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RFI Monitor System Design for the Dominion Radio Astrophysical Observatory

Stephen Harrison*(1), Aneet Lakhani(2), Jean-Pierre Lavigne(3), Nicholas Bruce(4), Timothy Robishaw(1), Robert Messing(1),
Charl Baard(1), Michael A. Smith(1), Benoit Robert(1), David Del Rizzo(1)
(1) Dominion Radio Astrophysical Observatory, Penticton, BC, Canada
(2) University of British Columbia, Vancouver, BC, Canada
(3) University of British Columbia – Okanagan Campus, Kelowna, BC, Canada
(4) University of Victoria, Victoria, BC, Canada

Abstract

In this paper we present the system design for the radio frequency interference monitor at the Dominion Radio Astrophysical Observatory (DRAO). Although the design is focused on requirements generated from the needs of local telescopes and personnel, we have made efforts to ensure that the design is adaptable to the needs of other radio observatories. We describe the design as it relates to the primary use case of calibrated full-bandwidth, full-sensitivity spectrum monitoring and scene analysis from 350 MHz to 1800 MHz at the DRAO site. We also present measured results that outline the progress made on system implementation during 2020.

1 Introduction

In order to operate Canada's Dominion Radio Astrophysical Observatory (DRAO) effectively, we must monitor the primary frequency band of all currently-operating telescopes on the site for local sources of radio frequency interference (RFI). The main focus of this monitoring effort is keeping the site RF-quiet to the extent possible for current science instruments. We believe that this monitoring effort will also help to position DRAO as an attractive site for future Canadian radio science endeavours.

Different groups of users stand to benefit from the RFI monitor effort. Firstly, the monitor serves the science community by confirming interference events in observation data and by enabling studies of the local RF environment to establish the feasibility of proposed experiments. Secondly, the monitor serves our local RFI hunters in the day-to-day effort of preserving the quality of the RF environment at the observatory. Instrument builders will be able to use the calibrated power measurements produced by the monitor to design for the typical power levels observed at the site. Spectrum managers can use the data to ensure that the right message is sent to national and international regulators. Finally, the monitor is intended as an open platform for researching advanced RFI detection and mitigation algorithms.

One obstacle to the success of previous RFI monitoring projects at DRAO has been the volume of data produced. These large volumes of data have been costly in terms of storage while producing very limited insight about the local RF environment. Our approach to data collection and analysis was previously presented in [1], which addresses this issue by representing a large number of events in a compact form that can readily be mined for insight about the environment. In this paper we present the design of the DRAO RFI monitor and a snapshot of the progress made on the system implementation during 2020.

2 System Requirements

The primary use case for the DRAO RFI monitor is to provide continuous coverage from 250 MHz up to 2 GHz, with defined performance targets from 350 MHz to 1800 MHz. This frequency range covers most of the operating instruments on site, as shown in Figure 1. This includes the Canadian Hydrogen Intensity Mapping Experiment (CHIME: 400–800 MHz), the John A. Galt 26 m telescope (JAG: 400–800 MHz, 900–1800 MHz), the DRAO Synthesis Telescope (ST: 406–410 MHz, 1402–1438 MHz), and the Dish Verification Antenna (DVA: 350–1800 MHz). Although a more costly solution than frequency-scanning, we assert that continuous monitoring is critical for characterizing the local RF environment at the desired level of detail, consistency, and sensitivity.

A secondary use case, envisioned as a follow-on project, is to provide a dual-input intermediate frequency (IF) system with 1 GHz of sampled bandwidth per input. This use case is driven by the proposed facilities shown in Figure 1 while acknowledging that continuous coverage up to the maximum proposed operating frequency of 50 GHz is cost prohibitive. One IF of this secondary system will continuously monitor 2–3 GHz, capturing the range of the 10.7 cm Solar Flux Monitor (SFM: 2.75–2.85 GHz) and the 2.4 GHz unlicensed band. Although no current or planned telescope observes at 2.4 GHz, we consider this range an important proxy for the number of consumer devices operating on site. The second input may be used to survey higher frequencies on an as-needed basis, and may be parked near the 5.7 GHz unlicensed band when not in use.

