VHF Direction Finding: An Effective System for the Location of Ships in Distress

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The latest statistics on maritime accident alerts are again demonstrating a high percentage of false alarms from Emergency Position Indicating Beacons (EPIRBs) in Spanish waters. Of a total number of 243 received distress alarms, only three were real and 123 were never identified; a very similar situation exists in the rest of Europe. To address this problem, as well as IMO Resolution A.814(19)/23.11.95, there is a Spanish proposal to install a receiver (121-5/243/406 MHz) on board ships, so that the seafarer can detect accidental activation of an EPIRB. The installation of EPIRBs, which had seemed to be sufficient to solve the problem of locating vessels in distress, apparently needs the help of other tools. One such tool could be the very high frequency radio direction finder (VHF/DF) proposed in this paper. Recent experiments using VHF/DF carried on board the ships *Salvamar Tenerife* and *Punta Salinas*, in conjunction with the traffic control tower of the Rescue Coordination Centre (RCC) of Santa Cruz de Tenerife (Canary Islands), demonstrated a number of advantages which are described in this paper.

1. VHF DIRECTION FINDING. With the intention of improving the efficiency of the primitive audio modulation (AM) DF in the LF and MF bands, radio engineers, in the early years of direction finding, gradually increased the frequencies of transmission until they reached the VHF band, thus obtaining greater accuracy in the location of vessels and airships. As we know, the density of electrons in the ionosphere is not enough to reflect VHF wavelengths and shorter, and it only reflects HF and longer wavelengths.[1] In 1939 the operation of VHF radiobeacons began, and these were very useful during the Second World War.[2]

The main component of any Direction Finding System (DFS) is the antenna, the element that gives the directive properties of the system. In VHF direction finding, the design normally fitted is the vertical 'Adcock' antenna, invented around 1917–19 but not commonly used until the Thirties.[3] It consists of a pair of vertical antennas arranged in counter phase[4] and, in modern equipment, they are mounted on an electrically isolated centre plate or tube.[5,6]

With VHF/DF the problems of horizontal polarisation were reduced[6] and, although the isolation of the horizontally polarised waves is not complete, this type of antenna made a great advance in the reduction of errors.

This system was initially designed for air navigation, and is made to be compatible with other airport traffic control equipment. In air navigation, the

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receivers are normally automatic with visual indication of the radio bearing by cathode ray tube. The unit works as a normal receiver, allowing communication with the aircraft at the same time as a radio bearing is obtained.[7]

Nowadays, the system is used with success on board search-and-rescue vessels, tug boats, fishing vessels and sailing ships. The majority of these DFS are automatic, and with them, it is easy to determine the incoming direction of any VHF transmission. If the antenna is sited at a high elevation, above the rest of the ship's antennas, the error in the radio bearing is normally less than $\pm 5°$.

As VHF signals do not normally exceed the visual range, they can only be received within a radius of approximately 15 miles from a ship (depending on the antenna's height). Therefore, it is essential that the antenna should be placed in the highest possible site on a vessel. On the other hand, since many Coast Radio Stations and RCCs transmitting in the VHF band have located their antennas on high places, these signals can be received from long distances and, if the exact position is known, can be very useful, especially for homing purposes.[8]

2. VHF DIRECTION FINDERS. Current marine devices are usually automatic with digital indication of the radio bearing. Essentially they are normal radio-telephones, some of them with more than 100 channels and 25 watts maximum transmission power, which are also equipped with a DFS, covering frequencies between 110·000 and 179·999 MHz with the addition of 243 MHz and also 406 MHz. An example is the Plath AMPLUS 12, which is capable of receiving signals from EPIRBs[11]. In operation, the VHF/DF will work as a normal receiver, until the moment when, by moving a switch, the operator changes to the position 'ADF' (Automatic Direction Finding). Then the transmission/reception antenna will switch off and the Adcock antenna will switch on. As the directive antenna has less gain than the whip antenna of the VHF radio-telephone, the intensity of the signal will be slightly reduced.

