3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Design of a mobile RFI monitoring station for DSA-2000 candidate sites surveys

V. Prayag(1), G. Hellbourg(2), and M. Virgin(1)
(1) Owens Valley Radio Observatory, California Institute of Technology, Big Pine, USA
(2) California Institute of Technology, Pasadena, USA

Abstract

The DSA-2000 radio telescope is currently being designed to become the fastest and most sensitive astronomical survey instrument. An important factor in this design is the future Radio Frequency Interference (RFI) environment of the telescope. A careful site selection and RFI risks assessment are important to ensure that the specifications of the telescope are met. To this end, a mobile RFI survey station has been developed to provide an accurate picture of the RFI environment of a candidate telescope site. This paper presents this monitoring station and preliminary results captured at the Owens Valley Radio Observatory.

1 Introduction

The DSA-2000 [1] will be an innovative radio telescope featuring a streamlined data processing pipeline - including array data correlation, calibration, radio frequency interference (RFI) flagging, and gridding - to achieve a real-time production of fully-sampled radio images every 15 minutes.

The monitoring of the local spectrum occupancy of the future observatory is crucial to the site selection process, but serves also many other purposes : it helps to assess the risk that the telescope is subjected to RFI corruption and hence infers its sensitivity limits, supports the hardware and software design of the instrument (e.g. need for additional analog filtering or an RFI-specific data flagger), and allows the identification and the reporting of potential illegal spectral activities.

To this end, we present here the mobile RFI monitoring station developed at the Owens Valley Radio Observatory (OVRO) and dedicated to evaluating the RFI environment of the candidate sites to host the DSA-2000 telescope. This paper describes the equipment and procedures implemented to conduct this monitoring.

Section 2 details the elements of the monitoring system. Section 3 describes the on-site calibration procedure operated prior to the survey. Section 4 presents preliminary results of a 24-hour survey conducted at the OVRO.

(a) Outside view of the RFI monitoring station.

(b) Inside view of the RFI monitoring station.

Figure 1

2 RFI monitoring system

An RFI monitoring system was built to survey the 500 MHz - 3.2 GHz frequency range at pre-selected sites that could host the DSA-2000 radio telescope. These sites are selected for their remoteness and radio quietness. Given that these sites might not be easily accessible, the system has to fulfill some critical requirements such as being fully automated and reliable and stable over a long period of time. Table 1 lists the user requirements that was used to design the system.

Table 1. Requirements for the RFI monitoring system

User Requirement	Hardware	Function
RFI measurements	Spectrum analyzers + antennas	Data acquisition
Monitoring of remote sites	Trailer	Mobility
Continuous data acquisition	Solar Panels + Deep cycle batteries + Inverter	Power Supply
Direction of arrival	Rotator + rotator controller	Rotation of antennas
Automated system	Laptop + Rotator Controller Interface	Control spectrum analyzers and rotator and runs independently

The list of equipment chosen to meet these specifications is given in Table 2. The monitor was put together and deployed at OVRO to test its functionality and overall performance. Preliminary data were also captured and presented in Section 4.

Table 2. List of test equipment

Qty	Description	Make and Model	Power
3	Spectrum analyzer	Siglent, SSA3032x	45W
1	Omni-directional antenna	ICOM, AH-8000 discone	
2	Directional antenna	Aaronia, Hyperlog4040	
3	50 ft coaxial cables	-	
1	15ft coaxial cable	-	
1	Laptop	Dell Inspiron	65W
1	Rotator	Yaesu, G-2800DXA	175W
1	Rotator Controllor	Yaesu, G-2800DXA	
1	Controller Interface	Yaesu, GS-232	
1	130ft 6-conductor control cable	Yaesu	
2	Solar Panels	Sharp, ND-224UCJ	
4	110Ah Deep Cycle Batteries	-	
1	Charge Controller	TriStar, TS-M-2	
1	AC-DC Inverter	Go Power	
2	SMA to N type adaptor	-	
1	N type to N type adaptor	-	
1	Fiberglass Mast	DX Engineering, DXE-TFK15	
1	Trailer	American Cargo Group, PP610S2	

The following sections are a breakdown of the individual subsystems that were used to assemble the RFI monitoring system.

