Radio Array of Portable Interferometric Detectors (RAPID) : Design and Applications

(Invited Paper)

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***Abstract*—The Radio Array of Portable Interferometric Detectors (RAPID) is a spatially diverse sparse radio array. It has been designed to be deployed and reconfigured easily for scientific applications. These applications include both geospace and astronomy experiments where a relatively small and sparse aperture is sufficient in size. Examples include the study of ionospheric turbulence using active and passive radar imaging, astronomical observations of galactic synchrotron emission, and localization of bright radio emissions such as those from the Sun and Jupiter. The high degree of mobility afforded by the system enables interferometric configurations that are tailored to specific experiments and can be changed in the field. RAPID can also be deployed to locations that are optimal for specific scientific objectives or that complement other existing facilities by adding baselines or serving as a separate imaging receiver array.**

I. Introduction

RAPID is a radio array designed for easy deployment and reconfiguration for use in diverse range of scientific applications ([1], [2]). The growing capability of software radio and radar systems has enabled instrumentation that is widely applicable where signal processing and analysis is implemented in scalable cloud computing. The motivation for the RAPID system has been to combine the scientific capabilities demonstrated by astronomical radio arrays and geospace radar systems (e.g. [3]). The instrument is campaign oriented with data collection in the field being a distinct activity from primary signal processing and analysis.

The system captures data from each element at the raw voltage level using solar and battery powered data acquisition systems. Data is collected in the field by swapping solid state disks. RAPID builds upon the Square Kilometer Array Low Frequency Aperture antenna (SKALA) to cover a frequency range of 48 to 615 MHz. Other antennas can be used to cover different frequencies or in a sub-array configuration to enable greater collecting area. The system supports wireless control for use in a highly distributed configurations. Schedule based operation can also be used where communications are not available or allowed (e.g. radio quiet zones).

II. RAPID Design

The array elements of RAPID are physically disconnected and are organized into field units that consist of a data acquisition system (DAQ), energy unit (EU), and a base that holds the components and also acts as a shipping container for the systems when stacked. The RAPID design has progressed through several demonstration experiments (DXP) that have been used to develop specific functionality. These include a giga-sample per second (GSPS) signal chain demonstration (DXP-1), functional prototypes using off the shelf Ettus radios (DXP-2), and a soon to be completed “form factor” prototype using a combination of custom hardware and off the shelf radios (DXP-3). A fully custom and integrated design is in development and combines the capabilities and features of the prototype systems into a single highly capable platform.

A. Field Unit and Base

The RAPID field unit (see Fig. 1) has been designed around the SKALA antenna described in [4]. Minor modifications to ease repeated deployment are made to the antenna resulting in a RAPID variant (SKALA-R). This version retains SKALA electromagnetic performance and compatibility with SKALA low noise amplifiers. In addition to the astronomy amplifier we have developed two custom designs for use in strong signal environments. One uses an integrated switch and calibrator discussed in [5] and the other uses a high dynamic range LNA without any switching elements. The RAPID base provides a platform for the antenna, mounting locations for the energy unit, batteries, and up to two data acquisition systems. The bases ship with the EU and DAQ installed and are pre-wired except for the connection to the antenna (which is assembled on site). The bases can be stacked up to eight high on a pallet with the antennas between base pairs. A spacer is used to hold the antennas and the bases are bolted together for shipment.

B. Data Acquisition Unit

The fully integrated RAPID DAQ unit will use a custom digital receiver supporting dual channels at 1.28 GSPS and 14 bit depth. Power consumption is expected to be approximately 27 W of average power during data acquisition. A flexible RF front end enables gain control, calibration, and sampling of RF signals from 10 MHz to 2 GHz. The integrated version of RAPID hardware has a custom GPS locked OCXO and supports a Chip Scale Atomic Clock (CSAC) as a deployment option. Data is processed by an onboard FPGA that uses PCI express to communicate with a low power embedded computer. This enables data acquisition to hot swappable solid state disks, ring buffer data collection with external triggers, and the ability to perform signal processing on data post-collection. WiFI and 4G radios can be used directly with the unit and integration of an optional satellite radio has been included in the design. The hardware is being implemented to produce very low levels of electromagnetic interference.

C. Energy Unit

A custom solar charge and battery controller has been implemented to provide element power. The Energy Unit supports up to a 65 W load. It has a metal enclosure and filters on all inputs and outputs to greatly reduce conducted and radiated emissions. A micro-controller and on-board sensors enable adaptation to different battery chemistries (e.g. advanced NiMH, LiFePO4, Pb, etc) and intelligent utilization of available energy. The EU can also act as a watchdog on the DAQ unit and provide for a deep sleep mode (mW) that enables startup at a pre-determined time.

Fig. 1. Photo of a prototype RAPID field unit.

III. RAPID Applications

We have previously discussed key RAPID scientific applications focused on radio imaging for geospace and astronomy in [1]. Geospace applications can take advantage of existing radars and transmitters of opportunity (i.e. passive radar) to investigate ionospheric irregularities at the equator, auroral zone, or mid-latitudes using multi-static radar imaging. This enables exploration of radar scattering as a function of wavelength and differing scattering geometries. It is also possible to use the system for distributed measurement of relative total electron content variations using dual frequency satellite beacons. Early testing for Geospace applications using prototype hardware is ongoing at Jicamarca Radio Observatory in Peru. Planned astronomy investigations include Galactic Synchrotron mapping and the localization of strong radio emissions from the Sun and Jupiter. Galactic emissions are relatively strong and mapping can be accomplished systematically by implementing experiments where the imaging configurations are optimized for each observation frequency. The measurements can also be made in the northern and southern hemispheres to enable full coverage of the celestial sphere. Observation of strong and localized radio emissions such as those produced by solar radio bursts or Jovian Decametric radiation (i.e. using an HF antenna) are enabled by the ability to deploy field units with baselines of 10 to 30 km. This can also be done in conjunction with existing low frequency radio telescopes to greatly enhance the number of available baselines.

References

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