Periodic WP2 Progress Report 1

Progress in Work Package 2 by Task Number

(Note: Task numbers and names refer to the original Description of Work)

WP 2.1: SKA Design

Objectives

WP2 is the main SKA design activity; it will produce a costed top-level design for the SKA and a detailed system design, incorporating costing, for Phase 1 of the SKA.

Progress

WP2.1 is the top-level system engineering task leading to the engineering design of the SKA. Its objectives are to set and review the specifications for SKA and Phase 1, undertake cost and performance optimization studies, examine trade-offs, and formulate conceptual SKA and detailed Phase 1 system designs. WP2.1 has been divided into the nine tasks reported on below. The project is coordinated by the UMAN(SPDO) with the work being done by all WP2 participants.

WP2.1.1: **SKA concept delineation**

- Significant progress has been made in the delineation of the SKA concept with the generation of a number of key documents: the Design Reference Mission* describing the science and technical requirements for a set of "envelope" components of the SKA Science Case, the System Engineering Management Plan (SEMP)*, the Document Standards Handling and Control Plan*, the Risk Management Plan* and the Risk Register.* The system engineering management approach to achieving PrepSKA WP2 milestones builds on experience in the Design Studies, Precursors and Pathfinders as well as a wealth of material available in the SKA memo series accessible on the SKA website (http://www.skatelescope.org/pages/page_memos.htm), and several other significant documents such as Guiding Principles, activities and targets for PrepSKA Work Package 2* (2008-11-02 Peter Dewdney), the International Engineering Advisory Committee report of 2009-06-01, amongst others.
- Further delineation of the SKA concept by the UMAN(SPDO) in collaboration with the SWG and the WP2 collaboration will be presented during the system Conceptual Design Review (CoDR) at T + 21. Work on the Design Reference Mission, which is a set of science cases from which the technical specifications are being derived, will continue into the next phase of the project and therefore the interaction between engineering and science will a*lso continue beyond this point. At the time of the CoDR at T+21 it will not yet be possible to present full details of technology solutions that will meet the majority of the science requirements. The work and tradeoffs in this regard will continue throughout PrepSKA.

This deviation from the original Description of Work will result in a comprehensive Project Plan in the project management sense that will allow for effective management of the time and resources committed to achieving WP2 Milestones by T + 45. It is anticipated that the Project Plan will be available by T + 20. This plan will become the platform from which monitoring and execution of the project will be managed.

WP2.1.2: **SKA specification**

- The first draft of the Design Reference Mission, created by the Science Working Group, was reviewed within the UMAN(SPDO) at T+18. The technical requirements for the instrument are being extracted from the DRM with a continual trade-off between science and engineering, constrained by the budget. It is anticipated that this process will be repeated several times throughout the project.
- An initial draft of the operations plan is now in circulation , with release to the SSEC planned in T + 20
- A detailed system specification was created by the UMAN(SPDO) for a possible Phase 1 scenario in order to derive first order costing and a high level schedule. It is foreseen that several iterations of these types of scenarios will take place in order to arrive at the final costed system design for Phase 1.
- UMAN(SPDO) has been analysing objective methods of technology selection in order to progressively work towards a feasible set of specifications.
- Cornell(TDP) has done extensive work on dish specification in preparation for the construction of a prototype, details of progress in these areas are dealt with in this

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* Documents are available in on-line Appendices, see below.

report under tasks 2.3 – 2.6. The AAVP will benefit from the extensive work on Aperture Array prototypes carried out during SKADS.

- Although a limited first draft of the SKA specifications will be available at the end of the System Concept Phase at T+21, the majority of the work to develop the system requirement specification will be performed during the Definition Phase. The full SKA system requirement specification (SRS) will be presented and reviewed during the System Requirements Review at T+39 (SRR), which will be carried out by the IEAC and various other internal and external reviewers. To be able to test, accept and commission the Phase 1 instrument it will be necessary to develop a dedicated Phase 1 requirement specification as a subset of the full SKA SRS. It is proposed that this specification be developed after the SRR (during the Preliminary Design Phase) as a subset of the full SKA SRS. The development of test, acceptance and commissioning procedures will also form part of this work package. The milestone for this work package will therefore be a limited first draft SKA SRS to be available at system CoDR at T + 24, the final SKA SRS to be available at SRR at T + 39, updates (if applicable) to be available at the PDR during the post-PrepSKA detailed design phase, and the Phase 1 SRS to be available at the PDR.

WP2.1.3: SKA life cycle study.

- The aim of this task is to outline an end-to-end life cycle description of the SKA, and develop a first-order cost model applicable to major stages of the instrument's life. A clearer understanding of the phases through which the SKA will develop is emerging through discussions within the WP2 collaboration by way of teleconferences with the design groups, and attending meetings with the astrophysics community relevant to the SKA. In particular, the requirement to produce a high level schedule to formulate the system engineering approach has laid the foundation from which sub system tasks are being constructed by the UMAN(SPDO) and the sub-system design groups.
- First order costs per domain have been developed for the dish+single pixel feed option by UMAN(SPDO) and the aperture array + dish option by SKADS. The cost per domain for the dish+single pixel feed and phased array feed option is still under development by CSIRO(ASKAP) .These are rough estimates which require additional iterations before being used to further develop the life cycle model.
- The majority of the work will be performed as part of the system Definition phase. This will ensure that the life cycle requirements will form part of the SKA SRR and the subsequent Preliminary design at T+ 39.

WP2.1.4: SKA operations plan

- A draft Operations Plan produced by the Operations Working Group is under review, and will be presented to the SSEC by the UMAN(SPDO) at T+19. Further work on this will be performed during the concept phase, but the majority of work will be performed as part of the system definition phase. It is foreseen that a reviewed version of the Science Operations Plan will be available at the system CoDR at T + 21. This plan will be expanded, refined and finalised during the definition phase, and presented for review at the SRR at T + 39.
- CSIRO(ASKAP) is building one of the Precursor arrays on a candidate site, the Australia SKA Pathfinder, and is developing this site as the Murchison Radio-astronomy Observatory (MRO). Its operational design of ASKAP is being undertaken with regard to the future operation of the SKA. As these plans mature, these will be developed in conjunction with the UMAN(SPDO).

