DDC Pool: Efficient down-conversion of signals for RFI monitoring

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Motivation

The RFI monitor system for the Dominion Radio Astrophysical Observatory [1] was designed to combine a standard integrating spectrometer commonly used in radio astronomy with machine learning (ML) and software-defined radio (SDR) features.

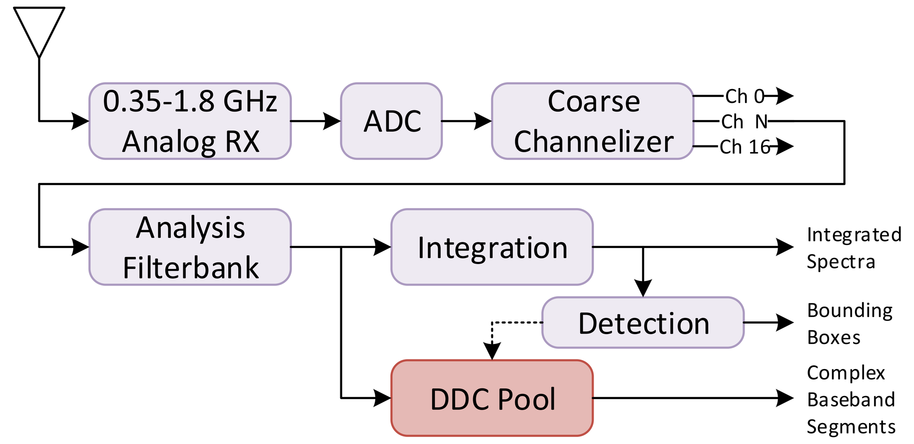


Figure 1. Simplified System Block Diagram

Signals are localized in integrated spectra using the algorithm presented in [2]. To do further analysis and classification (following the ML approach of [3]) we must extract the complex baseband timeseries of a single signal from the wideband timeseries containing many signals.

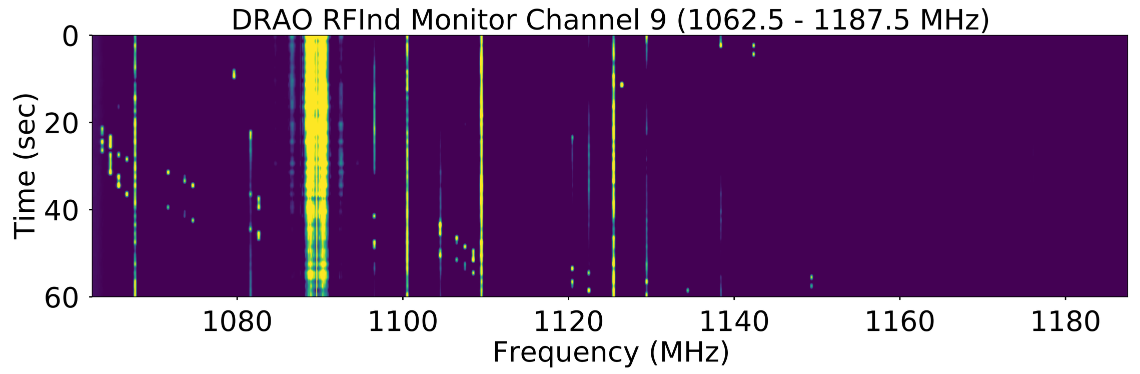


Figure 2. Typical integrated power spectrum (waterfall) from RFInd Monitor

The tool for extracting a single signal from a wideband timeseries is the digital downconverter (DDC). There are several possible DDC architectures. However, to efficiently extract multiple signals in parallel we propose to implement a collection of dynamically-assignable synthesis filterbanks following the ideas in [4, 5]. Implementing this in real time under the constraint of a fixed computing capacity requires a 'pool' of resources. Priority for pool resources can be assigned based on historical occupancy, where signals in low-occupancy channels are more likely to be interesting.

Analysis Filterbank & Detector

An analysis filterbanks output is integrated to produce power spectra such as is shown in fig. 2. Signal detections are done on this integrated power spectra yielding predicted bounding boxes in time/frequency space (fig. 3).

