

# **SKA Demonstrators, 2004**

## **An Assessment by the Engineering Working Group**

Submitted to the SKA Director

22 September, 2004

P. J. Hall (EWG Chair), On Behalf of the Committee

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## **SKA Demonstrators – Summary Remarks**

Peter Hall, 8 September 2004

### **1. Introduction**

The Engineering Working Group (EWG) (formerly the IEMT) has considered the six SKA demonstrator project plans received. Detailed initial demonstrator reviews were produced by individual Group members and these reviews were discussed at the recent EWG retreat. After the retreat, the initial reviewers produced revised assessments; these are included as Appendix 1 of this document. During the retreat the Group also rated the demonstrator projects quantitatively, according to previously-agreed criteria. (The rating criteria were, in fact, a sub-set of review guidelines given by the Chair for producing the detailed written reports – see Appendix 2).

### **2. Timeline for SKA Demonstrators**

Fig. 1 is a summary of important milestones for various SKA demonstrator projects as extracted from the submitted project plans. The EWG was asked by the SKA Director to consider whether there would be significant technical progress by the end of 2006, when an external engineering review could be held. The EWG judges that there should be major progress by this date but notes that the timeline depends heavily on successful funding outcomes for critical technology demonstration projects (e.g. in Europe, the USA and China). The usefulness of a 2006 review will need to be re-assessed in early 2005, when the international funding situation is clearer.

Considering the practicality of a 2008 technology selection, the EWG notes that the timescale is again very tight, with even the major projects likely to be incomplete by the end of that year. It is also important to bear in mind the disparity in aims between the present round of demonstrator projects: some focus squarely on low unit costs and mass production, whilst others – notably the large reflector projects – will deliver “demonstrator of demonstrator” (DoD) outcomes. Both large- and small-N concepts will require a phase-2 (large-area) demonstrator but the 2008 leap-of-faith will be greater for the large dishes, principally because of the less complete demonstration possible in the present, relatively small-scale, projects.

### **3. Quantitative Rating of Demonstrator Projects**

For more background on which major issues the EWG associates with various SKA concepts refer to the IEMT’s October 2003 report (SKA Memo 41). In general terms, the EWG’s 2004 assessment centred on how well the demonstrator project plans address the points raised in Memo 41, particularly the points relating to pivotal technologies for the various concepts. The latest EWG assessment also considered how far a project takes a concept towards being

ready for a large-scale roll-out by the end of 2008, say in a phase-2 (large-area) SKA demonstrator.

Additionally, the EWG considered what risk mitigation strategies had been built into the demonstrator plans, noting that risk mitigation was, perhaps understandably, more evident in the larger-scale programs (such as the European SKADS and US TDP projects) than in smaller demonstrators (such as SKAMP). Larger programs tend to have more review and branch points, whereas smaller demonstrators tend to rely on a linear progression through tightly-defined technology challenges. The consequence of failure in any one of these challenges has a great impact on the demonstrated applicability of the concept to the SKA.