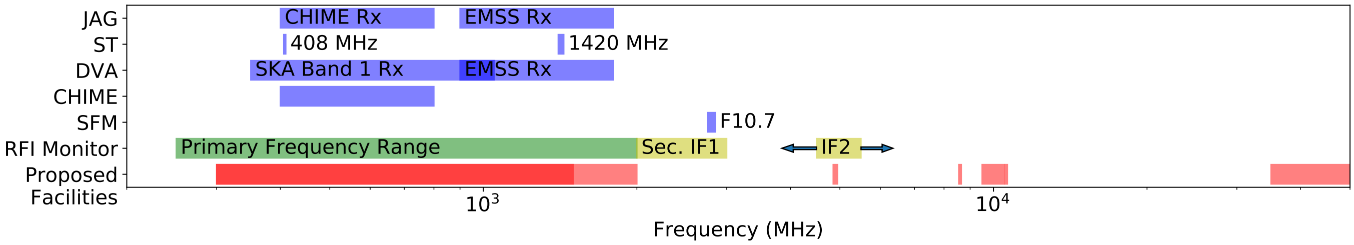

Figure 1. Radio frequency interference (RFI) monitor frequency ranges in the context of current and proposed facilities at the Dominion Radio Astrophysical Observatory (DRAO). The primary frequency range covers the majority of current and proposed instruments. A follow-on project is envisioned where a copy of the system is operated in dual-IF mode with a different analog receiver. IF1 would cover the Solar Flux Monitor (SFM) at 2.8 GHz while IF2 would provide a tuneable frequency slice for exploring higher frequencies.

The monitor must be capable of autonomously collecting calibrated RF measurements and producing an up-to-date live database of RFI detections. Human resources must not be required to collect or process the data, and there is no operational concept of observation planning or measurement sets. All users interact with the monitor through the same live database interface, although the intent of their investigations may be very different. The monitor must at minimum compute a time series of integrated power spectra in order to derive conventional metrics such as spectral occupancy [2].

The target sensitivity for detecting low-level interference by performing long integrations is

$$\mathrm{PSD} = -17\log_{10}(f_{\mathrm{MHz}}) - N\ \mathrm{dBm/Hz}, \qquad (1)$$

where f_{MHz} is the center frequency in MHz. $N = 175$ for fractional bandwidths of 1% and $N = 160$ when considering fractional bandwidths of 0.001%. These targets also set the minimum frequency resolution of the system to 0.001% of the lowest calibrated frequency ($\frac{0.001}{100}350\,\mathrm{MHz} = 3.5\,\mathrm{kHz}$).

These targets are derived from the Square Kilometer Array (SKA) EMI/EMC standards [3] with an offset of 17 dB. This offset was chosen such that low-level isotropic emitters within a 10 m radius around the monitor antenna, on the roof of the main building (an area where we expect low-level emitters), would reach the SKA thresholds at the JAG telescope 70 m away.

However, to ensure that the monitor is more than a poor substitute for a radio telescope it must simultaneously operate as a software-defined radio (SDR). We see this as the path to advanced site characterization by enabling techniques that operate on complex baseband waveforms or amplitude envelopes such as automatic modulation classification and RF transmitter fingerprinting. Rather than seeing the system simply as a spectrum monitor, we view the system as a platform for radio frequency scene analysis.

Finally, standard connectivity is critical for an open research platform. The various parts of the system must interconnect using standard connectors and protocols. To this end, we have specified VITA 49.0 over UDP/IP as the radio transport protocol for time domain streams [4]. Data transport is over 10 Gbit Ethernet using SFP and QSFP connectors. This allows the system to interface with a variety of commercial off-the-shelf (COTS) hardware.

3 System Design

In this section we describe the system design, referencing the functional flow block diagram in Figure 2. The system consists of the following elements: the antenna (ANT), primary analog receiver (ARX1), digital signal processing (DSP), observing software (OBSW), instrument structure (ISTR), and instrument software (INSW). Users interact with the system through software applications which query a detection database within the observing software (OBSW) functional block. Multiple users may attach live displays over the network to observe the RF spectrum in real time. The system operator may connect to assess the overall health of the system and troubleshoot any issues. The following subsections outline the progress made to date on implementing these elements.

