

The European Aperture Array SKA Demonstrator – Electronic **M**ulti**B**eam **R**adio **A**stronomy **C**onc**E**pt (**EMBRACE**)

1. Executive Summary:

In this paper the European Aperture Array demonstrator project plan is described. The European demonstrator is denoted as the **E**lectronic **M**ulti**B**eam **R**adio **A**stronomy **C**onc**E**pt (EMBRACE) which is planned as a 625 square metre aperture array with multiple 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 in combination with the Westerbork Synthesis array.

The EMBRACE project is embedded in a bigger framework project known as SKADS (SKA Design Studies). The SKADS Consortium, consisting of 32 institutes from around the globe, has submitted a research proposal to the European Commission under the Sixth Framework Programme (FP6) to further develop and demonstrate the Aperture Array concept suitable for the SKA, to develop and select the enabling technologies and to arrive at a system design for the SKA. Other demonstrator aspects within SKADS are related to exploring the multi-fielding potential for cylindrical arrays in collaboration with Australia (SKAMP project).

This paper will describe the details of the proposed project plan for EMBRACE. We also respond to the key technology related questions raised by the IEMT, the demonstrator extension to a full SKA concept and the cost related issues.

2. Introduction:

It has been agreed internationally that an SKA should cover the frequency range ~0.1 to ~20 GHz which is likely to involve at least two technologically different antenna concepts with as large an amount of common infrastructure for the data transfer, signal processing and data analysis systems, as feasible in view of the overall system costs and operational desirability. Here we will only consider the aperture array antenna concept in detail.

The European SKA Consortium has adopted the aperture array concept [1-6] as most promising to cover the science goals associated with observations to be conducted at low frequencies (0.1 – 2,0 GHz). In this concept beam pointing to the radio-source is electronically controlled over large scan-angles while interferers can be suppressed adaptively. By multiplying parts of the electronic subsystems such as station receiver chains and array correlator by, say M , simultaneous and independent reception of widely separated directions is possible without the need to multiply the basic mechanical structure. This in effect, corresponds to creating multiple Fields Of View. For example, for key science program like HI surveying this capability enhances the mapping speed in proportion to M .

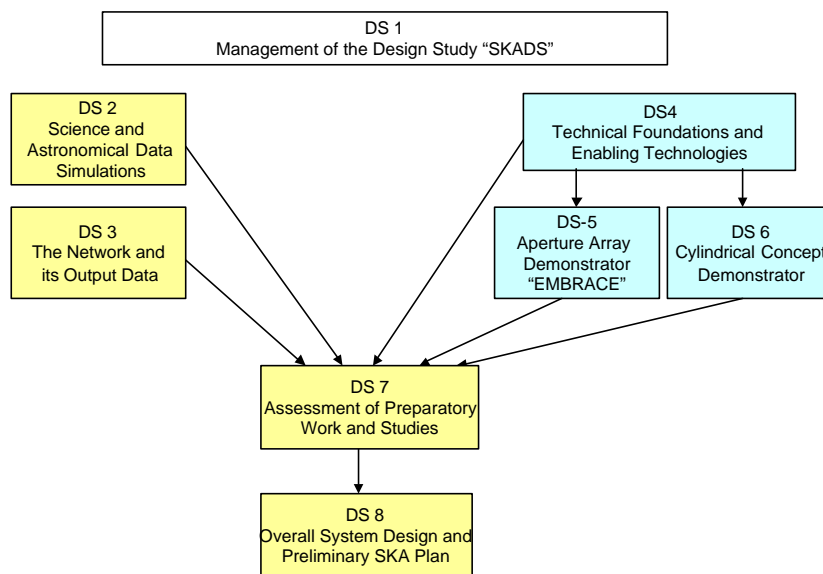
In the specific aperture array concept chosen, the aperture field of the incoming radiation, is sampled by a 2-D array of independent receivers at close range such that the distance between the neighbouring elements is half a wavelength at the highest frequency only. Hence the name dense aperture array. To compensate for the increasing Galactic noise at lower frequencies, a three band array has been chosen with increasingly larger collecting area. Table 1 summarises the partial but important performance parameters of the aperture array concept.

3. Overview of the SKADS proposal

The basic aim of SKADS is to establish cost-effective technologies appropriate for key low-frequency range science goals. The SKADS programme goes beyond the European SKA

demonstrator, i.e. it already has focus on SKA after EMBRACE. The European concept aims at the lower end of the SKA spectrum 0.1 – 2GHz where most other concepts may be less appropriate.

