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An overview of EMBRACE station processing

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Abstract. This paper shows an overview of the many tasks and data objects used in the EMBRACE station processing in order to deliver digital beams. Data rate troughout the processing chain and examples of station configuration are given.

1. Introduction

EMBRACE demonstrator is split into two receiving aperture arrays. The larger one (160 m^2) is located at Westerbork in the northern part of The Netherlands, the other one (90 m^2) is located at Nançay radio observatory in center of France.

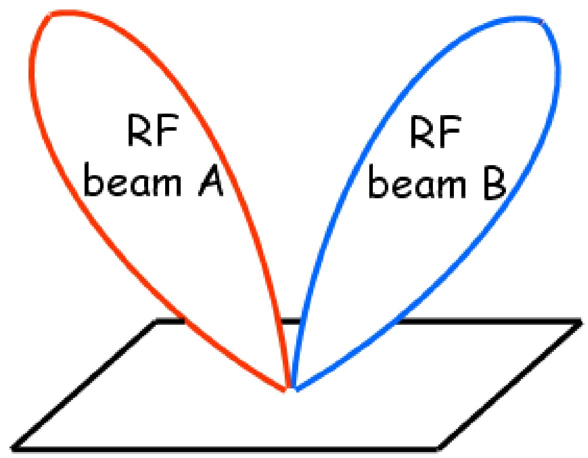

Fig. 1: EMBRACE tile

2. Station processing inputs

The base element of EMBRACE arrays is the EMBRACE tile (see Fig. 1) made of 72 dual polarized Vivaldi antenna elements. The frequency range is from 0.5 GHz to 1.5 GHz. An analog beamforming system allows one tile to deliver two independent RF beams (only one polarization). One RF beam signal is the phased sum of the 72 RF signals from the Vivaldi antenna elements (for only one polarization). The phased sum uses analog beamforming: phase shifting and a few time delays, giving maximum gain from one sky direction. Before digitizing the RF beams signals are frequency downconverted to a 100 MHz - 200 MHz frequency band, a Local Oscillator system selects the central frequency within the 0.5 GHz to 1.5 GHz range. Output of downconverter is a 100 MHz frequency window translated from central observing frequency to central IF frequency which is 150 MHz. Depending upon site configuration, one digitizer input is fed by one IF beam coming from one tile or by one IF beam coming from a tileset of four combined (time delays) tiles.

Digitizer bandwidth is 100 MHz, sampling 200 Ms/s, 12 bits. For station processing the input data rate is 2400 Mbits/s for each input. With 144 inputs (tiles) for beam A and 36 inputs (tilesets) for beam B, total input data rate for the Westerbork EMBRACE site is 432 Gbits/s. For the Nançay EMBRACE site with 20 inputs (tilesets) for beam A and for beam B, total input data rate is 96 Gbits/s.

Table 1: Configurations.

sky directions	*subbands*
2	248
...	...
8	62
...	...
496	1

3. EMBRACE digital beamforming

Usually synthesis of a digital beam is done by time delaying each digitized IF beam by the right values needed to point a sky direction, and then summing all time delayed IF beams. This is the right way to have widebandwidth digital beams. In EMBRACE, synthesis of a digital beam is done by a phased sum of all the digitized IF beams, each one being phase shifted by the proper value in order for the digital beam to point a sky direction. Using phase shifts rather than time delays is easier to implement but works only in small bandwidths where a phase shift is equivalent to a time delay. This generic way of digital beamforming requires the use of digital bandpass filters before phase shifting.

In EMBRACE phase shift is applied in 195 KHz bandwidth (subband).