3.1 Antenna and Structure

Although DRAO's location was chosen for low levels of RFI in 1957, the RF environment has since evolved and there is now significant contribution of RFI from nearby human activities. In addition to our staff who work directly adjacent to the telescopes, there are also contractors, couriers, and visitors regularly bringing cellular and other RFI-generating devices on site. The sensitivity of the analog receiver chain must not only meet the requirements for low-level interference detection during quiet periods, but must also be capable of operating without saturation during periods of high-level local RFI due to human activity on site. This has driven a requirement for a minimum path loss from any publicly-accessible area of the site which sets a maximum received power from cellular devices, the highest-powered interference typically observed on site. We have chosen to use the flashing of the main baidling as a diffracting edge [5] with the mounting height set to meet the path

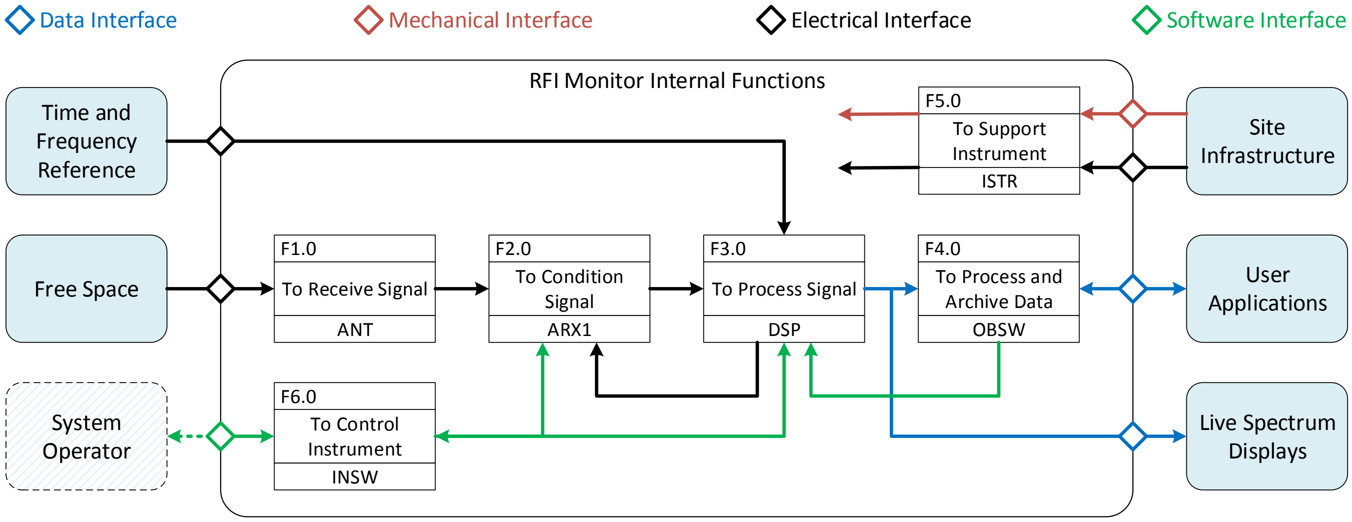

Figure 2. RFI monitor functional flow block diagram. The six functional blocks are the antenna (ANT), primary analog receiver (ARX1), digital signal processing (DSP), observing software (OBSW), instrument structure (ISTR), and instrument software (INSW).

loss requirement while minimizing the shadowing effect around the building.

The system requirements specify a wideband vertically-polarized omnidirectional antenna to provide 360° coverage of the terrestrial RF environment to ensure that all local interference events are captured. To meet this requirement we have selected the Alaris A0190 passive compact monitoring antenna, designed for operation from 20 MHz to 6 GHz.