2.1 Analog Receiver

Three antennas are used to capture the analog spectra. An omnidirectional antenna is used for the purpose of capturing any transient signal. Two similar directional antennas with a beamwidth of $\sim 30°$ are used to identify the direction-of-arrival (DOA) of specific signals. The specifications on DOA identification are given in Section 2.4. The directional antennas are aligned in the horizontal and vertical directions to capture the polarization characteristics of nearby transmitters. All three antennas are placed on a 14' fibreglass mast which is all held together by the rotator and antenna bearing mounted on the roof of the trailer. The height of the omnidirectional antenna is $\sim$22' from the ground while the directional antennas are at 14'11" and 13'7" from the ground, respectively. Table 3 gives the specifics of the antennas used, and Figure 1a depicts this setup.

Table 3. Antenna Characteristics

	Discone Antenna	Hyperlog Antenna
Type of antenna	Omnidirectional	Directional
Design	Discone	Log Periodical
Gain	$\sim$3dBi	$\sim$4.5dBi
Frequency range	100 MHz-3300 MHz	400 MHz-4000 MHz
Nominal impedance	50Ω	50Ω
RF connection	N-type	SMA

2.2 Signal Transfer

Three coaxial cables with N type connectors are used for transferring the signals to the digital receiver. The cables for the directional antennas are of same length, while the omnidirectional antenna is 15' longer. This extra length of cable is provided by the antenna constructor. All losses were however recorded and used later to calibrate the system.

2.3 Digital Receiver

The data acquisition is made with three similar Siglent SSA3032x spectrum analyzers. All analyzers have identical settings, and are controlled using a laptop via a USB connection. The band of operation goes from approximately 500 MHz to 3.2 GHz. The frequency resolution required by the telescope specifications is 100 kHz. A script controls a continuous loop over 751 $\times$ 100 kHz = 75.1 MHz frequency windows to overcome the 751 spectral bins limitation of the Siglent analyzers. The survey start frequency is set to 496.4 MHz MHz, and 36 $\times$ 75.1 MHz windows are required to reach the stop frequency at 3.2 GHz. This means that the collected spectra are made of 36 $\times$ 751 = 27036 points, with a true 100 kHz resolution. Each of these spectra are produced in about 6 seconds. The data capture system is depicted in Figure 1b.

Table 4. Spectrum analyzer settings

Parameter	Value
Start-Stop Frequency	$(n \times 75.1$ to $(n+1) \times 75.1) + 496.4$, $n = 0..35$
RBW	100 kHz
VBW	100 kHz
Sweep Points	751
Measurement Mode	OFF
Preamplifier	ON
RF Attenuation	0 dB
Detector Type	Pos Peak
Trace Type	Clear Write
Sweep Time	Continue
Amplitude Units	dBm
Reference Amplitude	-40 dBm

2.4 Direction Finding

It is important to identify the directions-of-arrival of the signals in order to identify them. To this end, a rotator controlled with a computer interface is used. The rotator rotates every 15 minutes by a 30° angle. After reaching 330°, the rotator returns to its original position. The rotator takes 3 hours to complete a full rotation surveying 12 cardinal directions. Both the rotation and the data acquisition are time stamped, allowing the matching of the antenna position with the data. The selected rotator unit is rated as heavy duty, making it suitable for rough environments with potentially high winds.

2.5 Power Supply

Power is supplied to the electronics using four 12V, 110Ah batteries and a 1000W DC to AC inverter. A solar charge controller is used to charge the battery pack and is able to automatically regulate the amount of charge going into the batteries. The power is provided by two 30V, 7.66A solar panels. The power budget of the system was overestimated, allowing the batteries and inverter to work optimally. The full monitoring station is therefore self-sustained even during the night.