- Current thinking is that the SKA phase 2 deployments will continue during phase 1 operations. Science test and commissioning observations will be underway during the latter stages of phase 1 deployment. This overlap of construction and operations presents challenges for the operations plan. The operations plan is also a prerequisite to developing the high level architecture for software subsystems.

WP2.1.5: SKA support model

- This aspect of the project is still in the early stages of development. The approach is to first determine exactly what it is that needs to be built and then to develop an appropriate support model.
- The plan to be developed during this work package will address all the support aspects of both the full SKA and Phase 1. The plans will not be limited to maintenance aspects only, and will extend to all support functions required. This would include comprehensive logistics support. The majority of the work on this work package will be performed as part of the system definition phase as described in the revised work plan. Looking at the current high level planning it is evident that the definition phase will be completed before the site decision. This implies that two support models will be investigated and carried until the site decision is made.

WP2.1.6: SKA cost and performance optimization

- CSIRO(ASKAP), UCAM and UOXF have developed the SKA cost and performance (C&P) software tool. A Basis of Estimate process is under development within the UMAN(SPDO) which will feed in to the C&P tool. Data is being collected from the precursors and pathfinders, industry contributors and actual experiences to further refine the tool both with respect to the technical specifications and associated costs databases. As the design of the system emerges and the accuracy of the costs of their component parts becomes more accurate, the basis of estimate will grade the accuracy of those costs and narrow down the options, including the costs of risk and its mitigation.
- The basics of the C&P tool are in place. The route to progressively elaborate the technical and costing aspects of the SKA has been charted through the System Engineering Management Plan and the revised Schedule and Responsibility Matrix.
- Work on this package will be ongoing throughout PrepSKA and will culminate in the fully costed system design.

WP2.1.7: SKA manufacturing studies

- Experience gained in the precursor and pathfinder instruments is informing the approach to mass manufacturing of certain elements of the SKA. An SKA industry capability database being developed within WP5.
- Reports from NRC- HIA indicate that studies of the mass manufacturing of composite reflectors for the antennas have the potential of providing a cost efficient alternative to traditional metal reflectors. A schedule of studies into mass manufacturing of various sub systems of the SKA will be part of the revised work plan, and these studies will be performed once a degree of certainty of the technologies to be used has been arrived at, and the process of technology selection is well advanced.
- The majority of this work will be performed during the system definition phase after T+21. Significant contributions and work will also have to be performed within the elements and subsystems of the SKA.

WP2.1.8: SKA technical documentation

- A documentation handling procedure (PrepSKA WP2 & 3 Documentation Standards, Handling and Control) has been developed and adopted by the UMAN(SPDO) at T+15. These standards will be made available to all the partners, and control of documentation is handled centrally from the UMAN(SPDO).

WP2.1.9: SKA system design

- The formulation of the System Engineering Management Plan and its internal UMAN(SPDO) review at T+15 represents significant progress on this work package task. The document provides the cornerstone of the developing project plans, and is currently being externally reviewed by all participants in the System Engineering Design Group.
- Preparations are in place for the managed System Concept Design Review (T+21), which included the establishment of the system engineering design group and teleconferences, visits to and from participating organisations, and the administration of the large amounts of information flowing through the SKA community.
- The majority of the work in this task will be performed as part of the system Preliminary Design Phase. The identification, development and management of interfaces and relevant interface documentation will form part of the work and milestones within this work package. With regard to interfaces, the first identification and definition of system level interfaces will be presented at the system CoDR at T+21, along with the first draft of the interface register. These documents will be further developed and refined throughout PrepSKA and presented in sequence at the SRR(T+39) and the PDR in the post-PrepSKA phase

WP 2.2: SKA Phase 1 sub-system specification and evaluation

Objectives

To expand the sub-system requirements formulated within the WP2.1.9 system design into a form enabling the design and test of hardware prototypes for SKA Phase 1.

Progress

- Work by the UMAN(SPDO) domain specialists and the associated design groups within the WP2 collaboration lies at the centre of the SKA system design. It is a continuous process with the first CoDR planned at sub-system level at T+27 for dishes and single pixel feeds.
- In the revised work plan, this task has been moved to System Design.

WP 2.3: Initial Verification System

Objectives

To produce an Initial Verification System (IVS), a field prototype which rolls together the most advanced SKA Phase 1 technology components and demonstrates the functionality, cost effectiveness and manufacturability of the adopted SKA Phase 1 design.

Progress

- Tasks 2.3 to 2.6 have been re-structured into the Dish Verification Program (DVP) and the Antenna Array Verification Program (AAVP). The details of these programs are being developed, and the revised work plan, which forms part of this report, outlines the new tasks, deliverables and milestones associated with these programs.

- The decision to adopt a systems engineering approach for these tasks and to deviate from the approach in the original work plan for an IVS, was taken in order to streamline and coordinate the many tasks and activities necessary to arrive at the milestone of a costed system design. The systems engineering approach will be carried through to project completion. The knowledge and experience of the available resources will be incorporated in a structured manner to achieve the required results.
- It must be stressed that the revision of the IVS to the DVP and AAVP does not detract from the progress made in all aspects of receptor design and development, but rather that it is as a result of progressive elaboration within the domain that the programs have emerged. All aspects of receptor design and prototyping will be considered, with a view to taking a systems engineering approach, instead of isolating the sub systems of the receptors, and developing them separately.

WP 2.4: Dish Design and Optimisation

Objectives

To evaluate cost-efficient dish antenna prototypes funded and produced by SKA Pathfinders and Design Studies, each antenna being constructed using manufacturing technologies having potential application to the SKA. In the context of the SKA system design, to provide a detailed analysis of these antennas in terms of performance metrics, cost-performance trade-offs and flexibility attributes.

Progress

- With optical analysis as the starting point, studies of various dish options are being conducted with a view to concluding a design review in T + 26, at which one or two designs will be selected for prototyping and verification testing in 2012.
- An offset fed Gregorian antenna with wide band single pixel feed and space available for a phased array feed is currently being studied by Cornell (TDP). Here the aim is to produce a design that has low level, stable side lobes. A combination of optics and mount design will have to allow for an acceptable range of elevation angles, probably down to 10 degrees.

