mandatory for GMDSS and other equipment used on RCCs, rescue vessels and aircraft.

In the next section, an attempt is made to verify the efficiency of some of the aforementioned systems, including those that require the correct operator participation and, finally, the proposal to equip vessels with automatic identification systems (AIS), similar to that used in air navigation, is discussed.

## 2. GMDSS – USEFUL EQUIPMENT FOR LOCATION AND IDENTIFICATION.

2.1. *VHF DSC ch70, MF DSC 2187·5 kHz and HF DSC 4, 6, 8, 12, 16 MHz.* The International Maritime Organisation (IMO) established DSC as a part of GMDSS in the VHF, MF and HF radio maritime frequencies. DSC is mainly intended to initiate radiotelephony and radiotelex calls, MF/HF ship/ship, ship/shore and shore/ship. The DSC calls can also be made to just one station or a group of stations. The DSC alerts are composed of a pre-formatted distress message, which initiates an emergency communication on board vessels and in RCCs. When DSC is fully developed and implemented, it will no longer be necessary for operators continuously to be on watch on certain radio frequencies or channels, such as VHF Channel 16 (156·8 MHz) and 2182 kHz on MF R/T, used in the past for distress and safety calls. These listening systems requirements were originally predicted to cease on 1st February, 1999.

DSC uses a digital signal for transmitting specific information that may contain the following data:

(a) The MMSI (Maritime Mobile Service Identity), 9 digits that automatically identify the calling station.
(b) The station or group of stations MMSI that are being called (called or receiving stations).
(c) Calling station position and time.
(d) Frequency and transmission mode in subsequent traffic after calling.
(e) Calling priority (Distress, Safety, Urgency, Routine).
(f) For Distress call, the type of emergency.

2.2. *INMARSAT A, B & C.* The communication satellite services, managed by the INMARSAT organisation using geostationary satellites, are of major importance to the location and identification of vessels, particularly when they are associated with precision positioning systems. GMDSS has three approved types of ship-to-shore terminals, INMARSAT A, B and C. INMARSAT A and B offer phone, fax and high speed data transmission services. They also have a priority service for distress messages using phone and telex. INMARSAT C permits the storage of satellite messages and subsequently data/telex, including pre-formatted distress messages.

INMARSAT also offers specific radiobeacon location services, known as INMARSAT-E 4, that operates as explained below.

2.3. *Emergency Position Indicating Radio Beacons* (*EPIRBS*). There are two types of GMDSS-approved radiobeacons: those using the COSPAS-SARSAT Organisation (121·5/406·025 MHz), and those from INMARSAT (1·646 MHz).

2.3.1. *COSPAS-SARSAT Radiobeacons*. The 406 MHz frequency has been internationally established for distress use only. COSPAS-SARSAT satellites detect the radiobeacon signal, which provides the distress position and ship's identity through a coded message. If the coded message is not present, SARSAT (Search and Rescue Satellite Aided Tracking) can also determine the approximate position of the casualty, but this takes a finite length of time. These satellites have global coverage, and the radiobeacon signals can also be received by other satellites like TIROS-N. The COSPAS-SARSAT Organisation (member states: USA, Canada, Russia and France), relays information relative to position and identification code to the appropriate SAR authorities in less than 2 hours from first distress signal reception. Some EPIRBS also transmit in 121·5 MHz, for location and homing by aircraft and rescue vessels.

Other types of radiobeacons transmit on 406 MHz, such as ELTs (Emergency Locating Transmitters), for air navigation and the PLBs (Personal Locating Beacons), for personal location (Poleo, 1997).

2.3.2. *INMARSAT-E Radiobeacons*. These radiobeacons transmit the distress signal to INMARSAT geostationary satellites. The signal contains an identification code and position very similar to the 406 MHz EPIRBS. The geostationary satellites can receive these signals from any position in the latitude band 70°N and 70°S. The distress alerts are retransmitted almost instantaneously to the associated RCCs from the INMARSAT Land Earth Station that has received the distress signal from the radiobeacon (Poleo, 1997).

