MONITORING THE UTILIZATION OF THE VHF MARITIME MOBILE BAND IN THE NORTHERN ADRIATIC USING SOFTWARE-DEFINED RADIO SCANNER

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Abstract

The Very High Frequency (VHF) maritime mobile band is regulated by the Appendix 18 of the International Telecommunication Union (ITU) Radio Regulations, which contains a list of channels and their designated frequencies. Shipboard VHF stations shall at least maintain a proper radio watch on the VHF channel 70 for Digital Selective Calling (DSC) purposes and on the radiotelephone VHF channel 16 for distress, urgency and safety communications, as well as for routine calling. In addition to the mentioned channels, the ships should also keep watch on the channels allocated for the reception of various information important to the safety of navigation, depending on the national rules valid in different navigational areas. In order to be able to maintain watch on all the mentioned channels simultaneously, it is necessary to have a suitable receiver(s). Considering

all the above, this paper provides an analysis of the use of a low-budget Software-Defined Radio (SDR) receiver for monitoring all transmitting frequencies in the VHF maritime mobile band, from a fixed location in the northern Adriatic. The results of the analysis show the frequency of (non)use of the VHF maritime mobile band in the line of sight of the fixed maritime VHF antenna, with special reference to the channels assigned to the Croatian Vessel Traffic Service (VTS Croatia). The above analysis can serve to consider the possibility of using small low-budget SDR devices in maritime communications in general.

1 INTRODUCTION

The VHF radio system constitutes a vital element of the Global Maritime Distress and Safety System (GMDSS), playing a crucial role in alerting, search and rescue (SAR) coordination, location determination, dissemination of maritime safety information (MSI), urgency and safety communications, as well as general radio communications. This system is mandated by Chapter IV of the International Convention for the Safety of Life at Sea (SOLAS), outlining the responsibilities of national administrations in providing radiocommunication services and specifying ship requirements for radiocommunication equipment [1].

Under the GMDSS, every ship is required to be equipped with VHF radio equipment for conducting distress, urgency, and safety communications, as well as general communications. The specific channels allocated for these purposes are detailed in Appendix 18 of the ITU Radio Regulations [2]. This appendix provides a comprehensive list of channel designators, their operating frequencies, and their designated purposes (refer to APPENDIX).

Notably, the international radio channel for distress, urgency, and safety communications, as well as general calling purposes, is set at a frequency of 156.8 MHz, corresponding to VHF channel 16. Additionally, the frequency of 156.525 MHz, or VHF channel 70, is exclusively designated for Digital Selective Calling (DSC) purposes, irrespective of the type or category of DSC call.

To ensure the crew's prompt responsiveness, the ship's VHF stations should maintain a continuous radio watch on the aforementioned VHF channels - namely, channels 16 and 70. Additionally, in accordance with Chapter IX of [3], ship's VHF stations should also have the capability to receive (and transmit) transmissions on the following frequencies:

- The primary intership radio frequency of 156.3 MHz (VHF channel 06);
- The intership navigation safety radio frequency of 156.650 MHz (VHF channel 13); and
- All the radio frequencies essential for their service, including ship movement service (VTS), notices to navigators, and meteorological bulletins from coast stations, among others.

To monitor these additional VHF radio channels effectively, the ship's VHF stations must be equipped with appropriate receiver(s). Most maritime VHF stations offer dual or triple watch functionality and multiple channels scanning capability. However, as per [4], ship's VHF radiotelephone equipment should include the possibility of automatic scanning of the *priority* channel (channel 16) and only *one* additional channel. Consequently, for monitoring more than two radiotelephone channels, ships should be equipped with more than one VHF station. An alternative approach could involve the use of budget-friendly SDR receivers for monitoring desired or all maritime VHF channels without utilizing actual VHF stations [5, 6]. SDR is a transformative technology that revolutionizes the traditional paradigm of radio communication by merging hardware and software components. In an SDR system, radio functions, traditionally performed by dedicated hardware, are instead executed through software algorithms running on computing platforms. This fundamental shift empowers users to modify, adapt, and customize radio functionalities dynamically, without the need for hardware modifications. By decoupling radio functionality from specific hardware implementations, SDR enables unparalleled flexibility and agility in communication systems. Moreover, SDR facilitates rapid prototyping, experimentation, and deployment of new communication protocols and waveform designs, accelerating innovation cycles in the field of wireless communications. This transformative capability to reconfigure and adapt radio functions through software makes SDR a cornerstone technology in modern communication systems, offering versatility and scalability across a wide range of applications, including telecommunications, defence, aerospace, and of course, maritime communication [7,8].

