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Implementation of the Listen-Before-Talk Mode for SeaSonde High-Frequency Ocean Radars

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Abstract: The International Telecommunication Union (ITU) Resolution 612, in combination with Report ITU-R M2.234 (11/2011) and Recommendation ITU-R M.1874-1 (02/2013), regulates the use of the radiolocation services between 3 and 50 MHz to support high frequency oceanographic radar (HFR) operations. The operational frame for HFR systems include: band sharing capabilities, such as synchronization of the signal modulation; pulse shaping and multiple levels of filtering, to reduce out-of-band interferences; low radiated power; directional transmission antenna, to reduce emission over land. Resolution 612 also aims at reducing the use of spectral bands, either through the application of existing band-sharing capabilities, the reduction of the spectral leakage to neighboring frequency bands, or the development and implementation of listen-before-talk (LBT) capabilities. While the LBT mode is operational and commonly used at several phased-array HFR installations, the implementation to commercial direction-finding systems does not appear to be available yet. In this paper, a proof-of-concept is provided for the implementation of the LBT mode for commercial SeaSonde HFRs deployed in Australia, with potential for applications in other networks and installations elsewhere. Potential critical aspects for systems operated under this configuration are also pointed out. Both the receiver and the transmitter antennas may lose efficiency if the frequency offset from the resonant frequency or calibration pattern are too large. Radial resolution clearly degrades when a dynamical adaptation of the bandwidth is performed, which results in non-homogeneous spatial resolution and reduction of the quality of the data. A recommendation would be to perform the LBT-adapt scans after a full measurement cycle (1-h or 3-h, depending on the system configuration) is concluded. Mutual cross-interference from clock offsets between two HFR systems may bias the frequency scans when the site computers controlling data acquisitions are not properly time-synchronized.

Keywords: high-frequency ocean radar; interference mitigation; frequency band adaptation

1. Introduction

Shore-based High-frequency oceanographic radar (HFR) systems, operating in the frequency range between 3–30 MHz, are nowadays routinely used for a number of different scientific applications and operational purposes. Depending upon the operational parameters, HFRs can resolve spatial scales in the range of a few hundred meters to hundreds of kilometers, at time scales of minutes, hour, day, seasonal or longer. These capabilities make them very attractive, for instance, for oil spill mitigation purposes, search and rescue operations, and ingestion into ocean circulation numerical models [1]. Over the past decades, the overall number of operational HFR systems increased significantly to the point that regional and global networks have been established [1]. Along the coasts of the US, for instance, more than 100 HFR systems are presently in operation, and the number of deployments steadily increases both in the Asia-Pacific regions and Europe. Extensive validation analyses and deployments in a variety of environments have also proven their general reliability [1–4].

The most commonly deployed systems are supplied by two manufacturers, Codar Ocean Sensors (COS) and Helzel MessTechnik, who provide commercial direction-finding (SeaSonde) and phased-array (Wellen Radar, or WERA) HFR systems, respectively. Other HFR systems are also available, such as the PISCES or the University of Hawaii's HFRs. See, for instance, [1–4] and references herein for a more exhaustive literature review and for an assessment of their interoperability.

In 2012, the International Telecommunication Union (ITU) Resolution 612 [5] allocated specific frequency bands between 3 and 50 MHz to support high frequency oceanographic radar (HFR) operations. The allocation of specific frequency band to HFRs was a formal recognition of the benefits to society through environmental protection, disaster preparedness, public health protection, improved meteorological operations, increased coastal and maritime safety and enhancement of national economies. ITU Resolution 612 [5] was also an acknowledgement of the efforts to reduce interferences to services within the same or neighboring frequency bands.

In combination with Report ITU-R M2.234 (11/2011; [6]) and Recommendation ITU-R M.1874-1 (02/2013; [7]), Resolution 612 [5] set the operational frame for HFR systems. An oceanographic radar should operate in low radiated power mode, with peak effective isotropic radiated power (EIRP) below 25 dBW. Band sharing capabilities should be implemented in order to reduce to a minimum the spectral occupancy of a regional or global deployment of radars. These capabilities include, for instance, the synchronization of the signal modulation and the use of accurate GPS timing [8]. The reduction of spurious emissions and offband leakage of the transmitted signal to neighboring band, resulting in unwanted out-of-band interferences, is achieved through pulse shaping and multiple levels of filtering. Finally, the use of directional transmit antenna is also recommended, where applicable and as required by the regulatory bodies, so to reduce the EIRP in the direction of the transmit antenna backlobe, and limit as much as possible emission over land.

In Australia, the Integrated Marine Observing System (IMOS) Ocean Radar Facility operates commercial-type direction-finding SeaSonde and phased-array Wellen Radar (WERA). HFR systems operate within the ITU Region 3 frequency band with secondary-type licenses, meaning that operations must not cause harmful interference to primary users within or outside the allocated frequency band.

Unfortunately, this is not the case and several breach warning notices have been issued in the past. The most recent episodes, occurred in December 2017 and July 2018, and involved the freshly installed SeaSonde systems in New South Wales (NSW) operating in the 5.250–5.275 MHz ITU frequency band. These systems were reported as an interference source to primary services at various locations across the country, particularly to two 3 KHz fixed and mobile services at 5.264 MHz and 5.2715 MHz operating remote area travellers safety networks.

Following the complaint, systems were forced off for 12 months while mitigation measures were implemented as requested by the Australian Communications and Media Authority (ACMA). Operations could resume only upon successful implementation of the mitigation measures in compliance with relevant ITU regulation for HFR systems (Resolution 612 [5], Report ITU-R M2.234 (11/2011; [6]) and Recommendation ITU-R M.1874-1 (02/2013; [7]).

