ELECTRONIC MULTI-BEAM RADIO ASTRONOMY CONCEPT: EMBRACE THE EUROPEAN DEMONSTRATOR FOR THE SKA PROGRAM

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Abstract
The European Aperture Array demonstrator project plan is described in this paper. This demonstrator is denoted as the Electronic Multi-Beam Radio Astronomy ConcEpt (EMBRACE) which is planned as about 300 square metre aperture array with multiple large independent Field of View (FoV) capabilities. The main objectives of EMBRACE are to demonstrate the technical and scientific potential of the aperture array concept using a low cost phased array station with the essential Square Kilometre Array (SKA) functionality. It will operate in the frequency band 0.4 – 1.6 GHz and will have at least two independent and steerable beams. An array of such a size can function as a radio astronomy instrument whose sensitivity is reasonably close to that of a standard 20-m diameter parabolic dish. The collecting area also represents a significant percentage (≈8%) area of a final individual SKA "station" when based on the aperture array concept. Therefore it is considered as a most challenging step towards SKA. As we are in the process of establishing the viability of aperture array technology for Radio Astronomy, the system design concept and configurations are presented in this paper.

Keywords: radio astronomy, phased array.

1. INTRODUCTION

The international radio-astronomy community is currently making detailed plans for the development of a new radio telescope known as the Square Kilometre Array (SKA). This instrument will be two orders of magnitude more sensitive and will have a much larger FoV than radio telescopes currently in use. It will operate in the 100 MHz to 25 GHz frequency range. Many institutes around the globe are considering the design of SKA antennas using parabolic and cylindrical reflectors as the collecting area, the properties of which are well known within the radio community. The novel antenna concept proposed by the Europeans for the SKA is the dense aperture array [1], in which elementary antennas are densely-packed and connected together with beam-forming circuitry. This is the most innovative concept under investigation for the SKA, and it offers unique features and potential opportunities for future growth in radio astronomy.

In this paper, we present a detailed description of the EMBRACE system concept, the requirement specification, the tile design and configuration. A brief overview of the proposed possible scientific test plan is also included.

2. EMBRACE SYSTEM CONCEPT

The EMBRACE system will be built on similar principles as used for THEA [2]. A large number of antenna tiles, each of area around 1 m^2, will form the collecting area. The signals from the integrated elementary radiating elements from each tile will be amplified and initial RF (i.e. analogue) beam forming will be applied. Here a trade of between FoV and required receivers per square metre is a fundamental issue. This property plays an important role in the optimisation of the design for cost. A tile may be split into quadrants, due to the limitations imposed by the use of phase shift control with large instantaneous bandwidth requirements. The outputs of these quadrants are then combined with time-delay units. Digital beam forming will not be integrated at tile level but this digital processing takes place at a central place near the station.

A system level block diagram is shown in Fig. 1, indicating the formation of two independent fields-of-view at the tile level and at the aperture array "station" level. Channel selection, digitisation and remaining digital station processing is done at a central back-end. The tile beam signals are transported to a central

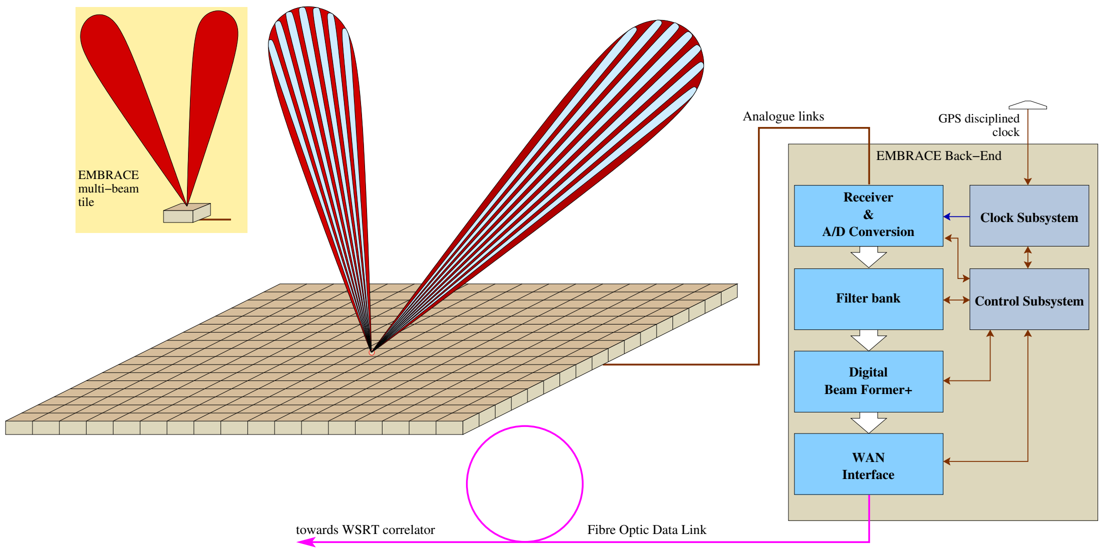

Figure 1: A system level block diagram of EMBRACE showing the formation of independent multiple fields-of-view at both the tile and station level, with processing at the back-end

station back-end using analogue RF links. For the analogue link we are pursuing an RF-on-fibre approach where the RF signal modulates a laser directly. However each photonic solution has to be competitive with an electrical RF transport implementation, which forms currently a viable cost effective option.