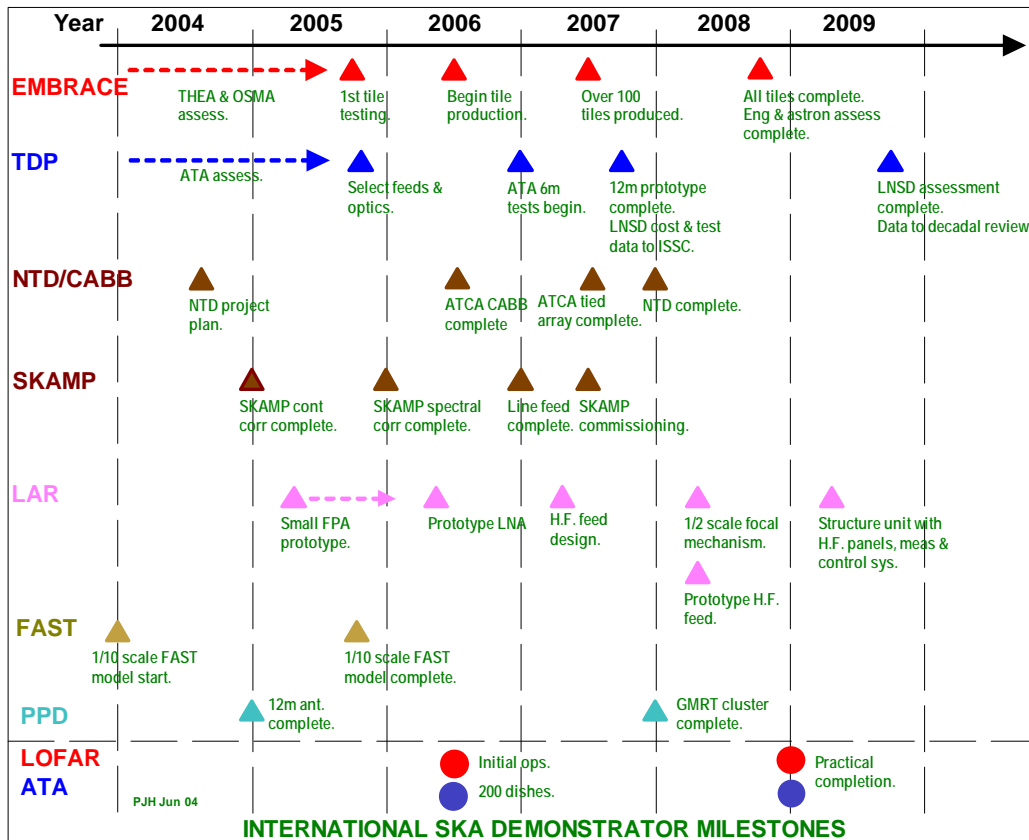


Fig. 1. Timeline for SKA Demonstrators

Table 1 (below) shows the EWG’s ranking of the six SKA demonstrator projects based on the above, and other self-explanatory, considerations. Note that no assessment was made of the Australian NTD project, since details of that project are still to be submitted. It was further assumed that the SKAMP demonstrator project is free to draw on the CSIRO and other technology programs outlined in the Australian submission.

Table 1. EWG Demonstrator Assessment

	<b>FAST</b>	<b>LAR</b>	<b>SKAMP</b>	<b>PPD</b>	<b>TDP/12m</b>	<b>SKADS/ EMBRACE</b>
Frequency range of demonstrator	< 5 GHz	< 1.8 GHz	< 1.4 GHz	< 5 GHz	0.1 – 25 GHz	< 1.4 GHz
Demonstration of pivotal and/or high-risk technology	3-4	3	2-3	3 <sup>(c)</sup>	4 <sup>(d)</sup>	3 <sup>(f)</sup>
Demonstration of cost reduction strategies	2	2	1-2	3-4	4	5
Demonstration of realistic risk management for concept or system	3	1	1	2	4	2-3
Likelihood of completion by end of 2008	0, 4 <sup>(a)</sup>	0, 2-3 <sup>(b)</sup>	3	3-4	0, 4 <sup>(e)</sup>	3-4
Likelihood of substantial added knowledge by end of 2006	4	4	4	4	4	4
Realism of project plan (milestones & timescale vs budget and manpower)	1-2	3	3	4	5	4
Definition of appropriate milestones (suitable for ISPO monitoring)	1-2	5	3	4	4	5
Security of funding for the project as defined	?	?	3-4	4	?	?
Quality of responses to IEMT Oct 2003 supplementary questions	1	4-5	NR	NR	4	4-5

**Key:**

- 0 Very poor; or very low
- 1 Poor; or low
- 2 Average
- 3 Good; or high
- 4 Very good; or very high
- 5 Outstanding; exceptionally high
- ? Indicates critical funding outcome still unknown
- NR = no response received

**Notes:**

- a. Higher score refers 30 m ‘demonstrator of demonstrator’
- b. Higher score refers to structure unit ‘demonstrator of demonstrator’
- c. Score is for single field-of-view (FOV) feed; would be higher with focal plane array (FPA)
- d. Score is for single FOV feed; would be higher with FPA
- e. Higher score refers to single 12 m antenna; would be higher with 2008 interferometry
- f. Score is for single polarization EMBRACE; would be higher for substantial area with dual polarization tiles

**4. Concept Risk Assessment In More Detail**

As part of the retreat discussion the EWG rated the risk involved in developing various concepts for SKA application and, in particular, for possible hybrid SKAs. For this early evaluation the assigned risk rating was simply “high”, “medium” or “low”. The risk was split into two parts: that associated with reaching the cost goals outlined in the SKA whitepapers, and that attached to reaching stated SKA performance goals. The risk summary is shown in Table 2.