To reduce direct impact of the SeaSonde HFR systems on the affected users, transmit power was decreased to the minimum (even below 1 W), the center operating frequency was shifted to 5.257 MHz, the bandwidth was reduced to 11 kHz (resulting in a radial range resolution of approximately 13.5 km). As a further mitigation measure, prototype modified components were provided by the system manufacturers so to limit spurious emissions through pulse shaping with longer ramping-deramping times, longer pulse width, and modified weighting windows.

SeaSonde make use of the proprietary GPS synchronization band sharing techniques described in [8] to reduce band usage. However, it was also decided to operate in interrupted, short-burst acquisition mode in which the transmitter is on/off for 512 s/88 s and to observe radio silence periods in order to facilitate possible distress or emergency calls. This was possible thanks to the advanced programming features available in the SeaSonde hardware [9] and the Applescript ® programming language [10], which require no access to the proprietary source code.

Finally, a customized prototype non-resonant, wide-beam, travelling-wave directional transmit antenna providing up to 30 dB front-to-back lobe suppression was developed by the IMOS Ocean Radar Facility [11] and deployed on field. Operating frequency and bandwidth for the two SeaSonde systems deployed in NSW are, respectively, 5.257 MHz and 11.029 kHz, the latter resulting in a radial range resolution of approximately 13.5 km. No significant performance losses in terms of range can be observed in comparison to more conventional, uninterrupted transmit and operation modes, thanks to the long integration times.

In an attempt to further mitigate the band usage, a listen-before-talk operation mode for SeaSonde systems was developed and is described here, in which the SeaSonde perform automatic frequency scans (Figure 1) before each short-duration transmit cycle, the frequency scan results are analyzed and optimized operation parameters are provided in real-time mode. Although feasible in principle, an application of the bandwidth reduction to real-time data stream is however discouraged to avoid inconsistencies during the radial averaging in the final stage of the radial map processing chain.

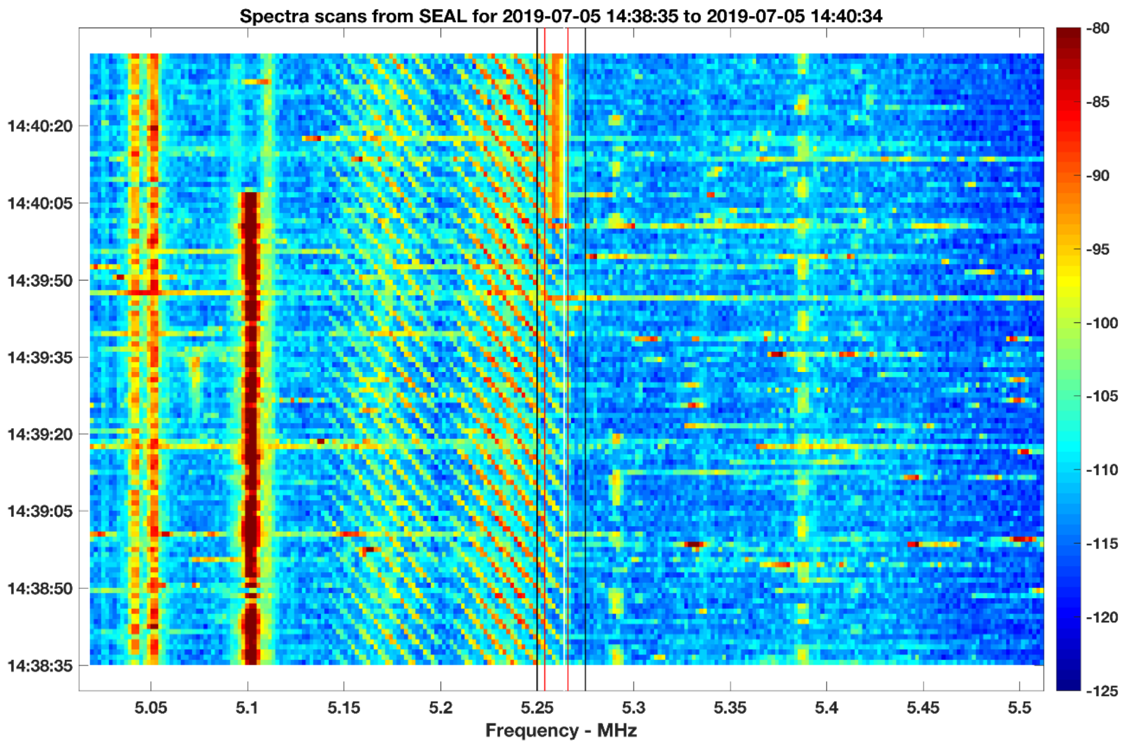

Figure 1. Example of a 2-min spectrum scan collected through receive channel 3 (the so called 'monopole' in the standard SeaSonde terminology) at the Seal Rocks SeaSonde HFR station (station code: SEAL). The station is located approximately 200 km N of Sydney (NSW). The scan was collected between 20190705T143835Z–20190705T144034Z and contains several recurrent features. Vertical black lines indicate the 5.250–5.275 MHz ITU band; red vertical lines show the 5.254–5.266 MHz band in use to the SeaSonde station located at Red Head, Newcastle (NSW), approximately 100 km apart from Seal Rocks; this station resumed transmission at 20190705T144000Z after being silent for approximately 90 s. Note the 50 kHz chirps (of unknown origin) contaminating the ITU frequency band allocated to HFR operations. Unit for signal power is dB.

The concepts of listen-before-talk, or listen-before-transmit (LBT), and dynamic bandwidth adaptation, or automatic frequency agility (AFA), are relatively straightforward: a technique used in radio communications in which a device first senses its radio environment before transmitting. Then, transmission will begin: unmodified, if the channel is free; modified, to adapt to the available portion of the channel otherwise; use a different channel, if available and allowed to operate on.