The SKADS program has been structured as a series of strategic *Design Studies* (DS) including both feasibility studies and technical preparatory work. The feasibility studies (organised in DS2; DS3; DS7; DS8) are “paper” exercises relevant to the design and costing of the SKA network and infrastructure, the overall assessment and a project plan. The technical preparatory work (structured in DS4; DS5; DS6) mainly involves hardware R&D associated with establishing the cost-effectiveness of our specific solution for an SKA “station”. Each of these *Design Studies* has been sub-divided into coherent *Design Study Tasks* with clear aims, milestones and deliverables. A schematic overview of the SKADS program is depicted in Fig. 1.



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Figure 1: The main linkages of the Design Studies within SKADS. The feasibility and assessment studies DS2, DS3, DS7, DS8 are shown in pale boxes. The technical preparatory work (DS 4, DS5, DS6) are shown in dark boxes.

The Design Studies will address the following aspects of the SKA:

- The management of Design Studies “SKADS” (DS1);
- The development of instrument specifications based on a quantification of key science drivers and a study of the technical requirements associated with the delivery of the science (DS2);
- An end-to-end study of the network, data handling and physical infrastructure from collection to the delivery of data to the astronomical users and its efficient use by them (DS3);
- The design of a cost-effective antenna system comprising an SKA station capable of forming beams in many directions in the sky simultaneously and independently. This will involve a range of R&D to develop the technical foundations and enabling technologies (DS4);
- The construction of an engineering demonstrator low frequency array resembling our vision of an SKA station and exploration of the practical issues involved in multi-beam acquisition and signal-processing concepts (DS5);
- The operation of links in SKADS (using the European research fibre network GÉANT) to join a number of SKADS multi-beaming demonstrators separated by distances up to many hundreds of kilometres, to demonstrate the high angular resolution imaging capabilities required by the SKA community (DS5);

- The application of phased array technology in the focal plane of mechanical field concentrators. This already takes into account the hybrid potential of aperture array technology (DS6);
- A continuous process of critical technical assessment and evaluation of all aspects of the SKADS programme(DS7);
- An overall system design (involving technology foresight) and a preliminary, multi-component plan of how to realise the SKA (DS8).

Europe already has a lead in radio astronomy applications of phased array (aperture plane) technology [7-14], and in this study we wish to build on this in the context of the SKA. A principal goal of the study and its proposed demonstrator programme is to establish the viability of aperture plane array technology for radio astronomy for the first time. We therefore intend to build a >600 m² phased array EMBRACE (Electronic Multi-Beam Radio Astronomy Concept), intended to demonstrate multiple, independent beam-forming capabilities of a quality appropriate for radio astronomy, and to demonstrate the ability to produce higher resolution beams using aperture arrays separated by long baselines (DS5). This promising, albeit technologically least mature concept, constitute breakthrough technology not being pursued elsewhere in the radio astronomy community. The EMBRACE array will be demonstrated working with the existing WSRT equipment.

The SKADS collaboration intends to study a second, solution involving cylindrical reflector for intercepting and focussing the incoming radiation (DS6). The hybrid application of aperture array technology is key here. Cylindrical antennas are long established in radio astronomy but the new options of digital beam forming and the use of phased arrays along their line-foci, offers the promise of a major improvement in their capabilities. Although not as flexible in principle as the aperture array concept, cylindrical reflectors with phased-array feeds, potentially offer a cost-effective way to obtaining the large sky coverage for the low-frequency survey science we are aiming at. A basic aim of this Design Study is, therefore, to compare and contrast possible technology solutions for our astronomical aims. The demonstrator part for this concept, BEST, will be situated in Medicina, Italy. This part of the program ties in with the Australian (USydney, ATNF/CSIRO) SKAMP project.

Although two demonstrators are being studied, the emphasis of the SKADS proposal is put on EMBRACE of which smaller versions will be located at Oxford, Cambridge in the UK and Nancy in France.

4. Aperture Array Demonstrator 'EMBRACE'

The aim of the EMBRACE technology demonstrator is to provide sufficient and detailed information regarding the phased array concept performance and the back end processing infrastructure, in order for the ISSC to evaluate its suitability for the SKA, around the 2008 time period.

