Square Kilometre Array Design Studies

SKADS- Annexes

List of contents **Page Number**

Annexe 1: Description of the Design Study tasks 2
Annexe 2 : Gantt Charts for DS5 and DS6.. 7
Annexe 3: A letter of support from the Chairman of the SKA International Engineering Management Team (IEMT) 9
Annexe 4: A letter of interest from IBM (The Netherlands) 10

Annexe 1: Description of the Design Study tasks

DS2 Science and technical specifications (feasibility study) To establish the scientific requirements in a quantitative manner; to establish the capabilities of the observing system necessary to deliver them and thus to derive a quantitative set of design specifications.
DS2-T1 Science Simulations: to quantify the observational implications of principal science drivers recently established by the international community (see section 1). Provide estimates of the types, numbers, distributions and detailed properties of radio-emitting objects which the SKA will be able to observe, and quantify the uncertainties in these estimates. Provide results in the form of "model skies" into DS2-T2. DS2-T1 will give priority to the key science accessible in the frequency range 0.1-1.4 GHz but will work on all five of key scientific areas identified by the ISAC.
DS2-T2 Astronomical Data Simulations: to establish the optimal gross configuration characteristics of the SKA based on the .science quantification. process of DS2-T1. In particular, to develop models of the aperture array (DS5) and cylinder array (DS6) concepts within the context of the International SKA Simulations Group software development efforts. Particular attention will focus on dynamic range and image fidelity issues, especially those associated with the time dependent nature of the electronic beam forming reception pattern. Exploration of the SKA configuration (spatial distribution of antennas) that optimally satisfies the main requirements associated with the key, low-frequency science goals. In addition, investigate new calibration/imaging techniques and data reduction methodologies (appropriate to the enormous SKA data output rates) using the current and projected capabilities of distributed super-computing resources. Finally, to study the implications of SKA for future space VLBI missions and for precision spacecraft navigation.

DS3 The Network and its output data (feasibility study) To study the intra- and inter-station signal connection networks, the (central) data handling and the physical infrastructure of the SKA.
DS3-T1 Network Infrastructure and data transmission: to study the *practical* issues associated with producing the most cost-effective overall architectural design for the SKA "network" in order to satisfy the requirements established in DS2. The principal issues are: 1) the data transport system: commercial standards (e.g. giga-bit Ethernet and its developments) are likely to be the preferred solution for distances <1 km; directly-modulated opto-electronic devices can be used up to 5 km—vertical cavity laser devices (VCSELs) are relatively inexpensive and arrays of VCSELs are being developed so range and data rates are the issue here. The SKADS team already has extensive experience in designing long distance (>5km) optical fibre links and so cost-reduction strategies for the network will be the major issue here. 2) the clock and local oscillator distribution systems including the potential of opto-electronics; 3) the electrical power requirements of the system and the most cost-effective ways to deliver it; 4) the civil works required.
DS3-T2 Array data handling: distributed computing and real-time control: to study the optimal signal handling and data processing issues arising from with the enormous aggregate of data produced by all the SKA stations. The main concern will be the "central processor" (correlator) but we are in a new situation where one can distribute processing power throughout the system and the study will address the optimal distribution of this power and the most cost-effective technology for delivering it. The principal strategic issues are: 1) the cost equation and its derivatives for a range of technologies/architectures; 2) the potential upgrade routes, since SKA's scientific output will be limited by the processing power available at any given time; 3) the requirements of the real-time system software system and the cost of delivering it.
DS3-T3 Data reduction & analysis - "SKA for the user": to study the ways in which the data from the central processor can be most effectively handled and put to scientific use by the astronomer and the astronomical community. Principal issues are: *1) Development of distributed, GRID-enabled pipelined reduction*: traditional methods of end-user data reduction are not appropriate for the SKA—instead we need to mirror the distributed hierarchical nature of the telescopes with calibration/imaging similarly distributed. We will investigate the design and implementation of GRID-enabled distributed

software for these tasks. We will share knowledge with the LOFAR consortium and with gravitational-wave and particle physics groups.