Table 2. Risk Attached to SKA Concepts

Concept	Frequency	Cost Risk	Performance Risk
KARST	< 2 GHz	High	Medium-High <sup>(2)</sup>
LAR	< 22 GHz	High	High <sup>(2,3)</sup>
CR	< 2 GHz	Medium	Medium <sup>(2)</sup>
PPD	< 5 GHz	Low <sup>(1)</sup>	Medium <sup>(2)</sup>
LNSD	> 1 GHz	Low <sup>(1)</sup>	Low
AA	< 2 GHz	High	Medium

**Notes:**

- 1. Technology risk is low but computing cost uncertainty may increase rating to medium
- 2. Low-frequency FPA unproven
- 3. Cooled FPA yet to be developed

## 5. Concluding Commentary

The EWG sees value in continuing the first-round SKA system definition work presented at the retreat and at SKA 2004. This work gives a framework for cost and performance estimation, and de-couples much of the system design from the specifics of antenna concepts. The major job of the newly-constituted EWG task forces over the coming year will be to develop descriptions of the various SKA sub-systems in a form suitable for inclusion in the system definition model, and to produce whitepapers discussing the sub-systems in detail. For reference, the task forces and chairs are listed in Table 3.

Table 3. EWG Task Forces and Chairs

<b>Task Force</b>	<b>Chair</b>
Systems	Dick Thompson
Antennas	Parbhu Patel
RF Systems	Sander Weinreb
Signal Transmission	Ron Beresford
Signal Processing	Larry D'Addario
Interference Mitigation	Frank Briggs / Steve Ellingson (joint)
Software and Computing	Tim Cornwell
Industrial Liaison	Peter Hall

The EWG noted that, with wide fields-of-view at low frequency now forming an important SKA goal, all concepts require the use of phased arrays, either in the aperture or focal planes. (Assuming that small dishes are taken as a single concept and require a low-frequency capability). It is a concern that no astronomically-capable aperture or focal plane demonstrator yet exists, given that phased array technology will be so critical beyond 2008. It is of course heartening that the science output from the few operational multi-feed arrays (such as the Parkes system) has been high, and encouraging that the European SKADS project is seeking to link a number of international groups active in phased array R&D. Nevertheless, the EWG re-iterated the earlier IEMT concerns about the pace of phased array development, given the pivotal nature of the technology to the SKA.

The costing of SKA concepts is heavily dependent on the amount of collecting area, which is in turn directly dependent on the estimated  $T_{\text{sys}}$ . The EWG is concerned that present projections of  $T_{\text{sys}}$  are both optimistic and non-uniform across the various concepts. In particular, the losses (ohmic and other) of radiating elements and transmission lines are probably under-estimated, and models of sky noise need more consistency. To assist concept proponents, the EWG Antenna and RF Systems task forces will produce uniform models enabling better  $T_{\text{sys}}$  estimates to be made.

One of the highlights of the Penticton gatherings was the spirited discussion on SKA software. This was prompted largely by the efforts of Tim Cornwell and colleagues and

served to underline that computing-related issues will be extremely important in charting the path to the SKA. The SKA project has come from a position of having essentially no overall analysis of its software needs to the point where key issues have been identified and can be examined over the next year.

## **Appendix 1 – Reviews of SKA Demonstrator Projects**

## EWG Demonstrator Review – European Aperture Array SKA Demonstrator (EMBRACE)

Peter Hall

Revised Version, 29 July 2004

The EMBRACE demonstrator project has stated science and engineering goals, namely “to demonstrate the technical and scientific potential of the aperture array concept using a low-cost phased array station with the essential SKA functionality in combination with the WST array”. In the form currently proposed it is fair to say that the primary aims of the project fall in the engineering domain although, with a total area of 625 m<sup>2</sup> (equivalent to a 25m dish), EMBRACE will be the first dense aperture array able to do meaningful radio astronomy. The authors are to be commended for defining such a challenging project: to get a new type of instrument functional and to demonstrate the required cost reduction factor will be a very substantial contribution to radio science. Still, even with the substantial resources (~ €30M) proposed for EMBRACE and SKADS, its over-arching European SKA program, it is important to recognize that the demonstrator will inevitably be less mature in 2008 than instruments based on better-known technology such as dishes.

From the engineering perspective, EMBRACE comes close to demonstrating a whole SKA concept. Sensibly, the focus is on further development and cost reduction in the antenna area, but the project does provide signal processing of sufficient power to do a real astronomical characterization of the array. The proponents, in Table 1 (page 4 of their document), clearly set out the technical goals of the project. Two aspects of the proposed design will make many readers pause for thought. First, the instrument is described as “single polarization”. Second, the instantaneous bandwidth is given as just 40 MHz.