4.1 Concept of Sparse and Dense Arrays

When designing a phased array, the optimum element separation, in both planes is given by the well-known equation:

$$d = \lambda / (1 + \sin(\theta))$$

Where d = elemental separation
 λ = wavelength of the operating frequency
 θ = maximum scan angle

Normally, the elemental separation is chosen such that the number of elements are minimised for a given aperture length and for a given scan requirement in a particular plane. The optimum separation is such that the grating lobes remain within the 'invisible region' for the maximum required scan. Normally, there are further refinements of the exact elemental separation, so as to avoid any significant beam broadening from one end of the frequency

range to the other. The elemental separation of the majority of the 'practical' phased arrays, therefore remain within $\lambda_0/2 \leq d \leq \lambda_0$. We have termed such phased arrays as 'Sparse Arrays'. In astronomical imaging using a synthesis arrays however, grating lobes are not necessarily problems.

For a phased array, such as EMBRACE, the frequency range is required to span several octaves, presents a challenge to the antenna design engineer. In this case, we design the array such that the elemental spacing is $= \lambda_0/2$, at the highest frequency. The electrical length at other 'lower' frequencies is therefore smaller than $\lambda_0/2$, as the frequency is decreased. This scenario therefore is equivalent to the over sampling case, encountered in many branches of science, and in particular is related to the reflector antenna design, where the aperture plane is required to be sampled at $\lambda_0/2$, when computing the radiation patterns from the integration of the aperture field within the projected aperture plane of the reflector. We have defined the phased arrays of this type as 'Aperture Arrays'.

Despite the above definition, it is most likely that EMBRACE will be designed with its separation at $\lambda_0/2$ at slightly 'lower' frequency, so as to optimise on the number of elements and hence achieve significant reduction in the cost.

4.2 Partial EMBRACE design drivers

For the purpose of the demonstrator, we have defined the specification, broadly based on the SKA requirements as given in [15] on the one hand and the next step beyond THEA on the other.

Frequency range of receiver chain:	400 MHz - 1550 MHz.
Element separation:	$\lambda_0/2$ at 1GHz
Polarisation:	Single polarisation
Physical collecting area A_{physical} :	25 x 25 m ²
Aperture efficiency:	>0.65
Electronic scan range:	Full hemispherical
T_{sys} :	<100deg K @ 1GHz (aim for 50degK)
Antenna element phase control:	4 bit
Instantaneous Bandwidth:	40 MHz
Dynamic range AD converter:	60 dB
Number of independently tuned FOVs (beams):	2
Number of digital beams:	8 of 20MHz per FoV

Table 1. Main EMBRACE Specifications

4.3 Project Plan for EMBRACE

The proposed project plan for EMBRACE is given below in figure 2 with brief explanation of some of the activities contained within the proposed project plan.

A key feature is the modular approach of our EMBRACE tile design that allows us to complete and evaluate a functional prototype tile in the first year using conventional technology. A separate production prototype tile will be enhanced with the proper elements like MMICs and low cost receptors.