2.4. *Search and Rescue Transponders SARTs* (*9 GHz*). These radar transponders, established in GMDSS, are the most important element for survival boats and rafts. The SOLAS Convention Chapter III, rules that these equipment must be stowed on both sides of vessels and, in the case of abandoning, have to be carried to the survival boat or raft and fitted in a fixed and high position. When they are activated, either manually or automatically, they send a signal only when interrogated by a radar in the vicinity. On a receiving radar screen (PPI) the signal is seen as a radial line composed of 12–20 dots indicating the bearing and range to the SART. Meanwhile, people on the survival boat know if there is a ship or aircraft searching in the area because the SART emits an audible and/or visible signal when it is responding to interrogation. SARTs are designed to be visible on a radar screen at a range of at least 10 nm when interrogated from a marine radar with its antenna rigged at 15 metres high, and at 30 miles from an aircraft with a maximum transmission power of 10 kW at an altitude of 2500 metres.

2.5. *X-Band Radar* (*9300–9500 MHz*). X-band radars are the necessary element to detect SARTs. Special care must be taken in the operation of these radars; a wrong adjustment in the tuning control and especially in the anti-clutter rain or sea controls can mean that the SART signal will not be detected.

2.6. *Portable VHF R/T*. In the SOLAS Convention Chapter II. R. 6.2.4, portable VHF sets are called 'Bi-directional Radiotelephony Devices'; they are intended for communication between survival boats or rafts, between survival boats and ships, and between ships and rescue vessels. It is not a mandatory requirement to carry one unit per survival craft, but there must be at least three radiotelephones on board a SOLAS ship. To comply with this regulation, it is possible to use other portable radiotelephones already existing on board a vessel, as long as these meet the required specification conditions such as: they can be operated by persons without experience in case of emergency, they are portable, their batteries must be rechargeable or renewable, etc (IMO, 2001).

## 3. OTHER EFFECTIVE EQUIPMENT AVAILABLE ON BOARD.

3.1. *MF Direction Finder*. The SOLAS Convention, signed in London in 1948, first established the mandatory installation of an MF direction finder on board vessels of 1600 grt and above. This regulation will remain in force until July 2002 (Chapter 5, Rule 12). There are some countries where installation is mandatory for vessels of 300 grt and above. In 1969, IMO established two functions for the system; the first as an aid to navigation and the second as a homing system in distress situations operating in the distress frequencies of 500 to 2182 kHz. With the complete implementation of GMDSS, and the disappearance of Morse Telegraphy, this second function will no longer be necessary. The system is also effective for search and homing on frequencies between 283·5 and 325 kHz (Bermejo, 1993).

3.2. *HF Direction Finder*. Normally installed on board fishing vessels and rescue vessels, direction finding in the HF Band is also effective for searching and homing operations (Bermejo, 1993).

3.3. *Other Systems*. Other on board equipment can be effective for search and rescue location, such as S-band radars (10 cm), and radar reflectors for small boats, particularly wooden and fibreglass or polyester boats.

## 4. NON-MANDATORY EQUIPMENT ON BOARD RESCUE VESSELS.

4.1. *VHF/UHF Direction Finders*. VHF DF is installed on fishing vessels, mainly those used for catching tuna (InfoMarine, 1998); VHF/UHF DFs usually have a connection to a radar for the bearing indication (C. Plath, 1993). These systems are used with success on board search and rescue vessels, tug boats, fishing vessels and sailing ships. The majority of DF sets are automatic, and they provide a ready knowledge of the incoming direction of any VHF/UHF transmission. If the antenna is fitted high on a mast, above other antennas on the ship, the error in the radio bearing is normally less than +/−5°. The normal range of VHF/UHF signals is only slightly above that of visual range; thus signals can be received within an approximate radius of 15 nautical miles between ships (depending on the antenna heights). Many coastal radio stations and RCCs transmitting in the VHF band have located their antennas on very high sites; these signals can be received from long distances, and if the exact position of the antennas is known, they can be very useful, especially for homing purposes.

