TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 14
Number 3
September 2020
DOI: 10.12716/1001.14.03.13

Application of Radio Beacons in SAR Operations

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ABSTRACT: This research features an overview of the available PLB technologies, their advantages, shortcomings and areas of their optimum application. A test of the locator transmitter emitting both 406 MHz AIS and 121.5 MHz signals was performed with a focus on tracking the homing 121.5 MHz signal. The efficiency of the homing signal was examined by using two separate radio locating systems. One of them comprised multi-purpose and widely available components and programs, while the other was a specialised radio beacon system with dedicated components. In addition to the results, their analysis and evaluation of efficiency, the paper discusses the applicability of the available PLB technologies and provides guidelines for adequate selection of the PLB devices and position indicating radio equipment.

1 INTRODUCTION

One of the inherent features of the maritime industry is that it often operates in adverse conditions that include heavy weather, extreme state of the sea and wind, work at night and in poor visibility, at height or on slippery surface. If we add other risks, e.g. insufficient experience, hardworking environment, watch length, inadequate equipment, inadequate supervision and other potential risks, it is clear that undesirable events such as injuries and MOB situations are likely to arise. Furthermore, additional risk stems from the fact that, in maritime shipping, seafarers are often far away from the shore and cannot be assisted timely in case of accident. Therefore, considerable efforts are made to prevent incidents on board and, if they do occur, to report them to the shore-based services as soon as possible in order to launch adequate assistance / rescue operations. Modern crews perform safety drills and establish safety procedures regularly, safety equipment is mandatory. Yet, all these measures are insufficient in MOB (Man Over Board) situations as the equipment itself does not provide timely alerts [4].

One of the measures for increasing the safety of on-board staff is the application of the personal locator transmitter, which makes part of the broad family of MSLD (Maritime Survivor Locating Devices) devices. The purpose of these personal locators is alerting and/or reporting the position of the persons who accidentally fall over board and are unable to return to the vessel or offshore structure by themselves. Since the chances of survival in the sea are directly related to the time spent in the water [8], it is necessary to detect the MOB situation and launch the search and rescue (SAR) operation as soon as possible. In the event the crew fail to respond timely, additional MOB situation requirements include [9]:

– Ensure the way of reporting the MOB situation to the maritime rescue coordination centres and other vessels in the vicinity,

– Ensure the means of defining the MOB position without compromising the GMDSS (Global Maritime Distress and Safety System),
– Ensure the way of updating the MOB position without compromising the GMDSS.

While the use of PLBs (Personal Locator Beacon) is mandatory in all offshore helicopter transport operations in most European countries [15], their use on offshore structures and vessels under way remains optional.

PLB devices apply a number of technologies since these devices are not used just in maritime industry. The use of PLBs is mandatory in air transport (ELT (Emergency Locator Transmitter) is a basic locating beacon designed specifically for use on general aviation aircraft; in certain situations, PLB and EPIRB devices may be installed as well) and their use is encouraged in a range of activities on land, e.g. mountaineering, expeditions, and the like. Today, PLB devices are widely available and they greatly vary in price and terms of service (subscription, prepayment), and in cost of activating the search/rescue service (free or not). Moreover, there are variations in consequences in case of false alarms (potentially sparing the beacon's owner from significant false alert fines). Finally, there are various degrees of individualisation, i.e. the beacon may or may not be registered to a specific person, and the very devices are quite different regarding the search precision, response time, range, reliability, etc.

The purpose of this research was to establish the efficiency of tracking the locator's homing signal transmitted on 121.5 MHz. The procedure included two separate antenna systems featuring adequate receivers and programs for processing the 121.5 MHz signal. The distance from the PLB was measured to establish the reception range and the quality of the signal that allowed to pinpoint the beacon's location.

2 TYPES OF TECHNOLOGIES APPLIED IN PERSONAL LOCATOR BEACONS

The requirements of PLB devices in the modern maritime industry are primarily based on the requirements of the offshore industries that regulate the PLBs in transfers from ship to ship and from helicopter/vessel to offshore structure, depending on the conditions and risks involved in these operations. For instance, the PLB must be attachable to the lifejacket, must be serviced once a year [8], activation should be automatic and the beacons should be visible on AIS receivers. Besides the signal reception by the AIS, and ability to operate in 121.5 MHz, there are a number of technologies designed to receive and forward the PLB signal.