3 Calibration procedure

The calibration of the monitoring system is crucial in order to produce reliable measurements and to not confuse the electronic footprints of the various system elements with true RFI. Calibration needs to be conducted at each site, accounting for the potential replacement of system elements, but also to adapt to the new environment. After a first look at the maximum spectrum over the full frequency span of the survey, the spectrum analyzers parameters (pre-amplifier, attenuation...) are set and will not be changed until the end of the survey.

The calibration for each spectrum analyzer is according to the following procedure:

1. 5 minutes of data capture with a 50 Ω load directly connected to the spectrum analyzer RF input.
2. 5 minutes of data capture with a dedicated coaxial antenna cable terminated with a 50 Ω load. The same cable will be associated with the same spectrum analyzer until the end of the survey.
3. A tracking generator data capture produced with the spectrum analyzer over its associated coaxial antenna cable to measure its frequency-dependent attenuation.
4. 5 minutes of simultaneous data capture for the three spectrum analyzers, alternating between the rotator controller turned off, the rotator controller turned on, and the rotator activated (full spin back and forth).

Each data set is properly logged and will be used at the postprocesing stage to remove the systemics of the spectrum analyzer itself, the antenna cable, and the rotator.

4 Preliminary Results

A preliminary survey with the mobile RFI monitoring station was conducted over a 24 hours span at the OVRO site (37.2312°N,-118.2951°W) on January 20-21-2022 to validate the reliability of the system and the collected data. Figure 2 shows an example of integrated spectra over both the *day* (6am-6pm) and *night* (6pm-6am) periods, captured with the omnidirectional antenna. The colored areas on these plots show the following US NTIA frequency allocations:

- Green : cellular communications
- Cyan : Television broadcasts
- Yellow : Radio astronomy
- Red : Aeronautical communications
- Magenta : Radio location services
- Grey : Satellite communications

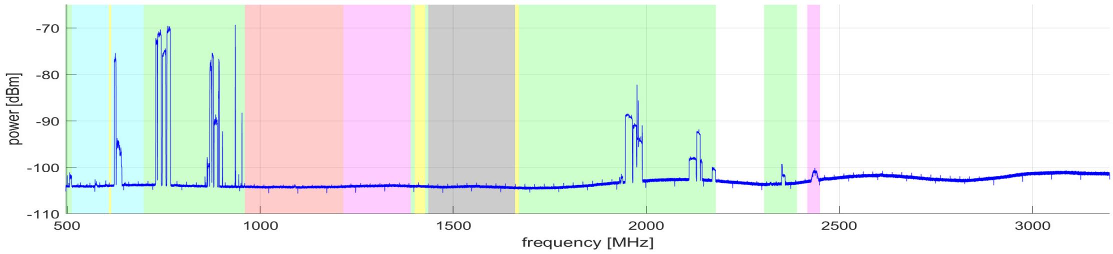
The oscillating baseline of the spectrum corresponds to the response of the pre-amplifier of the spectrum analyzer, and has not yet been calibrated. The spectra have been corrected for antenna cable frequency-dependent attenuation. Most of the RFI visible from the observatory are due to cellular communications (4G LTE and 5G). There is no obvious variation between the day and the night periods, suggesting that most of the RFI come from fixed cellular base stations in the vicinity of the observatory.

Figure 3 shows the 2-hours integrated spectra captured from the directional antennas (2 hours per angle for 12 angles) as a function of the angle-of-arrival (AOA). Figure 3a shows the horizontally polarized spectra, and Figure 3b shows the vertically polarized spectra. The cellular communication signals are maximized at about 90 degrees from our initial position pointing toward the South-West of the survey site. This angle corresponds to the town of Bishop, CA. A slight attenuation is observed with the horizontally polarized signals compared to the vertically polarized ones, as would be expected in man-made transmissions.

