Volume Title
ASP Conference Series, Vol. **Volume Number**
Author

Monitoring and Control of EMBRACE, a 4608 Elements Phased Array for Radio Astronomy

Patrice Renaud[1], Christophe Taffoureau[1], Philippe Picard[1], Jean Borsenberger[2], Steve Torchinsky[1], Henrik Olofsson[3] and François Viallefond[2]

[1]*Observatoire de Paris, Station de Radioastronomie de Nançay, France*

[2]*Observatoire de Paris-Meudon, France*

[3]*Onsala Space Observatory, Sweden, France*

Abstract. EMBRACE is a technology demonstrator for the decimetre wavelength range of the Square Kilometre Array. As a demonstrator instrument, the primary goal is to test and verify its merits as an SKA candidate design. For this purpose, we have developped the control software for EMBRACE including the real-time control software, the data acquisition and the observation setup systems. We have reused and adapted the LOFAR C++ control software and implemented a similar architecture on the LCU (Local Control Unit) computer. Station Control Unit (SCU) software provides a Python interface to LCU for users to easily setup observation scripts for various types of observation and to capture integrated data. Tests with satellites and strong radio sources are in progress to validate the system and characterize the demonstrator.

1. Introduction

EMBRACE is a SKA Pathfinder for the mid frequencies. Two EMBRACE stations were built,one at Westerbork in the Netherlands (G.W. Kant 2011) and the other at Nançay, largely financed by the European Commision Framework Program 6 project SKADS. EMBRACE is the first large-scale demonstrator of the dense aperture array technology for radio astronomy. EMBRACE@Nançay is a phased-array of 4608 densely packed antenna elements (64 tiles of 72 elements each). For mechanical, and electromagnetic performance reasons, EMBRACE@Nançay has, in fact, 9216 antenna elements, but only one polarization (4608 elements) have fully populated signal chains.

EMBRACE is capable of real-time analog beamforming in two independant directions using a LOFAR backend. Multiple digital beams can be formed inside each RF beam. Key parameters for the Station control software are:

Nançay Physical collecting area:	70 m^2
Number of polarizations:	single
Number of independant fields of view (RFbeams):	2
Max number of digital beams:	248
Tuning frequency range:	500 - 1500 MHz
Observable frequency range:	900 - 1500 MHz
Instantaneous bandwidth:	48 MHz

The observable frequency range was reduced by a high pass filter which was installed to eliminate high power transmissions from nearby digital television stations.

EMBRACE digital and RF processing is built from a LOFAR backend, which provides both integrated data (statistics) and raw data (beamlets). The LOFAR LCU (Local Control Unit) real-time control software was adapted to the specific needs of EMBRACE. An interface layer, implemented on a Station Control Unit (SCU) computer, provides interaction with the LCU and to setup and run observations. Tests are in progress to study functionalities of the demonstrator.

2. EMBRACE Processing

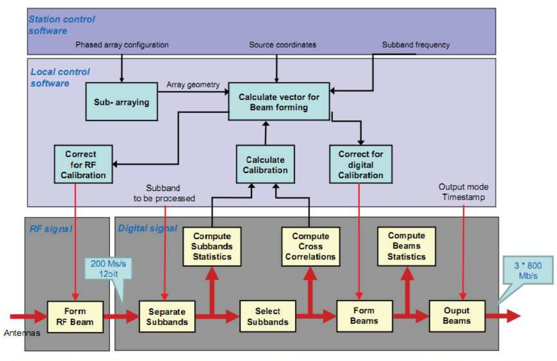

Figure 1. RF and Digital EMBRACE Processing

EMBRACE@Nançay uses a hierarchy of four levels of analog beamforming leading to 16 inputs to the LOFAR backend system for digital beamforming. The first beamforming is of 4 Vivaldi elements done on the integrated circuit "beamformer chip" developed at Nançay (S. Bosse 2010). The output of 3 beamformer chips is summed together on a "hexboard" and 6 hexboards make a tile. At Nançay, we have one further analog summing stage with 4 tiles making a tileset. The output of the tilesets is fed into a LOFAR-type RCU and RSP system for digital beamforming. The LCU (Local Control Unit) computer calculates coefficients for RF and Digital beamforming.

1 second integrated data (statistics data) are calculated by backend firmware for calibration. There are 3 kind of statistics: subbands statistics (power distribution for the total observation bandwidth -100 MHz-), beamlet statistics (power for each subband selected and for 2 directions), and crosslet statistics (cross-correlation data between all receiver inputs). Raw data (beamlets) are output to 3×1 Gbps ethernet ports.

Observation setup and integrated data acquisition is provided by Station Control Unit (SCU) software.

3. Local Control Unit (LCU) software architecture

The EMBRACE Monitoring and Control (MAC) system is based on the LOFAR Local Control Unit (LCU), with significant modifications and extensions added in order to operate on the EMBRACE array. EMBRACE has a 4-level hierarchy of analog beamforming making it more complex than a LOFAR station. In particular, the MAC must configure the phase-shift parameters applied by beamformer chips for each of the 4096 antenna elements. The number of parameters is double the number of antenna elements in order to configure the two independent RF beams. The LCU can also configure a time delay parameter available on each tile (group of 72 antenna elements).