Another method of producing a directional receiving system is to use the compulsory radio-telephone fitted on board by connecting an automatic DF to the audio signal output; that is to say, to connect it to the outlet to headphones or earphones. The accuracy of the radio bearings will be conditioned by the quality of the basic receiver. It would also be possible to connect the DF to a portable radio-telephone (walkie-talkie).[8]

The VHF/DFS can be operated to either search in some programmed frequencies, or across any frequency band, step by step. Some receivers can be connected to a gyrocompass to obtain a true radio bearing. In addition, some DFS can indicate, approximately, the distance to the transmitter by measuring the received signal strength.[8] Furthermore, some models are capable of receiving broadcast frequencies in FM (87·5–108 MHz), which is of great utility in homing operations if the exact position of the transmitting antenna is known.[12]

3. ACCURACY AND ERRORS. As noted above, VHF radiowaves have the property of not being reflected by the ionosphere, and thus we do not observe the night effect which is very common in AM direction finding at low and medium frequencies. Since the VHF system does not receive horizontally polarised radiowaves returning from the upper layers of the atmosphere, one of the principal errors in radio bearings is avoided. This characteristic is the biggest

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advantage of VHF direction finding. However, the system does have other typical AM/DF errors as follows.

3.1. *Land effect*. When the direction of propagation of a radiowave crosses the shoreline at an angle of less than 45°, it is refracted, thus causing an error in the radio bearing of the order of 4° or 5°. This error will be minimum when the radiowave crosses the shoreline at an angle close to 90°.[13]

3.2. *Re-radiation error or metallic objects error*. When the VHF/DF antenna is mounted at a distance of less than 4 m horizontally or 2 m vertically from other antennas, wires, mast, etc., considerable errors are observed in the radio bearings (of the order of 10°), due to reflections or re-radiation of the radiowaves from those objects.[9]

3.3. *Reflection from shore structures error*. When on shore and measuring the radio bearing from a distant vessel, it is possible to observe large errors caused by the reflection of the VHF signals from buildings, metallic panels, towers, etc. When this problem occurs, the incoming signals will seem to be from the shore and not from the open sea, because of the reflected signal.[8]

3.4. *Polarisation error*. In VHF communications the radiowaves are vertically polarised. If the transmitting and receiving vessels are sailing with significant rolling or pitching movements, the inclination of the antennas causes a displacement in the polarisation surfaces between the antennas, giving errors in the radio bearings. This error is lower in Adcock antennas than in Bellini–Tosi antennas, since the former have fewer horizontally disposed elements exposed to induction than the latter.

4. THE LOCATION OF SHIPS IN DISTRESS. Having briefly reviewed the system, the possible uses of VHF/DF in the detection of ships in distress and in contributing to safety at sea can be listed.

4.1 Detection and searching for an EPIRB transmitting at 121·5/243/406 MHz, especially when the SART (Search and Rescue Radar Transponder) does not work, or our X-band radar is out of service.[14] It is also possible to detect a 406·025 EPIRB with certain UHF/VHF DFS.[11]

4.2. The system can help in locating a mariner in distress who is transmitting a continuous wave signal in some channel.

4.3. The EPIRBs of 406·025 MHz transmit the position of the vessel in distress and also her name and call-sign;[14] thus, when in her vicinity, the vessel can be contacted by VHF radio-telephone and, with the VHF/DF, be approached with accuracy, especially in poor visibility conditions. However, many of these EPIRBs also transmit in 121·5 MHz.

4.4. The statistics of marine accidents (1994) are proving again the deplorable percentage of false alarms from EPIRBs in the Spanish Maritime area; the false alarm rate is very similar in the rest of Europe. Of a total of 243 received distress alarms, only three were real and it was not possible to identify 120 of them. Of the 243 distress alarms, 139 were on 121·5 MHz, 19 on 243 MHz, 47 on 406 MHz, 31 from the Inmarsat system (1·6 GHz) and 5 from digital selective calling (DSC).[15] To solve this problem a number of solutions have been proposed, one of them consisting of the installation of a receiver on the bridge to alert the watch officer to the accidental activation of his own EPIRBs. However, the risk

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will persist when a vessel is berthed or a plane is on the ground without a crew on board. This problem is also of interest to the rest of the European authorities where 98 percent false distress alarms have been received. There have been proposals to prohibit the use of EPIRBs on board yachts and small pleasure boats, especially in France and Germany.[16]

One of the possible solutions to improve the situation could be the utilisation of VHF/DF, before starting search and rescue operations. Using this method it should be possible to check if an EPIRB activation has occurred in port or at sea. This operation could be conducted from a RCC or from a rescue ship. To study the efficiency of this system, the following tests were conducted.