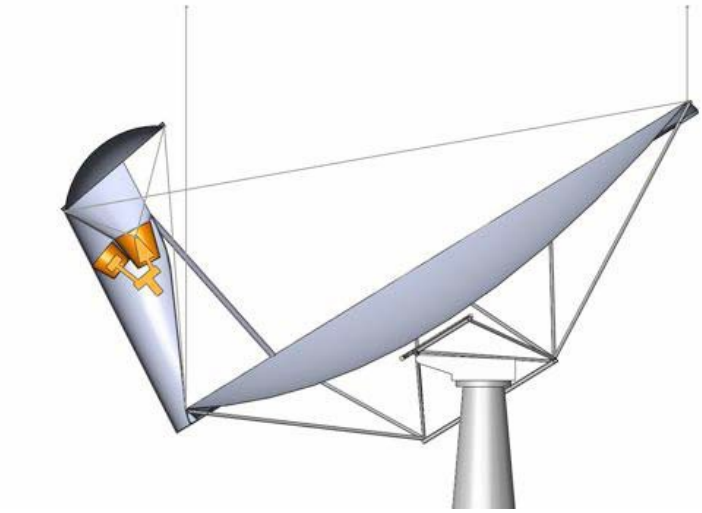

Figure 1. Offset Gregorian reflector model (Cornell-TDP)

- Initial studies by Cornell (TDP) have indicated a small cost ratio between symmetric and offset antenna configurations. There are several strong advantages of using an offset configuration: lower noise temperature, lower wide angle side lobes, and better main beam symmetry. There are mechanical advantages to an offset configuration, there is "real estate" available near the focus for multiple feeds, potentially a PAF and the mechanism to interchange them. Given all of these factors, the Cornell(TDP) Antenna Working Group has selected an offset, dual reflector concept for design and construction of the Cornell(TDP) prototype antenna. The prototype will be a major part of the Dish Verification Program, demonstrating the performance, cost and manufacturability of dish antennas for the SKA.
- Initial studies of optical designs for the Cornell(TDP) prototype, using conic sections, are complete and the results are being circulated by email and meetings and soon to be published as memos. Software to design dual offset shaped reflectors is available and has been described in two memos. Shaping allows a wider range of solutions of reflector antennas, simultaneously obtaining both high efficiency and low spill over.
- Cornell(TDP) initial mechanical design studies of reflectors, both symmetric and offset, are complete and have been circulated via email and presentations, memos are in process. The studies include:
    - A preliminary set of antenna specifications
    - Cost analysis of the Allen Telescope array
    - Production cost estimate of hydro-forming reflectors
        - Concept designs and initial analysis of mechanical supports for hydro-formed reflectors, both symmetric and offset.
        - Trade off study of mechanical implications for various optical designs.
- The Composite Applications for Radio Telescopes (CART) project at NRC-HIA began in January 2006. A costing analysis comparing designs in the 12m – 15m dish diameter range was undertaken. This included various manufacturing and assembly techniques applied to the reflectors only. Based on this study, composite reflectors appeared to offer advantages in cost, mass and frequency range over the other designs and manufacture methods. It was also determined that the Vacuum Infusion Process (VIP) offered the required strength, stiffness and dimensional control for astronomical instruments.
- Following a first phase consisting of the preliminary design and cost estimates, fundamental materials properties testing, and construction of a 1m reflector to verify RF and astronomical performance of composite reflectors, a second phase was initiated to construct a prototype 10m radio telescope to demonstrate concept feasibility and determine first order costs to a high degree of accuracy. This has been followed, as part of PrepSKA, by the construction of the Mk2 10m prototype, which incorporated lessons learned from the initial construction.
- Assessment of the Mk2 revealed that it has the same mass as the Mk1, but is much more production friendly, with a surface rms of 0.54 mm rather than 1.2 mm (*SKA Memo 106*). The deviations from the best-fit parabola are also much more evenly distributed than the Mk1 .The cost of this reflector design is \$1000US/m^2, with 60 % materials and 40% labour. Analysis of the Mk2 reflector under a variety of thermal load conditions characterized its thermal performance (*CART Memo 21*). In addition, a thermal finite element (FE) model of the Mk2 reflector was validated. The thermal modelling techniques can now be used to evaluate the thermal performance of future reflector designs.