2) Data products, archiving and scientific exploitation: Traditionally radio interferometers have delivered un-calibrated "visibility" data. What data products are needed and how should these be archived? How should the archive be structured in order to optimise scientific output? How do these considerations impact on the SKA design? The optimal extraction of sources is likely to involve pattern-matching against expected templates and will require accurate assessments of confidence in detected sources. (Interface to DS2). What should the interface to the Virtual Observatories be?

3) Observing modes and the user view of the SKA: Traditional use of telescopes has mostly followed the "peer-reviewed application for time", "scheduling of individual observations" and finally "analysis and exploitation by observers of specific projects". This is coupled with access to archive data. An alternative model is "undertake a systematic scientific programme" then "make data products available to all via a VO". What should be the model(s) for the SKA and what are the likely costs of each model in terms of end user support observatory costs etc. What are the impacts on scheduling. What are the implications of the telescope design?

DS3-T4 A study of siting and related issues: to study the interaction of the SKA technology and the selected location for the telescope. The task will involve close liaison with the International SKA Site Evaluation and Selection Committee (SESC). The task participants will provide detailed input to the SESC to assist in establishing appropriate site selection criteria for SKA that take proper account of the impact of site characteristics on various technologies. When the site is selected for SKA in 2006, the task participants will interact with SKADS engineers to ensure that SKADS design concepts are appropriate for the conditions at the selected site. Throughout the Study period the DS3-T4 ream will work with the ISSC and national and international authorities (e.g. the ITU) to maximise radio-quiet protection over the central site for SKA antennas. The task will involve theoretical studies, and on-site testing/monitoring of SKA technology in arid land environments to assess environmental conditioning solutions. The task will also involve assessing the radio-frequency background of candidate sites, as well as investigating reliability engineering, and plausible maintenance regimes. Finally the task will involve an environmental impact assessment.

DS4 Technical Foundations and enabling technologies (studies and hardware realizations of sub-systems) To establish the level of maturity of key technologies for a multi-fielding SKA; a make a set of technology selections; to identify the gaps where future work may be needed.

DS4-T1 Improved front-end technologies: to develop active semi-conductor devices and rf amplifier systems optimized specifically for radio astronomy applications rather than commercial and military one. The goals will be to combine low noise, high linearity and low power dissipation with manufacturability and low-cost. Achieving these aims involves a combination of materials and topology (lithography). The principal objectives of the programme are:

1) to develop new InP-based Pseudomorphic High Electron Mobility transistor (pHEMT) and Doped Channel Field effect transistors (DCFET) and MMIC circuits specifically for radio astronomy applications in the SKA;
2) to explore the possibility of significant improvement in device performance by tuning low noise, high voltage breakdown and high linearity;
3) to address the issues of "quantum manufacturability" (ie wafer uniformity and repeatability) for large scale production.
4) to measure the rf performance over a range of operating temperatures

DS4-T2 Aim: to understand the signal conditioning requirements relevant to either of the concepts in this Design Study. The work programme will involve study and hardware testing of modules to explore the following ssues:

1) The desire for early digitization → more flexible but more processing power required;
2) The dynamic range of A/D converters
3) The optimum number of bits required at various stages in the data stream
4) The low-power, low-cost requirements of electronics
5) The efficiency of up-down conversions
6) Cost-effective poly-phase filtering for signal shaping

DS4-T3 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.

DS4-T4 Wide-band integrated antennas for phased arrays: to develop "patches" of wide-band, low-cost, antenna elements for dual-polarised, close-packed phased arrays and to optimize their rf performance The principal objectives are:

1) to model and to characterise the properties of an over-sampled array of antenna elements paying attention to the effect of cross-coupling and its effects on the beam pattern and on the system noise performance;
2) to develop cost-effective solutions for integrating MMIC receiver components with an antenna element and optimizing the coupling between them;
3) to characterize their joint performance over a range of ambient temperatures.