5. TESTS CARRIED OUT TO ASSESS THE EFFICIENCY OF THE VHF/DF SYSTEM. The tests were carried out during the summer of 1995 on board the vessels *Salvamar Tenerife* and *Punta Salinas*, both belonging to the Spanish Salvage and Marine Safety National Corporation (Sociedad Estatal de Salvamento y Seguridad Marítima), to whom we are grateful for the important cooperation with our University. Both vessels are equipped with an automatic KODEN KS-538 VHF/DF installed by Equipos Navales e Industriales, S.A., well calibrated and with an Adcock antenna properly fitted on the top of the main mast of each vessel.

For collecting data, we used a format as illustrated in Table 1.

TABLE 1. FORMAT FOR DATA COLLECTION

				First relative bearing (any direction)			Second relative bearing*		
No.	Station	CH	Dis	True	RB	Error (°)	True	RB	Error (°)
038	TORRE	11	18·8	179	176	3−	000	000	0
085	M/N 'BATROS'	10	3·0	350	350	0	000	000	0
098	M/N 'BRASIL'	16	5·1	048	045	3−	000	000	0
089	PILOTS	14	1·8	010	011	1+	000	000	0

No., number of order; **Station**, transmitter name; **ch**, VHF radio-telephony channel; **Dis**, distance to the station; **True**, visual or radar relative bearing; **RB**, relative DF radio bearing; **Error**, difference between true and RB.

* With the vessel's head towards the transmitter. Both radio bearings were corrected from the calibration curve.

After taking the first bearing, the ship altered course towards the direction of propagation of the radio signal to take a new bearing. This procedure was repeated 129 times, as in Figs 1 and 2: 68 relative bearings to shore stations such as Tenerife Radio, Las Palmas Radio, RCC (Tenerife), Tenerife Pilots and Los Cristianos Pilots, from an average distance of 21·9 nautical miles; 55 relative bearings to vessels at an average distance of 4·1 nautical miles; 5 relative bearings to operators transmitting with portable VHF radio-telephones (walkie-talkies) at an average distance of 1·7 nautical miles.

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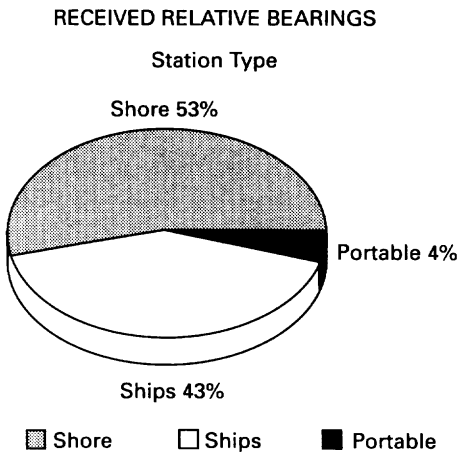


Fig. 1. Percentage of observations for each type of station

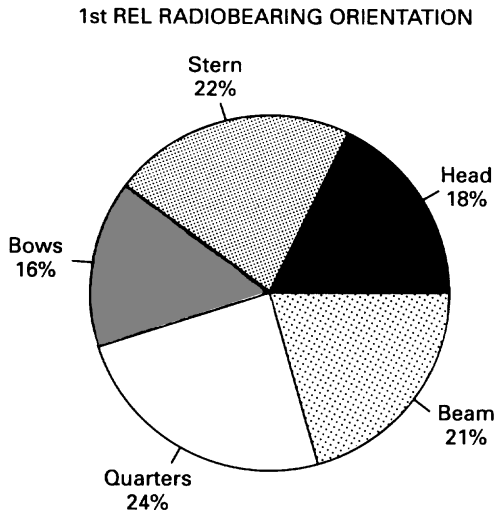


Fig. 2. Percentage of observations for each relative bearing direction

In Table 2 and Fig. 3 we show the average observed errors in the relative radio bearings in the moment of the first reception (error 1) and after the ship had been turned to head towards the transmitter (error 2).

As an additional check we took a few radio bearings to the RCC traffic tower in order to compare them with those obtained from the tower, values of which were transmitted to us by VHF RT. The check did not reveal important differences.

As can be seen, the first radio bearing has an average relative error of 1·8°, but that is reduced to 0·1° when the vessel heads towards the transmitter.