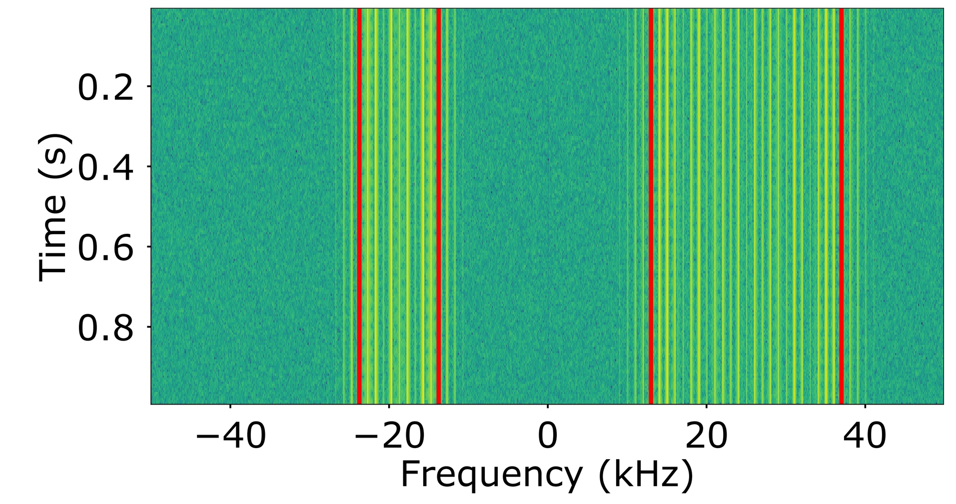


Figure 3. Detected bounding boxes

RF signals can span multiple frequency channels of the analysis filterbank, as shown in fig. 4. The channels intersecting a bounding box are fed to a synthesis filterbank which reconstructs the time series of the signal. As per [4] the analysis filterbank is oversampled by a factor of 2 to enable perfect reconstruction.

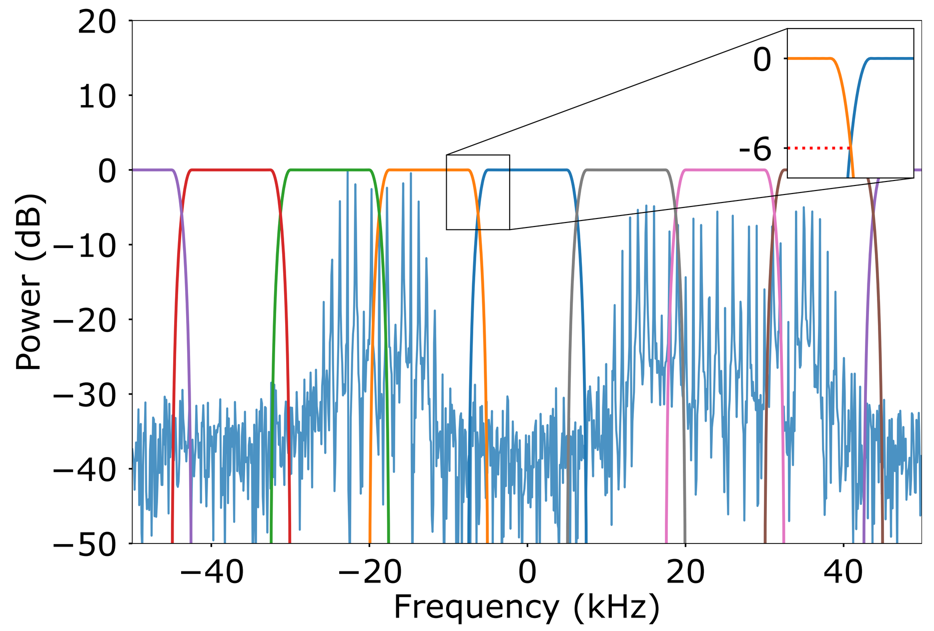
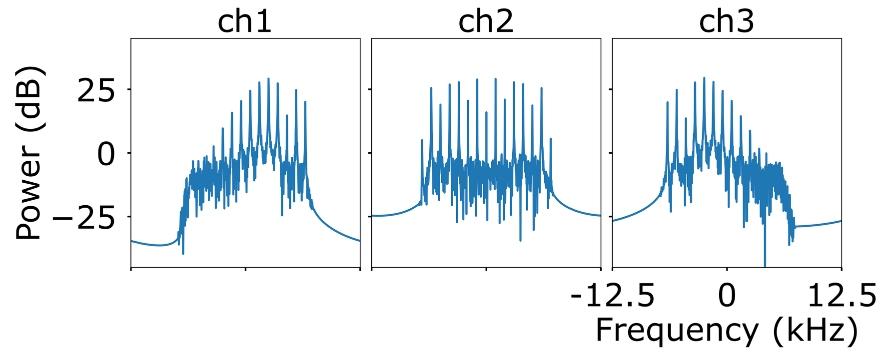