Given the preceding context, the primary objective of the research outlined in this paper is the utilization of an SDR receiver to scan all transmitting frequencies in the VHF maritime mobile band from a fixed location in the northern Adriatic. Additionally, the research aims to analyse the usage of VHF channels in the specified area during the scanning process with a maritime VHF SDR receiver.

2 EXPERIMENTAL SETUP AND METHODOLOGY

To achieve the primary objective and purpose of the research in developing a VHF maritime mobile band scanner, the research utilized specific equipment and software support.

The key components included the Nooelec NESDR SMArt v5 SDR, a dedicated receiver covering a broad frequency range from 100 kHz to 1.75 GHz. This SDR receiver features the RTL2832U demodulator chip and the R820T2 tuner chip, enhancing its capability to receive diverse signals and support various demodulation modes. Notably, it includes a built-in bias tee, enabling users to supply DC power to external devices like active antennas or low-noise amplifiers, enhancing flexibility in configuring the setup for optimal signal reception. Housed in a durable aluminium enclosure, this SDR receiver provides protection against electromagnetic interference, ensuring robust performance in various environments. Furthermore, the inclusion of a temperature-compensated oscillator (TCXO) enhances frequency stability, contributing to accurate and stable signal reception over time and varying temperature conditions. Its SMA connector and compact design allow seamless integration with various antennas [9].

The choice of the Marine VHF Glass Fibre Antenna at the geographical coordinates 45.3303° N, 14.436° E, with an elevation of 32 meters above mean sea level (AMSL), complemented this SDR receiver, offering an optimized solution for maritime VHF signal reception [10]. To facilitate connectivity, a male SMA to SO-239 nickel-plated adapter was used, ensuring compatibility between the SDR and the RG 213/U coaxial cable. The use of RG 213/U coaxial cable contributed to minimizing signal loss and interference, maintaining signal integrity throughout the transmission path.

The research also involved a computer equipped with an Intel i5 processor, 16 GB of RAM, and a 64-bit Windows 11 operating system. This hardware configuration ensured sufficient computational power and memory for processing and analysing the received signals. The SDR# (SDRSharp) software served as the primary interface for controlling the Nooelec NESDR SMArt v5 SDR. Its user-friendly graphical interface provides controls for frequency tuning, demodulation mode selection, and real-time spectrum visualization. SDR# supports various demodulation modes, including maritime VHF frequency/phase demodulation, catering to different signal types. The software facilitates audio output, enabling users to listen to the audio associated with received signals. Additionally, the spectral display visually represents the real-time radio frequency spectrum, aiding users in identifying active signals and detecting interference. Users can customize various settings within SDR#, such as adjusting signal gain, configuring filters, and modifying display options, providing flexibility to tailor the software to specific needs. The recording capabilities allow users to save portions of the radio spectrum for later analysis. With extensive frequency management features, SDR# aids in the identification of interesting signals and streamlines the monitoring process. Leveraging real-time signal processing capabilities, the software provides instant feedback on changes in the radio frequency spectrum, crucial for dynamic signal environments where quick adjustments are necessary. Support for plugins extends functionality beyond core features, allowing users to add additional tools or visualizations to the software [11].

Therefore, the research leveraged the FMSuite for SDR# plugin software, enhancing frequency management and scanning capabilities. This plugin allows for efficient organization of frequencies, spectrum scanning, and logging of relevant signal information. One of its primary features is the ability to create and manage a comprehensive frequency database within SDR#. Users can categorize frequencies into groups, assign labels, and customize entries, providing an organized and efficient approach to monitoring specific bands or services. The plugin introduces robust scanning functionality, automating the process of tuning through a list of frequencies and stopping on active signals. This feature is particularly advantageous for identifying and monitoring various radio transmissions without manual intervention. FMSuite integrates seamlessly with the

SDR# interface, presenting an additional panel for frequency management that allows users to navigate, organize, and control scanning functions directly within the familiar SDR# environment. Facilitating ease of use, FMSuite supports the search for frequencies within specified ranges and enables users to import these directly into the frequency manager. The plugin logs information about detected signals during scanning, creating a historical record of received frequencies, signal strengths, and other relevant details. This log can be invaluable for subsequent analysis or reference. Users can customize scanning parameters, including scan speed and dwell time on each frequency, tailoring the scanning process to individual preferences and monitoring requirements. FMSuite also includes alert and notification features, allowing users to configure notifications for specific criteria, such as when a signal surpasses a defined signal strength threshold. This capability enhances the ability to draw attention to notable or potentially important transmissions. The plugin also supports importing and exporting frequency databases, streamlining the sharing of configured settings between users or installations. Additionally, users can edit frequency entries directly within the plugin, providing a convenient means to update information, add notes, or make real-time changes to the frequency database [12].