LBT is part of the so-called fair coexistence code of practice and is included the regulatory requirements worldwide in several applications, from medical to communications [12,13]. Within the HFR operator's community, only phased array systems routinely implement the LBT mode with dynamical adaptation at their installations [14]. Typically, a frequency pre-scan is made across the entire licensed band before each data acquisition. The pre-scan data are used to identify regions of lowest external noise, and operational settings are optimized for subsequent acquisition cycle. It is worth noting that prescan and adapt measures were also suggested in [5–7], however SeaSonde HFR operators involved in the preliminary feasibility study deemed the consequence of a reduced bandwidth unacceptable in terms of data quality.

The problem of band sharing, coexistence and off-band leakage is now becoming of primary importance within the HFR community as it involves all ITU frequency bands allocated to oceanographic HFR systems. The paper is organized as follows: Section 2 details the implementation of the proposed LBT methodology. Section 3 presents examples of its application to real time data at locations across Australia and discusses some of the implications and assumptions for the LBT mode. Concluding remarks are presented in Section 4.

2. Materials and Methods

The proposed implementation of the listen-before-talk (LBT) mode for SeaSonde HFRs is meant to deal with in-band interferences, that is both interfering transmitter and victim receiver operate in the same spectrum band. It is a multi-step process that can be summarized as follows (Figure 2):

(1) perform a scan of the radio spectrum before data acquisition (Spectrum scan-SSA; Figure 2);
(2) analyze the frequency scan, and identify interference sources (Signal Detected; Figure 2);
(3) adapt the acquisition parameters and resume operations (Adapt SSC; Figure 2);
(4) resume operations (Start-Stop DAQ; Figure 2);
(5) repeat the cycle.

Control of transmit and data acquisition cycles are possible using the advanced SeaSonde software features, documented in [9], and the AppleScript programming language [10]. Similarly, SeaSondeAcquisition can be programmed via AppleScript to operate in SpectrumAnalyzer mode, perform a frequency scan around the operating frequency, and save the results of the spectrum scans in time stamped resource indexed file format. Data collected during the frequency scan through the receive channel consists of a set of consecutive time sweeps containing received signal voltage (V) over frequency [15]. Once the spectrum scan is complete, the integrity of the file is checked, and the content decoded, following [15], and converted to signal power (dB) for further analyses.

An example of a frequency scan through the vertical omnidirectional whip (the so called 'monopole' in the standard SeaSonde terminology), is provided in Figure 1. In this example, collected at the Seal Rocks SeaSonde HFR station (station code: SEAL) between 20190705T143835Z–20190705T144034Z, the raw file is composed of 120 consecutive sweeps collected at 1 Hz sampling rate. Raw voltage data can be converted to signal power (SP) in dB, as follows Equation (1):

$$SP = 20 * \log_{10}(V) - 67, \quad (1)$$

where −67 is a correction factor for the processing gain.

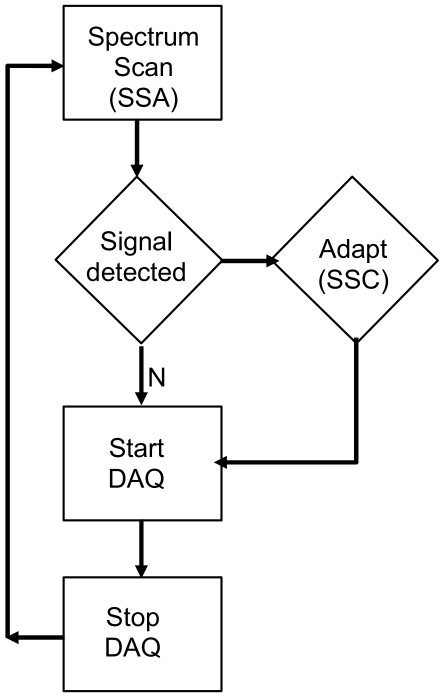

Figure 2. Flowchart for the proposed listen-before-talk mode: perform a spectrum scan using the built-in spectrum analyzer capability in the SeaSondeAcquisition (SSA) suite; adapt and pass acquisition parameters to SeaSondeController (SSC) suite; start and stop acquisition (DAQ) steps controlling the pulsed mode in the SeaSondeController suite.

In Figure 1, vertical black lines indicate the 5.250–5.275 MHz ITU band in use to the HFR systems; red vertical lines show the band in use to the paired SeaSonde station located at Red Head, Newcastle (NSW), approximately 100 km south of Seal Rocks. This station resumed transmission at 20190705T144000Z after being silent for approximately 90 s. The white line in the spectrum denotes the 3 KHz channel at 5.264 MHz that originally reported interferences to the ACMA. Note the 50 KHz chirps (of unknown origin) contaminating the ITU frequency band allocated to HFR operations.

The critical steps are, respectively, Step 2 and Step 3 in the flowchart:

Step 2: analyze the frequency scan and identify interference sources (signal detected; Figure 2).

A peak-detection algorithm is used to identify the presence of peaks, their prominence above the signal threshold, and their width, in the time-averaged frequency scan. Statistics of the signal power level within the ITU band are used to determine whether the peak is persistent, and as such it should be considered as unwanted signal, or transient, and as such should be neglected.

Peak detection is performed on the temporal average of signal power over frequency within the allocated frequency band. In this way, mean power over frequency within the allocated frequency band can be computed along with its standard deviation during the frequency scan. Any peak with a power level exceeding the noise floor level by a factor of one standard deviation is considered either as a potential service not be causing interference to, or an interference source to avoid Equation (2):

$$\text{Peak Power} \geq \text{NF}(f)_{band} + \sigma_{PL}, \tag{2}$$

where $\text{NF}(f)_{band}$ is the time-frequency averaged power within the band, with σ_{PL} its standard deviation during the frequency scan.

Step 3: adapt the acquisition parameters and resume operations (Adapt SSC; Figure 2).