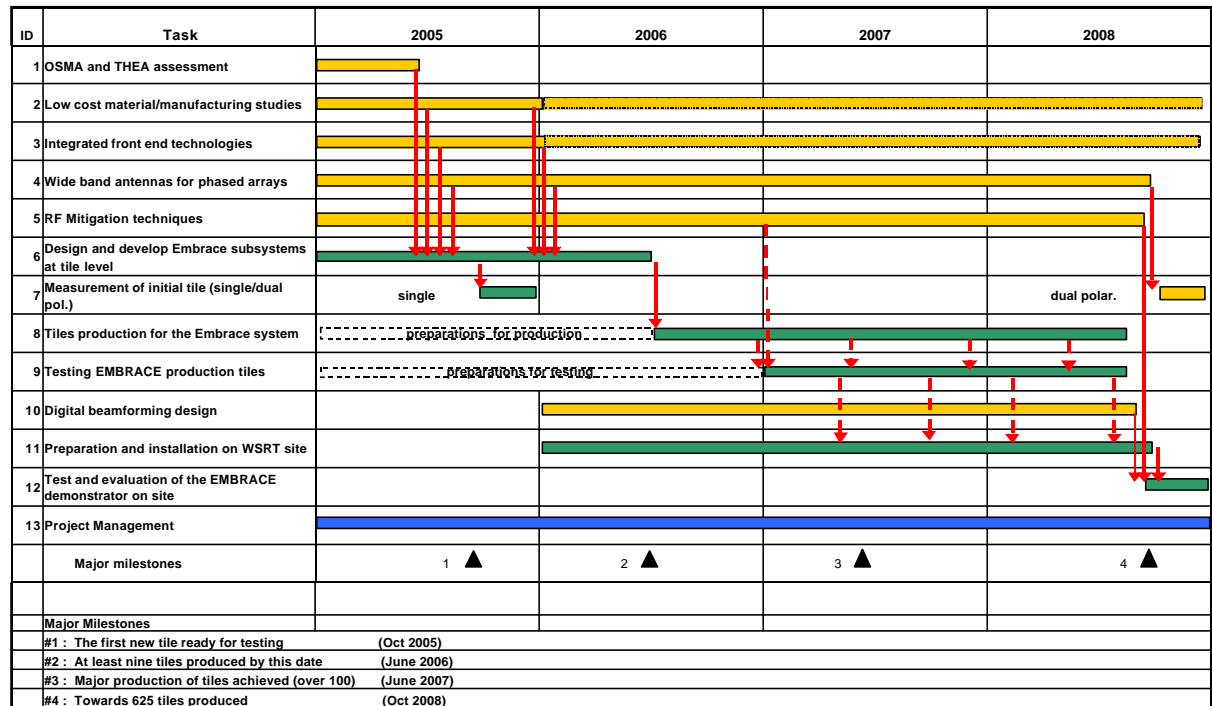


Figure 2: Proposed EMBRACE Technology Development and Demonstration Project Plan

4.4 Activities for the proposed Demonstrator Project Plan

Within the Project Plan there are many studies related to the technology evaluation programme, which will have immediate impact on the EMBRACE demonstrator and there are other studies, which will be most beneficial for the future SKA program, such as wideband, wide angle scanning, dual polarised low cost tiles. Both types of activities are considered within the Project plan and are outlined below.

1. One Square Metre Array (OSMA) and Thousand element array (THEA) Assessment:

A significant amount of work has already been done at ASTRON for the last six years or so and a considerable level of expertise exists. It is only prudent to capitalise on the existing expertise, which resides there. The principle studies will involve:

- A. To evaluate and assess the work which could be used for new EMBRACE tiles.
- B. To collate reports, software and hardware which could be useful for building of new EMBRACE tiles.

Milestones/Deliverables:

- To produce an assessment report on the work done to date. June 2005

2. Low cost design and manufacturing aspects:

The objective of this study is to invest in low cost manufacturing and design aspects in order to severely reduce the cost of a tile. Several studies will be initiated during the course of the work and the result will be used to achieve a low cost design of a tile. The principle studies will involve:

- A. Investigate low cost material for antenna design
- B. Study low cost manufacturing techniques
- C. Study low cost connector technology

Milestones/deliverables:

- Report on low cost material suitable for microwave circuits December 2005
- Mid term report on low-cost manufacturing techniques June 2006
- Report on connector technology June 2007
- Final report on the low-cost technologies December 2008

3. Integrated front-end technologies: to develop active semi-conductor devices and rf amplifier systems optimized specifically for aperture array applications. The goals will be to combine low noise, high linearity and low power dissipation with manufacturability and low-cost. The principal deliverables of the programme are:

- A. LNA integrated with the Vivaldi array elements as an interface to the RF beamformer. Low noise is essential and needs to be complemented with wideband high dynamic range performance. Also it is important to design an LNA with the correct gain characteristics.
- B. Integrated rf beam former circuit for nine inputs and two beam outputs with 4-bit range over the frequency band.

Milestones /deliverables:

- Evaluation report on first test run December 2005
- First production runs December 2006
- Final Technical Report on integrated Front-end Technologies December 2008

4. Wide-band antennas for phased arrays: to develop "patches" of wide-band, low-cost, antenna elements for dual-polarised, close-packed phased arrays without "groundplanes" and to optimize their rf performance The principal objectives are:

- A. to model and to characterise the properties of an over-sampled array of antenna elements paying attention to the effect of cross-coupling within a tile and with other tiles and its effects on the beam pattern and on the system noise performance;
- B. to develop cost-effective solutions for connecting MMIC receiver components to an antenna element and optimizing the coupling between them;

Milestones/deliverables:

- Evaluation report on prototype low cost dual polarised Antennas October 2005
- Evaluation report on prototype preproduction tiles March 2006
- Final Technical Report on Wideband Antennas for Aperture Arrays December 2008

5. **RFI mitigation:** to devise practical realizations of methods for ensuring RFI robustness and high data quality from an SKA station and to study solutions for the SKA as a whole. The programme will take into account the cost-effectiveness of the solutions given the different RFI environments at the potential sites.

Milestones/deliverables:

- Interim- report on Implementation of RFI Strategies December 2005
- Mid-term report on Implementation of RFI Strategies December 2006
- Final report on Implementation of RFI Strategies in December 2008

6. **Design and develop and demonstrate sub-systems:** to evolve the current patch-level architecture of the phased array concept-demonstrator THEA into the “second generation” architecture required for a ~625m² array – EMBRACE. The principal objectives are:

- A. to develop the design for the station Digital Processing including the station correlator;
- B. to develop the tile architecture and produce prototype tiles (1).
- C. On the basis of the experience gained in B, produce further 8 tiles.