The question of whether to build a larger area with one polarization, or a smaller array with two, has no doubt been the subject of much discussion amongst the proponents. The larger area allows better sensitivity and better signal-to-noise ratio on a host of measurements one can imagine being made in conjunction with the WSRT. On the other hand, effective dual polarization performance is a central part of the demonstration of an SKA concept. It is important not only in a range of imaging science, but in areas like pulsar timing, where EMBRACE and its descendents could, conceivably, excel. While the authors do mention that polarization will be dealt with towards the end of the EMBRACE project, or that alternate tiles in EMBRACE itself could be rotated orthogonally to provide a limited polarization capability, the demonstration of astronomical capability would be enhanced greatly by incorporating full polarization into the main EMBRACE array. Pursuing a dish analogy, a factor of two trade in collecting area reduces the dish diameter from 28 m to 20 m: still a useful size for astronomical characterization.

From an engineering perspective it is also significant that a fully populated, dual polarization, dense array is different in the electromagnetic sense from its single polarization counterpart, requiring demonstrator evaluators to extrapolate any success or failure of EMBRACE to the two polarization case. At the same time, it is true that that the manufacturing and cost reduction challenges facing EMBRACE’s designers are huge.

One can therefore understand their focus on deploying a sizeable collecting area as soon as possible.

I note that the EMBRACE development activities are split across several European groups, no doubt to muster the required resources and to meet the obligations outlined in the SKADS proposal. If technical and other considerations make it impossible to incorporate dual polarization into EMBRACE, my recommendation is to increase both the scale and pace of the work package dealing with the development of the dual polarization tiles. Even if EMBRACE itself is a single polarization instrument, the availability of a few dual polarization tiles (with an area sufficient to do some level of sky – perhaps satellite – measurement) by the SKA technology selection date would be enormously significant.

While it is not clear what fraction of the total budget is devoted to the remote (smaller) aperture array patches, the authors may want to think about foregoing the remote patches in order to offset partially the extra cost of enhanced dual polarization prototyping. The demonstrations of patch-to-patch correlation and fairly modest-rate VLBI data links are interesting but are one level below that of demonstrating a full-capability main array.

Turning to the bandwidth question, the limited instantaneous bandwidth (40 MHz) may be a function of the need to use particular technology (e.g. LOFAR style processing) to demonstrate the phased array antenna. This makes good sense provided that the back-end signal processing bandwidth limitations do not drive the design of the antenna-based components (e.g. beamformers). The EMBRACE demonstration will be convincing only if it is shown that the antenna and related components can achieve the desired bandwidths within the required price envelope. Processing a single segment of the available bandwidth is not greatly detrimental to the engineering demonstration but it might be worth exploring whether collaborations with other groups (including those outside Europe) could yield a wider bandwidth EMBRACE backend, perhaps by allowing multiple 40 MHz channels.

The authors have provided a good overview of the project in Gantt chart form. The overview contains a number of milestones, most of which are in a form suitable for tracking by the EWG or other bodies. A description of various major activities is also given and underlines well the amount of work involved in this ambitious project. No resource tables (manpower, cash) are provided, although indicative summaries are available in the full SKADS proposal. EMBRACE appears to be of a feasible scale for a body such as ASTRON (the major partner) but, assuming that SKADS is funded, it is clear that there will be challenges in terms of hiring manpower with the requisite skills on the timescales needed. Much rests on the SKADS proposal, and it is expected that its funding status will be known by late 2004.

While the demonstrator summary shows clearly the place of EMBRACE within the SKADS arena, it would be useful to see a management and technical organization chart for EMBRACE itself. Such a chart may allow further external commentary on the balance between various activities, should the proponents feel this is of value.

In terms of what might be available for an external concept review, the authors' Gantt chart indicates that much of the demonstrator system design will be complete, and the first tile characterized, by 2006. Indeed, they set a major milestone of nine tiles

completed by June 2006. My conclusion is that, if the schedule proceeds as outlined, external reviewers of SKA concepts will have important additional information about dense aperture arrays by late 2006. Looking towards a 2008 SKA concept choice, the EMBRACE plan shows all 625 tiles completed, and testing at the WSRT underway, by quarter-4 of that year. The timescale for a 2008 technology selection process is therefore tight but it is comparable with that of other major international SKA demonstration efforts. While there may be some scope for minor re-casting of the EMBRACE project plan to yield quicker astronomical characterizations of a part of the aperture array, there should be no doubt that, overall, the proponents have committed to an aggressive and well-thought-out plan. The plan seeks to establish scalability of the concept to the SKA and there is strong emphasis on achieving the required cost reduction factors.