Once a peak has been identified, additional parameters are required in order to determine the optimal operational settings to use for the following acquisition cycle. The peak frequency (f_P) and the peak width at half the power, (Δf_{P}, measured in Hz), are used to define the maximum usable bandwidth, BW_{max}, as follows:

$$BW_{max} = \max(f_{\mathrm{P}} \pm \Delta f_{\mathrm{P}}/2 - f_L, f_U - f_{\mathrm{P}} \pm \Delta f_{\mathrm{P}}/2), \tag{3}$$

where ($f_L, f_U, f_{\mathrm{P}} \pm \Delta f_{\mathrm{P}}/2$) are, respectively, the lower and upper limits of the allocated frequency band, and the band occupied by the interfering signal around the peak frequency f_{P}. In case BW_{max} equals the actual transmit bandwidth, no reduction is required and a new optimized center frequency for the transmitter can be determined as follows:

italic> $$TX_{opt} = (f_{\mathrm{L}} + BW_{max}/2), \text{ if } f_{\mathrm{P}} > f_{\mathrm{L}} \;\&\; f_{\mathrm{P}} \leq f_{\mathrm{P}} + (f_{\mathrm{U}} - f_{\mathrm{L}})/2 \tag{4}$$

$$TX_{opt} = (f_{\mathrm{U}} - BW_{max}/2), \text{ if } f_{\mathrm{P}} < f_{\mathrm{U}} \;\&\; f_{\mathrm{P}} \geq f_{\mathrm{P}} - (f_{\mathrm{U}} - f_{\mathrm{L}})/2 \tag{5}$$

Here it is assumed that the SeaSonde systems are not using the full available bandwidth but only a fraction of it is used during the acquisition cycle. This is the case for the SeaSonde systems deployed across Australia that use 50% of the available bandwidth.

There is the possibility that the transmit bandwidth also requires adjustments. If this is the case, the following alternative options can be discussed: (1) no adjustment is made, and acquisition is resumed without adaptation; (2) acquisition is stopped; (3) acquisition parameters are adjusted and acquisition resumed with reduced bandwidth. If this reduction is deemed acceptable, setting the new centre frequency in SeaSondeController and resuming acquisition in SeaSondeAcquisition is relatively straightforward.

3. Results and Discussion

In this section, some results of the algorithm described previously are summarized. For the sake of qualitative comparison, the same color scale is used across the frequency scans shown here.

The first spectrum scan was collected at Seal Rocks HFR station using the default parameters: the omnidirectional receive element, 256-point *fft*, 120 sweeps at 1 Hz sampling rate, resulting in a 2 min scan between 20190716T233810Z and 20190716T234009Z (Figure 3). The scan was processed and converted from voltage time series into signal power as described in Equation (1); the time- frequency-averaged signal level $\mathrm{NF}(f)_{band}$, the corresponding standard deviation σ_{PL} and the resulting threshold value are, respectively: −114.5 dB, 2.9 dB, −111.6 dB.

The peak-finding algorithm tracks two peaks: a first one, located at 5.2599 MHz, with signal level −108.76 dB, and a second one at 5.2717 MHz, with signal level −115.46 dB. In Figure 3, they are identified by the red diamond markers.

The second peak (5.2717 MHz) is below the band-averaged signal level and the detection threshold, and is associated with continuous narrowband (~3 KHz) downwards chirping signals at the initial and final 10–15 s in the scan along with similar short-duration (~5 s) chirps repeating every 10–15 s. The origin of this signal is unknown.

The first peak (5.2599 MHz) is above the detection threshold and as such it is considered as a possible interference source. This signal is associated with the SeaSonde station at Red Head (site code: RHED), New South Wales, located approximately 100 km southwest of Seal Rocks. The half-power peak width Δf_{P} associated with this signal is 2.55 KHz, which is less than 25% the real bandwidth of the SeaSonde chirp in use at the RHED station.

Following the presence of the peak at 5.2599 MHz, the algorithm suggests an optimal transmit frequency of 5.2694 MHz (center value) with a bandwidth of 11.3 KHz for which no reduction is required.