The integration of these software tools with the chosen hardware components created a comprehensive environment for exploring, monitoring, and analysing VHF maritime mobile communications from a fixed position in the northern Adriatic. The combined use of the Nooelec NESDR SMArt v5 SDR, SDR# software, FMSuite plugin, and supporting accessories formed a cohesive system aligned with the research's objectives in developing an effective VHF maritime mobile band scanner. This experimental setup was configured according to the model outlined in reference [13].

The settings in the software support were as follows. In the Source panel of the SDR# software, the sample rate was set to 2.4 MSPS, employing quadrature sampling mode, and RTL AGC was activated to ensure automatic gain control. The RF Gain was set at 0 dB for a balanced amplification.

Within the Radio panel, the chosen demodulator was Narrow FM (NFM), suitable for the frequency modulation commonly used in VHF communication. The frequency shift was disabled, and a Blackman-Harris 4 windowing filter was applied, providing a compromise between selectivity and reduced side lobes. A high-order value of 1000 was set for the filter, enhancing its frequency response. The selected bandwidth was 25 kHz, ensuring compatibility with maritime VHF channels. The squelch level was configured at 25, suppressing background noise while allowing signals above this threshold to pass. Correct IQ was enabled, ensuring proper processing of in-phase (I) and quadrature (Q) components.

Moving to the FMSuite scanner settings, the minimum signal strength was set to -50 dBFS, indicating the minimum acceptable signal strength for logging. A 5-second wait time was implemented to resume scanning after an activity pause. The scanning range covered frequencies from 156 MHz to 163 MHz, typical for transmitting frequencies in the VHF maritime mobile band (APPENDIX). Snap to step size was enabled for precise frequency alignment, and a cut-off timer was set to 6 seconds, resuming scanning for other active frequencies after this duration. The scan resolution was configured as low, prioritizing speed over accuracy, and a radio settle time of 250 ms allowed for stabilization between frequency changes.

In the Scanner Activity Logger settings, activities lasting less than 1 second were excluded from logging, streamlining the recorded data. The scanning operation commenced on December 19, 2023, at 11:00 AM local time and concluded on December 21, 2023, at 11:00 AM local time, providing a comprehensive dataset for subsequent analysis. The SDR# software interface with the configured parameters is depicted in Figure 1.

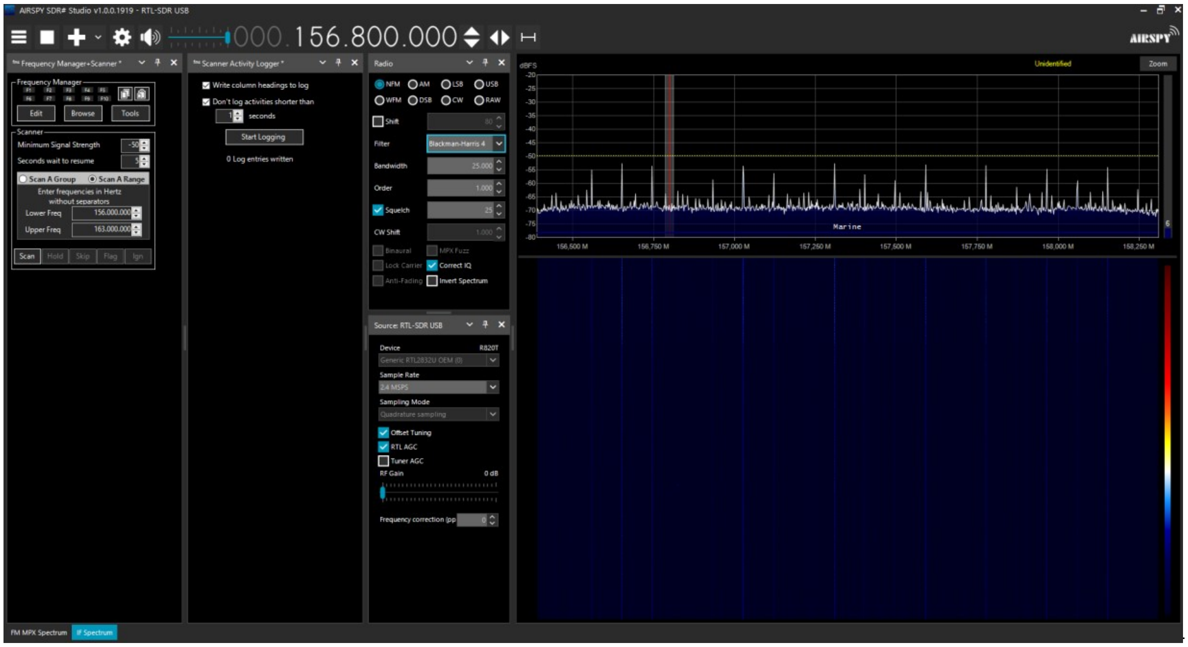


Fig. 1 The SDR# software interface

3 RESULTS ANALYSIS

The scanner logs were saved in CSV files for each individual day. A total of 935 activity records were documented on specific frequencies within the defined range, i.e., between 156 MHz and 163 MHz. Among these records, 57% experienced a signal power drop below the set minimum within 5 seconds after reception, followed by the resumption of scanning. For the remaining 43%, the cut-off timer interrupted reception after the set 6 seconds (refer to Figure 2).