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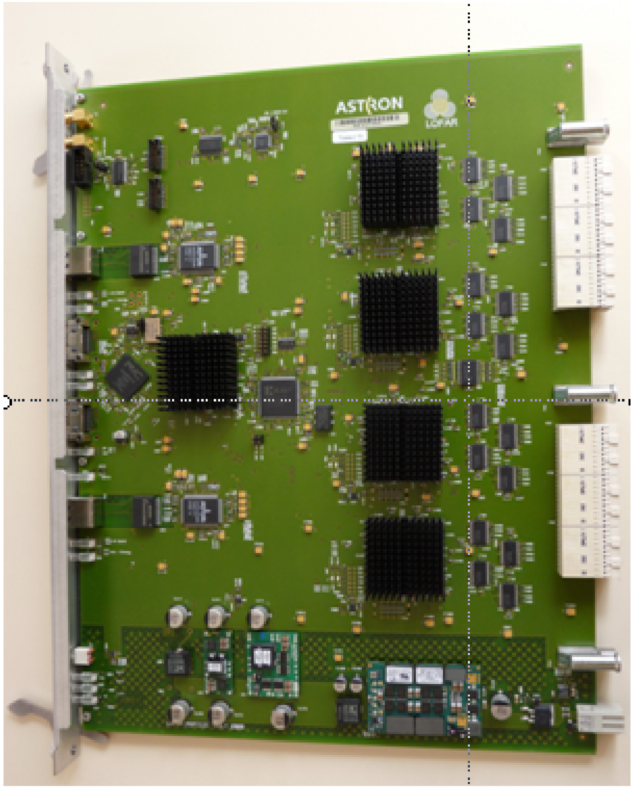

Fig. 2: Board picture

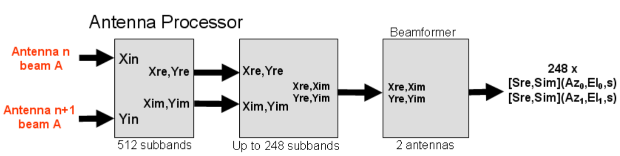

Fig. 3: Antenna processor

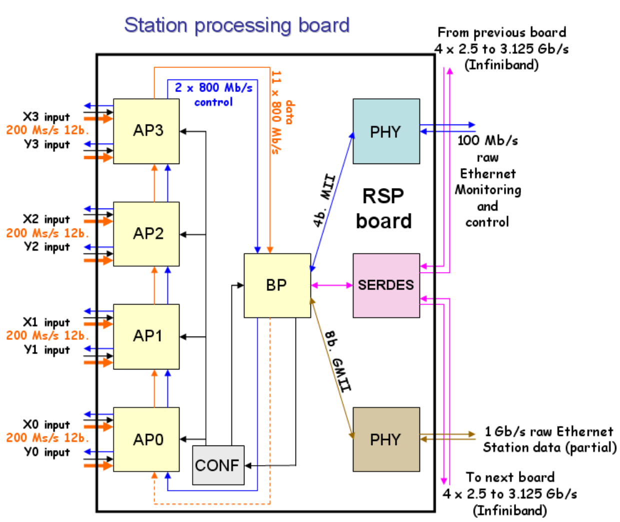

Fig. 4: EMBRACE station processing board

4. Antenna Processor

To reduce development duration, EMBRACE uses the LOFAR Back-End as hardware platform for station processing. Inside this platform, the Antenna Processor (AP) is the base processing element (see Fig. 3). One AP computes the phased sum of two antennas, for the same RF beam, delivering 248 data objects called beamlets. A beamlet is the sum for 2 sky directions in the same subband. All the required AP outputs are then summed to deliver the station beamlets. A station beamlet is the phased sum of all station antennas for the same RF beam, it contains two digital beams for two sky directions in the same subband.

As a result, an EMBRACE station always computes 496 digital beams for each RF beam, table 1 gives some configuration examples.

The main tasks done by an antenna processor are the two polyphase filters delivering 512 frequency channels (subbands) for each antenna input, the subband select task to compute digital beamforming on a subset of the 512 subbands (only 248), and the digital beamformer which applies gain and phase shifts to the selected subbands, for the required sky directions. The beamforming process for two antennas is a matrix multiply, beamforming weights being organized in a 4 x 4 matrix (for one subband) to provide beamforming coefficients for two antennas, one subband and two sky directions.

The monitoring and control software sends every second the subband select map (248 subbands) and the weights matrix (248 4 x 4 matrix for each subband and for each antenna processor) required by the antenna processors. Input data rate to an AP is 4.8 Gb/s and data rate inside an AP is 7.2 Gb/s at filters output (18b complex data) and 3.5 Gb/s at beamformer output.