It is important to underline that this research deals with the available technologies in maritime environment, with no reference to their performance on land or in air transport. Most of the available PLB devices combine two or more technologies.

2.1 *Epirb*

An emergency position-indicating radio beacon (EPIRB) buoy is a mandatory part of the vessel's LSA (Life Saving Appliances) equipment, which is automatically activated in the event of maritime accidents and is used in emergencies to locate vessels in distress and in need of immediate SAR operation. The system emits the 406 – 406.1 MHz signal that is detected by satellites operated by COSPAS-SARSAT (Cosmicheskaya Systyema Poiska Avariynyich Sudov – Search And Rescue Satellite Aided Tracking.), rescue services [5]. The signal contains the distress code, owner's identification code, and location identification code for SAR assistance, based on the Doppler frequency shift or GNSS (Global Navigation Satellite System) coordinates, along with a low-power homing beacon that transmits on 121.5 MHz (Radio direction finding tone), allowing SAR forces to home in on the distress beacon once the 406 MHz satellite system has provided the necessary position information [10, 11, 20]. When one of the COSPAS-SARSAT satellites detects a beacon, the detection is passed to one of the program's earth Mission Control Centres (MCC), where the detected location and beacon details are used to determine which Rescue Coordination Centre (RCC) to pass the alert to. The RCC investigates the beacon alert (45–60 min on average) [21], and launches the SAR operation. The system has global coverage and the position accuracy varies from 2–5 km (without GNSS signal) to 100 m (with GNSS signal) [11]. The average price of these PLB devices is around 300 US dollars [14]. The device has to be registered [6]. Due to the obvious advantages of 406 MHz beacons and the significant disadvantages to the older 121.5 MHz beacons, the International COSPAS-SARSAT Program stopped monitoring of 121.5/243 MHz analogue signals [1, 7, 10, 16]. However, the 121.5 MHz signal is still used for close-in direction finding by SAR parties.

2.2 *VHF DSC (Digital Selective Calling)*

This system transmits alerts on VHF 70 Ch. Although the GNSS position is shown, the bearing and distance from the MOB/devices are not defined. This PLB transmits the distress signal ('Mayday') until it receives acknowledgment. The signal transmission can be performed in two ways: in a closed loop, where the PLB must contain the registered MMSI (Maritime Mobile Service Identity) number of the mother vessel (otherwise the vessels in the vicinity will not receive any signal) and in an open loop, where the signal is emitted to all vessels, without the need of programming the mother MMSI number [8]. The priority is given to the open loop transmitting as the system can be set to alert the mother ship only for the first 5-10 minutes and then to switch to open loop option, alerting all vessels or a group of vessels using the MMSI format [12]. As most of the received DCS messages are false distress signals and secondary maritime information, it is very likely that the PLB signal transmitted via VHF DSC will remain unnoticed. The signal range varies from 15 NM (other vessels) to 150 NM (air-borne search resources) [21]. However, the system enables the signal reception by the mother vessel and the vessels in the vicinity, thus allowing a timely response to the MOB situation.

2.3 *SEND (Satellite Emergency Notification Device)*

Although originally designed for the use on land, this system can be used by maritime structures as well. The user part features personal transmitters assisting in locating a person via a satellite signal that is not part of the SARSAT system. Some designs of this device allow a two-channel radio-communication, message sending, navigation assistance, etc. The devices has to be registered, the service implies a monthly subscription or other ways of payment, as the system uses the satellites engaged in commercial systems, e.g. Globalstar or Iridium Satellite LCC [13].

