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An Analog Front-End for CASATTA – Caltech All-Sky All The Time Array

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1. BACKGROUND

Many of the most interesting phenomena in radio astronomy are exceedingly faint, rare, or both. Capturing a large enough sample size in a reasonable amount of time requires simultaneous observation of as much of the sky as possible. Examples include mapping large-scale structure with the redshifted 1420-MHz emission from neutral hydrogen (Furlanetto et al. 2006), detecting extragalactic fast radio bursts (Petroff et al. 2022), characterizing the newly discovered class of ultra-long period neutron stars (Caleb et al. 2022), and studying extrasolar analogs of space weather in planetary systems (Zarka 2018). More generally, the speed with which a fixed area on the sky can be surveyed to a certain depth is proportional to (field of view) $\times$ (sensitivity)^2 (Perley 2001). As individual radio receivers today approach within tenths of a percent of theoretical sensitivity limits, progress in survey speed is most easily achieved by increasing the number of antennas, and the field of view.

Radio telescopes are unique in their ability to directly record and analyze the incident electric field rather than the field intensity (e.g., photon counting). This means that large apertures, and therefore increased sensitivity, can be achieved by synthesizing signals from multiple radio antennas that individually have small fields of view. These so-called "large-number small-diameter" (LNSD) arrays are at the forefront of radio astronomy at frequencies $\lesssim$400MHz (e.g., LOFAR, MWA, LWA). However, several of the science drivers noted above require observations at higher frequencies, which are more challenging to work with for multiple reasons: antenna/receiver performance and electrical matching must be excellent due to increased sky noise; antenna effective area (and hence sensitivity) decays with (frequency)^2; and larger bandwidths need to be recorded.

2. OBJECTIVE AND APPROACH

A project is proposed to advance development of the Caltech All-Sky All-The-Time Array (CASATTA). CASATTA is a collaboration between the Caltech Radio Astronomy group, led by Prof. Vikram Ravi, and a group within the Australian CSIRO Astronomy and Space Science (CASS) led by Dr. Keith Bannister. CASATTA seeks to build the first scientifically useful wide-field phased array of antennas for frequencies >400MHz. The project leverages recent technological breakthroughs that make it feasible to scale-up the array to large ($>10^4$) numbers of antennas at reasonable cost. Specifically, these include advances in wideband phased-array antenna design (CASS); ambient temperature low-noise amplifiers (Caltech); ultra-low cost analog signal chain components (Caltech) and ADCs (CASS); and efficient signal processing implementations on GPUs (Caltech).

This SURF project will specifically involve assembly and testing of a 16-element analog front-end for CASATTA. Antenna and receiver designs, and component fabrication, will be completed by the CASS/Caltech teams before the summer. Thus, the aims of the project are:

(a) establish an efficient and scalable assembly process;

(b) measure antenna performance (directional S-parameters) in the CASS anechoic chamber via remote measurements;

(c) measure receiver performance (including noise figure, compression/intercept points, S-parameters) in the lab; and

(d) test the end to end system on sky at the Owens Valley Radio Observatory (OVRO) plugged into the existing DSA-110 digital backend.

The ultimate goal will be verifying performance in an environment with realistic radio-frequency interference, as well as detecting a few bright astronomical sources.

3. WORK PLAN

Weeks 1-2

- Review design documentation and assemble hardware

Week 3

- Analyze anechoic chamber results

Weeks 4-5

- Set up and conduct receiver lab tests

Week 6

- Deploy system at OVRO

Weeks 7-9

- Obtain and analyze OVRO data

Week 10

- Consolidate report

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