10.23919/URSIGASS.2017.8104992

The Low Frequency Receivers for SKA1-Low: Design and Verification

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Abstract

The initial phase of the Square Kilometre Array (SKA) [1] is represented by a ~10% instrument and construction should start in 2018. SKA1-Low, a sparse Aperture Array (AA) covering the frequency range 50 to 350 MHz, will be part of this. This instrument will consist of 512 stations, each hosting 256 antennas creating a total of 131,072 antennas. A first verification system towards SKA1-Low, Aperture Array Verification System 1 (AAVS1), is being deployed and validated in 2017.

1. Introduction

During phase 1 of the SKA, two telescopes will be realized, SKA1-Low being one of them. Key science cases for SKA1-Low include the Cosmic Dawn and Epoch of Reionization (EoR), pulsar search and timing and imaging of high redshift HI. SKA pathfinders and precursors including the LOFAR telescope [2] and the Murchison Widefield Array (MWA) [3], are expected to accomplish a first detection of the EoR power spectrum. Although more advanced technology will be pursued towards SKA1-Low telescope design, it is based on the same principles as LOFAR and MWA.

The Aperture Array Design and Construction (AADC) Consortium, which executes the Low Frequency Aperture Array (LFAA) element of SKA1-Low, is responsible for the design of the stations, the signal transport to a processing facility and the station beamforming, including the local software. Partners in AADC include ASTRON, Cambridge University, ICRAR (Curtin University), INAF (Italy), KLAASA (China), Oxford University and STFC Edinburgh. The design of this system poses a number of challenges, not only in terms of performance but also due to the high volume of the parts (antennas, receivers etc.) and the output data rate. In order to mitigate the design risks, verification systems have and will be realized.

Initially, small 16-antenna prototype (AAVS0.5) systems have been built, both in the UK [4] (figure 1) as well as near the proposed SKA site in Western Australia [5]. The next step is the realization of AAVS1. Characterization of AAVS1 will be done using methods already demonstrated on AAVS0.5, as well as possible complementary measurements using Unmanned Aerial Vehicles, which can be used to map the embedded antenna response. [6]

Figure 1. AAVS0.5 at Lords' Bridge, Cambridge, UK.

Key technology developments include: a wide band log-periodic antenna [7] and associated low-noise receivers, low cost Radio over Fiber (RFoF) signal transport and a compact high performance acquisition and signal processing board. In SKA1-Low signals of all antennas will be digitized, effectively generating a software controlled aperture that can be flexibly configured allowing correlation rich aperture synthesis, new calibration approaches and very high dynamic range imaging with the sparse array.

2. Aperture Array Verification System 1

The realization of AAVS1 is well on its way. Hardware production within Europe is ongoing, as well as soft- and firmware development. All items are tested and verified at the pre-AAVS1 array at Lords' Bridge, Cambridge, before being sent to Australia for full deployment. AAVS1 will be built near the SKA site in Western Australia, hosted by the MWA in the Murchison Radio-astronomy Observatory (MRO). It will consist of 400 antennas grouped in 4 stations, one full size, together with three smaller (48 antennas) stations, and will have all the elements of SKA1-Low included. Figure 2 shows the AAVS1 station locations, represented by the yellow dots.

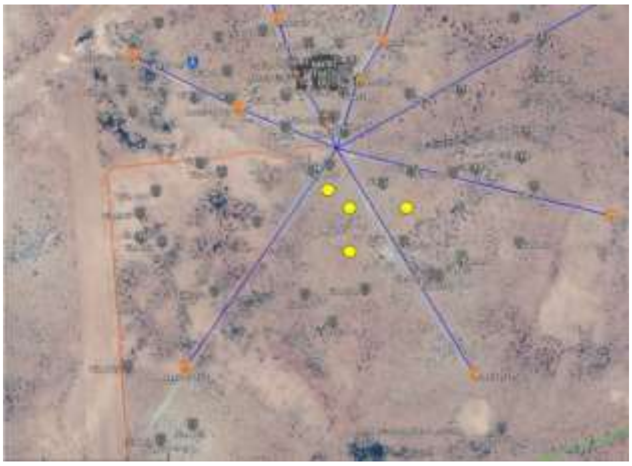

Figure 2. AAVS1 station locations inside the MWA's central region.

With the total collecting area of over 1000 m^2, science observation would be possible and will certainly be considered. However, AAVS1 will not be an instrument dedicated to science, as it will mainly act as a technical demonstration platform to validate the design and inform the design of the LFAA Element of SKA1-Low.