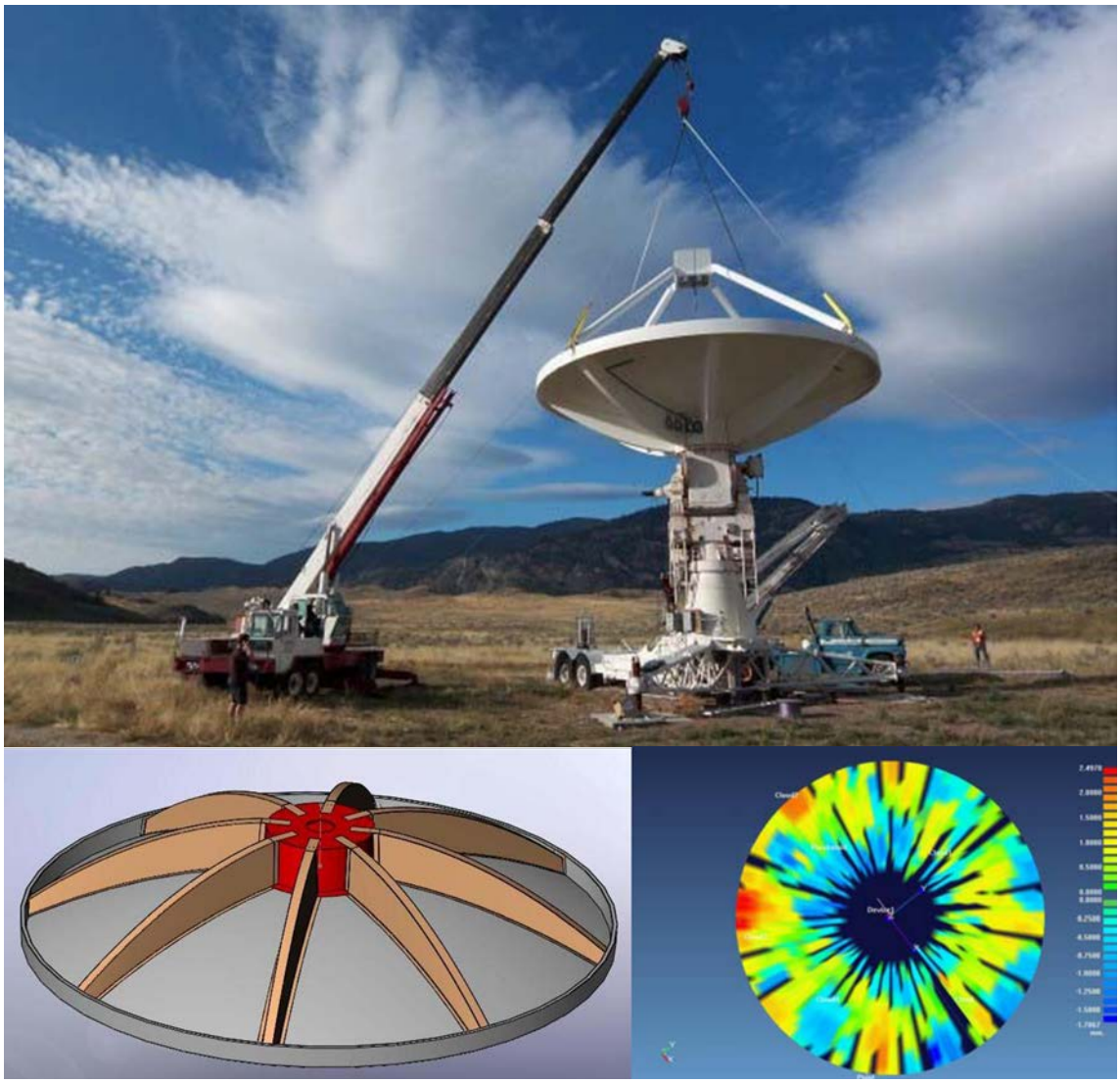

Figure 2. NRC-HIA CART MK2 Reflector
Top: Mk2 reflector being hoisted onto its pedestal.
Bottom left: structural design of the Mk2.
Bottom right: Laser metrology of the CART Mk2 reflector. The rms deviation from the best-fit parabola is 0.54mm.

- Work in NRC-HIA is now concentrating on the design of 12 and 15 m offset reflectors using optical designs developed as part of the US Cornell(TDP) program, and the further development of the associated mechanical and electrical interfaces to the overall system for inclusion into the DVP.
  To verify wind-loading estimates from model FE analysis, a contract has been let to the NRC Institute for Aerospace Research (IAR) for wind-tunnel testing of 1-m mock-ups of both a symmetric and offset reflector, with and without focus package and support. This testing is due in September 2009, with results in June 2010.
- NRC-HIA let a contract to Profile Composites, Sidney BC to establish production feasibility and costing at high volume manufacturing. The result was to recommend manufacture of all dish components near to the SKA site. The cost of complete composite reflector assembly (surface and backing structure) was determined to be \$400USD/m^2 for Phase 1 and \$371USD/m^2 for Phase 2, excluding profit margin. As a

check, the numbers and approach are compared with wind turbine blade manufacture, the only other similar volume and size production currently in composites. This report provides an excellent basis for accurate cost forecasting of large-scale production of future composite reflector designs.

- CSIRO(ASKAP) is building ASKAP as a specific demonstrator of the axi-symmetric wideband feed approach. It is working with the Chinese firm CETC54 on the design and construction of centre-fed panelled antennas. The system includes all aspects, from the antennas/feed to the computing and presentation of high-dynamic-range, wide-field-of-view images.
- NRF successfully constructed a 15m diameter one-piece moulded composite antenna at Hartbeesthoek during 2008/2009. Fourteen memos have been written documenting the construction, testing and performance metrics of the antenna. Following the design and construction of the 15m prototype antenna, the KAT-7 contract for 7 composite antennae in the Karoo has been awarded and construction in the Karoo is currently under way. Concerns surrounding materials used for composite reflectors (e.g. design issues related to mitigation of water ingress, UV life, long-term stability etc.) are being investigated
- Local funding in the Netherlands has been granted for the development of Polyplast dish elements, promising low cost and fast production.
- UOXF collaborated with Cornell (TDP) to verify the Cornell(TDP)'s new design code for shaped offset optics designs as part of the DVP. UOXF carried out full physical optics simulations of the Cornell(TDP)'s ray-optics based designs to verify that, including full scattering and diffraction effects, good cross-polarization and sidelobe performance can be achieved with an increase in aperture efficiency over non-shaped designs.

WP 2.5: Feed optimisation and prototyping

Objectives

To produce and evaluate prototype single-pixel, phased array and cluster feeds suitable for use with SKA dishes and to continue development of aperture phased arrays in order to optimize performance in accordance with WP2.1 SKA specifications.

Progress

- Cornell (TDP) is studying four broadband feeds for use in reflector antennas. There are prototypes of all these feeds and Cornell(TDP) has measured data for three of these, the Cornell(TDP) QSC, the Lindgren (Caltech) quadridge, the Kildal feed and simulated data on the updated ATA (log periodic) feed. This data has been placed in an online database for use in designing reflector optics. The characteristics of each feed are sufficiently different to require matching optical designs for each one. The performance of each feed will be analyzed while embedded in a matching optical design and graded on the composite performance of the entire system. The first iteration of this design process is complete and described in a progress memo. Improvements to each of the feeds and integration of the feeds with Low Noise Amplifiers continues.
- NRF is carrying out simulations of the MeerKAT feed and dish optics in order to optimize Ae/Tsys and sidelobe characteristics.
- CSIRO(ASKAP) is investigating the use of chequer-board phased array feed systems in other approaches, primarily offset Gregorian antennas, and a full report on this will

be available by T+24. They are working with the principal developers of similar technologies around the world to try and develop a collaborative and consensus approach.

