**Work Package Title:** Dish verification Program

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| **Work package number** | WP2.2 | | **Start date or starting event** | | | | | T+9 months | | |
| **Work package title** | Dish Verification Program | | | | | | | | | |
| **Activity Type** | RTD | | | | | | | | | |
| **Participant id** | 4 | 7 | | 8 | 9 | 10 | | | 11 | 12 |
| **Person-months per beneficiary** | 2 | (16) | | (14) | (6) | (2) | | | (4) | (96) |
| **Participant id** | 13 | 14 | | 15 | 19 | 21 | 24 | | NRAO | UMAN (SPDO) |
| **Person-months per beneficiary** | (6) | (6) | | (44) | (8) | (18) | (5) | | (24) | 70 |

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| **Objectives:**  To design, construct and evaluate at least one cost-efficient dish prototype funded and produced by PrepSKA participating organisations and institutes, using manufacturing technologies having potential application to the SKA. In the context of the SKA system design, to provide a detailed analysis of the antenna in terms of performance metrics, cost-performance trade-offs and flexibility attributes. |

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| **Description of work**:  The Dish Verification Program will produce at least one prototype antenna/feed/receiver for testing in conjunction with a well-calibrated existing 2-dimensional aperture synthesis array. SKA dishes will carry one or more single pixel feeds (SPFs), covering the frequency range 1 to 10 GHz, and possibly additional single pixel feeds going to 300 MHz if the cost and performance of phased array feeds (PAF) or aperture arrays (AA) in the 300 MHz to 1 GHz frequency range are less effective.  The prototype dish(es) will also be designed to accommodate a phased array feed (PAF) for the ~500-~1000 MHz frequency range if PAF technology proves feasible and cost effective for high dynamic range, wide-field survey observations. Optimisation of the antenna, feed and receiver designs is an interlocking process which requires continuous feedback from these three design areas into the overall design.  Two main options for the dish design are to be considered: PrepSKA primary work will concentrate on the design of an offset-fed Gregorian antenna complete with multiple feed systems (SPFs and possibly PAF). A fall-back design could be a symmetric centre-fed antenna like the ASKAP dish with a “sky mount” for use with phased array feeds (PAFs). The study of the fall-back option will not occur as an explicit work package unless difficulties arise with the primary option. The SKA dish diameter will be specified as part of the WP2.1.1 system design process. It is expected that antenna designs chosen in current SKA Pathfinders and Design Studies will all yield critical information. This diversity in dish design and realization is a practical risk mitigation strategy for the SKA design process.  A number of single-pixel feed designs are being pursued actively, with software engineering design tools and testing on antenna ranges informing the design considerations. A choice will be made before the prototype antenna construction is undertaken. Similarly, a number of PAF designs are actively under development including a chequer-board array concept for ASKAP, and Vivaldi element arrays for APERTIF and PHAD. Full-scale astronomical testing will be required before this technology can be adopted.  Low system noise antenna/receiver systems are key to the scientific performance of the SKA. While ambient temperature operation of most SKA receiving components is foreseen, the applicability of new-generation cryogenic coolers to the SKA mid and high bands will be explored, and may be crucial to the achievement of the required sensitivity. The DVP will verify, through simulation and prototyping, the overall SKA receiver chain and, via industry links, emphasize manufacturability and power consumption considerations.  Verification testing, against criteria generated from the Design Reference Mission, will be an essential part of the DVP. The antenna, together with its feeds and other integrated components, is the only analogue component of the SKA that can only be tested as part of a fully functional aperture synthesis system. The development of a fully integrated test antenna, complete with feeds and receivers will be an essential part of this work, and will culminate in a series of on-the-sky tests. Specifications for beam stability, sidelobe levels, instrumental polarization, and RF stability will be checked over the full frequency range, across bandwidths, in conditions of varying solar illumination, and in high winds. An evaluation of the methods of calibration, calibration accuracy, and frequency of calibration will be part of this work. The results will be evaluated against the required system performance in the most demanding applications. At the levels needed and in the time available, this can only be carried out in conjunction with a large, well-calibrated existing synthesis radio telescope. This will permit short-duration, high signal-to-noise measurements of the properties of the test antenna, so that variations in performance can be tracked. The Expanded Very Large Array is an excellent instrument for this purpose, and will be used to verify that the prototype system meet the performance needs of the SKA. Its two-dimensional array configuration and large number of baselines will permit field sources to be accurately subtracted. An initial test plan will be developed and reviewed, and updated as the testing programme proceeds, ultimately to produce convincing evidence of suitability for the SKA. In summary, the DVP will inform system design decisions and, via links with continuing Pathfinder and Design Studies work, will generate comprehensive design, cost, and performance data for SKA dish options. These inputs will be fed to the system design carried out in WP2.1.1.  Cost estimates using projected technology for SKA-ready implementation in 2015-2018 will be a deliverable of the DVP.  