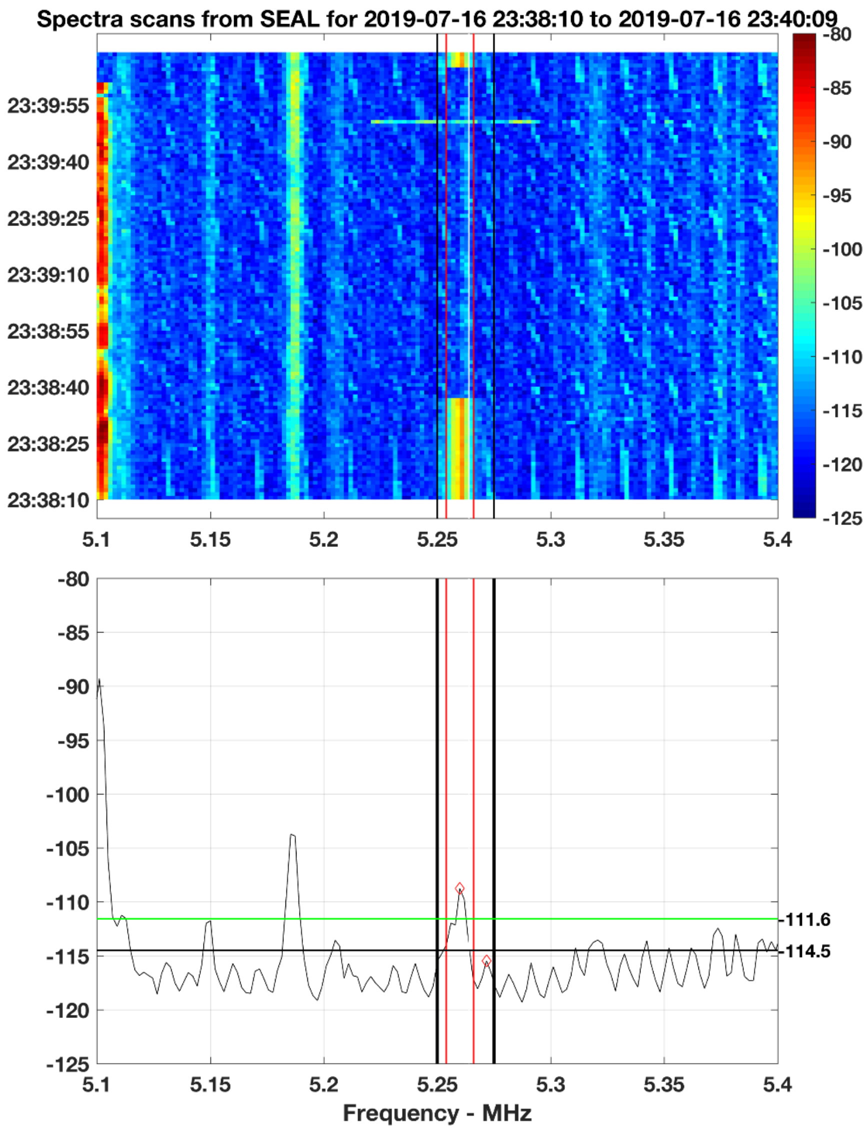

Figure 3. Frequency scan from SEAL HFR station collected between 20190716T233810Z–20190716T234009Z (upper panel) and time-averaged signal power (bottom panel). Red diamonds markers at 5.2599 MHz and 5.2717 MHz show the location of two potential interference sources. Vertical black lines indicate the 5.250–5.275 MHz ITU band in use to the HFR systems; red vertical lines show the band occupied by the RHED HFR station. The black horizontal line corresponds to the band-averaged signal level identify two different noise threshold. Units for signal level and frequency are dB and MHz, respectively.

As a second example, we consider the spectrum scan collected between 20190705T161835Z and 20190705T162034Z (Figure 4). This scan, collected again using the default values listed before (120 sweeps, 1 Hz sampling rate, 256 *fft* points) presents features similar to the case discussed previously, however it has also distinct features that were found to occur frequently in the region.

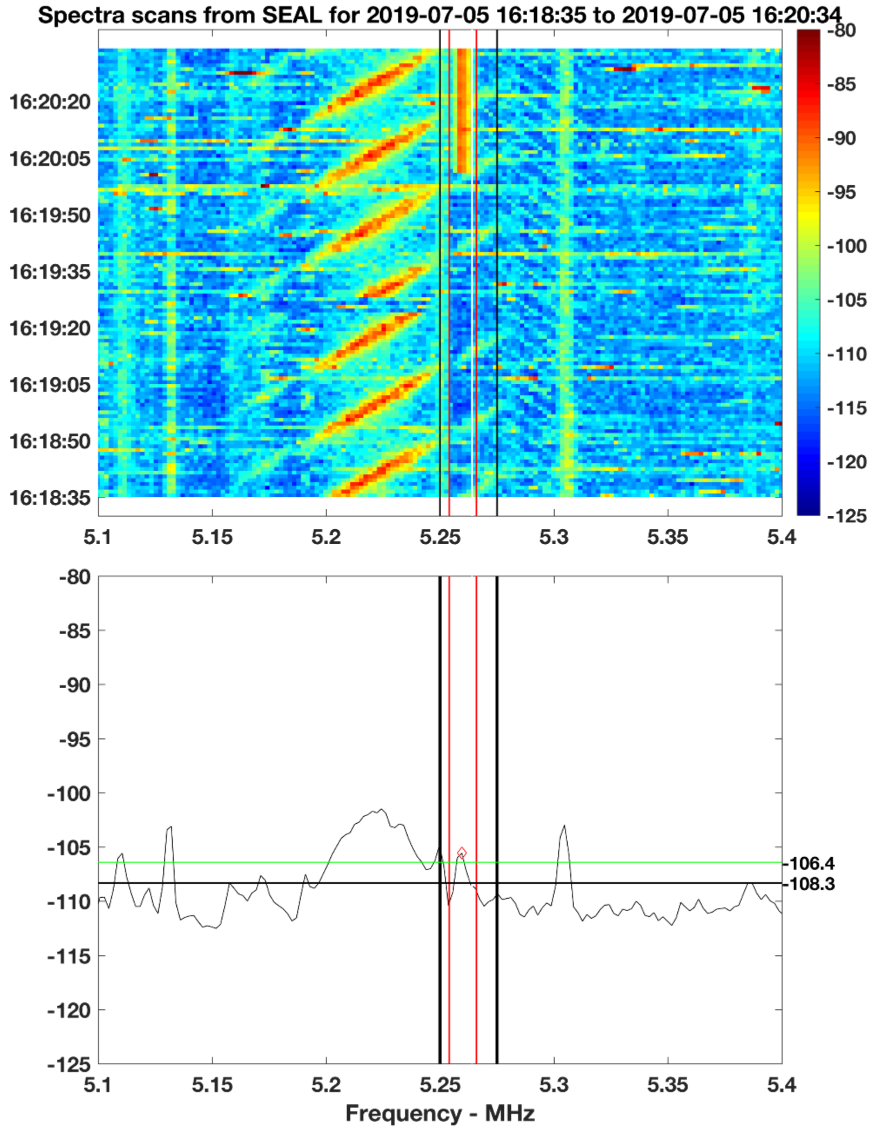

Figure 4. Frequency scan from SEAL HFR station collected between 20190705T161835Z–20190716T162034Z (upper panel) and corresponding time-averaged power (bottom panel). Vertical black lines indicate the 5.250–5.275 MHz ITU band in use to the HFR systems; red vertical lines show the band occupied by the RHED HFR station; green dotted lines show the allocated bandwidth and the center frequency for the new acquisition cycle.