- ASTRON's work on APERTIF has produced a first prototype of a phased array feed using Vivaldi elements which has been mounted on a dish at Westerbork and tested in interferometric mode with other dishes in the array. Results on the system temperature and efficiency of the system are very promising, and are being pursued further. System and front-end design, and back-end processing studies are being conducted, the results of which are relevant to the SKA.
- NRC-HIA is also investigating Vivaldi-based phased array feeds in a program called PHAD.This has demonstrated 1.) Calibration and beamforming of data using standard array signal processing techniques. 2.) High image rejection ratios (~40dB) can be obtained with direct conversion receivers using a self calibration technique 3.) Polarimetry measurements of a phase array feed on a reflector antenna for the first time and 4.) Instrumental polarization is a few percent and that ultimate performance will depend upon system stability. Planning is advanced for a 2^{nd} generation phased-array feed, building on the lessons from PHAD to produce an astronomy-capable array. This system will target the 0.7 – 1.7 GHz range, and it could be incorporated with a future CART reflector antenna to for a PrepSKA antenna verification system.
- In parallel with the construction and testing of PHAD, NRC-HIA has carried out simulations of the performance of Phased-Array Feeds from the viewpoint of carrying out astronomical observations, particularly calibration and data correction issues that will have to be resolved to attain high-fidelity, wide-field, and full-polarization imaging capability.
- A great deal of work has been done on Aperture Array systems by the SKADS collaboration. This will form the backbone of work to be done in the AAVP in PrepSKA. Aperture arrays were originally included as a sub-task of WP2.5, but such is their importance that in the revised Work Plan, this has been expanded to be the AAVP, jointly led by ASTRON and the UK. The revised work plan reflects the AAVP inclusion into the WP2 program.
- The low frequency sparse aperture array design for the SKA will be heavily influenced by the LOFAR and other designs. Good progress has been made, with the LOFAR project reporting first fringes from the international LOFAR station in Effelsberg in Germany and the Dutch stations.
- INAF is involved in the AA-lo part of the AAVP. Based on the experience gained in the BEST – SKADS activity (400-416 MHz), INAF is in charge of the design of the 75 MHz-450 MHz (AA-lo) aperture array prototype.
- In the UK work has focused on the development of the 2-PAD system, an all-digital, dual polarisation aperture array. 2-PAD (Figure 3) was funded through the SKADS programme, but work will continue under UK PrepSKA funding; it is designed to work from 300MHz through to 1GHz and is in the process of being fully commissioned and tested. 2-PAD has been designed as a flexible platform upon which a variety of subsystems can be tested and validated. 2-PAD currently has three antenna arrays which are plug-and-play compatible with the system, the BECA, the ORA and the FLOTT (a derivative of the ASTRON FlowPAD design) all of which have been fully characterised at the anechoic chamber at Selex Gallileo. 2-PAD has also been trialling the use of CAT7 cable as the analogue transport medium for distances of 20m and under. The use of a screened room and novel CAT7 to bunker RFI interfaces to minimise leakage into the surrounding area have also been a

significant area of progress. The 2-PAD DAQ board (Data AcQuisition Board: Figure 3) provides the interface between the analogue and digital domains. The board comprises a 2 Channel high speed analogue to digital converter, a large high performance FPGA device (Xilinx Virtex 5) and a PHY extender device to allow inter rack data transmission of up to 20Gb/s over 15m using standard data transport mechanisms. It provides a large programmable resource at the channel level along with fine grain control of channel to channel synchronisation. The board also provides debug and system management interfaces.

- The interface between the antenna element and LNA has been identified as requiring special consideration. World-wide telecons have been established to discuss this and face-to-face meetings will be arranged.

Figure 3.
Left: 2-PAD: the 3 x 3m steerable aperture array at Jodrell Bank
Above: DAQ: the 2-PAD data Acquisition Board.

WP 2.6: Receiver optimization and prototyping

Objectives

To produce a suite of advanced receiver prototypes covering the frequency range 0.1 – 25 GHz, based on technologies being developed in SKA Pathfinders and Design Studies.

Progress

- Cornell (TDP) is developing low noise amplifiers to be integrated with the broadband feeds, primarily in SiGe and InP. Techniques and hardware to interconnect LNAs and feeds is also under development. UCAL are testing room temperature 90 nm CMOS and 65 nm CMOS LNAs. ASTRON and CSIRO(ASKAP) are developing discrete transistor LNAs with Avago pHEMTs and OMMIC mHEMTs, and UCAl are doing similar work with Avago GaS transistors. UMAN is working on GaAs MMIC LNAs, both at room temperature and cryo-cooled, as well as developing their own foundry process based on InP.
- CSIRO(ASKAP) is continuing research efforts to develop appropriate “receivers-on-a-chip” with industry to bring down the cost of deploying systems.
- UCAL (Engineering Division of the Institute for Space Imaging Science) spent 2009 rebuilding their noise measurement system in order to obtain better accuracy and lower levels of interference, to allow precise measurement sub 0.2dB Noise Figure

LNA behaviour. UCAL plan to package the 90 or 65 nm LNA into the Vivaldi phased array feed at NRC-HIA in 2010.

- UCAL is developing an ADC based on a combination of a voltage-to-time converter (VTC) and a time-to-digital converter (TDC). The first version has been designed and submitted for fabrication. In 2010, a very high-speed low-power flash ADC will be designed for comparison with the time-based design, and to see which architecture gives the best results.
- NRF has designed and tested novel feed horns, OMTs and LNA coupling, low cost, low maintenance and high reliability cryogenic systems based on Stirling cycle refrigerators, integrated RF chain systems, wide bandwidth ADCs, temperature stabilization, and RFI shielding. Various commercial LNA samples have also been tested.. In addition, samples of co-axial cables have been tested using a purpose-built bending jig simulating a typical cable wrap on the KAT-7 antenna in order to determine the durability of the co-axial cable and the degradation in performance after a specified number of bends in the cables wraps.
- OBSPAR(UORL) is conducting a study of a low noise amplifier driven by CMOS 65 nm technology in the 300 MHz – 1GHz band. The aim is to produce an all-integrated design, eliminating external biasing and using integrated input and output capacitors. Reported results have shown that 50 and 100 Ohm impedance matching produces too much power in the first instance and poor common mode rejection in the latter. 400 Ohms impedance matching has produced the best results thus far.

Figure 4. Phased array feeds
Left: APERTIF Phased array feed at Westerbork developed and built by ASTRON
Right: Chequerboard array feed at ASKAP developed and built by CSIRO(ASKAP)

WP 2.7: Signal transport specification and prototyping

Objectives

To produce advanced prototypes demonstrating SKA signal transport on distance scales ranging from less than 20 m to more than 200 km, to report on solutions for transport over still longer distances, and to demonstrate techniques for generation and distribution of local oscillator and timing information within the SKA. A design for the Array monitoring and control systems, in detailed form for Phase 1, will also be produced.