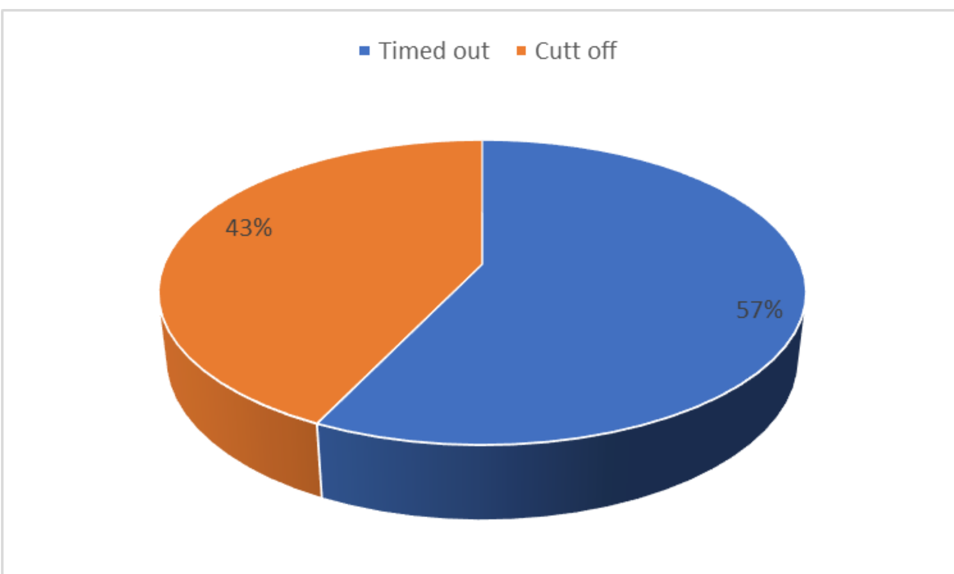


Fig. 2 Scan resume cause

Further analysis revealed 31 transmitting frequencies, with 15 not listed in Appendix 18 of the ITU Radio Regulations (APPENDIX). The distribution of records per individual frequency, i.e., maritime VHF channel, is depicted in Figure 3.