Essentially these DF equipments are normal radiotelephones, some of them with more than 100 channels and 25 watts maximum power of transmission, which are also equipped with a direction finding capability covering frequencies between 110·000 and 179·999 MHz with the added capability of receiving 243 MHz and 406 MHz, so enabling them to receive signals from EPIRBs. Some can receive in the modes of FM and DLB (AM) with the capability of selecting frequencies, changing by steps of 1 kHz. A typical equipment is the Plath *AMPLUS 12*, which can receive in the 108–410 MHz band. The VHF/UHF works as a normal R/T until the operator selects 'ADF' (Automatic Direction Finding), when the transmission/reception antenna is switched off and the Adcock antenna switched on. As the directive antenna has less gain than the whip of the R/T, the intensity of the received signal is usually slightly reduced.

Most DFs can be operated to search in some programmed frequencies or in all of any band, step-by-step. Some receivers can be connected to a gyrocompass to obtain true radio bearings. Some can indicate the approximate distance to the transmitter based on received signal strength. Moreover, some models are capable of receiving public broadcast frequencies in FM band (87·5–108 MHz), which is useful for navigation if the precise position of the transmitting antennas is known (Bermejo, 1998).

## 5. OTHER SYSTEMS TO ASSIST IDENTIFICATION AND LOCATION.

5.1. *Radar Target Enhancers* (*RTE*). Radar target enhancers transmit an answering signal (in effect, a retransmission with amplification of the received signal) when interrogated by a nearby radar but without an identification code. RTEs provide a more consistent response signal from far away navigation marks and assist the detection of small boats so reducing the risk of collision. It particularly helps target detection in the presence of clutter effects due to sea or rain; the amplified responses are not affected when anti-clutter controls are used except when they are close to maximum values, when almost all echoes are suppressed. They can also assist in maintaining track on a weak echo that is moving away (Ward, 1997a).

5.2. *RACONs*. IMO defines RACONs and Transponders in resolution A.615(15), Annex 1, as a device that automatically transmits when it is interrogated or when a transmission is initiated by a local command; it also states that the response may be displayed on a radar PPI, or on a display separated from the radar, or both. The transmission may include a coded identification in Morse. Operational and technical requirements for RACONs are drawn up by the IALA Radionavigation Committee. IALA have also published guidelines for their use. RACONs can be used in long-range navigation, up to the limit of the maximum radar range scale or RACON range, and may be used as landfall marks to indicate a harbour entrance or in a pair as a leading line. They can be used to mark an isolated hazard, to distinguish a coastline with no significant features on a radar display, or to highlight a wreck, etc. When used to mark bridges, they are placed to mark the best point of passage.

It may be possible to install RACONs that respond to FM/CW (Frequency Modulated/Carrier Wave) radars, if this type of radar comes into common use. Furthermore, for aids to navigation that move and are a long way from a recognisable coastline, a RACON fitted with the VHF DSC technology would make it possible to format messages, including the aid's identity and its current position derived from a navigation receiver. A ship would interrogate this pseudo-RACON by VHF, and the return signals would then be processed to extract the identification code and position data. Such a proposal has the problem that the DSC protocol may not provide the capacity to cope with a large number of interrogating vessels. One solution, to avoid overloading the DSC channel 70, is to operate in the same way as voice communications, using Channel 70 as the calling channel and incorporating in the message a working channel that would then be selected automatically (Ward, 1997b).

5.3. *Transponders*. Transponders have been in widespread use since their invention by Sir Robert Watson-Watt in 1935, as a means of identifying friendly aircraft as part of the UK Chain Home Radar Air Defence System (Identification Friend or Foe – IFF). The system, of which the transponder forms part, is known as secondary radar, differing from primary radar in that the target must receive and understand the radar transmission (known as *interrogation*), and make an active response to it by means of a special radio signal transmission (known as *reply*). Thus, in effect, two separate *transactions* are involved. The replies are coded so as to identify the target to an interrogating radar. The interrogations may also be coded so as to address particular classes of target or may even selectively address particular targets. Another method consists of a radar with special facilities, such as frequency deviation control for transponder detection, or using a specific channel (Trim, 1995).