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Table 2. Observed errors in relative radio bearings

Location of station	Average distance	Average error (1) (°)	Average error (2) (°)
On shore (68 obsrvs.)	21·9	±2·5	±0·2
Vessels (55 obsrvs.)	4·1	±1·1	±0·1
Portable walkie-talkies (6 obsrvs.)	1·7	±0·7	±0·0
Average relative error	13·5	±1·8	±0·15
Average absolute error	9·4	±1·4	±0·1

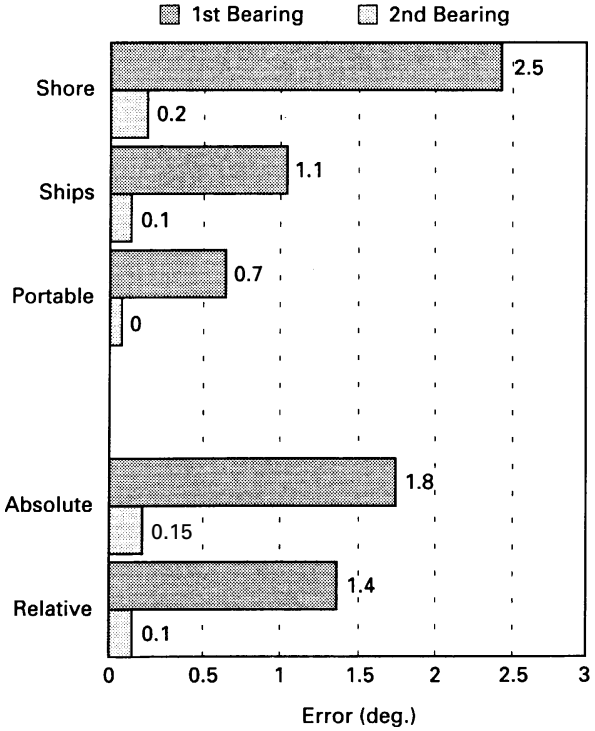


Fig. 3. Observed errors by station type

In order to evaluate which radio bearings are least precise, in Table 3 and Fig. 4 we classify the observed errors taking into consideration the direction of reception of the incoming signal; that is to say, the general relative bearing of the incoming signal: head, stern, bows, quarters and beams.

As a result of these data we observed more errors in the relative radio bearings from quarters, beam, stern and bows, due to the difficult operation of taking bearings in this type of rescue craft, which were sailing at a significant speed, with yawing and rolling movements especially in bad weather conditions. However, these errors were not serious and allowed us to alter our course towards the transmitter, following which the observed bearings were more precise.

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Table 3. Observed errors v. reception direction

Reception direction	Average error (°)
Quarters	±2·45
Beams	±2·40
Stern	±2·04
Bows	±1·3
Head	±0·48
Absolute average error	±1·8
Relative average error	±1·73

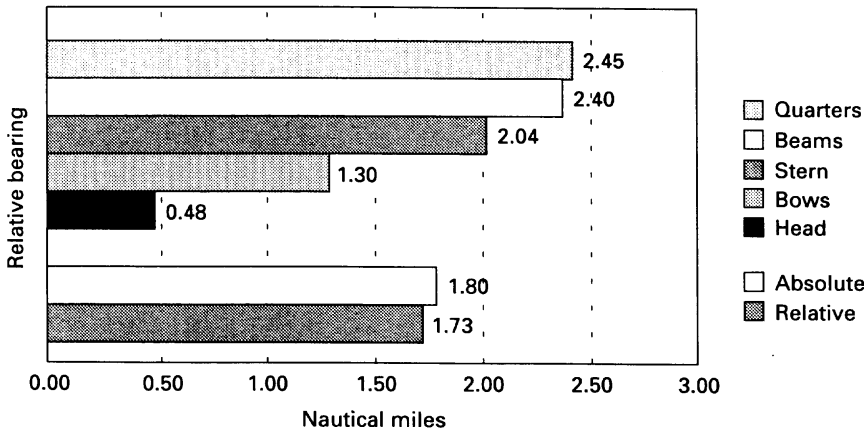


Fig. 4. Observed errors by reception direction

6. CONCLUSIONS.

6.1. The tests carried out demonstrate the acceptable accuracy of the system, mainly in the relative radio bearings taken on the ship's head, in which situation the errors are nearly zero. This confirms the potential efficiency of VHF/DFS for search and rescue operations.

6.2. The system is useful, not only for locating transmitters in distress, but also for use by police and customs authorities for the location of vessels employed in drug traffic, smuggling and carrying other goods prejudicial to public health.

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