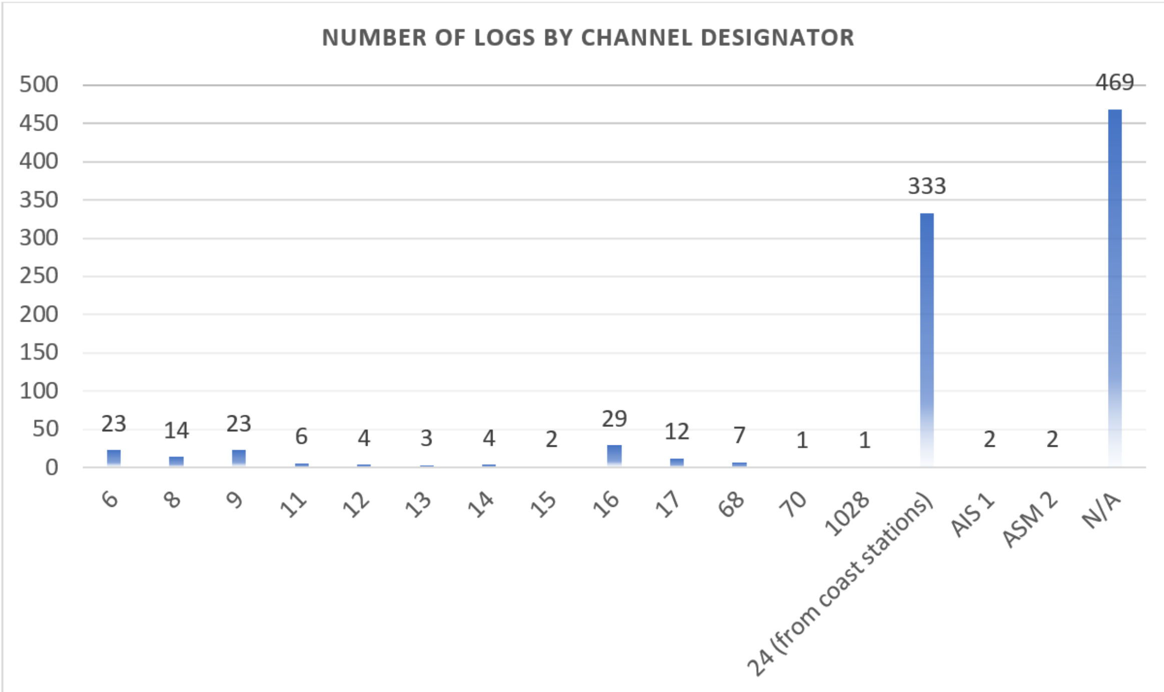
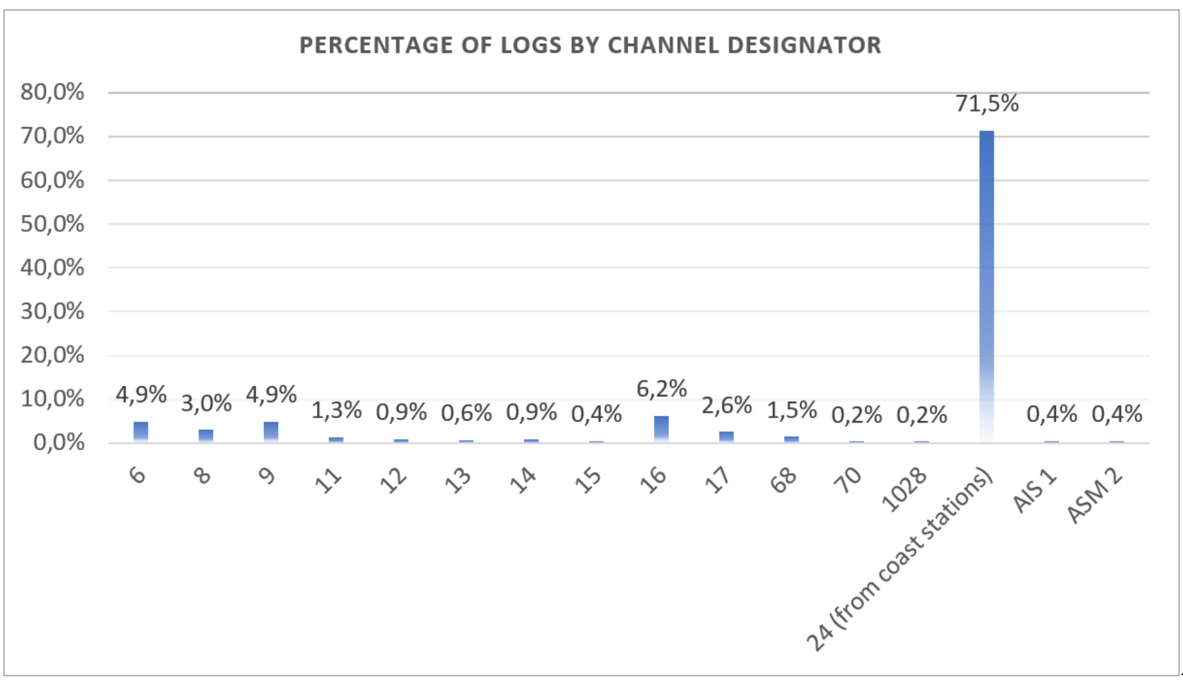


Fig. 3 Number of logs by channel designator[1]

After excluding unknown frequencies, a total of 466 records on VHF maritime mobile band channels remained. Figure 4 illustrates the percentage of usage for each maritime VHF channel during the scanning period.



[1] The "N/A" designation applies to frequencies that are not listed in the APPENDIX.

Fig. 4 Percentage of logs by channel designator

The international radio distress channel, VHF channel 16, was observed in 6.2% of records, while VHF DSC channel 70 was recorded in only 0.2% of records. Additionally, the primary intership VHF channel 06 appeared in 5% of records, and the intership navigation safety VHF channel 13 was noted in 1% of records.

VTS Croatia plays a crucial role in ensuring maritime safety and managing vessel traffic in Croatian waters. The VTS Croatia is divided into specific sectors, each utilizing designated VHF channels for communication, as shown in Table 1 [14, 15]. The VTS monitors and regulates vessel movements, providing navigational assistance, traffic information, and coordination to enhance the safety and efficiency of maritime traffic. This system is integral to the overall maritime infrastructure, contributing to the prevention of collisions, protection of the marine environment, and efficient navigation within Croatian waters.