Transponders based on IFF have been used in civil Air Traffic Control (ATC) since 1957 and are known as SSR (Secondary Surveillance Radar); the interrogations used include Mode 'A' for identification and Mode 'C' for transmitting the altitude of the aircraft; of course, both modes enable measurement of an interrogated aircraft's position. The latest system now being introduced is Mode 'S' (Selective), which also provides a two-way datalink of navigational information and Air Traffic Control data. SSR interrogations are made at a frequency of 1030 MHz and the transponder replies at 1090 MHz.

Military radar transponders are also fitted to some NATO naval aircraft including helicopters to assist in their identification and tracking, being interrogated by the shipboard surveillance radar transmissions and replying with a coded transmission. The Royal Dutch Navy uses a transponder-based system known as VESTA, which replies at VHF frequencies (Trim, 1995).

In civil marine applications, the interrogating signal is provided by the pulse transmission of a shipboard or shore-based primary radar, usually in either the marine 3 cm – X Band (9300–9500 MHz) or 10 cm – S Band (2900–3100 MHz) for RACON and SART detection. A difficulty that may be experienced using only one primary radar during the detection of radar transponders, is when anti-clutter rain signal processing is in use (electronic differentiation). This has the effect of breaking up extended blocks of echoes from precipitation. Unfortunately, its effect upon radar transponder reply signals is to reduce the normal coded radial line to an extremely small dot at the relative position of the transponder as observed on the radar display, which is very easily lost in other clutter. This problem can be solved if anti-clutter is not activated and if the effective isotropic radiated power (EIRP) of the transponder reply is large enough to be visible against a background of sea or rain clutter (Trim, 1995).

One of the main obstacles to the wider use of radar transponders in marine applications has been the risk that, if reply signals from a number of transponders are presented simultaneously on a radar display, a cluttered and unusable radar picture will result, with a risk that radar echoes of navigational significance will be overlaid and rendered invisible by transponder replies.

The future of transponders would be better using frequencies outside the radar bands, like VHF transponders used for identification in VTS applications (Ward, 1997b). Various trials with a VHF transponder using the DSC protocol have shown that it works well in busy shipping lanes, enabling positive identification of vessels at all ranges within coverage of VHF communication stations.

## 6. THE NEXT IDENTIFICATION AND LOCATION SYSTEM.

6.1. *Automatic Identification System* (*AIS*). The IMO Safety Committee at its 45th session agreed that, during the next MSC session, regulations on the requirements for Automatic Identification Systems (AIS) will be defined. AIS will be the next mandatory SOLAS installation with a schedule for new vessels over 300 grt as – 1st of July, 2002 and existing vessels – 1st of July, 2008 (MTNG, 1999). The proposed system uses self-organising time division multiple access (TDMA). Such a system was first developed in Sweden and South Africa for maritime traffic control and is based on military datalink technology; it uses GPS time for timeslot allocation on a VHF channel. A standard specification is being developed for this equipment, which will include the option of using another communication medium, such as satellite communications where VHF is not available (Ward, 1997b).

## 7. TRIALS WITH SOME OF THE AVAILABLE SYSTEMS.

In other papers, various tests have been carried out to assess the efficiency of MF and VHF Direction Finders (Bermejo, 1993; Bermejo, 1998). Further trials have now been conducted with SARTs, X-Band radars, radar reflectors and radar target enhancers.

7.1. *Equipment*. The equipment tested included: 2 SARTs, a radar reflector, a target enhancer, an X-band radar on board a training yacht, the X-band radar at RCC Tenerife, a liferaft, a lifeboat and a GMDSS VHF-RT.

7.2. *Method*. The equipment was tested in different positions, antenna heights and weather conditions with the aim of checking, in particular, the effect of anti-clutter rain and sea controls, rolling motion, etc. To check the efficiency of the SARTs and the portable VHF RTs, 156 tests were carried out from the training Yacht *Escuela Náutica Tenerife* and 14 from the Tenerife RCC, in Santa Cruz de Tenerife road, during September 2000. Figures 1 and 2 show data gathering in progress in Tenerife Roads. The following proforma shows a typical data collection recording.