Milestones/deliverables:

- New EMBRACE tile completed by October 2005
- Up to nine EMBRACE tiles completed by June 2006

7. **Measurement of initial new tile (single and dual pol) :** to measure the performance of the new EMBRACE tile and report on the readiness of the tile development for production.

Milestones/deliverables:

- Measurement report on first EMBRACE tile in November 2005.
- Measurement report on first dual polarised tile Oct 2008

8. **Tile production for the EMBRACE system:** to build more aperture-array demonstrator tiles. The principal objectives are:

- A. to produce the Station Digital Processing on a larger scale,
- B. to produce the remaining low cost tiles,

Milestones/deliverables:

- Completion of more than around 100 tiles June 2007
- Completion of more than 600 tiles October 2008

9. **Testing EMBRACE production tiles:** to test the tiles as they are produced in a fairly large scale. The objective here is to test the tiles as they are produced in preparation for mounting at the Westerbork site.

Milestones/deliverables:

- Completion of testing the production tiles and transporting the tiles to Westerbork.(December 2008)

10. **Digital beamforming design:** to understand the signal conditioning requirements. The work programme will involve study and hardware testing of modules to explore the following issues:

- A. the desire for early digitization → more flexible but more processing power required;
- B. the dynamic range of A/D converters
- C. the optimum number of bits required at various stages in the data stream
- D. the low-power, low-cost requirements of electronics
- E. the efficiency of up-down conversions
- F. cost-effective poly-phase filtering for signal shaping
- G. to measure the rf performance over a range of operating temperatures

Milestones/deliverables:

- Interim- and Final Technical Report on Signal Conditioning and Digitisation June 2006
- Final Technical Report on Signal Conditioning and Digitisation December 2008

11. **Preparation and installation of WSRT site:** to carry out site clearance and install the necessary utilities in preparation of siting the measured tiles as they become available for system level testing.

Milestones/deliverables:

- Interim report on Westerbork site development plan June 2006
- Mid-term report on Westerbork site development plan December 2007
- Final report on Westerbork site development plan December 2008

12. **Test and Evaluation of the EMBRACE demonstrator at the Westerbork site:** to compare the performance of the EMBRACE arrays with that of current radio telescopes and to look ahead to the SKA requirements. The astronomical tests should be fully-quantitative. The principal objectives are:

- A. to establish the *total intensity* beam forming capabilities of the 625m² EMBRACE in comparison with that of a “standard” 25m radio telescope of comparable collecting area;
- B. to establish the *complex voltage* beam-forming accuracy of EMBRACE by operating part of a well-understood short-baseline interferometer (the WSRT). For these tests the existing WSRT correlator can be used.
- C. to test the wide-area network (hundreds of km) aspects of the SKA design by feeding multi-EMBRACE data into the European VLBI Network (EVN) correlator at the Joint Institute for VLBI in Europe (JIVE; the Netherlands) acting as a model for the central processor within SKA. These tests will require the modification of VLBI digital hardware currently being developed and will involve the practicalities of the data transport via a public network (GÉANT).

Milestones/deliverables:

- Complete the Technical and Astronomical Assessment and Performance Report December 2008.

13. **Project Management:** to oversee the activities within the project and provide cost and technical information to the ISSC at the end of the project for evaluation and comments.

Milestone/deliverables:

- Complete the cost analysis and technical evaluation and provide the data to the ISSC for SKA concept evaluation Oct 2008.

5. Further questions from IEMT’s October 2003 report.

There are two further questions asked by the IEMT[16]. They are:

(i). The proponents’ comment about the harsh RFI regime at lower frequencies is a good one and one may expect to learn much from the 75 m demonstrator. Some of the practicalities of broad angle receptors, low-cost receivers and limited-resolution quantizers are better dealt with in the context of real-world experiments rather than theoretical projection, if only because of the complex nature of most RFI environments. It would be useful to begin more immediate experiments with practical hardware, especially as the results are applicable across a range of SKA concepts.