VTS SERVICES AND COMMUNICATION IN THE VTS AREA			
SECTORS	SERVICES	VHF CHANNEL(S)	CALL SIGN
SURVEILLANCE SECTORS			
Sector A	Information Service*	Channels 10, 60	VTS CROATIA
Sector B	Information Service	Channels 10, 60	VTS CROATIA
ROUTING SECTORS			
Sector RIJEKA	Information Service, Traffic Organization Service	Channels 14, 62	VTS RIJEKA
Sector ZADAR	Information Service, Traffic Organization Service	Channels 12, 60	VTS ZADAR
Sector ŠIBENIK	Information Service, Traffic Organization Service	Channels 14, 60	VTS ŠIBENIK
Sector SPLIT	Information Service, Traffic Organization Service	Channels 12, 62	VTS SPLIT
Sector PLOČE	Information Service, Traffic Organization Service	Channel 14	VTS PLOČE
Sector DUBROVNIK	Information Service, Traffic Organization	Channel 12	VTS DUBROVNIK

	Service		
MANOEUVRING SECTORS			
PULA	Information Service*	Channel 09	PULA TRAFFIC
RIJEKA	Information Service*	Channel 09	RIJEKA TRAFFIC
ZADAR	Information Service*	Channel 09	ZADAR TRAFFIC
ŠIBENIK	Information Service*	Channel 09	ŠIBENIK TRAFFIC
SPLIT	Information Service*	Channel 09	SPLIT TRAFFIC
PLOČE	Information Service*	Channel 09	PLOČE TRAFFIC
DUBROVNIK	Information Service*	Channel 09	DUBROVNIK TRAFFIC

* Information Service only in the case of imminent danger to navigational safety

Table 1 VTS Croatia sectors with services and VHF channels

Comparing Figure 4 and Table 1 reveals that 5% of records correspond to VHF channel 09, used in manoeuvring sectors, while 2% of records pertain to VHF channels 12 and 14, utilized in routing sectors.

Moreover, according to [16], there are three coast radio stations in Croatia with corresponding specific VHF channels, as illustrated in Figure 5.

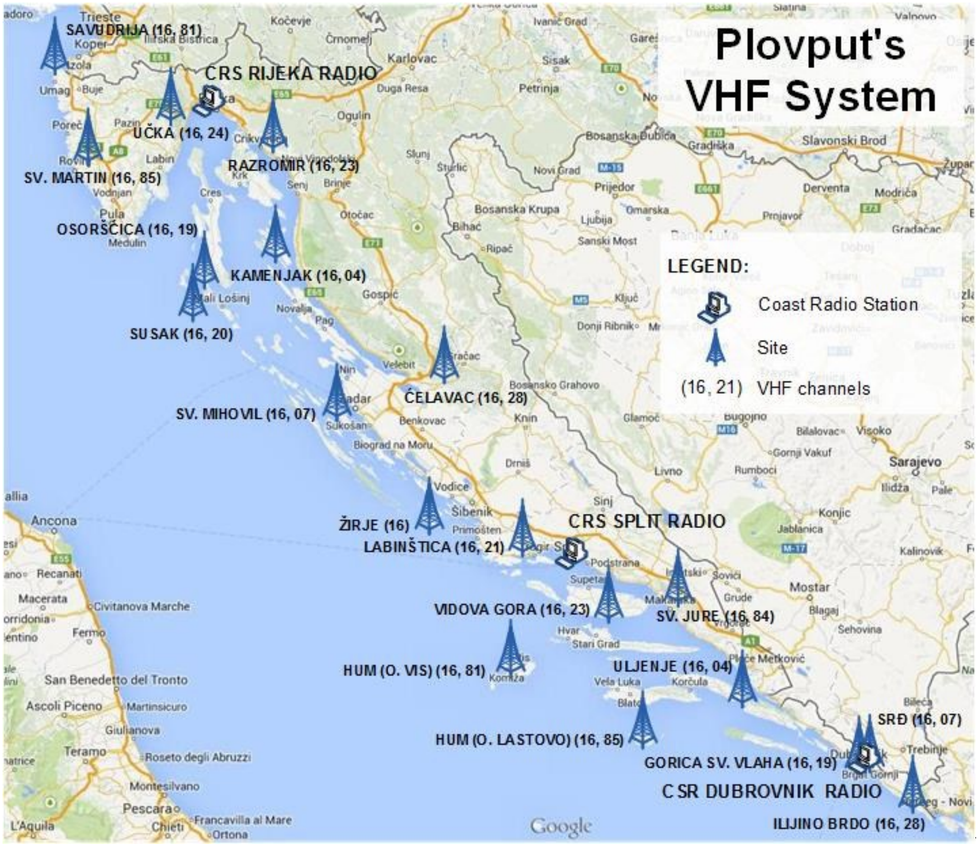


Fig. 5 Croatian VHF radiotelephone system [16]

Comparing Figures 4 and 5 shows that the majority of logs (71.5%) were recorded on VHF channel 24, where the transmitter is located on Mount Učka. This result is unsurprising, given that the coast radio station Rijeka Radio has a predefined MSI broadcasting schedule, occurring at least four times daily [16, 17].