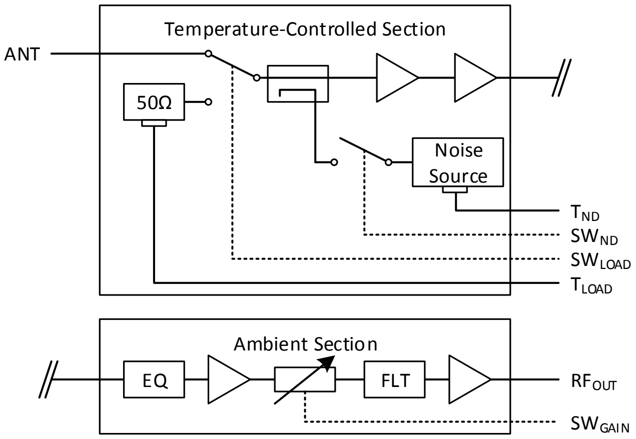

Figure 3. Primary analog receiver (ARX1) simplified block diagram. The temperature-controlled section is deployed outdoors on the antenna mast, and contains the calibration hardware. The ambient section is deployed indoors and contains an equalizer, adjustable gain, and anti-aliasing filter. The sections are connected by 75 m of coaxial cable.

3.2 Analog Receiver

A simplified block diagram of the analog receiver is shown in Figure 3, where the general arrangement of components is similar to other radiometry receivers. Our receiver consists of a temperature-controlled section, which contains a matched load and a noise source for calibration. Physical temperatures of the load and noise source are monitored, and switching controls are provided. An ambient-temperature section is co-located with the Digital Signal Processing (DSP) subsystem to equalize the line loss, and boost the signal level into the ADC, and provide an anti-aliasing filter.

3.3 Digital Signal Processing

The Digital Signal Processing (DSP) subsystem has features typical of a single-dish back end and is largely reused from design work done for the JAG telescope. The first stage of digital signal processing is a coarse oversampled polyphase filterbank ($O = 16/15$) which produces 16 single-polarization channels from a single source or eight coherent channels from two sources. The sample rate of each coarse channel is 133 MHz, with a usable bandwidth of 125 MHz. The filterbank is implemented on the ICE platform [6] and makes use of the available board management and control software. The ICE platform provides support for interconnection with high-performance computing (HPC) resources via multiple 10 Gbit Ethernet links.

4 Conclusions and Future Work

In this paper we have presented the motivation for the RFI monitor system at DRAO in the context of current and proposed instruments operating on site. We have also presented an overview of the system requirements and design, which leverages significant reuse from other projects. The key features of this system are continuous frequency coverage, autonomous operation, SDR-like capabilities, live