DS4-T5 Beam forming "patch" and "station" levels for phased arrays: to study, design, construct and test cost-effective beam-forming systems for forming multiple independent fields-of- view from an individual coherent "patch" of antenna elements and compare the cost-effectiveness of different solutions for forming multiple "station beams" within the separate fields-of-view. Are special-purpose programmable chips the best way or can commodity (PC) processors take over this role?
The principal objectives at "patch" level are:
1) to compare the cost-effectiveness of rf and digital solutions for wide-band beam forming;
2) to study the role of photonics in beam forming;
3) to devise cost-effective connections and outputs on optical fibre using commercial standards.
The principal objectives at station level are:
1) to implement a "software beam-forming" solution based on processing with commodity PC-clusters
2) to implement the interface hardware to the get the data into the PC-cluster
3) to compare special-purpose and general-purpose hardware solutions for the SKA, involving technology foresight.

DS5 Aperture Array Demonstrator EMBRACE: To design, develop and critically assess the performance of a multi-field aperture array demonstrator system for high sensitivity radio astronomy observations. **See Gantt Chart Annexe2**

DS5-T1 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 ~500m^2 array – EMBRACE with two independent fields-of-view. For this 24-month R&D period the DS5-T1 team will work closely with the DS4 teams and in some cases share membership. The principal objectives are:
1) to develop the design for the station Digital Processing including the station correlator:
2) to develop the tile architecture.

DS5-T2 Develop and demonstrate the EMBRACE systems: to build the (1+3) aperture-array demonstrators. The principal objectives are:
1) to produce the Station Digital Processing;
2) to produce the tiles
3) to develop and produce the infrastructures at the 4 proposed sites
(WSRT; Nancay; Jodrell Bank and Cambridge, UK.

DS5-T3: Test the EMBRACE systems: 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:
1) to establish the *total intensity* beam forming capabilities of the 500m^2 EMBRACE in comparison with that of a "standard" 25m radio telescope of comparable collecting area;
2) 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.
3) to test the wide-area network (100s km) aspects of the SKA design by feeding multi-EMBRACE data into the European VLBI Network (EVN) correlator at the Joint Insitute 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 (GEANT).

DS6 Cylinder Demonstrator: BEST To design, develop and critically assess the performance of a multi-field cylindrical concept demonstrator for high sensitivity radio astronomy observations. **See Gantt Chart in Annexe 2**

DS6-T1 Design develop and demonstrate sub-systems: to complete the development of the architecture and technology for beam-forming appropriate for a cylinder array. In some cases almost complete sub-systems have already been either simulated or developed and tested by the CNR group in the first phase of the BEST programme. The principal objectives are to finalize the designs of
1) Front End (narrow and wide-band versions).

2) Digital receiver design
3) Short-distance (<1km) optical transportation using *ad hoc* analogue techniques

DS6-T2 Develop and demonstrate BEST: a staged programme to re-engineer a part of the Northern Cross to produce cylinder array demonstrators of increasing size: phase 1) (4 receivers on a single N/S cylindrical concentrator, complete April 2004; national funding); phase 2) (32 receivers on 8 single N/S cylindrical concentrators, complete early 2005, national funding). The principal objectives for BEST are:

1) To produce receivers. A total of 192 receivers on 48 cylindrical N/S concentrators and 24 receivers on 6 E/W single concentrators will be produced. This will create an 8000 m^2 effective area.
2) Produce data transmission via optical fibre link (digital)
3) To develop the data processing at the main station level
4) To develop appropriate calibration software

DS6-T3 Assessment of Performance: to compare the astronomical performance of the BEST array with simulations The primary objectives are:
1) to develop a simulation (using Matlab) of the expected performance of BEST including deterministic null-beam steering (front-end level) and adaptive beam-forming algorithms (back end level).
2) quantitative comparison of the results of astronomical observations with the simulated performance

DS6-T4 A feasibility study of the impact of phased array technology on concentrator concepts: to combine the results of the sub-system studies in DS4 with the results of DS6-T3, in a feasibility study of the cylinder array concept for the SKA. The primary objectives are:
1) to assess in a quantitative manner, the capabilities of a cylinder array when outfitted with 2-D phased receiver arrays along its line focus and the cost-effectiveness of this solution for the SKA in the band 0.1-1.4 GHz.
2) to assess the applicability of phased array technology in the band 0.1-1.4 GHz. to an SKA consisting array of small paraboloids

DS7 Assessment and Critical Review To continually assess the whole programme of work and to organise the mid-term and final design reviews.