It is not clear from the proponents' submission whether there is any formal risk assessment or risk mitigation process with the EMBRACE plan, nor is there any discussion of contingencies. One might infer that there are possibilities ranging from acceptance of e.g. a more limited RF range, through to abandonment of the two-dimensional array in favour of a cylindrical reflector and its (substantially) 1-D linefeed. Presumably there are design and test reviews associated with the EMBRACE milestones; these could usefully be spelled out and the process of managing contingencies addressed in a little more detail.

There is no explicit mention of software in the demonstrator description. While some of the required effort may be absorbed into the "preparation and installation on the WSRT site" activity, one suspects that there is substantial control and related software needed for the phased array itself. Elements of such a package may exist from the THEA project but the explicit identification of software activities in the project plan would make those familiar with software projects less nervous.

The installation of the EMBRACE demonstrator at Westerbork will certainly be a first step to illustrating the infrastructure needs of such an instrument. While the site is hardly remote and the challenges of e.g. power generation will not be present, simply operating the phased array and its associated electronics in an outdoor environment (with the attendant swings in e.g. temperature and humidity) will establish much about the ruggedness and robustness of the design.

Operating EMBRACE in conjunction with the WSRT will enable a range of important astronomical tests to be performed, including basic evaluations of sensitivity, pointing, and beam-shape stability under the influence of e.g. finite-resolution beamforming. As it happens the WSRT, with its polar mounts and clean optics, should be an exceptionally suitable instrument for this type of investigation. Any phased-array peculiarities should be relatively easy to characterize. As mentioned though, EMBRACE as proposed has no dual-polarization capability (refer to earlier comments). One thing which could be included in future demonstrator descriptions is a commentary on how the simultaneous RF FOVs might be used; presumably it is possible to correlate WSRT sub-arrays with separate EMBRACE FOVs.

The importance of wideband phased arrays to a range of SKA concepts is well known and EMBRACE will deliver further knowledge relevant to both aperture and focal plane applications. The full SKADS proposal has gone to some lengths to identify several collaborations and it may be that EMBRACE itself could benefit by closer links in some

key areas (e.g. with the Australian RF CMOS integrated receiver project). Industry links have not been identified explicitly by the authors of the demonstrator outline. However, collaboration with companies familiar with the mass production of RF electronics is obviously important in driving down the cost of “all electronic” antennas. It would be useful to see a short outline of the proponents’ plans in this regard.

The authors of the EMBRACE proposal have given comprehensive answers to the IEMT’s supplementary questions (see the 2003 IEMT review of the Aperture Array concept). Their graphical illustration of cost as a function of number of FOVs is interesting and will need careful consideration in science and operations discussions. That one gets smaller incremental sensitivity gains for additional FOVs is not in doubt; the real question is what additional astronomy is opened up by more FOVs (say M-off) and true operational parallelism. That question remains an obviously outstanding one for the SKA science community and other astronomers; its answers are unlikely to have much to do with simple  $M^{1/2}$  sensitivity scaling. This is not intended as a criticism of the EMBRACE proponents but rather a call for greater general focus on the gains of parallelism.

Quantitative Scoring (on the basis of the Proposal as Submitted):

<b>Criterion</b>	<b>Rating</b>
Demonstration of pivotal and/or high-risk technology	3 <sup>(a)</sup>
Demonstration of cost reduction strategies	5
Demonstration of realistic risk management for concept or system	2-3
Likelihood of completion by end of 2008	3-4
Likelihood of substantial added knowledge by end of 2006	4
Realism of project plan (milestones & timescale vs budget and manpower)	4
Definition of appropriate milestones (suitable for ISPO monitoring)	5
Security of funding for the project as defined	?
Quality of responses to IEMT Oct 2003 supplementary questions	4-5

Notes:

a. Score is for single polarization instrument; would be higher for substantial area with dual polarization tiles.

