DSA-2000 Test Array Characterization

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1 Background

The Deep Synoptic Array (DSA-2000) will be a large leap forward in radio telescope instrumentation. It aims to transform observations at radio wavelengths by functioning as a "radio camera" that produces reliable, high resolution images (Figure 1). If successful, it will give new insights into the origins of the enigmatic fast-radio bursts (FRBs) [2], significantly impact multi-messenger astrophysics by helping locate the radio counterparts to gravitational wave sources, and enhance our understanding of cosmic history via the distribution of neutral hydrogen throughout the universe [4].

The driving concept underlying the DSA-2000 interferometer is to make a huge leap in scale, using an unprecedented 2000 antennas. This is enabled by key technological breakthroughs such as the radio camera approach, the development of stable low-cost antenna platforms with ambient temperature receivers, and the ability to combine and correlate their signals in real time using advances in computer hardware [1]. The scale and stability of the array will allow for the real-time creation of wide-field, well-resolved radio images, without the sidelobes from bright sources that typically obscure faint signals in other radio interferometers.

The majority of telescope observation time (65%) will be used to take "radio images" of the sky, allowing for detection and characterization of more than 1 billion new radio sources, a 1000-fold increase relative to all prior surveys combined [2]. Another 25% of survey time will be spent implementing a multi-year timing array of 200 pulsars as part of the NANOGrav project [2], which will enable characterization of the nanohertz gravitational-wave universe. Finally, the remaining 10% of time will be used to study deep drilling fields and to follow up on compact binary mergers detected by ground-based gravitational-wave detectors (LIGO-Virgo-KAGRA) [2].

The DSA-2000 will be built at a quiet site in Nevada. Ahead of its construction, a test array has been constructed at the Owens Valley Radio Observatory (OVRO), near Caltech. This test array consists of five antennas of one design and four of another design, providing an opportunity to evaluate different configurations before full-scale deployment.

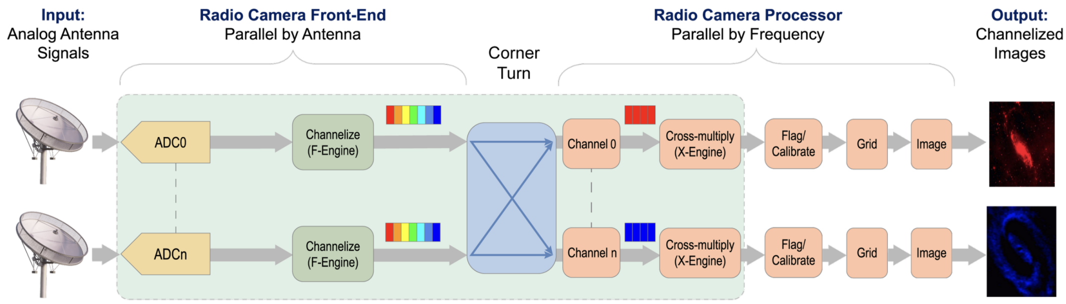

Figure 1: Schematic of DSA-2000 radio camera pipeline. Analog signals entering each antenna are digitized by analog-to-digital converters (ADCs) and channelized into frequency bins by the F-Engine. These signals are transported via custom optical fiber link from the dishes to a central processing building where a corner-turn reorganizes the data. The Radio Camera Processor (RCP) then cross-correlates each frequency channel across all antennas. Subsequent flagging, calibration, gridding, and imaging steps remove noise and generate radio images of the sky. Figure retrieved from [1].

2 Objective

Before constructing the final array, the basic interferometric properties of the test array must be characterized to ensure that they meet requirements. My primary objective is to evaluate the sensitivity of the two antenna designs and to determine the system's noise floor. A key concern within the DSA-2000 group is that if the sensitivity of the array falls short of expectations or the noise floor is unexpectedly high, these issues could compromise the ability of the DSA-2000 to achieve its scientific objectives.

3 Approach

Several factors are expected to negatively impact system sensitivity and noise floor. One potentially significant issue is irregularities in the primary beam — the response of an individual dish on the sky. Such irregularities may allow radiation from unexpected sources to leak into observations, generating spurious signals [4]. Another source of contamination may be cross-talk between antennas. Although each dish is shielded to prevent incoming signals from being reflected to neighboring antennas, the effectiveness of this shield still needs to be tested. Finally, human-generated radio-frequency interference (RFI) or polarization leakage can also contaminate observations [4].

To assess the impact of these noise sources, I will characterize key system parameters, including the System Equivalent Flux Density (SEFD), system temperature, effective collecting area, and gain. The system temperature is synonymous with the antenna noise floor, as it quantifies noise contributions from the receiver, sky, and other potential sources of contamination. SEFD is a useful metric for evaluating sensitivity, as it quantifies how bright a source must be to produce a signal comparable to the system's intrinsic noise [3]. A lower SEFD value indicates greater sensitivity. SEFD is given by:

$$\mathrm{SEFD} = \frac{2kT_{\mathrm{sys}}}{A_{\mathrm{eff}}} \tag{1}$$

where k is the Boltzmann constant (1.38×10^{-23} J/K), T_{sys} is the system temperature (K), and A_{eff} is the effective collecting area of the antenna (m^2). A higher than expected SEFD or system temperature could indicate unmodeled noise and other issues, such as RFI, primary beam irregularities, or cross-talk.

To obtain these measurements, I will use common techniques such as performing calibrations against bright known sources in the sky. I may also tap the data pipeline at different stages (e.g. cross-correlated data from the Radio Camera Processor, individual raw antenna data from the Radio Camera Front-End, etc; see Figure 1) to isolate noise sources as needed.

Overall, I will take an iterative approach in characterizing the test array. The first step will be to familiarize myself with the physical system and gain a thorough understanding of the relevant background. This will involve reviewing the DSA-2000 technical documents, which I have already begun, and spending approximately one week at the OVRO test array site to study its setup firsthand. I will then conduct initial observations and measurements of the test array and attempt to completely understand my data, seeking guidance and clarification as needed. Based on my understanding of my data, I will take additional observations to test and refine my hypotheses, and repeat this process.

Throughout the project, I will collaborate with scientists and engineers working on the DSA-2000 and work closely with Professor Vikram Ravi, the co-Principal Investigator of the project.

References

[1] Deep Synoptic Array, Technology Overview. Available: `https://www.deepsynoptic.org/technology`.

[2] G. Hallinan et al., "The DSA-2000 – A Radio Survey Camera," arXiv preprint, arXiv:1907.07648, 2019. Available: `https://arxiv.org/pdf/1907.07648`.

[3] NRAO, "Performance of the VLA - Sensitivity," VLA Documentation, 2013. Available: `https://science.nrao.edu/facilities/vla/docs/manuals/oss2013A/performance/sensitivity`.

[4] R. Byrne et al., "21 cm Intensity Mapping with the DSA-2000," arXiv preprint, arXiv:2311.00896v2, 2023. Available: `https://arxiv.org/html/2311.00896v2`.