The EMBRACE LCU permits the creation of multiple digital beams pointing towards astronomical sources on the sky. Beams are formed by complex weighted addition of the sub-band separated signals of up-to $n \times 72$ antenna elements, where n is the number of tiles. The LCU can also configure the station into multiple sub-arrays. For example, it is possible to create an array of half of the antennas and another array consisting of the remainder.

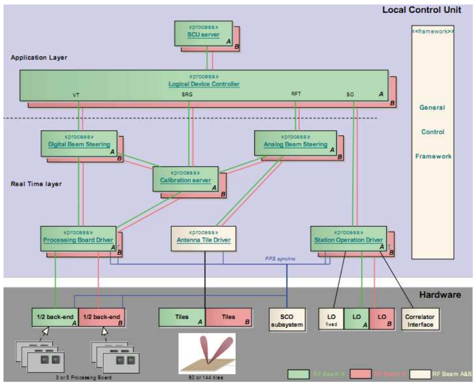

Figure 2. Control architecture

RFBeams can be calibrated to correct complex electronic phase differences between the different signal paths. The phase corrections computed are applied by combining them with the directional station beamformer weights. The same principle is applied for digital beamforming. All control commands are synchronized to the SYNC signal from the Station Control Operation (SCO) subsystem which includes time signals from GPS, a rubidium clock, and local oscillators.

There are two independent control systems, one for each RF beam. Each control system is composed of independent processes, except for the the antenna tile driver which is common to both RF beam chains, as there is only one hardware address per tile.

The LCU is accessible by a server inside the application layer.

4. Station Control Unit (SCU) Software

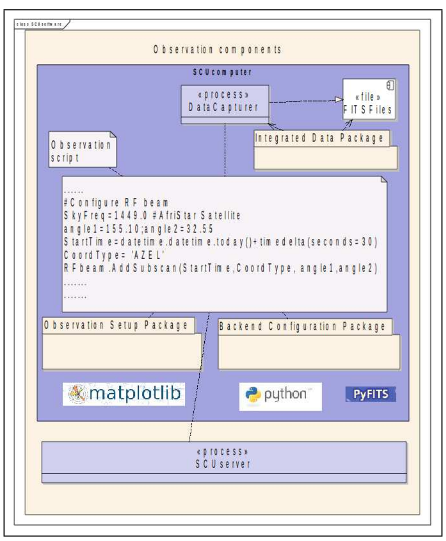

Figure 3. Observation script software components

Station Control Unit (SCU) is the interface between the EMBRACE user and the control software (LCU). An extensive Python package library was developed for EMBRACE and is installed on the SCU (Station Control Unit) computer. This software gives scripting functionnality for users to easily setup observation scripts for various targets and types of observation. With access to the powerful functionality of the Python scripting language, the EMBRACE user can build complex observation setups by using the numerous standard packages provided by Python.

Integrated statistics data calculated continuously by the firmware backend at 1 second intervals are acquired by the SCU from the LCU and saved into FITS files. Raw data (beamlets) are captured from LCU Ethernet 1 Gbps outputs by a dedicated acquisition program (for performance reasons) and saved into binary files.

Other capturer processes provide real-time acquisition of configuration parameters during the observation. These include amongst others: directions, calibration parameters, digital beam weight coefficients, etc. These data are used for instrument characterization and tests.

Future plans include the implementation of SDM (Scientific Data Model) to continue EMBRACE characterization

5. Observation results

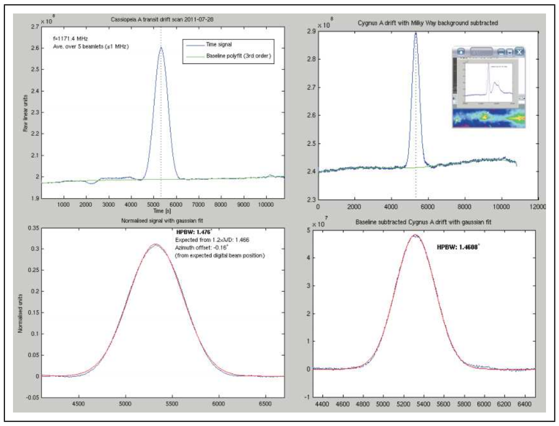

Figure 4. Cassipeia-A and Cygnus-A observation

EMBRACE@Nançay does routine observations of strong radio sources Cassipeia-A (a super nova remnant) and Cygnus-A (a radio galaxy). The figure shows a drift scan of the continuum source Cas-A (left in Fig. 4) and Cygnus-A observed in the HI line (1420 MHz, right in Fig. 4). The drift scans are used to measure the main lobe profile of EMBRACE. The main lobe is Gaussian to a high degree, and the beam width matches the expected value.

References

G.W. Kant, e. a., et al 2011, IEEE Trans. Ant. Prop., 1990
S. Bosse, e. a. 2010, Proceedings of the 40th European Microwave Conference, Paris, France