Figure 4. Input spectra with the oversampled filter overlaid showing the channels and −6 dB cross-over point

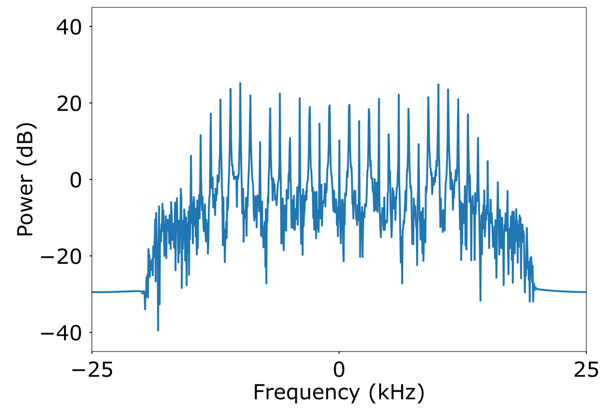
As shown in fig. 1, the DDC pool of synthesis filterbanks is fed with the bounding boxes detected in the integrated spectra of fig. 3 along with the non-integrated channels of fig. 4. Figures 3 and 4 each show the same spectra containing two FM signals, each fragmented into multiple channels.

Synthesis Filterbank

Figure 4 shows two signals, spanning 2 or 3 out of 8 channels. In figs. 5a and 6a we show the spectrum of each analysis channel containing signal fragments. We then show the resynthesized spectra in figs. 5b and 6b. In the 3-channel case we have added a fourth channel of zeros while in the 2-channel case we have added 2 channels of zeros ensuring no signal fragments are wrapped near the edges of the synthesis filter banks FFT.

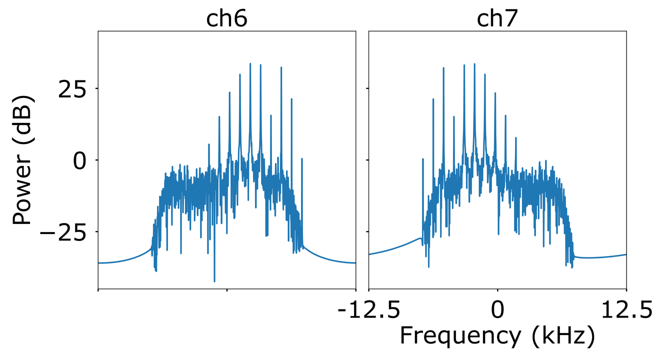


(a) Channels to be synthesized

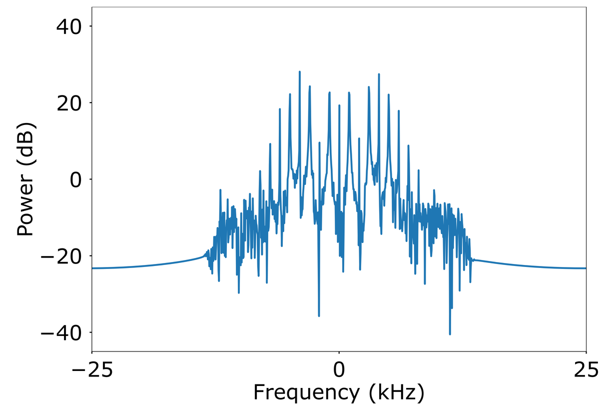


(b) Synthesized result

Figure 5. Input and output of a 2-channel synthesis filter bank



(a) Channels to be synthesized



(b) Synthesized result

Figure 6. Input and output of a 3-channel synthesis filter bank

Application

We apply the synthesis filterbank to extract short segments of complex baseband signals for further classification using ML methods. We have found segments of 128-1024 samples are suitable for this task, although longer segments could be synthesized.