Progress

- The UMAN(SPDO), in collaboration with INAF, IT, NRF, ASTRON, MPG, and CSIRO(ASKAP) has established a work program for the study of suitable purpose-made and commercially available transmission systems that could be used to good effect on the SKA. Viewing the instrument from a systems engineering perspective has been instrumental in highlighting the interfaces of the Signal Transport and Networks domain with all of the other domains.
- Accurate tests and evaluations of the optical link used on the BEST system at INAF have been continued. At the same time new optical links, from a local company, are under evaluation to determine whether they can be suitable for AAVP activities with regard to both performance and costs.
- CSIRO(ASKAP) is working closely with the STaN domain specialist to define the best specific technical approaches. It is working on all aspects of signal transport for ASKAP, as well as technologies for SKA, e.g. inexpensive RF over fibre. CSIRO(ASKAP) is also investigating "low-overhead" digital data transport, important given the approximately 2 Tbps communications needed back from every ASKAP antenna. It is installing its own ~400km optical fibre cable from the MRO to its support facility in Geraldton and is investigating likely SKA data transport technologies. CSIRO(ASKAP) is also investigating cable transfer mechanics and its photonic implications.
- Based on extensive discussions with MPG and the STaN domain specialist at UMAN(SPDO), the focus of MPG involvement has shifted to this work package in close cooperation with INAF. A detailed schedule has been agreed upon and progress has been made on RF on fibre measurements on COTS broadband transmission lines at the Effelsberg telescope under operating conditions, an RF on fibre system up to 10 GHz bandwidth costing, and a 10 GbE direct link is being built from a FPGA based source to establish boundary conditions, production issues and costs for the digital transmission options. There has also been a first investigation on the projected availability of 100GbE devices in 2015, which has yielded a positive result with the assurance that appropriate components will be available at that time.
- UMAN has been using Merlin/eMerlin to test LO phase transfer over fibre. The system has been in use without problems to the MERLIN Pickmere telescope over a period of several months. In early October 2009 the trial has been extended to allow Darnhall to operate using LO over fibre with Pickmere reverting to the microwave links. The fibre LO at Darnhall has been routed out and back via Pickmere to extend the distance and to demonstrate a multi hop path. Observations are continuing in order to evaluate the performance of the system but initial indications are that it is operating without problems, including measurement of telescope offsets at 22GHz.
- The tasks within this domain have been rearranged and now involve 4 tasks in total. Details of the revised approach are available in the revised work plan which forms part of this report. The redistribution and precise specification of tasks and deliverables is being finalised.

WP 2.8: Signal processing optimization and prototyping

Objectives

To design and demonstrate the SKA signal processing chain from antenna through to the correlated or time-detected data.

Progress

WP2.8.1: Station digital signal processing

- The DSP domain specialist was the last UMAN(SPDO) member appointed, at T+14, and has been fast tracked into the program in order to align this domain with the progress made in others. Despite this late appointment, significant progress has been made.
- NRF is a key contributor to the CASPER collaboration that is working on large array processor design using an FPGA-based approach. The aim is to continuously track Moore's law in the design paying particular attention to the reduction in power utilization for fixed functionality, which should reduce the telescope running costs. The development of the ROACH II board is underway, which will double the processing capabilities of the first generation technology. The goal is to be ready for production in 18 months, hence demonstrating the key advantage of this approach tracking Moore's law.
- CSIRO(ASKAP) is developing architectures for energy-efficient signal processing and computing. It is implementing FPGA signal processing which is the most energy efficient and cost effective solution for a precursor instrument. In addition CSIRO(ASKAP) has identified signal transport both between modules and within modules as area where savings can be made. CSIRO(ASKAP) will work with the international project office on effective specific non-imaging signal processing.
- The Multi-dimensional Signal Processing Research Groups at the University of Calgary and the University of Victoria are using previous experience in synthesis, design and implementation of analog and digital multidimensional (MD) filters for real-time space-time applications such as array processing for terrestrial wireless applications to study ways in which these new filter methods might be useful in radio astronomy. Specifically they are developing 1) a Hardware-Accelerated Frequency-Domain Focal Field Synthesizer for Paraboloidal Reflectors, 2) 3D Space-Time Digital Pre-Filtering for Dense Phased Arrays, 3) Fractional Delay Multidimensional Space-time Filters, and 4) Infinite Impulse Response (IIR) Real-time 2D/3D Space-time Filtering Methods.
- ASTRON has been involved in the design of the next generation beam former chip, improving upon the current design used by SKADS/EMBRACE, which consumes too much power to be useful in a SKA application.
- OBSPAR(UORL) has been studying a one channel, dual beam RF beamforming chip. Results from this study have led to the design of a single channel RF beamformer chip, with the aim of reducing noise interference. An RF interface chip, developed by OBSPAR(UORL) in 2008 and tested in early 2009 has shown that isolation between transmission and reception needs to be improved; studies are continuing. Work is also being carried out on a fast Analog to Digital Converter chip. A first version was fabricated and tested early in 2009 which confirmed the theory. The next version will be sent to the Foundry in November 2009 and tested in 2010.
- The UOXF DSP group has been in discussions with a consortium of UK ASIC design houses plus a major Far Eastern silicon foundry to facilitate the design process for a DSP ASIC for aperture arrays, once PrepSKA UK funding becomes available. A UK company has applied to the UK Technology Strategy Board for a grant to support a design study on such a chip for SKA.
- UOXF has commissioned a design study from a leading UK technology company on integrating the analogue RF chain for mid frequency aperture arrays in to a small

analogue ASIC chip set, in preparation for aperture array verification work within PrepSKA.

WP2.8.2: Correlator

The Correlator is being considered as two distinct areas, viz:

1) Software Correlator for Phase 1. Korean and Indian colleagues have expressed interest in this area and have forwarded preliminary design parameters for initial benchmarking to the UMAN(SPDO) for review.

2) Initial discussions with CSIRO(ASKAP), NRAO, JIVE, UMAN, and UOXF have resulted in an agreement on the top level architecture concept for the Correlator for both Phases 1 and 2 of the SKA

WP2.8.3: Radio frequency interference mitigation

- It is intended to take a system level approach to RFI Mitigation with measures taken in all the areas of Signal Processing. OBSPAR and UORL are the joint lead institution for RFI mitigation, together with ASTRON, and have reported significant progress on this aspect as a result of their RFI mitigation studies for Pulsars and LOFAR. These are based on simulations with synthetic and real data, with the aim of designing real time filtering algorithms to deal with RFI corrupted radio astronomy observations. The MPG, CSIRO(ASKAP) and the UCAL will also be involved in this arena.
- INAF are investigating different adaptive beamforming algorithms that point zero (es) of the beam pattern in the direction of the interferer(s). Further studies in this field are going ahead for PrepSKA at IRA, especially for the more promising algorithm as the Minimum Variance Distortionless Response (MVDR). The future plan is to implement such an algorithm on the AA-lo as soon as a subsystem composed by a certain number of antennas will be available (the plan is within T+32).