2.4 *AIS*

The mandatory AIS system may be used for receiving PLB signals within the reach of the VHF transmission. It is considered as best in MOB locating, provided that the AIS devices displays the MOB symbol accurately and triggers the MOB alarm, otherwise the PLB AIS signal may remain unnoticed. Depending on the very PLB device and the antenna direction, the range varies from 8 NM (AIS receivers on vessels) to 75 NM (AIS receivers on air-borne search resources) [8, 21]. The system is most efficient when a MOB situation is handled with the mother vessel, since the AIS receiver cannot re-transmit the MOB message [20].

2.5 *121.5 MHz PLB. AIS.*

The 121.5 MHz is originally an analogue aviation band distress frequency that can be used by PLB devices independently or in combination with any of the above-described technologies. If used independently by PLB equipment, the signal can be received across 2/3 of the global surface [11]. The system does not indicate the GNSS position and the beacon position is determined by the signal's direction and intensity. The devices does not have to be registered and is used anonymously [2], which has resulted in a large number of false alarms and unnecessary SAR operations (around 2% of the received signals referred to real accidents) [11]. Moreover, a 121.5 MHz signal may be triggered by cash machines (ATM), video walls, large screens at playing fields and the like, and the interference from other electronic and electrical systems is common. The frequency is often routinely monitored by commercial aircraft, but has not been monitored routinely by sea-going vessels and the necessary response may fail. Another downside is that the devices are subject to national legislations and are not present worldwide. For instance, the use of PLBs transmitting only analogue signals in maritime environment is banned in Japan, Korea and Malta, and is limited in Spain, Poland, Australia, Canada, Germany, etc. [3, 19]. The results of previous testing of the range and efficiency of these devices are shown in Table 1.

3 FINDINGS

In early November 2019, tests were carried out on the training-research vessel "Naše more" in Brački Kanal (Brač Channel between the Island of Brač and City of Split on the mainland). The weather conditions included the state of the sea 2–3, WSW wind 3m/s, waves 0.5–1.25 m. A PLB model M100 made by Ocean Signal company was used for testing. In addition to the analogue 121.5 MHz, the device transmits AIS signal as well. Table 2 presents technical specification of the PLB transmitter.

The testing was performed through simultaneous reception of signals by two separate systems. The first system included the antenna HYPER LOG 7060 and receiver SPECTRAN HF 6065, with their respective specifications in Tables 3 and 4. The signals were processed by a dedicated program MSC Realtime Spectrum Analyzer Software, designed by the same manufacturer.

Table 1. Average detection range of AIS and 121.5 MHz devices

System frequency	Typical surface detection range by ship/(antenna height)	Typical detection range by aircraft/(altitude)	Detectable by low earth orbiting satellite
156.525 MHz (Annex 2)	1-5 NM (2-9 km)/(10 m)	20-30 NM (37-56 km)/(2,000 ft)	No
121.5 MHz (Annex 4)	8 NM (14.8 km) /(2 m)	40-70 NM/(30,000 ft)	No

Source: [16]

Table 2. Specification of PLB M100 transmitter

Homing Transmission	
Transmit Power	50 mW
Frequency	121.5 MHz
Modulation	AM, Sweep tone
AIS transmission	
Transmit Power (EIRP)	1 Watt
Frequency	161.975 / 162.025 MHz +- 500 Hz
Baud rate	9600 baud
Synchronisation	UTC
Messages	Message 1 (Position), Message 14 (MOB status)
Repetition interval	8 messages/minute; Message 14 sent twice every 4 minutes

Source: [17]

Table 3. Technical specification of the antenna Hyperlog 7060

Design	Active Logper
Frequency range	700MHz-6GHz (down to 120MHz with limited directivity)
Preamp Noise	„linear“ increasing, 100MHz: 3,5dB, 3GHz: 4dB, 6GHz: 4,5dB
Preamp Gain (Typ.)	„linear" falloff, 1MHz: 40dB; 3GHz: 37,5dB; 6GHz: 35dB
Nominal Impedance	50 Ohm
WSVR (typ.)	< 1:2
Gain (typ.)	45 dBi
Calibration points	533 (10 MHz steps)
RF-connection	SMA (f) or N (see optional adapter)

Source: [18]

