Dense Array Developments in France for SKA

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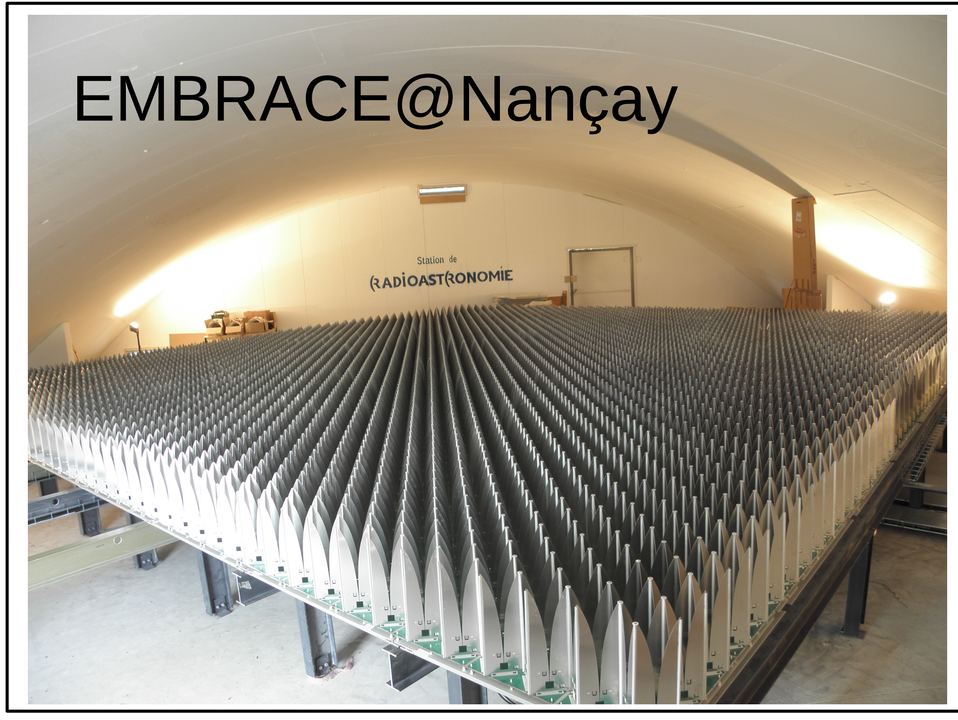
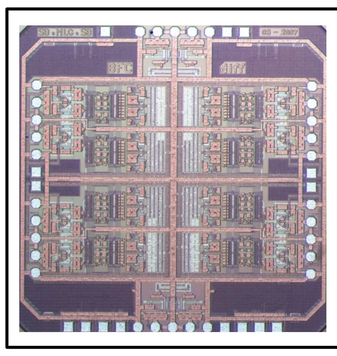


EMBRACE is a SKA Pathfinder for the mid frequencies. Two EMBRACE stations were built, largely financed by the European Commision Framework Program 6 project SKADS. EMBRACE is the first large-scale demonstrator of the dense aperture array technology for radio astronomy.

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@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. 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.

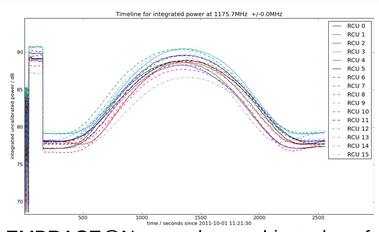


Beamformer Chip

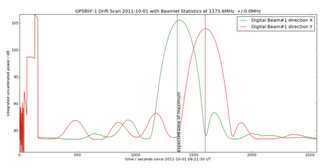
At the heart of EMBRACE is the integrated analog circuit called the Beamformer Chip which was developed at Nançay. This chip applies the phase shifts necessary to four antenna elements to achieve pointing in the desired direction. The beamformer chip forms two independent beams for each set of four antenna elements. Over 4000 chips were produced for the EMBRACE stations at Westerbork and Nançay.