WP2.8.4: Non-imaging processors

- OBSPAR and UORL have reported progress in the studies of RFI mitigation for pulsars, which improves the quality of astronomical observations that are mitigated by interference from spurious RF signals. The studies are based on the use of synthetic and real data. An implementation will be proposed on the pulsar instrumentation based on the Graphical Processing Units (GPU) designed at the Nancay Radio Astronomy station.
- The MPG digital group has developed a special version of their Pulsar Fast Fourier Transform Spectrometer (PFFTS) board enhanced with a dual input 8 bit ADC and an additional Gigabit Ethernet interface. In addition, a novel Pulsar FPGA core has been developed which allows processing up to 750 MHz bandwidth in two polarisations, building the power spectrum, adding both polarisations, integrating the spectra over time and finally dumping the frequency channels out to a PC via Gigabit Ethernet. The latest core version allows decomposing the input signal into 512 spectral channels and transferring the data every 32 micro seconds to a PC cluster for further signal analysis. The board has a more efficient pre-processing algorithm with significantly reduced frequency scallop loss, less noise bandwidth expansion, and faster sidelobe fall-off. Tests at Effelsberg have produced positive results in the 100MHz bandwidth and the infrastructure is being extended to cope with the amount of data being collected by the PFFTS backend.

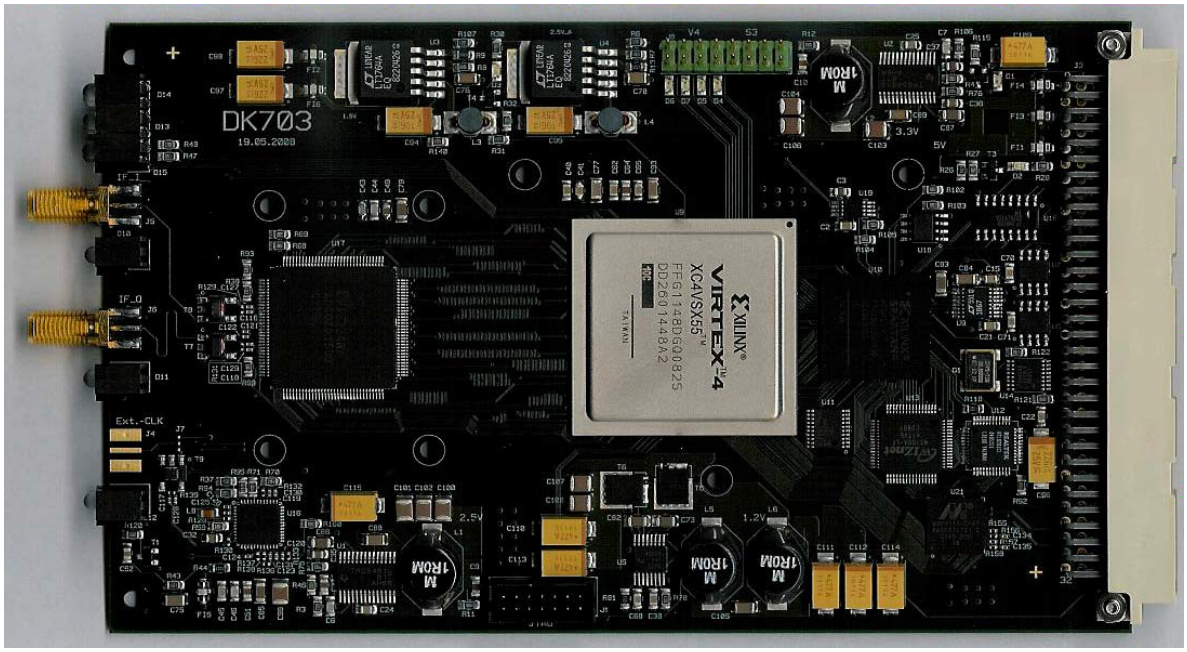

Figure 5: Dual input Pulsar Fast Fourier Transform Spectrometer (PFFTS) Board (MPG)

WP 2.9 Software/computing specification and prototyping

Objectives

To formulate and demonstrate strategies for the implementation of SKA computing hardware and software, data management solutions, calibration techniques and science application software.

WP2.9.1: computing and software specification

- This task focuses on the key requirements of the software and computing subsystems to be reflected in the SKA and Phase 1 system designs. Initial work on extracting non-functional performance requirements from the Design Reference Mission (DRM) has been carried out. Project documentation for several contemporary significant scale projects developing software and computing systems for radio astronomy has been reviewed and summarised to inform top down software and computing architecture development.

WP2.9.2: computing hardware

- This task investigates hardware options – with a focus on Commercially Off The Shelf (COTS) solutions – for SKA computing. The non-functional performance requirements identified from the DRM together with the reported performance of current best-in-class algorithms for calibration and imaging indicate a processing requirement of order 1 Exaflop. Current computational performance efficiencies of the world's largest and most efficient general purpose High Performance Computers (HPC) fall well short – by at least two orders of magnitude – of delivering this level of required throughput at reasonable (in the order of 10MW) power consumption. Commercially available High Performance Reconfigurable Computing (HPRC) architectures are being examined as potential candidates to meet the computation needs of SKA data processing for both imaging and non-imaging applications.

WP2.9.3: software engineering

- This task establishes software engineering methods and tools and develops the high level software architecture for the SKA, focusing on use of industry best practices and reuse of existing codes and COTS solutions. The scale of the required effort in software development has been exemplified by reference to the size of existing codes developed and refined over 30 years for calibration and imaging in radio astronomy: order of 1 million Source Lines of Code (SLOC). Using publically available benchmark data, this translates into order of 1,000 person years of effort for a fully integrated and documented solution set. This implies the need to coordinate the collaborative activities of several groups of development activity – most likely distributed across the globe in geographies, time zones and cultures. Further work is underway to disaggregate the problem space into a more detailed Work Breakdown Structure (WBS) amenable to global software development and industrial partnership.
- ASTRON is leading this sub-task and has accumulated a set of best practices for SKA software based on lessons learnt from LOFAR. They have also developed an outline of the software architecture for the SKA.