In the current EMBRACE system architecture the approach is to use distributed units with only just the essential functionality and integrating the more complex functions at a central (non distributed) facility. The approach with central receivers and digitisation, has the advantage that the local oscillator and clock signals have to be distributed inside the station back-end cabinet only. For EMBRACE, a low IF receiver architecture has been adopted. After frequency conversion, digitisation takes place at low IF. Next, the filter bank divides the signals in narrow band channels with a bandwidth suitable for the digital beam former given the size of the array. The resulting station output beam signals are transported using digital fibre optics towards a central correlator. The EMBRACE beams will be correlated against the Westerbork Synthesis Radio Telescope (WSRT) signals using the WSRT correlator.

3. EMBRACE REQUIREMENT SPECIFICATION

In Table 1 the specifications for the key parameters of the EMBRACE system are given. From the collecting area and a $\lambda_0/2$ spacing at a suitable frequency, it is estimated that in the order of 20,000 antenna elements will be required. The final element spacing should be determined in order to optimise the array performance over the frequency range. The system will be built with tiles approximately of 1×1 metre size although larger building blocks will also be considered. A low minimal instanteneous bandwidth has been chosen since this is sufficient for compatibility with the (WSRT) correlator back-end. However, the current design provides 80 Mhz bandwidth and proper phase shifter application in combination with time delays enables bandwidths over 300 MHz.

Table 1: EMBRACE key parameters

Frequency range	500 – 1500 MHz
Polarisation	single linear polarisation
Physical collecting area	300 m^2
Aperture efficiency	> 0.8
System temperature	< 100 K @ 1400 MHz
Instanteneous bandwidth	> 40 MHz
Number of independent steerable RF beams (FoVs)	2

4. LOW COST ARRAY DESIGN

The effort regarding the array design shall focus on the selection and optimisation of a suitable antenna element, balancing electromagnetic behaviour, mechanical manufacturability and cost. Cost is an important parameter. A suitable element, known as the Vivaldi radiator has already been identified. Much work on this element has already been completed at ASTRON. The work will therefore concentrate on the integration of Vivaldi elements with LNAs, phase shifters and other components to produce a design which will give low noise and low cost design for the array.

The signal transport distance between element and amplifier has to be small such that resulting loss shall not dominate the noise performance. Therefore, a low noise amplifier has to be placed behind each element, close to element excitation. This implies distribution of these amplifiers, so high scale integration is not a suitable technique for the first amplifier in each signal path. However, low cost design implies the use of high scale Integrated Circuit techniques as soon as possible in the signal path. Therefore, the gain of the first amplifier shall be just high enough to define the system temperature and after the LNA the signals have to be transported to a central place in a tile where Integrated Circuits can be deployed. A fundamental problem is related to these distributed amplifiers. The gain of an LNA cannot be too large. Too much gain can lead to instability, since the antenna with feed structure connected to the LNA may resemble a perfect resonator at out of band frequencies. Furthermore distortion has to be taken into account. As soon as the received signals are transported to a central place within a tile, high scale integrated circuit technology shall be applied.

5. RF BEAM FORMER

The ultimate all sky beam former requires the highest density of digital receivers with corresponding demand on digital signal processing and signal transport. By means of RF analogue beam forming the required density of digital receivers can be reduced and therefore balancing costs and FoV. In EMBRACE, RF analogue beam forming is used to reduce the cost while demonstrating the flexibility in FoV.

One of the key aspects of EMBRACE is the ability to form multiple independent beams. Only two beams are considered for EMBRACE, however without loss of generality, more beams can be integrated in a tile by scaling the beam former. The RF beam former will be optimised for noise level and dynamic range by optimising the gain budget along the signal path. It may be convenient to combine tile beams at a second level of beam forming. Inter tile beam formers may be used to further reduce the number of required digital receivers. The multiple independent beam feature makes the dense aperture array instrument a *multi-user* instrument. The effective observing time can be expended without loss of sensitivity simply by providing more electronics and computing power to create more beams.