Participants: UMAN(SPDO) will lead this task. Participants are Cornell (TDP), NRC-HIA, NRAO, ASTRON, UCAL, CSIRO(ASKAP), NRF(MeerKAT), IT, MPG, NAOC and CETC54 as detailed in the subsequent sections.  WP2.2.1: **Antenna Design**  Recognizing the work done in WP2 so far, this task will focus on producing a costed design for an offset-fed Gregorian antenna, utilising a metal or composite reflector, optimized for operation in a number of frequency bands. If this design cannot meet requirements, a fall-back design will be a symmetric reflector. The task will draw on progressive results in WP2.1 (system design) in order to specify the dish diameter and related attributes of system-wide importance.  The task is coordinated by UMAN (SPDO), with the Domain Specialist in Antennas, Feeds and Receivers being the overall project leader. A study of optical designs is the starting point in the design process, followed by an examination of a range of antenna design options with a view to optimizing the mechanical design to give the best possible performance versus cost. This optimization will include selection of materials and manufacturing processes for the reflector manufacture, as well as design of the mount and drive systems appropriate to the selected reflector design(s). The aim of the overall design will be to maximize sensitivity, and imaging dynamic range for the full SKA. For each design type, performance, cost, manufacturability and other attributes will be reported against standard metrics developed by UMAN (SPDO). While including comprehensive commentaries on specific antennas, all tasks will report on the design flexibility attributes of the base technologies and manufacturing techniques employed.  Participants: UMAN (SPDO), working closely with Cornell (TDP), will lead this task. NRC-HIA (Canadian SKA Program), will take a leading role in the design of dish reflectors. There will also be contributions from CSIRO(ASKAP), NRF(MeerKAT), UK (UCAM, UOXF, UMAN), ASTRON, KASI, NAOC and CETC54. Pathfinder inputs will come from CSIRO(ASKAP) and NRF(MeerKAT). NRAO will be a major contributor to the Verification Test Program.  WP2.2.2: **Wide Band Single Pixel Feed and RF Design**  This task consists of four sub-tasks: feeds, low-noise amplifiers (LNAs), receivers and cryo-cooling. These items are closely coupled into an overall RF design for the antennas. Although these developments are described here as a separate task, they are inextricably linked to the optics and mechanical design of the dishes.  WP2.2.2.1: Feeds: Substantial antenna feed/RF development is necessary if the science goals of the SKA are to be met. Single pixel feeds may be required to cover the frequency range 0.3 to 10 GHz: it is unlikely that this can be achieved efficiently with a single feed, but it is likely that two feeds will cover the range with acceptable efficiency. Additionally a WFoV option for dishes is being explored for the candidate dish designs in the form of phased array feeds, covering a restricted frequency range at the lower end of the frequency range; if feasible, this may replace one of the SPFs.  This first part of the task will evaluate at least four wideband feeds: the ATA feed, the Eleven Feed from Chalmers, a quad-ridge feed from Caltech, and a quasi-self-complementary feed from Cornell. Work within the task will include electromagnetic design and evaluation of the feed designs in conjunction with the dish optics-analysis and structural work. Feed designers will work closely with LNA designers to produce integrated feed/LNA packages. Prototypes will be tested on appropriate antenna test ranges. The outcome will be one or more viable feed solutions for the SKA in the frequency range 0.3 to 10 GHz. WP2.2.2 will also coordinate feed design and cost input to the dish antenna reviews.  Participants: This task will be led by Cornell (TDP) which will conduct the main single-pixel design study. The final review documentation will be produced in conjunction with other WP2.2 participants.  WP2.2.2.2: LNAs: This will deliver at least one prototype receiver in the mid (0.3 – 10 GHz) SKA band. The project will verify, through simulation and prototyping, the overall SKA receiver chain and, via industry links, emphasize manufacturability and power consumption considerations.  Ambient temperature operation is foreseen for most of the SKA RF components apart from the LNAs. While ambient temperature operation may be possible for some LNAs, in most cases cryogenic cooling will be required (see below). The design of both cooled and ambient temperature LNAs will be explored whenever possible. Studies of LNA cooling and/or temperature stabilization requirements will also be undertaken, and a final review of all SKA receiver developments produced. LNA design and development will necessarily be carried out in close collaboration with feed and antenna element designers.  Participants: This task will be coordinated by Cornell (TDP). Contributors include ASTRON, UK (UCAM, UOXF, UMAN), UCAL, and IT.  WP2.2.2.3: Receivers: Receivers for single-pixel feeds will need to process the very wide frequency RF channels to produce wide-band baseband or quasi-baseband outputs in digitized optical format suitable for distribution to the correlator. They must be capable of sufficient RF dynamic range to handle interference at the two candidate sites. They must also be sufficiently stable so as not to be a limiting factor in system performance.  Participants: This task will be led by CSIRO (ASKAP), which, with UCAL, will concentrate on low-cost, monolithic CMOS receivers. UK (UCAM, UOXF, UMAN) will focus on high performance, custom-fabricated sub-systems, while ASTRON, IT and Cornell (TDP) will contribute specialist knowledge of advanced connection and packaging solutions.  