Note that in general the average noise level in the entire spectrum is significantly higher than the previous example reported in Figure 4: time-frequency-averaged signal level $NF(f)_{band}$ and the detection threshold value have increased to, respectively: −108.3 dB and −106.4 dB. Interestingly enough, standard deviation σ_{PL} has on the opposite decreased to 1.9 dB, consistently with a persistently increased noise level within the band. The peak-finding algorithm tracks the peak associated with the RHED transmit signal, centered at 5.2596 MHz, starting at 20190705T162000Z (red marker in Figure 4), with a signal level of −105.5 dB, half-power peak width Δf_P = 3.2 kHz. Note also the intense upwards chirp centered at 5.225 MHz (origin unknown), which is entering the ITU frequency band.

Following the presence of the peak at 5.2596 MHz, the algorithm suggests an optimal transmit frequency of 5.2694 MHz (center value) with a reduced bandwidth of 9.1 KHz resulting in a transmit chirp in the frequency band 5.2648–5.2739 MHz. The optimized transmit bandwidth is 80.5% the bandwidth originally available at the site which results in a radial range resolution of 16.48 km.

A more complex case is presented in Figure 5, collected between 20190705T143835Z and 20190705T144034Z in which the chirp from the RHED station can again be noticed, along with two significant 50 kHz down-sweeping chirps centered at approximately 5.175 MHz and 5.225 MHz. The algorithm correctly identifies the peak associated with RHED station (signal level −102.8 dB) at 5.2576 MHz. This signal exceeds the detection threshold (−104 dB) and consequently the algorithm suggests the following parameters for the next data acquisition cycle: center transmit frequency 5.2694 MHz, optimal bandwidth 11.3 KHz, with upper-lower limits for the sweep between 5.2637–5.2750 MHz.

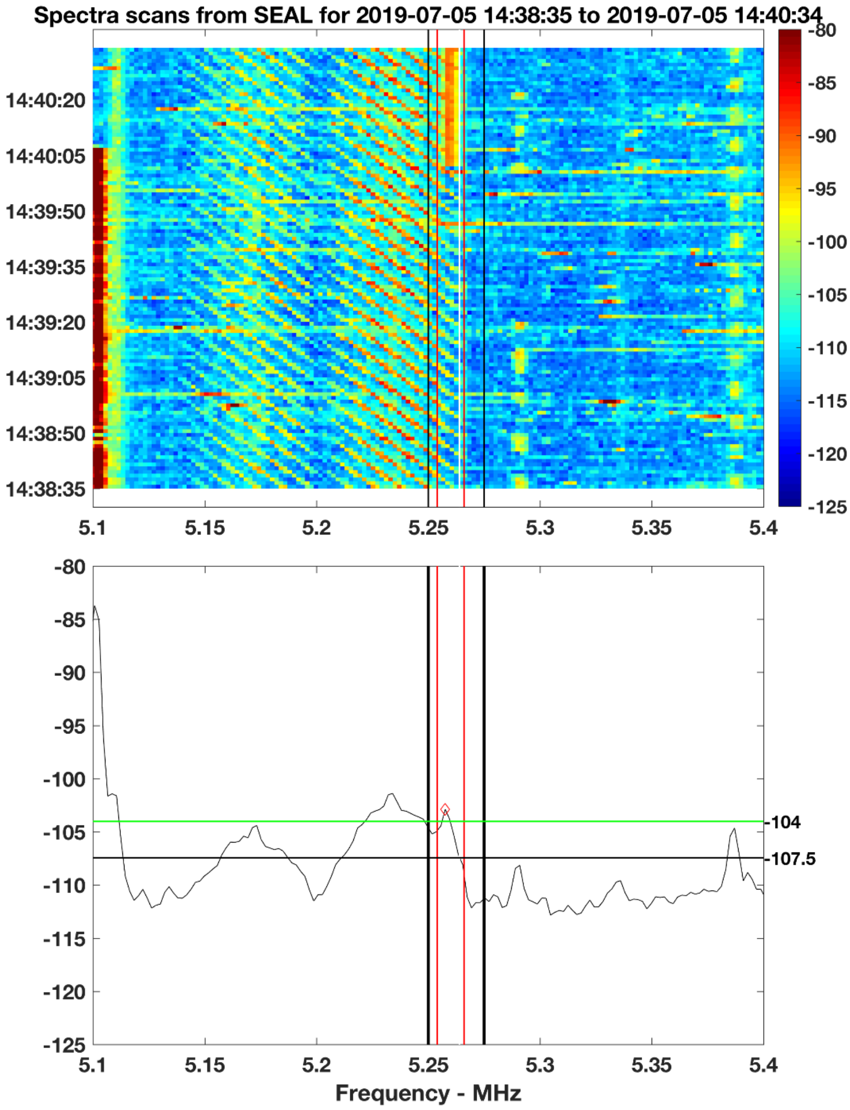

Figure 5. Frequency scan from SEAL HFR station collected between 20190705T143835Z–20190705T144034Z (upper panel) and corresponding time-averaged power (bottom panel). Vertical black lines indicate the 5.250–5.275 MHz ITU band in use to the HFR systems; red vertical lines show the band occupied by the RHED HFR station; green dotted lines show the allocated bandwidth and the center frequency for the new acquisition cycle.

Adjustments in the data acquisition parameters (centre frequency, bandwidth) are likely to impact on the data quality. Adjustments (i.e., reduction) in the transmit bandwidth (BW) after a peak is detected in the frequency scan would result in variations in the the radial range resolution (ΔR, km) as described in Equation (5):

$$\Delta R = c/(2^*BW), \tag{6}$$

where $c = 2.99 \times 10^8$ m/s the speed of light in a vacuum, BW the sweep width (Hz) of the transmit HFR chirp, and the factor 2 accounting for the two-way path between HFR and target. As an example, Figure 6 shows the decreased range resolution between two consecutive data acquisition cycles (20191026T000000Z–20191026T002000Z) after BW was reduced from 25 KHz to 12.5 KHz. Data were collected at the Seasonde site at Lancelin, WA, approximately 100 km North of Perth.