Reply:

The Thousand Element Array (THEA) demonstrator has been designed and tested in an RFI environment that is similar to the WSRT. Both Dwingeloo and Westerbork are located at about 15km distance from a TV transmitter. There is however a large difference of the EM field intensity at ground level and the intensity at 20 meters above it. Also the antenna element pattern has a low gain at elevation angles close to the horizon. RFI power levels with THEA and the power levels in a reflector system of the WSRT can differ as much as 20dB. At the THEA evaluation site, RFI levels have been measured with maximum carrier signals of -55dBm. These levels have led to a system specification of THEA, for the 2nd and 3rd order Input Intercept Points. In particular the IIP2 specification is more severe due to the large frequency bandwidth of the system and could not be realized with off-the-shelf components. IIP3’s realized with THEA complied with SKA requirements, inter-modulations products below

-135dBm/Hz. IP2 often gets less attention since majority of high volume RF applications are small narrow band and IP2 becomes irrelevant for the front end part of the circuits. However, for SKA IP2 is crucial. For the realization of the IIP2, with about 15dB improvement, dedicated (differential) components should be developed.

(ii). *The choice of four FOVs per band is interesting. It would be useful to examine more widely the economic arguments for this choice, perhaps by deriving a function describing the array cost with number of FOVs, assuming the total sensitivity remains constant. In other words, what are the economics of trading number of FOVs for effective area?*

Reply:

The aperture array concept uses RF beamforming per tile, which limits the FOV to 0.05 steradians at the highest frequency of the mid and high tiles and provides 25% bandwidth. In each field a number of digital station beams is formed to provide sufficient sky coverage. There are four of such RF beams for each array to support 12 independent directions and frequencies to be observed simultaneously.

We have computed the cost versus the number of beams (FOV), with the total sensitivity remaining the same and is given below in figure 3.

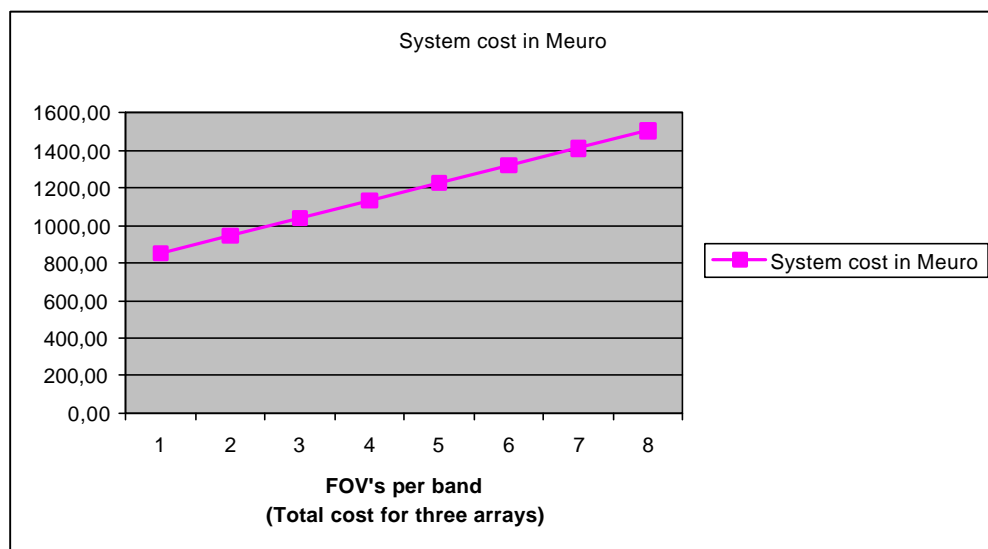


Figure 3: Cost versus number of beams (FOV) of the Three-Band array as shown in Geraldton 2003

The total cost for the Aperture Array has been computed as we increase the number of beams. Please note that this is the total cost for the three array concepts proposed earlier [1]. It includes the cost of further signal processing required as the number of beams are increased. Also note that in the event that the number of antennas needed to cover the low frequency bands are reduced by increasing the bandwidth of the radiators, then there will be proportionate reduction in costs.

Another approach would entail the so-called Two-Band approach. In this case, we have assumed that the lowest band (up to about 200MHz) is covered by a sparse array in (low cost) LOFAR technology and that technology improvement allows to increase the frequency ratio per band to be about three (so far we have assumed about 2.4).

Also, we have increased the receiving area of the highest (out of the two) band to conform to the A_{eff}/T_{sys} requirement of 20000 from 500Mhz to higher frequencies. Resulting cost- and sensitivity curves are shown in Figures 4 and 5 below respectively.