Key:

0	Very poor; or very low
1	Poor; or low
2	Average
3	Good; or high
4	Very good; or very high
5	Outstanding; exceptionally high

## EWG Demonstrator Review - Australian SKA Concept Demonstration Activities

A. R. Thompson and G. W. Kant  
June 30, 2004,; Revised Aug. 12, 2004

In pursuing the SKA concept in Australia, attention is being turned away from the Luneberg Lens (LL) concept and focussed towards aperture arrays and concentrators (particularly cylindrical reflectors) and related technology. A major goal is the development of a New Technology Demonstrator (NTD), which will have a collecting area of 3000 sq. m, located at a relatively quiet site in western Australia. This will be based on aperture array, cylindrical reflector, or parabolic dish technology. Technological developments relevant to the SKA are being pursued through the improvement of several existing instruments. These include development in the areas of line feeds, wide bandwidth hardware for continuum observations, modern correlator technology, signal connectivity and signal processing. It is pointed out that the existing collecting area in Australia includes almost 6000 sq. m (the ATCA and the Parkes dish), plus 18,000 sq. m in the Molonglo cross telescope. Thus it is economically more efficient to make use of these existing instruments in demonstrating the SKA technology than to build a demonstrator of comparable area.

### Development Areas

The program includes development of MMIC amplifiers using various semiconductor technologies. Since neither AA nor cylinder technology is suited to the use of cryogenically cooled front ends, developing the best uncooled systems is clearly important. Integrated receivers and wide bandwidth amplifiers for use with photonic data transportation are also mentioned.

Signal processing and connectivity involves work by Swinburne University and includes disk-based recording for VLBI observations and new computer systems for pulsar observations at the Parkes telescope and the AT compact array.

A new broadband backend and correlator for the AT compact array will increase the maximum bandwidth from 128 MHz to 2 GHz. This project commenced in 2002, and is listed as providing technological development useful to the SKA.

### Molonglo Telescope

Upgrading the Molonglo telescope (SKAMP project) to cover a frequency range of 300-1400 MHz will involve a number of new technologies including the linefeed, beamformers, digital filtering, wideband spectral correlator, control system, and RFI mitigation, all of which are of relevance to SKA concepts. A milestone calls for the upgrade to be completed for commissioning tests in June 2007. It is interesting to note that the Molonglo Cross came into operation about 40 years ago with a linefeed capable of operation at 408 MHz (Mills et al. Proc. IRE Aust., 24, 156-165, 1963). At that time there were to be 22 front-end amplifiers along the mile-long E-W arm and 177 N-S. For the proposed 1400 MHz feed system with dual polarization there will be approximately  $1.5 \times 10^4$  dipoles per arm. A modern low-noise implementation will require many more front end transistors than in the original linefeed. The relative cost of electronics has greatly decreased over 40 years, but the development of a linefeed with sufficiently low system temperature and adequate beamforming flexibility, within a reasonable cost, is a crucial task for the Australian concept.

### New Technology Demonstrator (NTD)

As mentioned above, the demonstrator will have a collecting area comparable to the Parkes telescope, (3000 sq. m) but its usefulness will be greatly enhanced by having an instantaneous field of view of  $50 \text{ deg}^2$ . This will provide high speed for surveys including pulsars. Although the basic technology is not specified, it is stated under the SKAMP program that the NTD project will link closely with SKAMP, and acceleration of the linefeed development is specifically mentioned. Thus it seems reasonable to conclude that the cylinder technology is likely to be the choice for the NTD. Provided that a sufficiently low-cost line feed can be developed, the use of cylinders offers a very practical way to produce a large collecting area. The NTD project plan is being developed in collaboration with MIT, and the milestone for completion is 2007. In addition to antenna and receiver technology, the NTD will provide experience with the low RFI environment that the Western Australia site is hoped to provide, connectivity with eastern observatories, and provision of electrical energy at the site.

### Strengths and Weaknesses of the Cylinder

Strengths and weaknesses of the cylinder concept are briefly discussed in the 2003 review (see the IEMT Report dated 3 Oct. 2003). Strengths include the wide instantaneous field of view and the mounts, which are mechanically simpler than for circular paraboloids. Weaknesses include the complexity of the linefeed, and the impracticality of cryogenic cooling. These factors are likely to limit the upper frequency of operation to something of order 2 GHz. Also, pointing of the beams in elevation is restricted by the mechanical pointing of the reflector, and multibeaming is possible only in the orthogonal direction. The polarization characteristics of the cylinder antennas may not be as good as those of paraboloids or of aperture arrays, but further investigation is required on this point.