DS7-T1 Continuous assessment: to provide a semi-continuous monitoring of progress by a core team consisting of a "*Design Study* Scientist" and "*Design Study* Engineer" funded from within the project. The principal objectives are:
1) to critically examine the results of the feasibility studies and the technical preparatory work
2) to act as channels for the flow of information around SKADS
3) to act as channels for the flow of information to and from the International SKA Project Office.

DS7-T2 Design Reviews: to provide a full-scale assessment and validation of all the work carried out within the *Design Study*. Two major review meetings (Mid-term/Preliminary Design Review and a Final Design Review) will be held. The Design Review Committee will contain experienced scientists and engineers drawn from a wide community both within and outside the partnership, including industry consultants. The principal objectives of the Design Review Committee are:
1) to critically examine the findings of the Assessment Studies (DS2; DS3) and the Technical Preparatory Work (DS4; DS5; DS6) and offer opinions on the progress of the work against expectations;
2) to offer opinions on the relative merits of the two specific concepts (DS5; DS6) studied and also on all issues relevant to the realisation of the SKA as a whole;
3) to produce detailed reports giving their conclusions.

DS8 Overall system design and preliminary SKA plan: To produce the overall system design and a preliminary project plan.

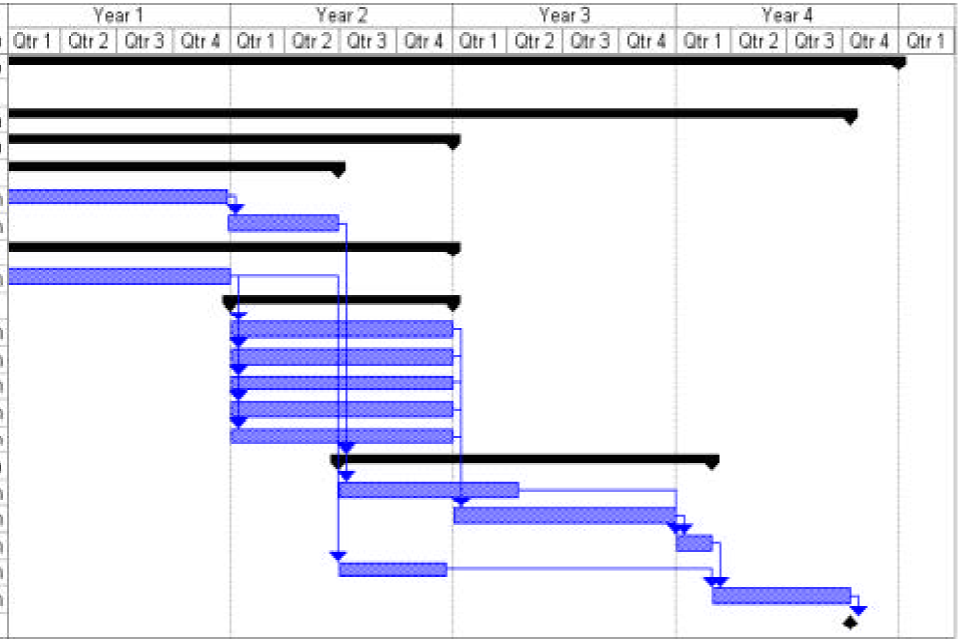
DS8-T1 Overall system design: to optimise the *station* architectural design and in terms of scalability, functionality and to minimise the cost vis-à-vis anticipated technology changes; to produce an "end-to-end" architectural and functional design for the preferred concept. The principal objectives are:
1) to follow the advice of the Design Review Committee and to use the outcomes of the technical preparatory work to establish a multi-parameter cost equation and its derivatives for a range of station technologies/architectures.
2) to examine the most cost-effective upgrade routes, since SKA's scientific output will be limited by the processing power available at any given time.