### TRIALS PROFORMA

Own ship: "*E.N. Tenerife*" Type: *Yacht*
Length: *12·8 m* Breadth: *3·9 m* Draft: 2·*0 m* Deadweight: *9·5 MT*
Radar antenna height: *3·5 m* (*similar to rescue boats*)
VHF antenna height: *21·2 m*
Survival craft: *Lifeboat* Persons: *24*
SART height: *1·2 m*
Portable VHF antenna height: *1·2 m*
Test no.: *037*

| | |
|---|---|
| 1. Date: 15 September 2000 | 2. UTC: 13:06 |
| 3. Course: 254° | 4. Speed: 5·0 kts |
| 5. Relative bearing: 019° | 6. Range: 5·8 nm |
| 7. Lat: 28°23·45′ N | 8. Long: 016°17·86′ W |

Figures 1 and 2. Data gathering in Tenerife Roads.

9. Sea state (0–8): 4
10. Rolling (period/list): 5s/20°
11. Scanning period: 24rev/min
12. Pulse: Long
13. Anticlutter sea level: 0
14. Anticlutter rain level: 0
15. No. observations/min.: 5
16. Resolution: good/regular/poor
17. Range scale: 12

Remarks: *no interferences*, *VHF audible*

(A) SART theoretical maximum range: 6·54–6·47 nm (with list)
(B) VHF theoretical maximum range: 12·56–12·47 nm (with list)
(C) Visual maximum range: 6·17–6·10 nm (with list)

(A) R = 2·2048 (SQRT Hs + SQRT Hlb).
(B) R = 2·2048 (SQRT Hs + SQRT Hlb).
(C) R = 2·08 (SQRT Hs + SQRT Hlb).
Where R = range; Hs: Ship's height (observer or antenna); Hlb = Life boat height (observer or antenna).

## 8. RESULTS.

Once the data was collected, classified and analysed, the following results were obtained:

8.1. *SART Maximum Range*. The average of the maximum SART ranges observed was 3% less than theoretical in fair sea conditions and 5·5% less in bad weather conditions. In the above example, the maximum range observed was 6·1 nm.

8.2. *SART Minimum Range*. At an average range of 1·45 nm, false echoes and interference began to be visible on the radar screen and, at an average range of 0·94 nm, the SART dots change to circular signals that prevent bearing determination. From the RCC, this problem appeared at an average range of 0·5 nm. These false echoes and interference thus limit the minimum range of SART use and are impossible to attenuate with the anti-clutter controls.

8.3. *Effect of Anti-Clutter*. The activation of anti-clutter above 25% suppresses the SART signals.

8.4. *SART Reception*. For a standard antenna and SART heights similar to the above example (increasing and reducing the SART height by +/−0·5 m), the observed average reception of the SART signal was as follows:

| | | |
|---|---|---|
| *Good*: | 3·2 nm | |
| *Regular*: | 2·2 nm (shortest range) | 4·62 nm (longest range) |
| *Poor*: | 1·45 nm (shortest range) | 5·22 nm (longest range) |

From the RCC, the reception was *Good* at all ranges.

8.5. *SART Signals*. The average number of SART signals observed per minute at different ranges was:

| | |
|---|---|
| 6 nm | 1 every 2 min |
| 5·5 nm | 5 times/min |
| 5 nm | 2 times/min |
| 5–1·5 nm | 12 times/min or more |
| 1·5 and less | continuous circular signals |

Note: SART produces a response every 0·25 sec.

8.6. *VHF Range.* Although the theoretical VHF radio range was 12·5 nm, from 6 nm and above it was impossible to establish any communication with the VHF portable R/T.

## 9. CONCLUSIONS.

(a) SART represents an effective location and homing system for survival craft, but there are problems with final homing at short ranges especially at night and with poor visibility conditions. Additional systems, such as VHF DF or infrared detectors, are still essential on rescue boats for final location purposes.

(b) A transponder system provides an effective method for location and identification when a ship is still afloat. EPIRBs and SARTs are fundamental for location and homing to survival craft.

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