### RFI

Under RFI mitigation, it is stated that RFI surveys will be undertaken at the ATCA and Parkes sites, using the equipment already available there. Under the NTD it is mentioned that the Western Australia site is expected to be very RFI-quiet. Since most interference to radio astronomy originates from satellites, it is not clear how much better the RFI environment in an area of low population density can be expected to be. There is no specific mention of an interference survey at the Western Australia site. It is mentioned that the political and social aspects of protecting the radio quiet environment at the NTD site are being pursued. Mitigation studies using data from the ATCA and Parkes are planned and a milestone in Section 2.7 of the demonstration document calls for mitigation in real time at the correlator to be implemented in mid 2007. It presumably remains to be seen how effective this will be, i.e. how close to the noise any residual interference responses will be.

### Science Goals for the Demonstrators

Section 5 of the demonstration document gives brief details of astronomically important programs that will result from the planned demonstration activities on the Molonglo telescope, the NTD, and the ATCA.

### Rotation of the Beams

It was pointed out in Section 11(vi) of the cylinder review in the 2003 IEMT Report that the non-circularity of the cylinder beam contours, and their rotation on the sky with hour angle, could be a complicating factor in observations requiring several hours of tracking.

This would cause variation of the synthesized beam and the SNR over the field of view. The cylinder details given last year include overall dimensions of 110 x 15 m and construction as four mechanically separate units. Individual units would be 27.5 x 15 m, with uniform illumination in the long dimension, resulting in roughly 2 to 1 variation on beamwidth for the individual unit. At the IEMT meeting in Penticton (July 13-15, 2004) it was learned that it is proposed to use beamforming with sections of the line feed, so that for each cylinder there are several beams with approximately equal angular widths in elevation and in the orthogonal dimension. The approximate circularity of the beam contours will greatly reduce the problem of the rotation of the beam on the sky, which would be much more serious if the full cylinder aperture were used to form a single beam. Possible use of 15 m diameter parabolic dishes with focal-plane array feeds, rather than cylinders, was also briefly mentioned at Penticton..

### Beamwidth and Computing Load

The beamwidth of the proposed cylinders in elevation is determined by the 15 m dimension of the reflectors. As mentioned above, beamforming to provide beams with approximately circular contours of width determined by the 15 m dimension is planned. At the lower frequencies, the wide beamwidth could result in a serious increase in the computing load. This increase would result from the requirement to compensate for non-coplanar baselines, as discussed by Cornwell in SKA Memo 49. Cornwell considers antennas with circular apertures, and finds, for example, that a decrease in antenna diameter from 25 m to 12.5 m at 1.4 GHz results in an increase in computing costs by a factor of approximately 256. Further study is required on computing requirements with respect to this point.

### General Conclusions on the Cylinder Concept

The question of the upper frequency limit of operation with the cylinder technology is not discussed, and proposed science demonstrator projects with the NTD are largely H1 studies. Since the number of radiating elements in a linefeed increases in proportion to the observing frequency, and losses in transmission lines also increase, the number of front-end amplifiers etc., and hence the cost, will increase with frequency. An upper limit above 1400 MHz is certainly to be hoped for. Overall the concept demonstration plan makes a very good case for the practicality of pressing ahead with the proposed demonstrators for the lower frequency end of the SKA coverage.

### Questions Provided by Peter Hall, April 23, 2004

Questions to help focus the reviewing process are given in italics below, and each is followed by a brief answer. The answers are generally in the range of very good to satisfactory, except for question 12 on supplementary questions raised in the IEMT 2003 Report.

1) *What is the main purpose of the project? SKA technology demonstrator, SKA pathfinder science instrument, or other? Some projects will have several purposes and it would be appropriate to give the reviewer's feeling on primary and secondary motivations.*

The main purpose is judged to be a technology demonstrator (the NTD). Also testing SKA-relevant technology in upgrades to some existing instruments.

2) *What does the project demonstrate in engineering terms? A whole concept, major subsystem(s), critical component(s), infrastructure, other?*

Demonstrates a major part of the cylinder concept. In particular the crucial linefeed cost and performance.

3) *What is the approximate scale and duration of the project? Financial and manpower summaries, together with an overall plan, should have been provided by authors.*

The cost given is \$18.4M over 4 years. The reviewers have not analyzed the manpower requirement.

4) *How much of the project is actually funded? If there are outstanding funding applications, when will the results be known?*

The project appears to be largely funded except for expenses of location of NTD in Western Australia (see para. 3 of Section 1 of the demonstration document).