Monitoring and Control Software

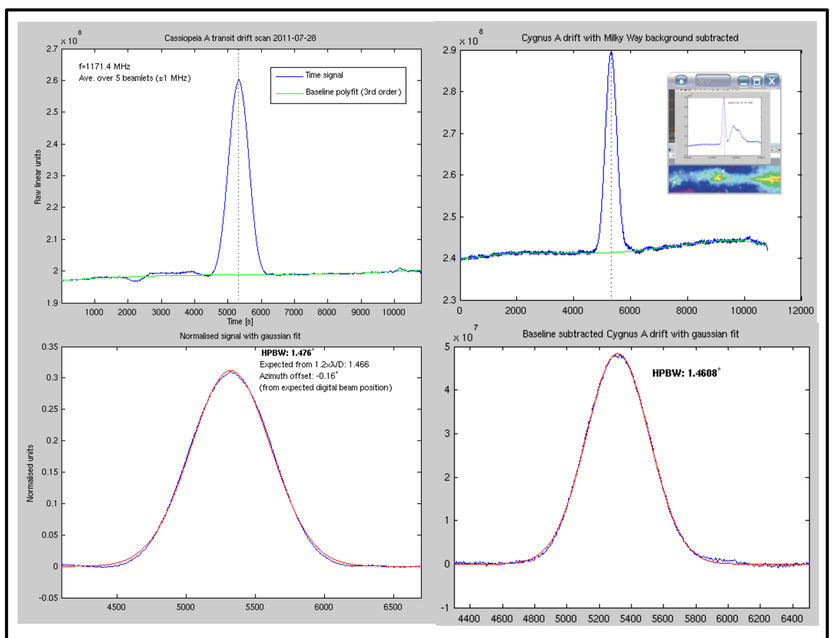
The Monitoring and Control software for EMBRACE was developed at Nançay, and continues to be improved. An extensive Python package library on the SCU (Station Control Unit) computer gives scripting functionnality for users to easily setup observation scripts for various targets and types of observation. Integrated statistics data are acquired from the LCU and saved into FITS files. Raw data (beamlets) are captured from LCU Ethernet 1Gbps outputs and saved into binary files. Future plans include the implementation of SDM (Scientific Data Model) to continue EMBRACE characterization



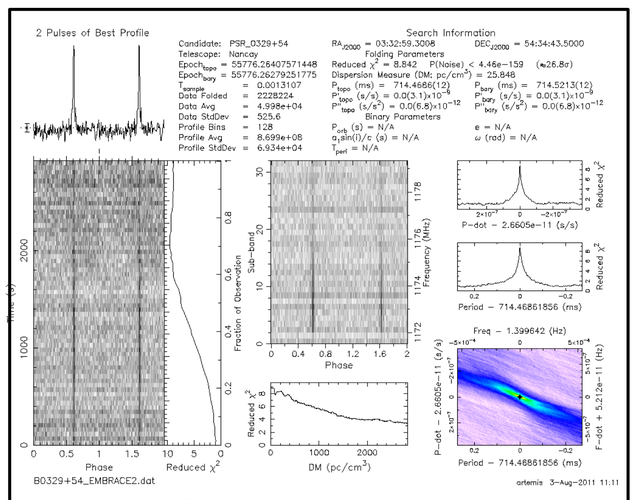
EMBRACE@Nançay has a hierarchy of four analog beam forming stages. The first three are done on the tile boards, while the last one is done on the Control and Down Conversion (CDC) card in the shielded container. The cables running from individual tiles to the CDC cards are 15m in length, and there are phase perturbations between the various connectors and length of cable leading from each tile. This is calibrated out using an algorithm implemented in the Local Control Unit. In the figure above, a drift scan was done of satellite GPS BIIF-1 and each line is the output from a different tileset. As can be seen, each tileset is phased-up correctly, and they all show the satellite peak at the expected time. Gain equalization has not been applied, but may be implemented in the future. The data here are from the Subband Statistics.



The LOFAR backend used with EMBRACE produces Beamlet Statistics which are the formed beam for the entire array, integrated over 1 second, and for each subband. For EMBRACE, a beamlet is the formed beam in one subband with two directions. This is different from LOFAR which has one direction, but two polarizations per beamlet. In the figure above, the satellite GPS BIIF-1 drifts across the beam. The second direction of the digital beam was pointing at a position 4 minutes later along the orbit of the satellite. This is clearly seen in the figure.