Table 4. Technical specification of the receiver Spectran HF 6065

Rf frequency range:	10Mhz to 6Ghz
Danl displayed average noise level	-135dBm(1Hz)
Max. Power at Rf input:	+10dBm
Lowest sample time:	10mS
Resolution (rbw):	3kHz to 50MHz
Units:	dBm, dBµV, V/m, A/m, W/m² (dBµV/m, W/cm² etc. via PC software)
Detectors:	RMS, Min/Max
Demodulator:	AM, FM
Input:	50 Ohm SMA RF-input (f)
Accuracy:	+/- 2dB (typ.)
Interface:	USB 2.0/1.1

Source: [18]

The other system included the antenna (Table 5), USB DVB-T+FM+DAB 820T2 receiver and SDR program. The antennas of both systems were placed at the height of 4.6 m. The antenna polarisation was not altered during the test. The antennas used in both systems are yagi directional antennas.

Table 5. Technical specification of the antenna (system B)

Indoor TV antenna	
Frequency range	vhf:87.5-230mhz uhf: 470-862mhz
Preamp noise	5db
Preamp gain (typ.)	vhf30db/uhf36db
Nominal impedance	75 ohm

Minimum requirements for the 121.5 MHz maritime radio beacon system are shown in Table 6.

Table 6. Basic features of the maritime 121.5 MHz radio beacon systems

Sensitivity (i.e. correct operation at minimum wanted signal)
Minimum wanted signal = 10 DBMV/M
Directivity (minimum resolution and accuracy) compass safe distance test
±5 DEGREES IEC 60945

Source: [9]

The device was attached to the life jacket, activated manually and moved away from the vessel, measuring its distance in a controlled way (Figure 1).

Figure 1. PLB M100 transmitter attached to the life jacket

The results of the signal reception are presented in Figures 2 to 13. Each figure shows the simultaneous reception of the signals by systems A and B at the same distance from the transmitter. As the 121.5 MHz signal is also a homing signal, the reception of the signal was tested by the antennas directly focusing to the transmitter (Figure a) and at the antenna deviation of 45o from the source of the signal (Figure b).

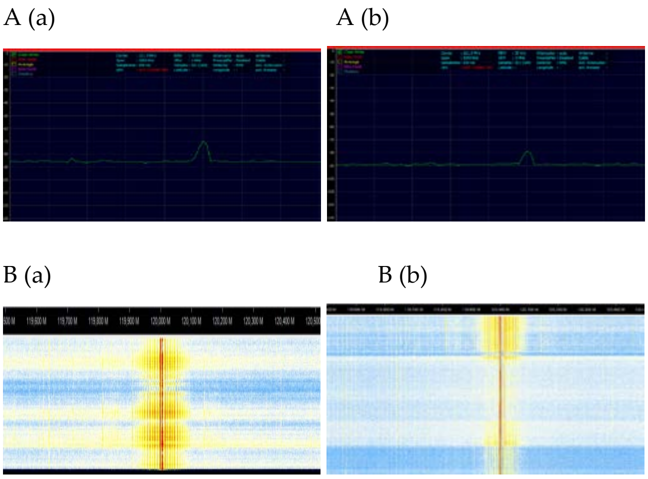

Figure 2. Reception of the systems A and B at 55 m distance.