DS8-T2: Preliminary SKA plan: to provide an overview of the plan from design to construction, including a study of funding sources There are two main products: an organisational plan and an operational plan. Other issues to be considered include
1) industrial partnerships
2) an IPR plan
3) funding mechanisms
4) links with international SKA effort and possibility of a "hybrid" design involving more than one collector technology.
5) maintenance requirements of the SKA
6) a reliability analysis (assessment of failure modes) of the SKA
7) a risk analysis for the entire plan

Annexe 2 : Gantt Charts for DS5 and DS6

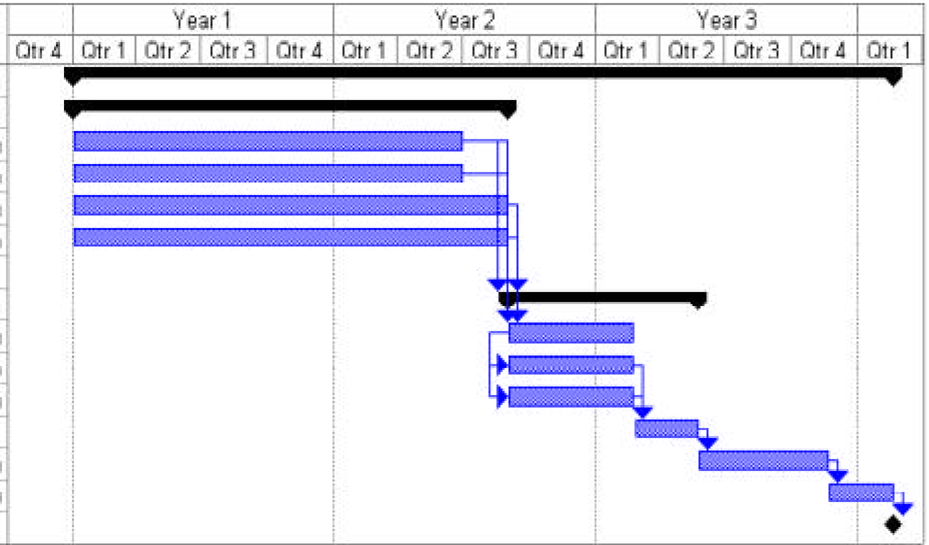
Gantt Chart for DS5

ID	Task	Task Name	Duration
1	**DS1**	**SKADS**	**48 m**
3			
4	**DS5**	**Aperture Array Demonstrator "EMBRACE"**	**45,5 m**
5		**DS5-T1 Design of EMBRACE Subsystem**	**24 m**
6		**To Develop the Station Digital Processing including correla**	
7		Preliminary Design	6 m
8		Final Design	6 m
9		**To Develop the Aperture Array Tile**	
10		Preliminary Design and Validation (RF)	20 m
11		**Final Design**	
12		Wide Band Integrated Antenna	12 m
13		Beam former Design	12 m
14		Receiver Design	12 m
15		(RF) Fiber link Design	12 m
16		Low Cost Housing Design	12 m
17		**DS5-T2 Develop EMBRACE Demonstrator**	**14 m**
18		Produce the Station Digital Processing	10 m
19		Produce the Aperture Array Tiles	12 m
20		Comission Array	2 m
21		Produce Site and infrastructure	6 m
22		DS5-T3 Assessment of Performance	7,5 m
23		EMBRACE Demonstrator and Assessment Report	



Gantt Chart for DS6

ID	Task	Task Name	Duration
1	**DS6**	**Cylindrical Concept Demonstrator**	**39 m**
2		**DS6-T1 Design of Cylindrical Subsystems**	**20 m**
3		Front End Testing and Optimizing	18 m
4		Digital Receiver Design	18 m
5		Optical Signal Transportation	20 m
6		Simulation of Beamforming Algorithms	20 m
7			
8		**DS6-T2 Develop Cylindrical Demonstrator**	**10 m**
9		Receiver Construction	6 m
10		Beamforming Design and Test	6 m
11		Data Transmission Design and Test	6 m
12		Data Processing Calibration Software Test	
13		DS6-T3: Assessment of Performance	6 m
14		DS6-T4 Aperture Array Feeds for Cylinders	3 m
15		Cylindrical Demonstrator and Assessment Report	