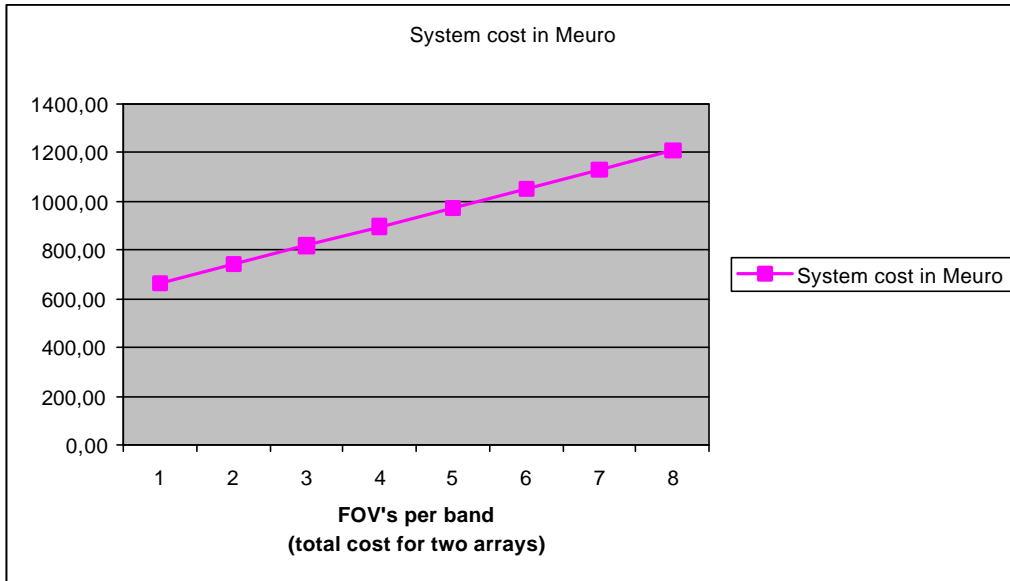


Figure 4: Cost versus number of beams (FOV) of the Two-Band aperture array

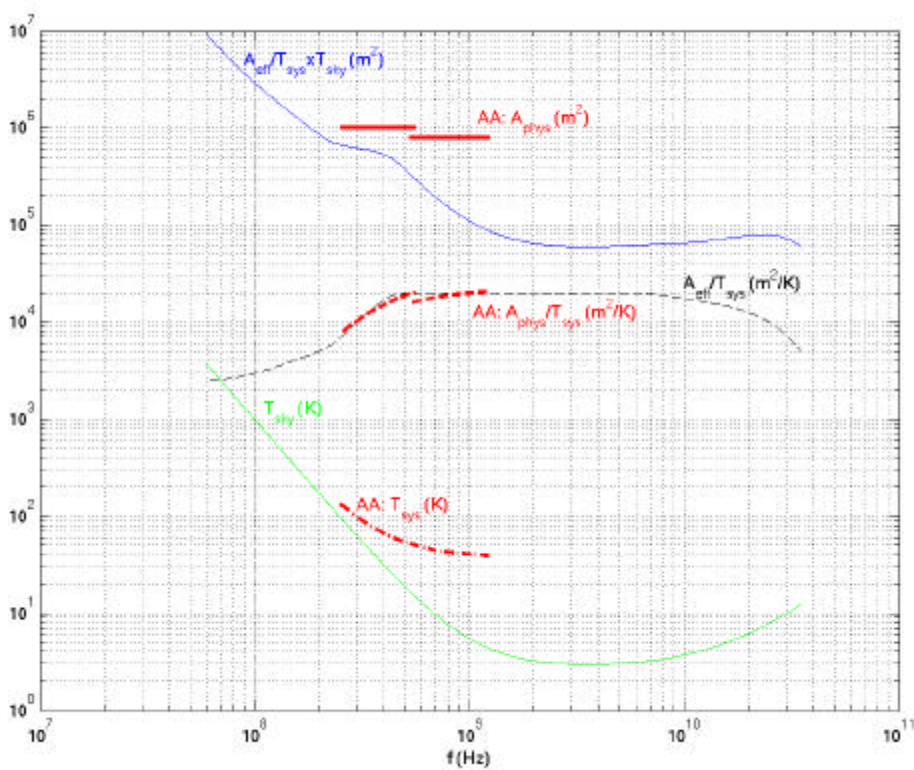


Figure 5: Sensitivity curves of the two-band Aperture Array. Also shown is the collecting area in sq. meters and the system noise in K. Further optimization is possible without increasing cost e.g the frequency range can be extended from about 200 to 1500MHz (not shown) as it is possible to use the array in a frequency range where the distance between elements is larger than half the wavelength at the expense of decreasing sensitivity.