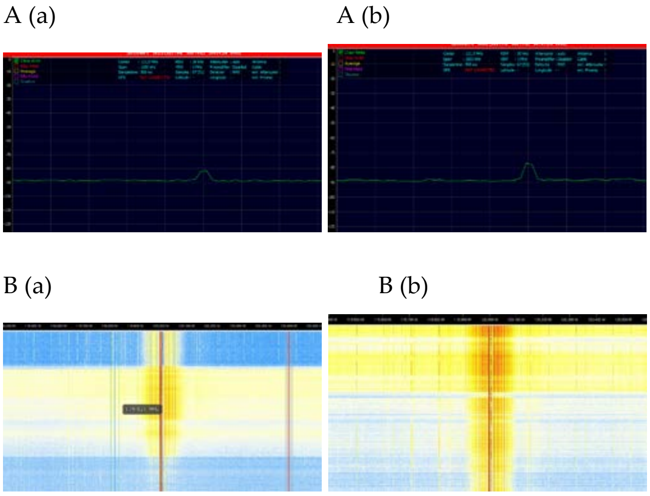

Figure 3. Reception of the systems A and B at 105 m distance

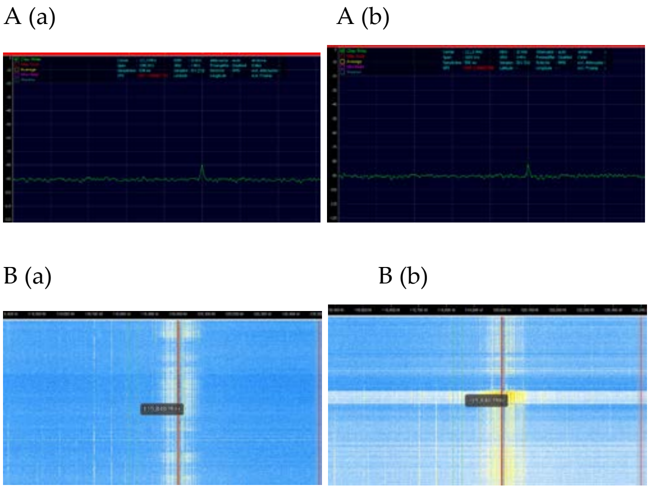

Figure 4. Reception of the systems A and B at 155 m distance.

Figures 2 – 4 show the reception of the signal at distances up to 155 m. Figures 2 and 3 show a clear and well isolated signals in both systems, while reception interference starts to appear in both systems at distances above 155 m (Figure 4).