In the fig. 7, we show three signals detected in time-frequency space from the SPAWC 2021 Wideband Signal Recognition competition dataset [6]. Below that is the resynthesized spectrum and the corresponding complex baseband waveform. Note that the resynthesized signal has been centered with respect to the synthesis bandwidth. The corrects for the residual frequency offset between the analysis filterbank channels center frequencies and the detection box center frequency.

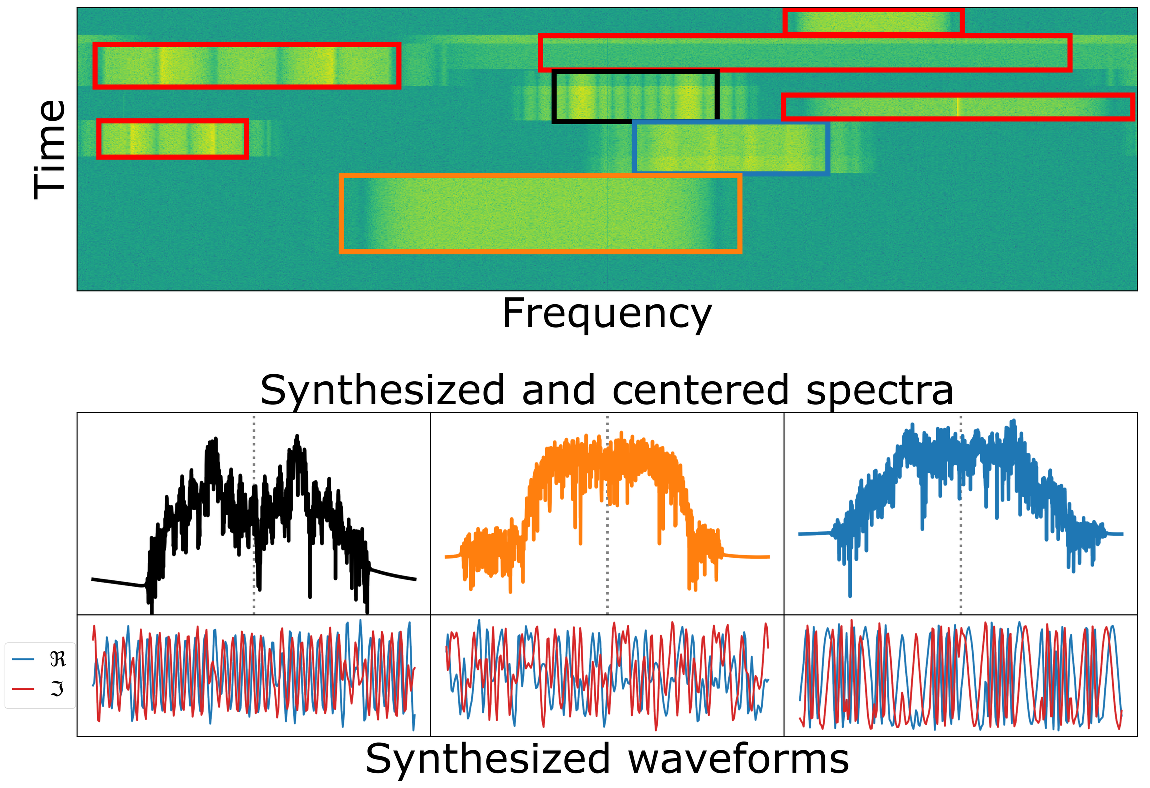


Figure 7. Waterfall plot (top) showing detection boxes with some of the signals synthesized (bottom)

Table 1 gives information about each of the signals. The synthesized waveforms clearly correspond with the expected modulation types.

	Black	Orange	Blue
No. of synthesized channels	4	8	5
No. of padding channels	2	2	1
Modulation type	FSK2	PSK4	FSK4

Table 1. Synthesized signal information

Conclusions & Next Steps

We have prototyped the DDC Pool concept in Python and used it to extract complex baseband waveforms from various wideband timeseries. The next steps are to:

- develop a GPU version of this and integrate with the existing GPU-based analysis channelizer,
- investigate fractional oversampling ratios,
- complete a rigorous performance analysis.

References

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