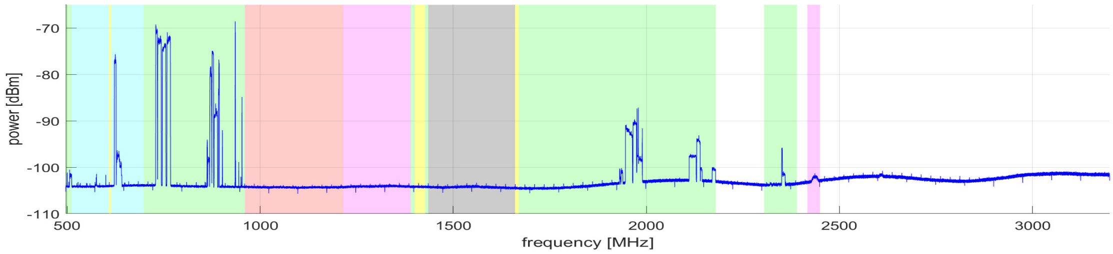
The DSA-2000 candidate sites will be selected based on their remoteness, such that less spectral activity would be expected compared to OVRO.

5 Conclusion

We presented a fully operational mobile RFI survey station to be used in the process of site selection for the DSA-2000 telescope. In addition to providing a long-duration spectral integration (of the order of days), the system also provides directional information to precisely identify the sources of RFI. The system is fully autonomous, powered by solar energy and automated by a dedicated software. A preliminary test survey at OVRO validated the specifications of the system. It will soon be deployed to various cadidate DSA-2000 sites to accurately assess their spectral characteristics.



(a) Integrated spectrum over the day (6am-6pm).



(b) Integrated spectrum over the night (6pm-6am).

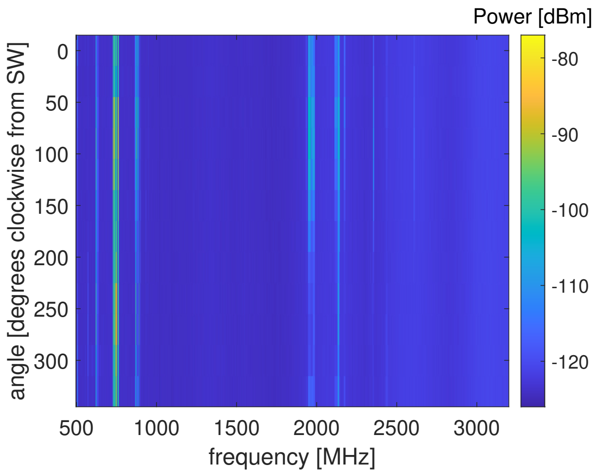
Figure 2

6 Acknowledgements

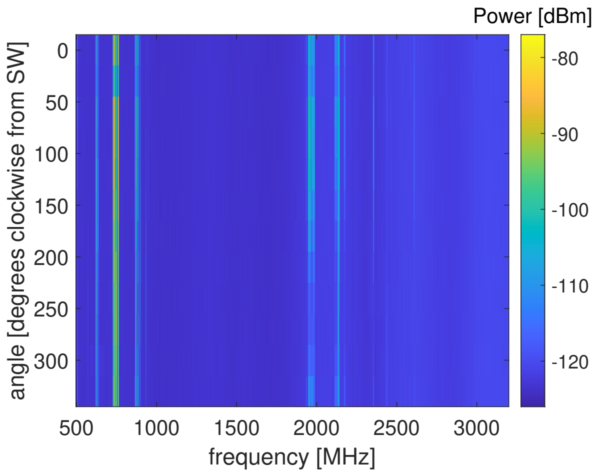
This work is funded through the NSF #1828784 supplemental award. The authors thank the Caltech and OVRO teams for the support they provided.

References

[1] Hallinan, Gregg, et al. "The DSA-2000–A Radio Survey Camera." arXiv preprint arXiv:1907.07648 (2019).



(a) Horizontally polarized spectra vs. AOA.



(b) Vertically polarized spectra vs. AOA.

Figure 3