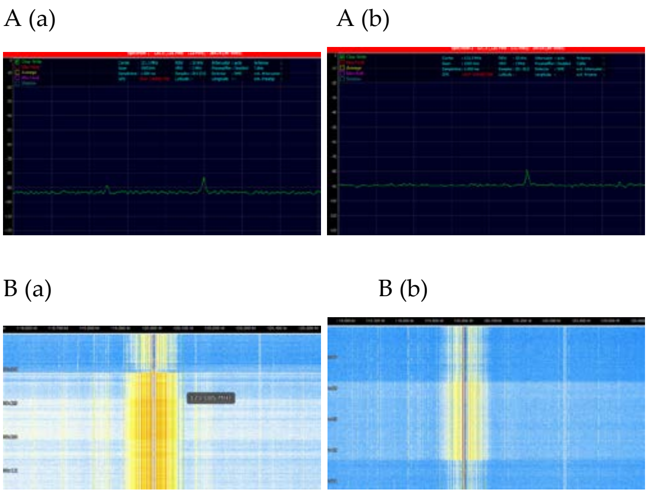

Figure 5. Reception of the systems A and B at 205 m distance

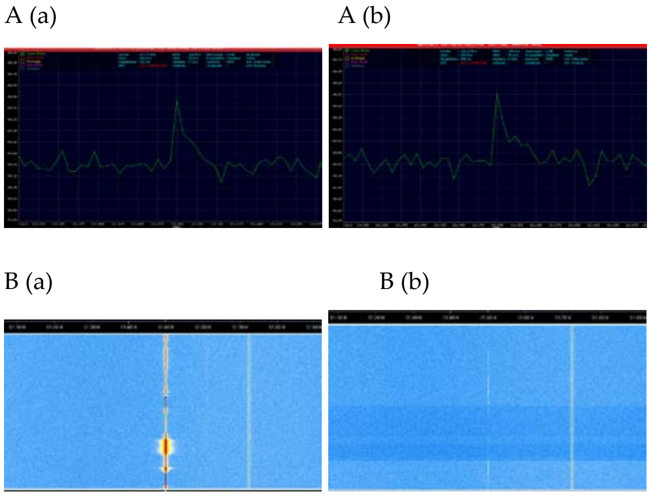

Figure 6. Reception of the systems A and B at 250 m distance

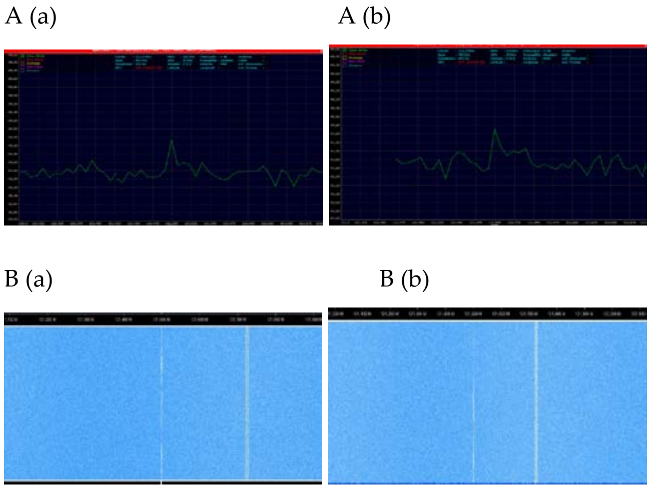

Figure 7. Reception of the systems A and B at 310 m distance

Figures 5 – 7 show the signal reception at distances from 155 to 310 meters. At 205 m, the signal is still clearly visible in both systems without any need of additional receiver adjustment. Because the signal reception gets remarkably weaker as the distance increases, the signal becomes successfully isolated and visible through adequate adjustment of the span function in system A (Figures 6 A(a) and 6 A(b)). The system B's reception is remarkably weaker (Figure 6 B(a)), especially with the antenna deviated by 45o (Figure 6 B(b)). The distance of 310 meters represents the maximum range at which system B recognises the signal but the reception quality is the same at both antenna positions, and the signal's display and quality have no practical radio locating value any more (Figures 7 B(a) and 7 B(b)). In system A, a higher level of interference is obvious, but the signal is clearly isolated (Figures 7 A(a) and 7 A(b)).

A (a) A (b)

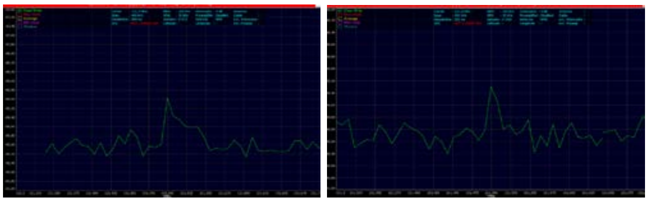

Figure 8. Reception of the system A at 400 m distance.

A (a) A (b)

Figure 9. Reception of the system A at 510 m distance.

A (a) A (b)

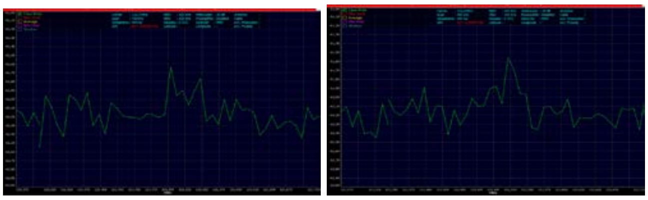

Figure 10. Reception of the system A at 650 m distance

Figures 8 – 10 show the signal reception at distances from 310 to 650 meters. The signal was received only by system A. Higher levels of interference and oscillations in signal consistency can be noticed. Furthermore, there was a temporary signal loss at 510 m and at the antenna deviation of 45o (Figure 9 A(b)). Upon adjusting the receiver and increasing its sensitivity, the signal was successfully recovered and isolated at 650 m distance, in both antenna positions (Figure 10).