EMBRACE@Nançay does routine observations of strong radio sources Cassiopeia-A (a super nova remnant) and Cygnus-A (a radio galaxy). The figure shows a drift scan of the continuum source Cas-A (above left), and Cygnus-A (above right) observed in the HI line (21cm). 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. (images by Henrik Olofsson).



EMBRACE@Nançay made its first pulsar observation in August 2011. The array was configured with a bandwidth of 7.8125MHz (40 beamlets) centred at 1175.6MHz during an integration of one hour. The array was phased-up using the GPS BIIF-1 satellite during the afternoon of 2 August, and the parameters were applied for the observation the following morning for B0329+54. The high data rate output from the RSP boards was read by a data acquisition system running the Oxford ARTEMIS pulsar processing software.

The observation was made possible by significant contributions from Henrik Olofsson (Onsala) and Aris Karastergiou (Oxford), who spent an exended summer visit at Nançay working with EMBRACE. Aris Karastergiou also provided the ARTEMIS backend used during the observation.

A Generic Science Data Model for Radio Astronomy SDMv2

With the telescopes of the future, more sophisticated on-line data reduction will be required, making it necessary to include in the data model the description of the processing paths including the parameters applied. The reliability of the data product will depend entirely on this on-line data reduction.

In a collaboration with Nançay and led by LERMA at Observatoire de Paris, a highly generic data model for radio astronomy is being developed. The Science Data Model (SDMv2) uses principles of object oriented programming, and has its foundation in fundamental mathematics.

As an example, with the SDM, it will be possible to include all the necessary information to describe the formation of the primary beam with phased arrays. Using parametrisation, the SDM avoids propagating the complexity for a given category of telescopes to all instruments. This is demonstrated by instantiating subsets of the SDMv2 meta model for instruments as different as ALMA and EMBRACE.

EMBRACE@Nançay, with over 4000 antenna elements, is amongst the most complex radio astronomy instruments in operation EMBRACE@Nançay serves as a test bed for the SDMv2.

Focal Array for Nançay (FAN)

A Phased Array Feed is being developed for the large decimetric radio telescope at Nançay for use at L-band. The system consists of 192 densely packed Vivaldi elements in an 8x24 array. Analog summing is used on 2x8 groups of elements creating 12 inputs to the digital beam former. Each Vivaldi element is equiped with a room temperature Low Noise Amplifier developed at Nançay. The system has 250MHz instantaneous bandwidth. Digitization and signal processing are done on boards developed at LAL/CNRS and IRFU/CEA in France, using real-time software beamforming. Future possibilities include using UNIBOARD for remote digital signal processing and real time RFI removal algorithms.

The FAN project is a collaboration between the Observatoire de Paris, the IRFU laboratory of the Commissariat à l'Energie Atomique et aux énergies alternatives (Saclay, France), and the Linear Accelerator Laboratory of IN2P3/CNRS (Orsay, France).

Pictured above, the FAN prototype at the focal area of the Nançay decimetric Radio Telescope.

Future Work: The Aperture Array Integrated Receiver Project (AAIR)

The AAIR project is funded by the National Research Agency of France for 816kE over the next 4 years. This project is a collaboration led by the Nançay radio observatory, with partners at the Laboratoire d'Astrophysique de Bordeaux, NXP, and ASTRON.

AAIR is structured in harmony with the SKA Project Execution Plan and represents the major participation of France in Work Package 6.

The goal of AAIR is to develop an integrated receiver system for radio astronomy for use in dense aperture arrays. Integrated systems offer the best compromise between performance, power consumption, and cost. The AAIR program concentrates on LNA development, a beamformer chip with integrated time delay for wide band performance, and fast ADC chips with integrated serializer in a System-on-Chip package.

The ultimate goal of AAIR is a high level of integration such that a dense aperture array tile would have digital output resulting in a cost effective, and low power consumption dense aperture array for the mid frequencies of SKA. AAIR will continue into the Advanced Instrumentation Program of the SKA.

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