**Work Package Title:** Aperture Array Verification Program (AAVP)

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| **Work package number** | WP2.3 | | **Start date or starting event** | | | | T+ 24 months | | |
| **Work package title** | Aperture Array Verification Program | | | | | | | | |
| **Activity Type** | RTD | | | | | | | | |
| **Participant id** | 4 | 9 | | 10 | 13 | 14 | | 17 | 21 |
| **Person-months per beneficiary** | 4 | (48) | | 20 (+20) | (48) | (48) | | 24 (+46) | (12) |
| **Participant id** | 23 |  | |  |  |  | |  |  |
| **Person-months per beneficiary** | (126) |  | |  |  |  | |  |  |

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| **Objectives:**  To design, construct and evaluate at least one cost-efficient aperture array 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 array in terms of performance metrics, cost-performance trade-offs and flexibility attributes, including the use of results from simulations and other existing arrays to predict the performance of SKA scale stations. |

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| **Description of work:**  As a coordinated programme, the AAVP will bring together the technologies and institutions which are working on aperture arrays to develop an optimised SKA system. The optimum technology of this system will change over time as the relative costs of analogue and digital technology evolve. This will be clearly identified for the period of the SKA construction. The AAVP is undertaking detailed SKA scale performance and cost modelling. This will steer the precise frequency ranges, sizes and other characteristics of the AA system, operating in concert with the higher frequency dish based system. The AAVP covers all of the aperture array work, including the low-frequency (70 – 450 MHz) and mid-frequency arrays (300 - 1000+ MHz aiming at 1400MHz)  The aperture arrays will be designed and simulated to operate as a consistent system to meet the science objectives described in the Design Reference Mission. Further, the technology and implementation for processing and data distribution will be designed to use as many common systems as possible, for cost and maintainability. The AAVP will build on the work of the FP6 SKA Design Study (SKADS). As with the DVP, the AAVP will need to demonstrate performance, sensitivity, power requirements, calibrate-ability, manufacturability, reliability and maintainability. While the demonstrators in the AAVP will necessarily be built from existing technology without substantial customisation of semiconductors, it will show implementation roadmaps for the systems in the SKA  *SKA-Lo*: The collectors for the lowest frequencies will be sparse aperture arrays. Sparse arrays are chosen as a cost efficient means of building sufficient Aeff to overcome the rapidly escalating sky noise below ~300MHz. These will build on the technology and work from arrays currently being implemented e.g. LOFAR, MWA, PAPER etc. While the actual technology implemented will naturally evolve to take advantage of mainstream commercial developments e.g. in processing, connector interfaces etc., many of the underlying beamforming and imaging algorithms will be both part of the AAVP and implemented for the SKA**.** For SKA-Lo, the AAVP will collate the information and results from arrays currently being implemented. In addition the AAVP will undertake further development of the element designs to increase their bandwidth. If possible, this work will produce a single element design that can cover the entire range from 70 to 400+ MHz, but a fall-back will require two element types. This would then require two low-frequency arrays. A comparison of these two approaches will form part of the AAVP work at the end of PrepSKA. The AAVP will build a demonstration array which will utilize processing hardware similar to the dense aperture array (see below). It may be the same hardware with an exchange of elements for testing. There will be substantial work on the integration of the front-end hardware to provide an easily installable system e.g. the possibility of solar powered independent elements linked to the processing systems over digital fibre, removing the need for power distribution to the elements.  *Dense Aperture Arrays*: A dense AA technology is a regular matrix-style array of closely coupled elements, operating at mid-frequencies from 300MHz ideally up to 1.4GHz, and was the main focus of the SKADS programme. This technology is more ambitious than sparse AAs, but will have very high scientific return if it can be achieved. It is recognised that dense AAs can, in principle, provide very high survey speeds, excellent receptor performance in terms of imaging, dynamic range and polarisation purity and multi-beaming flexibility. The challenges lie in the implementation to provide high sensitivity, high performance processing algorithms and manufacturability within a restricted cost and power budget. The basis of the implementation concerns is the number of elements required to provide a substantial Aeff; volume is also the root of the solutions, since a high volume of relatively low cost parts is attractive to industry, which is familiar with the techniques required for mass manufacture.  Informed by the results from SKADS (EMBACE and 2-PAD), the AAVP will design, build and demonstrate at least one dense-AA demonstrator, capable of development for SKA deployment in 2015-2018. The demonstrator array will be used to verify a dense-AA design that can meet SKA specifications. For example, imaging capability is clearly important; the imaging performance of the dense-AA demonstrator will need to be verified as part of the AAVP. It is proposed that a suitable set of small dense-AA arrays will be built which are capable of astronomical imaging demonstration. The results of astronomical measurements will be compared with simulations to illustrate their ability to meet SKA imaging specifications. The techniques needed to calibrate AAs will require post processing software adapted from algorithms now being developed for current low-frequency telescopes (e.g. LOFAR).  Verification testing, against criteria derived from the Design Reference Mission, will be an essential part of the AAVP. The development of a test array 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 must be checked over the full frequency range, across bandwidths, in conditions of varying solar illumination. An evaluation of the methods of calibration, calibration accuracy, and frequency of calibration will be part of this work. The impact of the results will be evaluated against the required system performance in the most demanding SKA applications. Techniques to evaluate aperture arrays are currently under development as part of the SKADS program; these will lead to a rigorous test and measurement scheme for the AAVP. An initial test plan for the AAVP will be developed, reviewed, and updated as the testing programme proceeds.  The full results from the AAVP will include analysis of results from the demonstrator described above, simulations of a full SKA AA station and array of AA stations, results from arrays being implemented currently including LOFAR, MWA, and PAPER. The final deliverables of the AAVP will be a verified AA design for the SKA, reviewed in a series of design reviews.  