A (a) A (b)

Figure 11. Reception of the system A at 760 m distance

A (a) A (b)

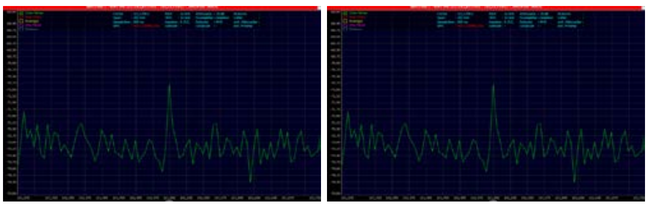

Figure 12. Reception of the system A at 870 m distance

A (a) A (b)

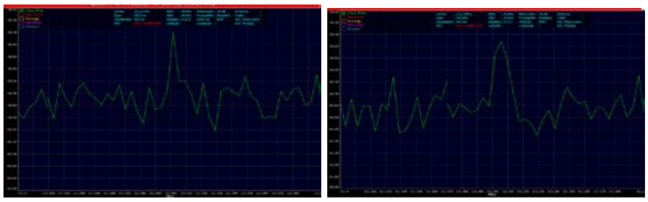

Figure 13. Reception of the system A at 960 m distance

Figures 11 – 13 show the reception of the system at distances over 650 m. At the distance of 760 m, a further reduction in signal/interference ratio can be noticed; this is particularly obvious at 870 m, when receiving the signal by the antenna deviated by 45° from the source (Figure 12 A(b)). Upon further bandwidth reduction of frequency range to 200 kHz from the central frequency, the signal was detected at the distance of 960 m, at both antenna directions, and was good enough to be useful (Figure 13).

At initial distance points, the signals were clearly isolated and could be used to home in on the source of transmission. There is no observable difference, in any of the two systems, in the signal reception between the antenna directly focused and the antenna deviated by 45°. As the distance becomes larger, the received signal becomes weaker, and the band width of the observed frequency is changed by altering the span value. As the targeted frequency is known, the span of system A is set within 1 MHz and less as the transmitter moves away and increases the distance. System B continues to operate within the initial parameters. The difference in reception between systems A and B becomes significant, as shown in Figures 6 and 7. System A clearly isolates the signal intensity in the range of –88.8 to –91.2 dBm, whether the antenna is directly focused or deviated. At the same time, system B with a directly focused antenna manages to detect the signal up to 250 m distance, whereas the signal received by a deviated antenna becomes remarkably weak. The greatest distance at which system B was able to detect the signal was 310 metres.

As the transmitter moves away, system A requires the adjustment of sweeptime period to increase the time, i.e. resolution and accuracy of scanning the selected frequency bandwidth, because an excessive scanning interval may result in poorer signal detection, given the position and movement of the transmitter at sea. Parameter VBW (Video band Width) is used to reduce the present clutter, but it must be taken into consideration that an excessive reduction of the VBW parameter reduces the targeted signal as well. Therefore, as the transmitter drifts away, the smallest usable value is set. Moreover, it is desirable to activate the preamp function in the menu "internal attenuator", thus increasing the receiver sensitivity by 15 dbi. This procedure was also applied while testing at greater distances. The alteration and combined adjustment of the above parameters were aimed at isolating the signal. The results are presented in Figures 10 – 12. It can be noted that the signal is clearly isolated in both antenna positions, its minimum value amounting to over – 58.4 dBm. The greatest effective distance of the signal reception was about 960 metres; the quality of the detected signal allowed focusing towards the source of the transmission.

4 DISCUSSION

Although the testing did not achieve the average values, as presented in Table 1, the results indicate that there are considerable differences in performance between the ordinary antenna system (system B) and the professional system for signal reception and processing (system A). The most important differences lie in the receiver and the associated signal processing software. As the power of the emitted signal is 50 mW, the ability to adjust the parameters of the signal reception and the receiver sensitivity are the crucial features.

Professional equipment in SAR vessels should include an omnidirectional polarisation antenna for receiving the emergency signals that are often weak and transmitted in poor weather conditions. Although the sensitivity of such an antenna is usually lower, it would ensure detection and tracking the transmitter upon entering the transmission area, as the 121.5 MHz signal primarily acts as a homing signal. On the other hand, it is obvious that the AIS signal with 1W output is the primary source of the emergency alarms. If the transmitter does not feature a GNSS module the AIS message does not contain the coordinates, it is necessary to combine the AIS signal to locate the source of the transmission accurately and the 121.5 MHz homing signal to pinpoint the transmitter.