WP2.2.2.4: Cryogenic Cooling for LNAs: This work will identify cost-effective cryogenic solutions for use with single-pixel feeds. Considering the relationship between system temperature and physical temperature for various LNAs and available cryogenic technology, provide recommendations on the most cost effective physical temperature and cryogenic design for the front-end systems. In this analysis, particular attention will be paid to the impact on SKA system cost (total cost of ownership) and performance. In carrying out this task, there will be considerable interaction with vendors and independent experts, to enable the assessment of commercial coolers in terms of lifetime, failure modes, reliability, maintenance requirements, power consumption and efficiency.  Participants: This task will be led by Cornell (TDP), while inputs from UK (UCAM, UOXF, UMAN), MPG, CSIRO (ASKAP) and NRF (MeerKAT) will provide specifications, customization studies and, if applicable, test platforms for practical cooling systems associated with various SKA feed types.  WP2.2.3: **Phased Array Feed (PAF) Design**  This task consists of five sub-tasks: feed-array, LNA, receivers, beamformers, and cooling.  Phased array feeds consist of a 2-dimensional array of compact antenna elements placed at the focus of a dish. The array can be used to form tens of beams, increasing the field-of-view of the antenna accordingly. This task will show, through simulation and demonstration, the suitability of PAF technology for the SKA, adapted for use with the dish-optics design selected for study in WP2.2.1. It will leverage work in ASKAP and APERTIF, which will be the first interferometers to use PAFs. Performance, cost, power and bandwidth will be major issues to be studied. The task will also address methodologies for large-scale manufacture of PAFs.  The following components are ultimately part of an integrated PAF system, whose performance characteristics are closely coupled. They are described as separate tasks below, but ultimately must be evaluated as a feed subsystem. Thus primary deliverables for PAFs are reports on the performance of complete PAF subsystems, rather than for individual components.  WP2.2.3.1: Feed-Array: Several types of elements are being used in experimental PAF developments at CSIRO (ASKAP)), ASTRON (APERTIF), and NRC-HIA (PHAD). The results of this work will inform the project on the best combination of antenna elements with LNAs and beam-formers. This task will produce one or more PAF element arrays and evaluate them as part of a delivered PAF subsystem.  WP2.2.3.2: LNAs: Because PAFs require several hundred LNAs located across the array, they will likely have to be optimized to operate at ambient temperature, although cyro-cooling is also being considered (see below). As in other feeds, the LNAs must be closely integrated with the array elements and the array/LNA performance considered together. While there is commonality among all types of LNA designs, this task focuses on those optimized for use with the PAF elements being developed in the previous task. This task will design and fabricate candidate LNAs, test them on the bench, integrate them with the PAF elements noted above, and test their performance as part of a complete PAF feed. There will be a close connection with WP2.3.1.4 in which aperture arrays are designing similar devices and front-ends.  WP2.2.3.3: Receivers: Highly integrated low cost, low power receivers for phased array feed systems are particularly important because of the number of receivers required. As in single pixel feeds, they will need to process the very wide frequency RF channels to produce wide-band baseband or quasi-baseband outputs in digitized format suitable for distribution to the beamformer. This task will design and fabricate candidate receivers, test them on the bench, integrate them with the other components of a complete PAF feed, and test their performance.  WP2.2.3.4: Cooling: Despite the difficulty of cyro-cooling PAF feeds and LNAs the benefits of cooling are substantial, especially from the perspective of cost/performance ratio. Micro-cooling techniques, in which each LNA is cooled separately, or cooling the entire array/LNA assembly might be possible. This task will carry out an investigation of possible techniques for cooling PAFs, evaluate the performance improvements potentially possible, and to assess the cost of PAF cooling.  WP2.2.3.5: Beamformers: PAFs require a digital sub-system to form the output beams from the PAF subsystems. The beamformers are probably the most expensive part of PAFs and will be responsible for most of its power consumption. An efficient design and placement of the beamformers in the dish system are an important part of the design. This task will design and fabricate a beamformer, integrate it with the other components of a PAF so that a complete PAF feed can be tested.  Participants: This task will be led by CSIRO (ASKAP). Other support and contributions will be from UCAL, which will concentrate on low-cost, monolithic CMOS receivers. UK (UCAM, UOXF, UMAN) will focus on high performance, custom-fabricated sub-systems of PAF’s, while ASTRON, IT and Cornell (TDP) will contribute specialist knowledge of advanced solutions. |

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| **Deliverables:**  WP2 deliverables will be structured according to a series of standard Design Reviews (DRs), as laid out in the introductory part of this document. The documentation from all Work Plan sub-system tasks will be combined into an integrated document set for the particular review in question. A DR report on each review will be produced by an independent review team. The WP2 deliverable for each DR will be a report written by the UMAN (SPDO) referencing the DR report and all the input documentation. The items below describe the deliverables expected in the PrepSKA period. Subsequent DRs will take place after the end of the PrepSKA period (T+45 months).  1. CoDr Report for the DVP.  *Type*: Report. *Delivery*: T+26  2. SRR Report for the DVP.  *Type*: Report. *Delivery*: T+45 |