Annexe 3: A letter of support from the Chairman of the SKA International Engineering Management Team (IEMT)

P.O. Box 2, 7990 AA Dwingeloo, The Netherlands
Oude Hoogeveensedijk 4, 7991 PD Dwingeloo
Tel : +31 (0)521 595271
Fax : +31 (0)521 597332
www.skatelescope.org

European FP6 Program

Dense phased arrays using wideband elemental antennas are central components in many concepts for the international Square Kilometre Array (SKA). Recent SKA design studies from international groups show that aperture arrays could be the ultimate solution at frequencies below 1.5 GHz and that closely-related focal plane arrays are central to the success of large concentrator (e.g. dish) solutions at frequencies as high as 22 GHz. Aperture arrays allow multiple fields-of-view and would offer several users simultaneous access to what will be the most sensitive radio telescope ever built. The significance of this cannot be over-stated and, while results from early phased array development programs are promising, the question of whether performance and cost issues can be resolved on the SKA's 2015 timescale remains; this central question is addressed directly by the FP6 program. (Of course, many results from aperture array programs translate directly to focal plane applications).

It is the view of the SKA's International Engineering and Management Team (IEMT) that the European FP6 work outlined in the accompanying proposal is central to the development of the SKA. In constructing a multi-fielding telescope based on aperture arrays the program will deliver a crucial engineering demonstrator which establishes the viability of phased arrays for the SKA. The program is unique in its scale and no similar demonstrations of array technology are planned by other groups. Notably though, the European effort seeks to build links with key international R&D groups. The IEMT endorses the directions of the program and commends the proponents on an ambitious and far-sighted proposal.

P. J. Hall

Dr Peter J Hall
Chair, SKA IEMT

16 February, 2004

Annexe 4: A letter of interest from IBM (The Netherlands)

IBM Nederland N.V.
Johan Huizingalaan 765
Postbus 9999
1006 CE Amsterdam
Verkoopafdelingen & Informatie (020) 513 51 51
Internet http://www.nl.ibm.com

ASTRON,
Attn. ir. A. van Ardenne,
Director Research & Development
Oude Hoogeveensedijk 4,
7991 PD Dwingeloo

Amsterdam, March 2, 2004

Subject: SKADS EU Proposal FP6

Dear mr. Van Ardenne,

It was a great pleasure to learn in more detail about your intended breakthrough technology program Square Kilometer Array, and the next major step, the Design Study for SKA. The SKA program is clearly aimed at substantially bringing forward state-of-the-art technology in several areas of interest, which is not only important for basic research fundamentals as such, but also applicable to multiple areas relevant for sciences, economics and society.

Important parts of the SKADS program lie in areas in which IBM is performing core activities. Very recently, the ASTRON-led consortium and IBM started a scientific collaboration aimed at realizing the unique Low Frequency Array Radio-telescope project LOFAR in the 2005 – 2006 timeframe. Hence, we expect to be able to participate in SKADS with relevant knowledge and expertise and with special technologies, as well as to establish fruitful scientific collaborations with our Research and Technology Divisions. Areas of mutual interest would include the Network, Output Data, Technical Foundations and Enabling Technologies.

Detailed discussions will be required to define the extent and best way of operation for such a collaboration. This might result in a membership status of IBM Nederland N.V. within the SKADS consortium, assuming this is acceptable to all parties involved.

We trust on a successful SKADS program.

With kind regards,
IBM Nederland N.V.,

Drs. J.B.J. Geise,
Scientific Research Programs,
Public Sector Division.

IBM Nederland N.V. Gevestigd te Amsterdam
Inschrijving Handelsregister Amsterdam
Nr. 33054214