The lower bound for the minimal detectable flux with an interferometer follows from

$$S_{\min} \geq \frac{k \cdot T_{\text{sys}}}{A_{\text{eff}} \cdot \sqrt{B \cdot t}}$$

where k is Boltzmann's constant, T_{sys} is the system temperature of the stations forming an interferometer pair, A_{eff} is the effective aperture of each station, B is the bandwidth of the signal which is correlated and t is the integration time.

It is important to understand that multiple FOVs do not alter the instantaneous sensitivity ($A_{\text{eff}}/T_{\text{sys}}$) of the instrument, which is the primary SKA specification. As long as this sensitivity may not be compromised, multiple FOVs cannot be treated for sensitivity.

The economics of the optimum choice for four beam sets follows from the analysis of the cost graph given in figure 2. An increase in total cost by a factor 1.35 (from a single to a four beam solution) results in a survey speed increase of a factor 4 or a factor 2 in survey sensitivity. Rescaling the whole array to the initial cost will still give a survey sensitivity improvement of a factor 1.4, although the sensitivity with a single beam is then reduced by a factor 1.35. A further increase to eight beams requires an additional cost increase factor of 1.3 but provides only a factor 1.4 in survey sensitivity. After rescaling to the original cost we lost an additional factor 1.3 in single beam sensitivity and gained only 1.1 in survey sensitivity. We clearly passed the point where the marginal performance over cost ratio for additional beams is larger than unity.

6. Scalability to SKA

The Aperture Array concept phased array will be designed using an infinite array approach, which in this case is a viable method, as the number of radiating elements involved for the demonstrator is in excess of 50,000 elements.

The entire demonstrator will be made up of small tiles of approximately 1m x 1m (final size yet to be determined) and therefore will contain 625 such tiles. Once the combined number of tiles to form an antenna is greater than about 10 tiles, the antenna performance will be very predictable as more and more tiles are added. Furthermore, extending this concept to an antenna with a much larger size than the demonstrator antenna, i.e. towards the size of SKA antenna, will be a much easier task, as scaling will involve adding more tiles to make the antenna behave more and more like an infinite array.

Designing the demonstrator using small tiles brings further benefits in terms of costs as economy of scales can be applied, as more manufacturers may be able to bid to manufacture the antenna subsystem.

We appreciate that the demonstrator is a single polarisation antenna whereas the SKA antenna requires dual polarisation. Within the SKADS proposal, there is a task activity, which is specifically aimed at designing a dual polarised tile. By the time the demonstrator is completed, we will have also completed the dual polarisation tile development programme, ready for inclusion in the SKA programme.

Furthermore there exists a possibility that even with tiles polarised only in one polarisation, it may be possible to rotate the adjacent tiles to demonstrate a degree of dual polarisation with the EMBRACE demonstrator.

7. Hybrid opportunities

There are six demonstrators being considered as possible antenna options for the SKA. Five of these are reflector based either parabolic or cylindrical in shape. The reflector based antennas are more suited for higher frequency range i.e. > 1GHz, although the cylindrical reflector is also being considered for the low frequency application. These reflector based antennas are therefore perfectly suited for the higher end of the SKA frequency region. We believe the Aperture Array on the other hand is perfectly suited for the lower end of the SKA

frequency region. The Aperture Array concept therefore offers maximum opportunity for forming a hybrid antenna with any of the other five reflector based antennas for SKA. In fact the ISSC has selected the Aperture Array concept with Large Number Small Dishes as a possible hybrid for further analysis. This hybrid will soon be submitted to the ISSC for further evaluation.

8. Present activities in SKA e.g. Faraday and Pharos

Besides the phased array activities the European Institutes are involved in two focal plane array (FPA) projects. Within the EU project Faraday, ASTRON is building an FPA in the frequency band of 2.5 to 5 GHz. This array should be capable of creating at least two closely overlapping beams, which will be a first demonstration of the possibilities of FPAs: The surveying speed of large reflectors can be increased by one or two orders of magnitude when the focal fields are sampled with a dense phased array. In a dense array consisting of a large number of antenna elements (100 up to 1000), multiple beams can be synthesised and steered electronically. This collecting and manipulating of the entire electric field in the focal plane creates the possibility of a simultaneously improvement in the efficiency of existing telescopes and open up wide fields-of-view.

In the second EU focal plane array project PHAROS, ASTRON with IRA (Italy), JBO (UK), MECSA (Italy), UBIR (UK), TCfA (Poland) from European institutes, together with CSIRO (Australia) to realize the next step. In a higher frequency band, 4 to 8 GHz more than 4 beams will be realized with a cryogenically cooled system.

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