Although AAVS1 isn't a full SKA1-Low, it will be built in such a way that it resembles the current SKA1-Low design as much as possible with the exception of elements outside the scope of the AADC consortium, such as the correlator and telescope manager. For these the MWA correlator and an emulator will be used respectively. Detailed design of the subsystems include the antenna, by Cambridge University, the RFoF links, by INAF, ASTRON and Cambridge, the Receiver by INAF, the Tile Processing Module (TPM) by INAF and Oxford and the local infrastructure by ICRAR including the connection with MWA.

AAVS1 is being built to test hardware and software designs in the prototyping period before the AADC Critical Design Review and construction of the LFAA. A major task in the pre-construction period is the development of station calibration methodologies for LFAA. The current architecture of LFAA is such that there is a clear distinction between station level calibration and array level calibration such that each station must be able to calibrate itself in a standalone way without using the rest of the sensitivity of the array.

Many of the verification tasks for AAVS1 will be performed using astronomical sources and require a correctly formed station beam from AAVS1, either in standalone mode or in cross-correlation with MWA. In standalone mode, measurements can be performed by operating the main and/or smaller AAVS1 stations as an interferometer. This mode can be used to verify both station beam characteristics and individual elements against system L1 specifications.

The main characteristics of AAVS1 are summarized in table 1.

Parameter	Value/Description
Frequency range	50 - 350 MHz
Antenna type	log periodic
Number of antennas	400
Antennas per station	256 (1 stn), 48 (3 stn)
Number of stations	4
Station diameter	35 meter
Polarizations	2, linear
Inst. bandwidth	300 MHz
Beamforming	Full digital

Table 1. AAVS1 main characteristics.

3. Status of AAVS1

The SKALA2 antennas were shipped in Q4 2016 from University of Cambridge (UCAM) (by sea) to ICRAR.

Figure 3. SKALA2 Antenna transport.

During Q4 2016/Q1 2017, all low noise amplifiers (LNAs) have been ordered by UCAM and the first batch (600 pcs) have been factory tested, after which they will become available for integration into the first batch of ``pyramids'' (the top node of the antenna, housing electronics). After testing the pyramids at UCAM, they will be shipped to ICRAR.

The first 440 Front End (FE) modules have been produced and tested during Q1 2017 by INAF. The FE modules host the optical transmitter, as well as RF-electronics. 40 pyramids have been pre-assembled, connecting a bespoke hybrid cable to the mechanics within the pyramid. The hybrid cable hosts 2 copper wires to transfer DC power to the antenna electronics. It also hosts fibre optic cable to transfer in one media, the two polarizations to the processing system using Wavelength Division Multiplex (WDM).

The first batch of 40 antennas, will enable us to start the deployment of the first AAVS1 station in early March 2017. After system integration and validation, the remainder of the hardware will become available towards deployment, which will complete the full-station, as well as realize the three auxiliary stations. The inter-station correlation will allow for stand-alone characterization and the station locations have been chosen to optimise this process.

The Analog to Digital Units (ADUs) are produced in two batches. The first production run (Q4 2016) has finished, resulting in 33 factory-tested boards. Only 2 boards needed some rework, resulting in an excellent production-yield. The second production run will be produced early February 2017. After factory testing, the boards are lab-tested (full RF and digital) at INAF Medicina Radiotelescope laboratories, after which they will be integrated with the PRE-ADUs, (PRE- Analog to Digital Unit, which performs filtering and gain adjustments of the analog signal) creating the Tile Processing Modules (TPMs). The TPMs will be put into 7 sub-racks, each holding 4 TPMs. The subracks will be assembled and tested at INAF, with the support of Oxford and Malta staff.

Figure 4. Tile Processing Module.

At the MRO site, all station locations have been prepared and are awaiting the arrival of antennas. Ground planes, concrete bases and the Antenna and Power Interface Units (APIUs) have been deployed, as shown in figure 5.

The APIUs are connected to mains power at the MRO, as well as fiber optic cable to transport the RF-signal to the Central Processing Facility. All single fibre connections from the antennas are merged into a single multi-core cable, which goes back to the central building at the MRO via buried trenches.

Figure 5. A section of the main station of AAVS1 showing the prepared area, ground mesh, APIU and concrete bases for the SKALA2 antennas.

3. Conclusion

We have provided an overview of AAVS1 and provided additional information on its role within SKA1-Low. As earlier demonstrators inside the consortium have shown great success, we are confident AAVS1 will be the next step forward to the SKA.

4. References

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