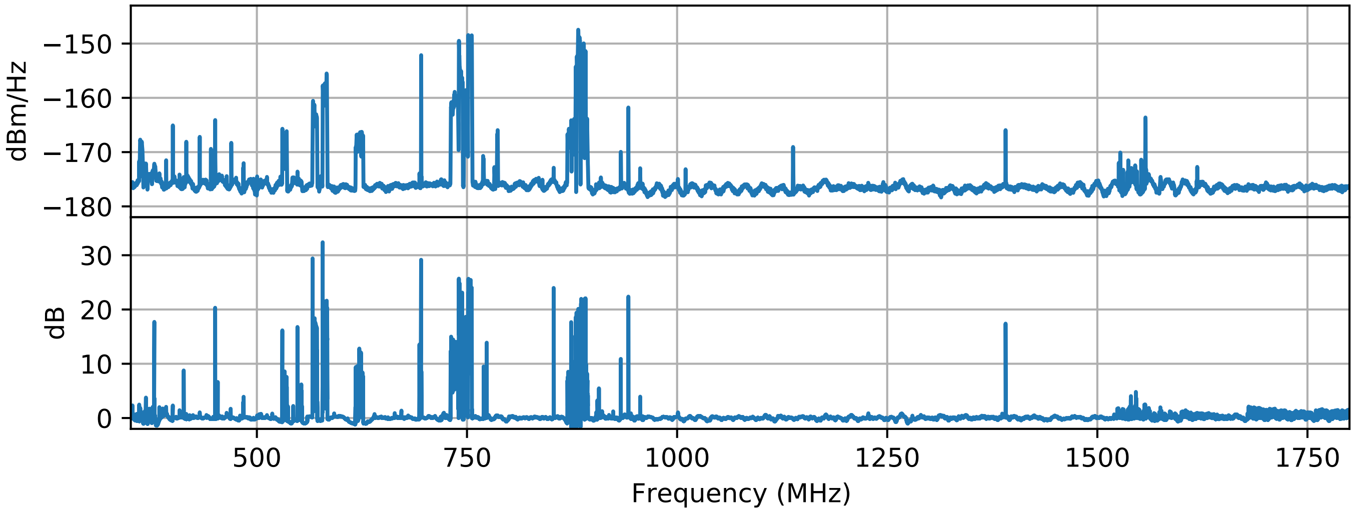

Figure 4. A qualitative comparison of spectrum monitoring at DRAO. Top: Full-bandwidth calibrated results observed at the output of the oversampled polyphase filterbank (January 28, 2021). Bottom: Uncalibrated results observed with an Ettus USRP X310 SDR, stitched together from 80 MHz slices (December 24, 2020).

spectrum displays, and support for the data analysis approach previously presented in [1].

With respect to Figure 2, significant progress has been made on the antenna (ANT), primary analog receiver (ARX1), digital signal processing (DSP), and instrument structure (ISTR) elements. From these elements we have produced the preliminary calibrated spectrum shown in Figure 4 by capturing the output of the oversampled polyphase filterbank on the HPC. For a qualitative comparison, we also show an uncalibrated spectrum collected using an Ettus USRP X310 SDR, scanned in 80 MHz slices. We see several similarities between the spectra, in particular the cellular signals around 750 MHz and 850 MHz as well as broadcast television in the 500–600 MHz range. Although the average noise power spectral density matches the expectation, the apparent 2 dB peak-to-peak ripple leaves some room for improvement of the analog receiver and the calibration process.

To enable SDR-like processing, we have designed a GPU-based Digital Down Converter Pool (DDCP) software using concepts from [7]. DDCs in the pool are subscribed to the center frequencies and bandwidths associated with RFI detections produced by the observing software. An excerpt of the complex baseband time series associated with the detection can be stored for the purpose of applying modulation recognition techniques such as machine learning [8] or cyclostationary features.

Although significant progress has been made, outstanding effort includes implementing the remaining functions within the DSP element, adapting the INSW element from the JAG telescope, and implementing the OBSW element to automate the observation process and provide database access. Implementation of the RFI monitor system is expected to continue throughout 2021, with early results available at the end of summer.

References

[1] Stephen Harrison, Rory Coles, Timothy Robishaw, and David Del Rizzo, "RFI novelty detection using machine learning techniques," in *RFI2019: Coexisting with Radio Frequency Interference*, 2019.

[2] ITU-R, "Spectrum occupancy measurements and evaluation," SM.2256-1, 2016.

[3] P Dewdney, G-H Tan, H Smith, T Tzioumis, and J Jonas, "SKA EMI/EMC standards, related procedures and guidelines," SKA-TEL-SKO-0000202 Rev. 3, March 2017.

[4] ANSI/VITA, "VITA radio transport (VRT)," VITA 49.0, 2015.

[5] ITU-R, "Propagation by diffraction," P.526-15, 2019.

[6] K Bandura, AN Bender, JF Cliche, T de Haan, MA Dobbs, AJ Gilbert, S Griffin, G Hsyu, D Ittah, J Mena Parra, et al., "ICE: a scalable, low-cost FPGA-based telescope signal processing and networking system," *Journal of Astronomical Instrumentation*, vol. 5, no. 04, pp. 1641005, 2016.

[7] Fred Harris, Elettra Venosa, Xiaofei Chen, and Bhaskar D. Rao, "Polyphase analysis filter bank down-converts unequal channel bandwidths with arbitrary center frequencies," *Analog Integrated Circuits and Signal Processing*, vol. 71, no. 3, pp. 481–494, 2012.

[8] Timothy James O'Shea, Tamoghna Roy, and T Charles Clancy, "Over-the-air deep learning based radio signal classification," *IEEE Journal of Selected Topics in Signal Processing*, vol. 12, no. 1, pp. 168–179, 2018.