Other channels received by the VHF SDR scanner and recorded in the scanner's log serve the following purposes. In accordance with [2], VHF channel 08 is designated for maritime mobile service and functions as a general ship-to-ship communication channel. Channel 11 is allocated for both ship-to-ship and ship-to-coast communication, commonly used for non-commercial purposes. Channel 15 is reserved for intership communication, often utilized for non-commercial exchanges and navigational safety. Channel 17 is allocated for ship-to-ship and ship-to-coast communication, specifically for non-commercial interactions. Channel 68 is designed for non-commercial ship-to-ship and ship-to-coast communication, frequently employed for local or regional interactions. Channels 1028 (157.4 MHz) and ASM 2 (162.0 MHz) collectively represented what was known as channel 28, used until January 1, 2017. Following this date, channel 28 was separated into the "lower" frequency (channel 1028) and the "upper" frequency (channel ASM 2). According to the decisions made at the World Radiocommunication Conference 2019 (WRC-19), channel ASM 2 is designated for Application Specific Messages (ASM), as outlined in the most recent version of Recommendation ITU-R M.2092, while channel 1028 is allocated as a single-frequency analogue channel specifically intended for port operation and ship movement. Nevertheless, it is plausible that, in this particular case, the "former" channel 28 was employed, as mandatory alterations have been deferred until January 1, 2028. Lastly, channel AIS 1 operates on 161.975 MHz and is part of the Automatic Identification System (AIS) used for vessel tracking and identification. Each of these VHF channels plays a distinct role in facilitating various aspects of maritime communication and safety.

4 CONCLUSIONS

In conclusion, the research successfully employed an SDR receiver, specifically the Nooelec NESDR SMArt v5 SDR, to scan and analyse transmitting frequencies in the VHF maritime mobile band from a fixed location in the northern Adriatic. The experiment aimed to understand the usage patterns of VHF channels in the specified area and provide insights into maritime communication dynamics.

The utilization of the SDR# software, along with the FMSuite plugin, facilitated efficient frequency management, spectrum scanning, and logging of relevant signal information. The experiment revealed a total of 935 activity records within the defined frequency range, with detailed analysis showing distinct patterns in signal interruptions and cut-offs.

Further examination identified 31 transmitting frequencies, 15 of which were not listed in Appendix 18 of the ITU Radio Regulations. This discrepancy emphasizes the dynamic nature of VHF maritime communication beyond regulatory documentation. The distribution of records across individual frequencies highlighted varying usage, with notable occurrences on VHF channels 16, 70, 6, and 13.

The importance of VTS Croatia in managing vessel traffic and ensuring maritime safety was underscored. The division of VTS sectors, each utilizing designated VHF channels, plays a crucial role in enhancing the safety and efficiency of maritime traffic. The predominant usage of VHF channel 24, linked to the coast radio station Rijeka Radio, aligns with the predefined MSI broadcasting schedule.

The research also brought into focus the varied functionalities of maritime VHF channels, capturing a spectrum that spans from general ship-to-ship communication to the transmission of AIS reports. Additionally, it's noteworthy that these channels were actively recorded by the scanner, adding a valuable dimension to the research insights.

In summary, the combination of SDR technology, advanced software tools, and specific hardware components provided a robust and flexible platform for monitoring and analysing VHF maritime communication. The findings contribute valuable insights into the real-world utilization of VHF channels, emphasizing the need for adaptive technologies and continuous monitoring to ensure effective maritime communication and safety.

The authors are of the opinion that SDR systems present a plethora of opportunities for the maritime sector, offering a dynamic and adaptable approach to communication. With the ability to be reconfigured via software updates, SDR systems provide unparalleled flexibility, enabling seamless integration with diverse communication standards and protocols utilized in maritime operations. This adaptability not only streamlines equipment requirements but also potentially reduces costs and simplifies maintenance, making it an attractive option for maritime organizations seeking efficiency gains. Moreover, SDR facilitates spectrum efficiency through advanced signal processing techniques, optimizing bandwidth usage and enhancing communication reliability amidst the complexities of maritime environments.

However, implementing SDR systems in the maritime sector comes with its own set of challenges. The complexity of SDR technology demands specialized expertise in software development, signal processing, and radio frequency engineering, which may pose obstacles for organizations lacking in-house technical capabilities. Additionally, ensuring compliance with maritime regulations and standards necessitates thorough testing and certification processes, adding layers of complexity to deployment efforts. Security concerns also loom large, as SDR systems are vulnerable to cybersecurity threats such as unauthorized access and signal manipulation, necessitating robust safeguards to protect maritime communications.