Cost estimates using projected technology for SKA-ready implementation in 2015-2018 will be a deliverable of the AAVP.  Participants: This task will be led by an AAVP Management Team comprising of UK and ASTRON, under the auspices of the European SKA Consortium, and working in close coordination with UMAN (SPDO). There will be European wide plus ICRAR (Australia) participation in the diverse aspects of the AAVP. Participants are ASTRON, UK (UCAM, UOXF, UMAN), MPG, OPAR, INAF, and IT(PRAC).  WP2.3.1 **Wide Field of View Aperture Array Tiles**  The aim is to produce a readily manufacturable system which has the minimum number of elements consistent with required sensitivity, frequency range and beam performance.  The two main tasks of WP2.3.1 are to develop the best element design and integrate this into the most effective array configuration; this has to be done separately for both SKA-lo as a sparse array (AA-lo) and the dense AA in the higher frequency range. The design parameters are specified from the cost and performance modelling. The array for SKA-mid developments is managed jointly by ASTRON and the UK. The SKA-lo work has two main strands: use of a highly integrated single element array, covering the full SKA-lo frequency range, led by ICRAR and a dual array, covering the same frequency range with two different element types, led by INAF. In each case the element design has to work closely with the LNA developments to produce a highly integrated design that optimises cost and performance. The reduction of power and cost through integration are critical, although the SKA levels of cost and power will not be achievable using the technology available and affordable to the AAVP, it will aim to provide convincing evidence, in collaboration with industry, that the targets required for the SKA can be attained. Alternative designs will be evaluated and the optimum built into the demonstrators and reported upon.  WP2.3.1.1: SKA-lo (AA-lo in AAVP) single-element design. This work will develop an element and array configuration to cover the frequency range from the lowest specification of the SKA, 70MHz, up to a cross over frequency with the dense AAs in the range 300-450MHz. The design will incorporate the LNA, gain, equalisation, plus possible multiplexing and digitisation electronics. The signal for a polarisation pair of elements will be compatible with a single dense-AA polarisation to enable identical processing hardware to be used for both types of arrays. A target is to make the element ‘self-powered’, incorporating solar cells and storage, with a fibre data output.  Participants: ICRAR, UK (UCAM, UXOF, UMAN), and ASTRON.  WP2.3.1.2: SKA-lo dual-element design. This will also cover the frequency range of 70MHz up to 300-450MHz. This will be using two more conservative log-periodic or dipole element designs. These will be individually amplified and then combined in a diplexer. The design will include the analogue sub-systems.  Participants: INAF, ASTRON  WP2.3.1.3: Dense-AA design (AA-hi). The dense AA has a number of alternative element designs: Vivaldi, BECA and ORA. They each have trade-offs in terms of performance, maturity and implementation cost. This task will select the most appropriate element using results from SKADS and some further level of development and testing. The array design will be a consequence of the required frequency range, performance and sensitivity needed, derived from the science requirements and element type selected.  Participants: This task will be co-led by ASTRON for Vivaldi designs and UK (UCAM, UOXF, UMAN) for BECA and ORA designs.  WP2.3.1.4: AAVP integrated front-end. The aperture arrays use a very large number of receiver elements with associated LNAs. Clearly further reductions in system temperature will be highly beneficial for cost and power through a smaller required Aeff, so considerable work will be assigned to front-end development. Due to the large number of front-ends they will necessarily operate at ambient temperature, hence, the detailed mechanical layout and matching of the LNA with the element is essential to achieve SKA sensitivity requirements. This task is therefore closely related to WP2.3.1.3. The deliverable is a design for the AA front end element with the LNA providing an analogue signal which can be transmitted to the gain chain or analogue beamformer systems. The LNA development or identification is critical, and both in-house and industrial designs will be considered. All appropriate semiconductor technologies will be considered using a range of materials: InP, GaAs, Si, SiGe etc. The LNA packaging will be integrated with the antenna element, for the shortest possible feed connections (since the feed connections are at ambient temperature, they can contribute significant noise).  Participants: ASTRON, UK (UCAM, UOXF, UMAN), OPAR  WP2.3.2: **AA** **Signal Processing**  Aperture arrays detect the incoming signals through sampling via the antenna elements. To form these signals into beams and then treat them in a similar fashion to dish systems requires beamforming. More generically the AA signal processing is required to both extract the required signal information from the incoming raw data and to calibrate the AA station. Beamforming is straightforward in principle: it is necessary to normalise the amplitude and apply appropriate delays to the signal from each element and combine them all to form a beam. This is repeated many times to form as many beams as required for the FoV. It is likely that the process will largely be performed in the frequency domain, using phase shifting with complex weights and summation in narrow frequency channels. The processing for a full SKA AA station will necessarily need to be in a hierarchical structure to constrain processing and communication costs. The signal processing system for the AAs will need to be flexible to support alternative algorithms for different experiments, and also flexible in the selection of data to process by frequency, pointing and resolution. Furthermore, the processing will need to support calibration schemes to maximise the performance of the arrays.  Multiple aperture arrays will be required to cover the frequency range required; the signal processing hardware and architecture will be designed to be common across these arrays to minimise implementation and support costs. The power and costs of the processing systems are major contributors for the system, hence they will be minimised. The AAVP will design a scalable processing system and implement a demonstration system. However, this will not use the components for the SKA since this would fix the technology too early in the design cycle.  Participants: ASTRON, UK (UCAM, UOXF, UMAN), OPAR |

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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 Revised Work Plan. 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 AAVP.  *Type*: Report. *Delivery*: T+30.  2. SRR Report for the AAVP or a Final PrepSKA Wrap-up Report at T+45, whichever comes first.  *Type*: Report. *Delivery*: T+45. |