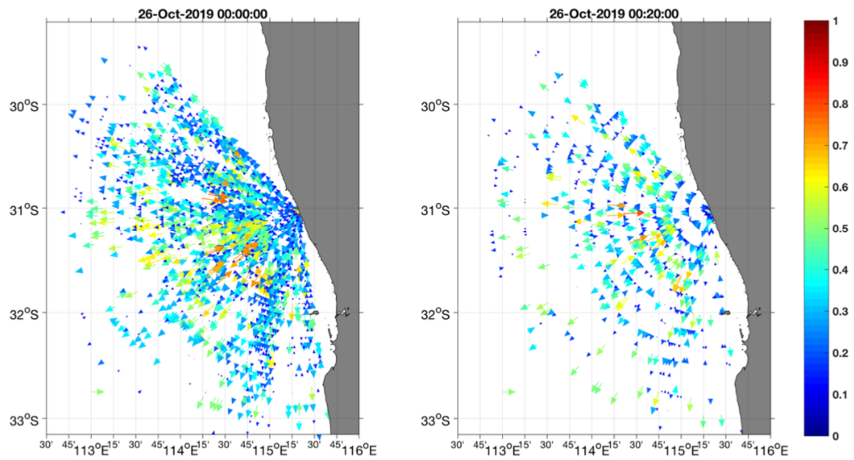

Figure 6. Example of the effects of bandwidth reduction between two consecutive radial maps at Lancelin SeaSonde station (Western Australia). To the left: radial map collected on 26 October 2019, 00:00 (UTC) with 25 kHz bandwidth, resulting in a radial range resolution of 6 km; to the right, radial velocity map collected on 26 October 2019, 00:20 (UTC) with 12.5 kHz bandwidth, resulting in a radial range resolution of 12 km. Operating frequency is 4.463 MHz. Unit for radial velocity is m/s.

The effects of the LBT on the operations of other system, for instance WERA HFRs deployed in Florida, have been investigated with great details in [14]. Authors suggest that changes in the local external noise levels will likely result in different bandwidths both spatially and temporally between paired sites in a HFR network. However, they also conclude that the application of the WERA LBT adaptive algorithm, along with a wide enough bandwidth to operate within, increased data coverage and improved the overall signal-to-noise ratio (SNR) conditions. In the example illustrated in Figure 6 relative to the SeaSonde system in Lancelin (WA), the 50% BW reduction corresponds to variations in the radial resolution from 6 km to 12 km within 20 min. SeaSonde systems typically require continuous transmission and averaging at a spectral level to increase the statistical significance of the Doppler spectra, decrease noise level, and improve the spectral inversion processes, and at a temporal and spatial level, to reduce errors in the final radial output. As such, it is likely that impacts of adjustments to the radar processing parameters, specifically bandwidth, are detrimental if repeated frequently. Depending on the operational settings and transmit band, a full measurement cycle is typically performed within 1 h to 3 h for the high-frequency (13 MHz, 25 MHz) and low-frequency (4 MHz, 5 MHz) systems, respectively. Additionally, low-frequency systems would be more affected than high-frequency counterparts by the limited bandwidth allocated by [5]: 150 KHz for the 25 MHz band, 100 KHz for the 13.5 MHz and 16.1 MHz band, 50 KHz for the 9.33 MHz band, and 50 KHz (25 KHz) for the 4 MHz (5 MHz) bands, respectively.

Other aspects that need to be accounted for are the losses in efficiency in both the transmitter and receiver antennas following changes in the transmit-receive bands. SeaSonde systems are particularly sensitive to the local environment and require calibrations of the so called antenna beam pattern in order to account for coupling with metal structures within the receive antenna near field. In principle, calibration should be repeated upon changes to the transmit frequency; however, this is unpractical, and it is commonly accepted within the HFR community that a calibration for a center frequency f_C is applicable within $\Delta f = \pm 100$–200 KHz (Brian Emery, personal communication). To some extent, this is an aspect in common with phased-array HFRs such as the WERAs in which the optimal spacing for the antenna elements in the receive array is strictly dependent on the wavelength of the transmitted signal. Changes in the center frequency f_C are likely to affect beam-forming capabilities. In both cases, more detailed investigations are needed in order to quantify effects on HFR accuracy. When it comes to the transmit antennas, changes in transmit frequency may possibly increase losses along the transmission line and as such decrease antenna radiation efficiency, cause distortions in the transmit signal, increase the fraction of power reflected at the radiator and trigger the power amplifier protection circuitry if available, or damage the amplifier. It is clear that a similar issue is platform-independent and would affect in similar ways both SeaSonde and WERA HFR systems.

Figure 7 shows a typical resonance curve for a standard low-frequency SeaSonde transmit antenna in terms of the voltage standing wave ratio (VSWR) spectrum. Data were collected in April 2019 during the most recent SeaSonde installation in Dongara-Port Denison, located approximately 400 km north of Perth. VSWR is commonly accepted as a measure of impedance matching of a load to the characteristic impedance of a transmission line and basically is a measure of antenna radiating efficiency with VSWR = 1 when 100% of the transmit power is radiated [16]. For this specific example, which refers to the 4.438–4.488 MHz ITU band, VWSR is in the range 2.4–1.9 resulting in 17%–9.6% of the transmit power being reflected along the transmission line. Typical transmit power barely exceed 10 W for the SeaSonde systems deployed in WA, and is below 3 W or less at the NSW deployments. Assuming the same VSWR values apply to both deployments, changes in transmit power are found in the range 8.3–9.04 W and 3.3–3.6 W respectively, and do not significantly affect overall system performances.