The add process of all the AP outputs is distributed among APs: each AP adds its results (beamlets) to the results of the previous AP in the chain. The last AP in the chain delivers the station beamlets which are the station digital beams. Station output data rate is 3.1 Gb/s, four 1 Gb/s Ethernet interfaces are used to send the station digital beams to data recording systems or to post processing systems.

5. Station processing board

A station processing board is populated with four antenna processors, being able to manage eight antennas (one RF beam, one polarization). The LOFAR Remote Station Processing board is used for EMBRACE station processing board. One antenna processor is embedded in one FPGA (90 nm process). A board processor FPGA is used for control management and data output management. All station processing boards are linked in a peer to peer external ring using four Infiniband lanes (4 x 3.125 Gb/s) in order for each board to add its results (beamlets) to the results of the previous board in the chain (see Fig. 4 and Fig. 2).

6. EMBRACE station data output

Station processing creates two types of data, 1s averaged data and high temporal resolution data. All the 1s averaged data are

Table 2: Storage capacity to record N beamlets, in Tbytes.

beamlets	*datarate*	10*min*	1*hour*	10*hours*
62	93*Mbytes*/*s*	0.054	0.325	3.2
124	185*Mbytes*/*s*	0.108	0.651	6.4
186	278*Mbytes*/*s*	0.163	0.976	9.6
248	370*Mbytes*/*s*	0.217	1.3	12.8

locally stored in the Local Control Unit, the station control computer. For each RF beam, they are:

- power of all 512 subbands for each antenna,
- power of all 248 station beamlets,
- cross correlations of all antennas, for one subband.

The high temporal resolution data are the digital beams sampled (complex data) for subband bandwidth, 5.12μs per sample. They are not stored inside the Local Control Unit. An EMBRACE station can deliver for each RF beam up to 248 station beamlets on up to 4 x 1Gb/s ethernet links. Specific storage system or post processing system can be fed by these data, using the ethernet links.

For use of external data analyser systems with analog inputs (e.g. the Westerbork correlator), an analog output is available through the External Correlator Interface which delivers an analog version of digital beams, with beam output bandwidth up to 20 MHz and output starting frequency of 0 to 40 MHz. Before digital to analog conversion, a digital synthesis filter computes a wide bandwidth from beamlets of consecutive subbands and same sky direction.

7. Data recording and tools to access post processing

Real time data recording requires specific system due to high data rate. A specific computer hardware using low cost COTS components is developped to allow real time recording of at least 124 beamlets (2 Gb/s data rate), the recording software is under test. Table 2 shows the required storage capacity when operating a few hours.

8. Monitoring and Control software

A Local Control Unit (LCU) runs the EMBRACE station Monitoring and Control software (MAC). The MAC task is to compute and deliver all the required parameters to the processing boards, the tiles array, the LO subsystem, in order to operate EMBRACE station for a specific observation. Parameters are set on a 1s based synchronizing system. Inputs to the MAC software are the RF center frequency (0.5 to 1.5 GHz), the source coordinates, the array geometry. For system health monitoring the MAC software continously reads voltages and temperature sensors, and verifies integrity of command data. MAC links to processing boards is done by 100 Mb/s raw ethernet links, one link for each processing board. A Station Control

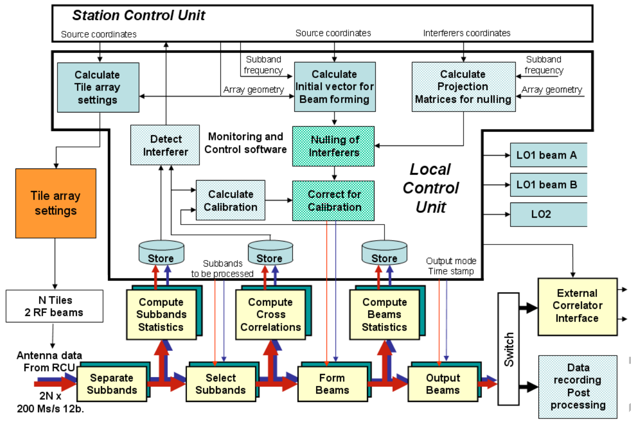

Fig. 5: EMBRACE station processing architecture

Unit (SCU) is used for observation scheduling and sequencing built from a specific python script. Fig. 5 shows system architecture and all functionalities which will be embedded in the MAC software.