6. EMBRACE TILE ARCHITECTURE

The tile provides the physical area to receive the incident electromagnetic waves in the required frequency range with a single polarisation. It hosts the receiving elements, low noise amplifiers and an RF beam former as well as interface electronics for signal transport and control.

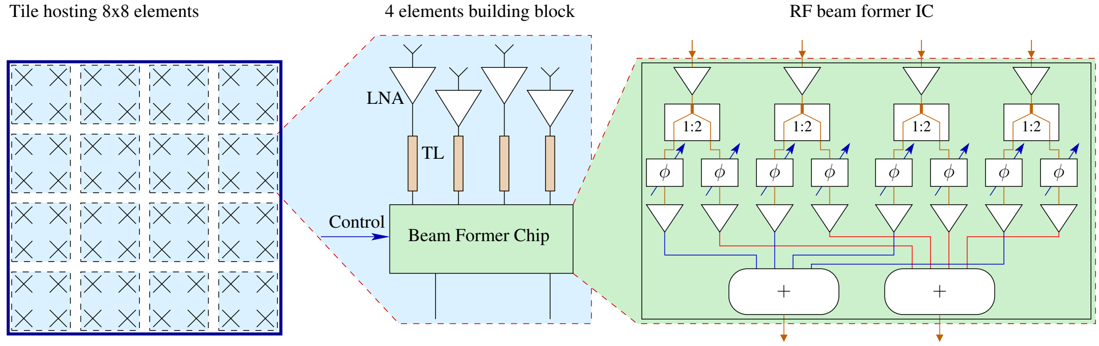

Figure 2: EMBRACE tile front-end architecture

Fig. 2 gives an overview of the tile front-end architecture. It shows a 4 elements building block which is based on a large scale integrated beamformer IC with 4 inputs and 2 beam outputs. In each tile the 16 building blocks are further combined and the resulting 2 RF output beams are transported to the central facility. A first proto IC has been designed in a GaAs process. Currently this design is ported to a silicon process to enable even larger integration density.

7. TEST PLAN FOR EMBRACE

The EMBRACE instrument of about 300 m^2 will be built close to the WSRT as this strategy offers several advantages:

1. It will allow the use of existing infrastructure to speed up the validation process of EMBRACE;
2. The WSRT correlator has four available spare signal channels allowing several configurations to be tested. One example can be 2 beams formed with 2 WSRT sub-arrays of 7 telescopes correlated with the two independent FoVs of EMBRACE;
3. It will also allow for access to a 10 Gb/s fibre link for real time data transport to the Joint Institute for VLBI in Europe (JIVE), data processing centre, allowing Very Long Baseline Interferometer experiments;

It will serve as a first testbed for high resolution multi fielding astronomy. A possible location for the siting of EMBRACE at Westerbork is shown in Fig. 3. The positions of the existing telescopes are clearly visible; the EMBRACE proposed site is located approximately 1 km to the south of dish no. 10.

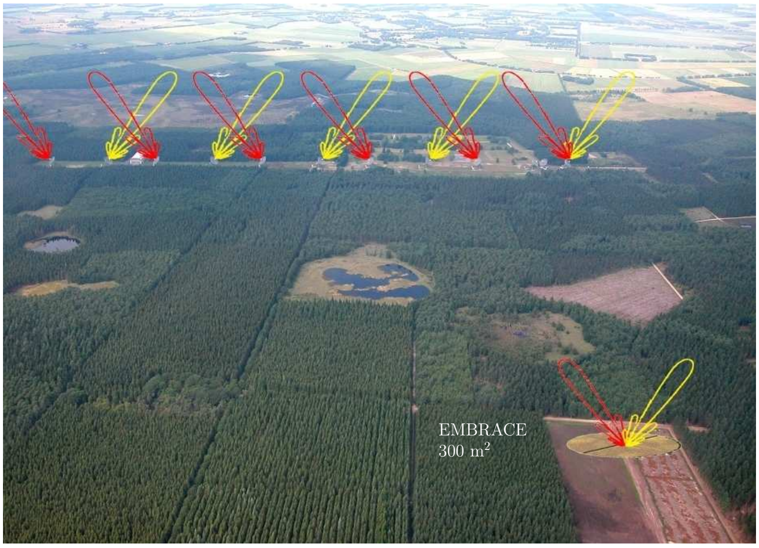

Figure 3: Possible location for EMBRACE at Westerbork

8. CONCLUSION

We have presented a description of the EMBRACE demonstrator, which is next in a series of demonstrators designed and demonstrated here at ASTRON, leading towards our ultimate goal of achieving the Aperture Array station for the SKA. Whilst the concept of simultaneous multiple beams has been shown conclusively with the THEA demonstrator, this phase of the demonstrator will concentrate on the low cost production aspect of designing phased arrays and provide concrete experience of operational issues associated with large phased arrays.

References

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