Moreover, the power consumption of SDR platforms may be a concern in maritime applications where energy efficiency is paramount, especially aboard vessels with limited power resources. Environmental factors such as saltwater corrosion, temperature fluctuations, and electromagnetic interference further complicate the reliability and performance of SDR systems deployed in maritime settings. Additionally, interoperability with existing legacy infrastructure poses challenges, requiring retrofitting or additional interfaces to ensure seamless integration and backward compatibility.

Despite these challenges, the adoption of SDR systems holds significant promise for the maritime sector, offering enhanced communication efficiency, flexibility, and interoperability. By addressing these challenges and leveraging the capabilities of SDR technology, maritime stakeholders can unlock new opportunities to improve safety, operational efficiency, and situational awareness across the maritime domain.

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APPENDIX

Table of transmitting frequencies in the VHF maritime mobile band [2]

Channel designator	**Transmitting frequencies (MHz)**		**Inter-ship**	**Port operations and ship movement**		**Public corres-pondence**
	From ship stations	**From coast stations**		**Single frequency**	**Two frequency**	
60	156.025	160.625		x	x	x
01	156.050	160.650		x	x	x
61	156.075	160.675		x	x	x
02	156.100	160.700		x	x	x
62	156.125	160.725		x	x	x
03	156.150	160.750		x	x	x
63	156.175	160.775		x	x	x
04	156.200	160.800		x	x	x
64	156.225	160.825		x	x	x
05	156.250	160.850		x	x	x
65	156.275	160.875		x	x	x
06	156.300		x			
2006	160.900	160.900				
66	156.325	160.925		x	x	x
07	156.350	160.950		x	x	x
67	156.375	156.375	x	x		
08	156.400		x			
68	156.425	156.425		x		
09	156.450	156.450	x	x		
69	156.475	156.475	x	x		
10	156.500	156.500	x	x		
70	**156.525**	**156.525**	**Digital selective calling for distress, safety and calling**			
11	156.550	156.550		x		
71	156.575	156.575		x		
12	156.600	156.600		x		
72	156.625		x			
13	156.650	156.650	x	x		
73	156.675	156.675	x	x		
14	156.700	156.700		x		
74	156.725	156.725		x		
15	156.750	156.750	x	x		
75	156.775	156.775		x		
16	**156.800**	**156.800**	**DISTRESS, SAFETY AND CALLING**			
76	156.825	156.825		x		
17	156.850	156.850	x	x		
77	156.875		x			
18	156.900	161.500		x	x	x
78	156.925	161.525		x	x	x
1078	156.925	156.925		x		
2078		161.525		x		
19	156.950	161.550		x	x	x

Channel designator	**Transmitting frequencies (MHz)**		**Inter-ship**	**Port operations and ship movement**		**Public corres-pondence**
	From ship stations	**From coast stations**		**Single frequency**	**Two frequency**	
1019	156.950	156.950		x		
2019		161.550		x		
79	156.975	161.575		x	x	x
1079	156.975	156.975		x		
2079		161.575		x		
20	157.000	161.600		x	x	x
1020	157.000	157.000		x		
2020		161.600		x		
80	157.025	161.625		x	x	x
21	157.050	161.650		x	x	x
81	157.075	161.675		x	x	x
22	157.100	161.700		x	x	x
82	157.125	161.725		x	x	x
23	157.150	161.750		x	x	x
83	157.175	161.775		x	x	x
24	157.200	161.800		x	x	x
1024	157.200	157.200	x (digital only)	x (digital only)		
2024	161.800	161.800	x (digital only)	x (digital only)		
84	157.225	161.825		x	x	x
1084	157.225	157.225	x (digital only)	x (digital only)		
2084	161.825	161.825	x (digital only)	x (digital only)		
25	157.250	161.850		x	x	x
1025	157.250	157.250	x (digital only)	x (digital only)		
2025	161.850	161.850	x (digital only)	x (digital only)		
85	157.275	161.875		x	x	x
1085	157.275	157.275	x (digital only)	x (digital only)		
2085	161.875	161.875	x (digital only)	x (digital only)		
26	157.300	161.900		x	x	x
1026	157.300					
2026		161.900				
86	157.325	161.925		x	x	x
1086	157.325					
2086		161.925				

Channel designator	**Transmitting frequencies (MHz)**		**Inter-ship**	**Port operations and ship movement**		**Public corres-pondence**
	From ship stations	**From coast stations**		**Single frequency**	**Two frequency**	
1027	157.350	157.350		x		
ASM 1	161.950	161.950				
87	157.375	157.375		x		
1028	157.400	157.400		x		
ASM 2	162.000	162.000				
88	157.425	157.425		x		
AIS 1	161.975	161.975				
AIS 2	162.025	162.025				