In SAR resources, especially in air SAR, more effective would be the systems with directional antennas. Although these antennas have the angularly directed area of reception, the sea surface that is covered is large enough to allow systematic search operations. As a rule, such systems are more sensitive than omnidirectional systems, and their reception capacities and quality of the received signals are considerably higher. In the practical use, such systems require greater crew engagement

Besides the adequate personal locator beacon, the crucial factor in search operations is the type of the maritime structure and the potential search area that it covers. In case of fixed maritime objects, e.g. oil rig or similar off-shore structure, the resources based on the 121.5 MHz signal are able to efficiently perform a search operation, provided that these structures are fitted with the equipment for radio direction finding. If, at the same time, an additional alert is emitted (VHF, AIS), there is a greater chance of detecting the MOB signal timely by the staff on the maritime structure. An early activation of the transmitter (manually or automatically) is essential. In case of the ocean-going vessel, there is a realistic possibility that the emergency signal could remain unnoticed. The 121.5 MHz frequency is not routinely monitored by SAR centers, and if the transmitter does not emit an additional emergency signal, the transmission is likely to be undetected. Likewise, the AIS and/or VHF signal may be sent automatically and remain unnoticed because there are no other vessels within the VHF range or due to oversight of the navigating bridge staff to detect the signal and launch the timely SAR action. The use of 121.5 MHz devices is much more justified in case of the vessels engaged in coastal navigation and the leisure craft. Coastal areas are under constant surveillance by SAR and Vessel Traffic Service (VTS) centers that routinely monitor AIS and VHF frequencies, so that the mother vessel's failure or inability to render assistance is not crucial. The radio direction finding equipment used by VTS and SAR centers depends on the search resources they use and on the potential search area. The direction finders designed for the air SAR resources make use of the devices that are capable of simultaneous multi-band monitoring of the 121.5 MHz VHF, Ch 16 VHF, 243 MHz UHF and 406.025 MHz (COSPAS-SARSAT). Direction finders on SAR vessels, depending on the configuration, are also able to receive VHF air band: 118.800 – 124.000 MHz and VHF marine band: 156.000 – 162.025 MHz [22]. Again, it is desirable that the device transmits an additional AIS and/or VHF signal. The fact that the International COSPAS-SARSAT Program stopped monitoring of 121.5 MHz does not present a major drawback in this situation.

5 CONCLUSION

The testing of 121.5 MHz PLB devices revealed a limited efficiency if the signal locating is performed exclusively by the systems installed on vessels and if only this frequency is monitored. The tested maritime radio beacon systems clearly prove that the use of professional equipment is justified. Although the testing did not achieve the average nominal values, the analysis of the results proves that the possibilities of specialised equipment far outstrip the abilities and usefulness of the universal ordinary components. The results imply that radio locating with dedicated professional equipment is more effective in MOB situations, even at larger transmission distances from the ones tested in this research, provided that AIS / VHF signals are monitored at the same time. The purpose of the 121.5 MHz signal is homing and pinpointing the MOB location, while the emergency alert is more efficiently performed by transmitting AIS and/or VHF signals. However, their application on ocean-going vessels is not recommended, given the work conditions and organisation on board such vessels. There is a realistic possibility that PLB alert messages sent through AIS / VHF frequencies may remain unnoticed and that the response of the crew to the MOB situation may fail. Hence, the 121.5 MHz signal may remain undetected by the SAR locating resources as well. The termination of COSPAS-SARSAT processing of 121.5 MHz signals reduces the efficient application of PLB devices to coastal seas and the areas that are home to off-shore structures. For these reasons, the use of this type of devices in maritime traffic is prohibited or limited by many countries. The advantages of PLB equipment include low costs and unregistered use. In the international maritime trade, the most efficient type of these devices are the PLB EPIRB devices whose signals are monitored by COSPAS-SARSAT, while the area of efficient application of PLB AIS / VHF equipment remains in coastal navigation and fixed off-shore structures.

ACKNOWLEDGEMENTS

Research activities presented in this paper were conducted under the scientific research project "Use of a radio locating in SAR operations-2675/2017" supported by the University of Split-Faculty of Maritime Studies, Croatia.

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