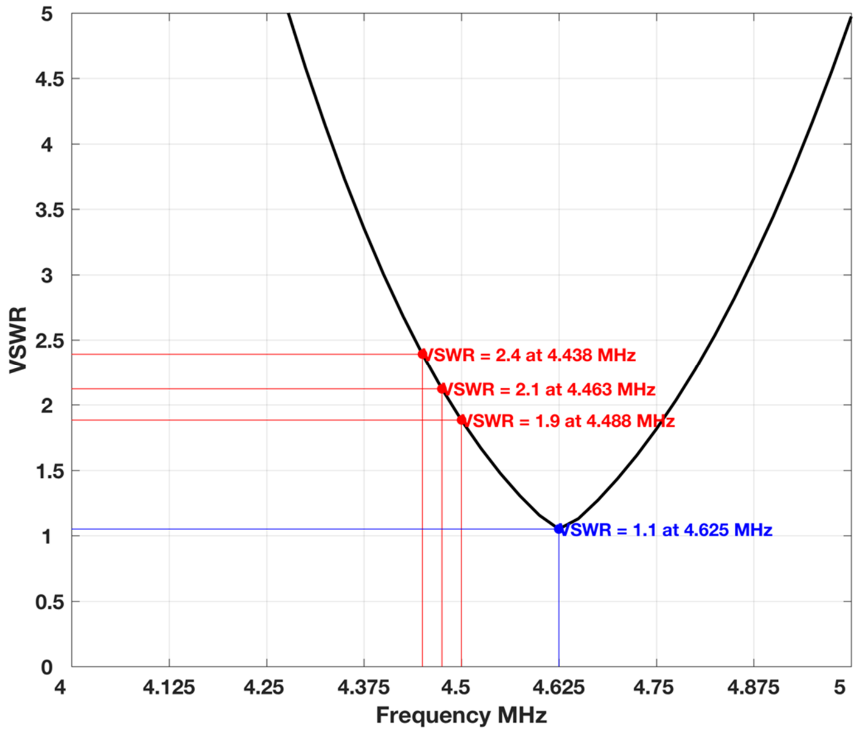

Figure 7. Voltage standing wave ratio (VSWR) data for the SeaSonde transmit antenna at Dongara—Port Denison HFR site, located approximately 400 km·N of Perth (WA). VSWR values for the 4.438 MHz, 4.463 MHz and 4.488 MHz frequency are reported in red on the VSWR curve. These frequencies correspond to the upper, center and lower frequencies for the ITU frequency band in use at the site. The minimum VSWR value is also reported in the plot, along with the corresponding frequency. Unit for frequency is MHz; VWSR is dimensionless.

One last aspect that needs to be accounted for, is the potential mutual cross-interference from a second SeaSonde system. This is the case illustrated across Figures 3–5 showing the chirp from the second station either at the beginning or the end of the frequency scan. The proprietary software is capable of handling in a very effective way several SeaSonde systems in the same frequency band through the proprietary GPS synchronization and band sharing capabilities [8]. The present peak identification algorithm appears on the opposite to interpret the chirp as a potential interference source. As such, an accurate timing is required across a HFR network, so to minimise or avoid false-alarm detection. This is a critical aspect since SeaSonde systems rely on commercial Macintosh systems in which the clocks can drift significantly.

4. Discussion

The operation of HFR systems in Australia is dependent upon the fulfillment of the ITU regulation, particularly for what concerns the band sharing capabilities, the interference mitigation measures and the reduction of the offband leakage. ITU Report M.2234 and Recommendation M.1874-1 [4,5] describe some of the possible mitigation measures, such as directional transmit antennas to reduce signal transmission over land or at unwanted directions, the use of pulse-shaping and the band sharing capabilities, and discuss of the possible implementation of the listen-before-talk and bandwidth adaptation mode and report possible significant impacts on data quality which is deemed unacceptable by the HFR operators. SeaSonde systems already implement the GPS syncronization capability, that allows for multiple sites to operate in the same band without mutual interference and allow for a more efficient use of the radio frequency spectrum. WERA systems typically operate with directional transmit arrays and have the capability to dynamically adapt their operating frequency and bandwidth in response to strong interference sources. Pulse shaping with longer ramping-deramping times, longer pulse width, and modified weighting windows have been satisfactorily deployed in the SeaSonde systems across Australia in order to reduce off-band leakage. Experimental directive antennas are used to limit the signal emission over land, and an interrupted transmit operation mode is also used to allow for radio silence periods between intermediate acquisition cycles. To further avoid interferences to primary users operating a 3 KHz channel at 5.264 MHz, center frequency and transmit width have been modified accordingly to 5.257 MHz and 11 KHz respectively, so to remain within the allocated ITU frequency band. The approximate 90 sec radio silence period between each acquisition cycles can be used to monitor the frequency band for either interferences or in case HFR transmission needs to be modified to account for primary users within the band.

Two main results are reported here. It is shown here that radio frequency scans can be acquired using the existing SeaSonde hardware, using the spectrum analyzer capabilities embedded in the proprietary software. No additional external hardware components are required. The resulting spectrum scans can be analyzed and the real-time acquisition parameters can be adapted in case of need, as shown in this work. However, an adaptation (i.e., reduction) of the transmit bandwidth would result in variable radial range resolution if performed too frequently, with consequent degradation of the quality of radial velocity data. It is as such suggested to perform an adaptation at the end of a full acquisition cycle. Spectral scans can still be collected at regular intervals for diagnostic purposes. It is also important that users and operators of the HFR systems are actively involved across all stages of HFR operations and that an informed decision is taken also in light of a fair-use policy for band sharing.

It is confirmed that operating HFR systems within the ITU frequency bands with a secondary-type license, that is on the basis of no interference to, and with no rights of protection from primary users, is complicated and may require extensive modifications to the hardware and acquisition parameters in order to comply with the national and international regulations. It is also confirmed that operating HFR systems within the ITU bands is prone to extensive interferences of unknown origin, especially in the low frequency portion of the radio frequency spectrum, as already reported previously [17].

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