WP2.9.4: data products and virtual observatory

- This task establishes the strategies for the delivery of SKA and SKA Phase 1 data products to the astronomer, and for the management of the massive data sets produced and it is led by UCAM working with RUG, the International Centre for Radio Astronomy Research (ICRAR), and UCAL. Operations of similar scale activity at CERN have been investigated which are informing planning of this work.
- RUG has made progress on handling of large amounts of data – which potentially can be scaled to SKA requirements. The long term archive for LOFAR developed by RUG serves as a good model for the SKA and includes
    1. Distributed data storage on independent data storage nodes (basically one storage node per one group participating in the project)
    2. Distributed data processing on independent processing nodes managed by participants
    3. Distributed metadata storage which implements the common data model (the data model will be created by collaboration of all participants), the data model describes all data produced by the project from the raw data till the science ready data product and can be adjusted during the data processing
    4. Distributed development of the data processing software (pipelines) based on the common data model and common approach to the software development
    5. Centralized quality control
    6. Common data interfaces for an access to the data for participants of the project
    7. Common Virtual Observatory-based data interfaces for an access to the end product data for external users.
- UCAL has been granted funding to start in October 2009 to support the design and development of SKA cyber-infrastructure to address the need for a global and national cyber-infrastructure for SKA key science. There are three basic tasks to be accomplished 1) Development of a managed cyber-space for Canadian SKA key survey science, 2) Development of software and infrastructure for specialized data processing of SKA raw data streams within a distributed international development network, and 3) Interactive, Dynamic data mining.

WP2.9.5: calibration

- This task establishes the overall calibration strategy for creating images from SKA data, and it develops the architecture and algorithms for the SKA calibration system. Contemporary developments in algorithms to address the challenges of SKA-type data reduction have been reported and published in various forums including CALIM 2009 held at NRAO's facilities, Socorro March 30 – April 3 2009.
- CSIRO (ASKAP) staff led international calibration and imaging activities and is actively studying architectures and algorithms to yield sample astronomical fields. They are developing pipelines for automated processing of radio synthesis data on high performance computing systems, and are also working on the theory and practice of calibration and imaging for synthesis telescopes with phased array feeds. They are using SKADS-generated model skies for testing imaging performance in various ways, including structural and flux density accuracy.
- UCAL is working on calibration and imaging issues related to wide-field polarimetric imaging with focal-plane array systems, with emphasis on developing the techniques required for deep, high-dynamic-range imaging of polarized emission with the SKA. This includes 1) Imaging Exploration of the Deep polarized Sky, 2) Simulations of the deep sky to sub-microJy levels in full polarization, and 3) Algorithms and Software for wide-field imaging from the PAF-based $u - v$ data. Good progress has been made in all these areas.

WP2.9.6: science post-processing

- This task addresses the final processing required for imaging and non-imaging observations. Imaging algorithms are closely associated with algorithms being developed for calibration, and activities for this task are reported for WP2.9.5 above.
- Algorithms for non-imaging applications such as search for and analysis of pulsar and transient signals are being developed by various groups including ASTRON and UCAM.
- UCAL is focussing work in this area on polarimetric imaging science and has contributed a chapter on this subject to the Design Reference Mission. Algorithms and techniques are being developed through a combination of simulations and SKA path finding observing programs. Two specific programs are polarisation stacking and the processing of large area spectro-polarimetric surveys. Developments achieved to this point include: 1) Infrastructure for computation and storage of massive survey data set has been set up; a multi-core compute cluster with fast optical fibre link to a storage area network of several hundred Terabytes. 2) A software processing pipeline for calibration and imaging from focal-plane feed array observations.

WP 2.10 Design study management:

Objectives

This project will provide support for the WP2 engineering study in terms of project planning, reporting, and financial and related interactions between UMAN(SPDO) and regional SKA programs.

Progress

- Monthly general and technical meetings have been established from which minutes and action item lists are derived and managed. Based on the Documentation Handling and Management Guidelines adopted by the UMAN(SPDO), a shared repository has been set up for document storage and control. Monthly reports are submitted to the PrepSKA coordinating group. All scheduled reports, such as the report to the IEAC in April 2009, are submitted after managed reviews within the UMAN(SPDO). An event calendar has been set up and is managed. Finances and interaction with the host organisation, UMAN, are administered by the Executive Officer. Extensive work on the revision of the work plan has been undertaken and a revised plan will form part of this report. This plan will continue to be managed according to internationally accepted Project Management practices. Scheduled teleconferences are held within every domain, and transcripts are kept in the document repository.
- Regular coordination meetings are held with the SSEC and UMAN(SPDO) management.
- Interaction between WP2 and WP3 is enhanced with monthly week long visits to UMAN(SPDO) by the Site Engineer. Interaction between the Science Working Group and UMAN(SPDO) is facilitated through scheduled teleconferences and planned visits to UMAN(SPDO) by the Project Scientist.
- The adoption of the system engineering management approach, with the System Engineering Management Plan providing the basis upon which plans have been developed, has led to a revision of the WP2 tasks. The revised work plan forms part of this report. This has resulted in a new project management plan being implemented and managed.(Revised Gantt chart appended) The revised plan is sufficiently detailed in every domain within WP2 to allow for each to run as an individual project contributing in a managed format to the program as a whole.
- Global engineering communications, through the establishment of design work groups, and scheduled teleconferences has proven to be a cost effective and efficient means of getting required input from the geographically dispersed contributors within all domains. Additional means of communications and information dissemination are the SKA WIKI and SKA website, which are updated on a regular basis. All major conferences and meetings are attended by relevant members of the UMAN(SPDO) to ensure communication between all stakeholders remains current.
- Recommendations from the IEAC report, which include the endorsement of

the
Revised Work Plan, have been taken note of and are being introduced to the
UMAN(SPDO) WP2 operations. A response to the IEAC report is being drafted and reviewed and is planned for submission to the SSEC

APPENDICES.

NOTE: All Appendices to this report are available by following this link:
http://webmail.jb.man.ac.uk/PrepSKAwiki/EcReportAppendicesDocuments *Or these URLs*
http://www.skatelescope.org/~adams/Design_Reference_Mission.pdf
http://www.skatelescope.org/~adams/Guiding_Principles.pdf
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