5) *Which institutions are key players?* Institutions involved include CSIRO (ATNF), U. of Sydney, Swinburne U., MIT.

6) *How is the project co-ordinated? Is the management structure straightforward or complex?* Management structure is not discussed in detail, but CSIRO should be capable of handling a program like this.

7) *What are the major milestones? Are the milestones tightly defined? Will it be possible for the IEMT and ISPO to track progress over the coming years.*

Milestones are defined and should help to track progress.

8) *Are the overall goals and milestones plausible given the resources available?*

The milestones seem plausible if no major problems arise.

9) *Is it likely that the project will add substantial knowledge (e.g. about a concept) prior to the 2006 external review of SKA engineering progress?*

By 2006, the project should be able to provide some details of the cost of linefeeds, which are crucial for assessment of the cylinder concept.

10) *Is it likely that the project will deliver its major outcomes in time for selection of SKA technologies in 2008?*

Delivery of major outcomes, such as linefeed testing and accurate costing, seem possible by 2008. Plan calls for NTD to be completed within 2007, but it is likely to take more than a year to get good experience with its operation.

11) *How well does the project address the key technology questions raised by the IEMT in its 2003 report?*

Key questions concerning the performance of the cylinder array include the upper frequency limit, which depends upon the linefeed technology and the noise performance of the uncooled amplifiers. These will be answered by the ongoing studies. Other questions include the possible effects on computing costs related to the wide beamwidth at the lower frequencies.

12) *How well answered are the supplementary questions raised by the IEMT in its 2003 report? Are there major outstanding issues?*

Further questions (Section 11 on p. 19 of IEMT Report dated 3 Oct. 2003) have generally not been specifically addressed, except for the question concerning ellipticity of the beam contours, on which information was given at Penticton (see information under "Rotation of the Beams" above).

13) *How well does the demonstrator establish scalability to SKA (including areas such as connectivity and data transfer, in the case of concept demonstrators)? Is there a clear plan in place to demonstrate the cost reductions needed to make SKA feasible?*

Connectivity and signal processing are being addressed by people at Swinburne U. (Section 2.2 of the demonstration document).

14) *Does the project outline a systematic approach to risk assessment and risk management? What contingency options are discussed and what effect does this have on the concept or system in the SKA context?*

Contingency is probably OK but reviewers cannot be sure.

15) *Is there any software and/or computing component to the project? If so, what are the main issues addressed?*

Some computing component is presumably required with in the Swinburne U. work and in testing of the new high bandwidth backend at ATCA. See also remarks on international cooperation on SKA software in Section 3.3 of the demonstration document.

16) *Does the plan incorporate activities for further development and review of relevant mechanical engineering and mechatronics?*

Mechanical engineering will be involved in development of cylinders for NTD.

17) *Does the project include activities which demonstrate aspects of SKA infrastructure development? If so, what areas are covered (e.g. remote area construction, passive climate conditioning, remote power provision, wideband data links to remote sites, etc.).*

Infrastructure development will be required for locating of the NTD in Western Australia.

18) *Will the demonstrator do at least basic astronomical measurements and interferometry (perhaps in conjunction with an existing telescope)? Are there plans to characterize important performance aspects prior to 2008? (Such aspects might include sensitivity, bandwidth, polarization purity, pointing, beamshape stability, etc.).*

Impressive astronomical programs for the NTD and other instruments involved in the technology demonstration are listed in Section 5 of the demonstration document.

19) *Does the project have applicability to other SKA concepts or research efforts?*

A number of aspects are applicable to other SKA concepts, e.g. connectivity, signal processing, wideband correlator, RFI mitigation, and experience at a remote Western site.

20) *Are there identified links with other international SKA groups, or other major astronomy projects?*

International groups with which there are links include MIT, PHAROS (EU FP6 RadioNet), EMBRACE (EU FP6 SKADS). (see Section 3 of the demonstration document)

21) *Are there identified links with industry participants? If so, what is the form of the industry involvement?*

Four areas of collaborative work with Australian industry are listed in Section 4 of the demonstration document.

Rating

On most points we would give the Australian demonstrator plan high marks. Numerical scores were assigned at the meeting in Penticton, based on joint discussion by the IEMT group. In the present case the assignment of scores is focussed on the SKAMP project, since details of the NTD have not been given. It has been assumed that SKAMP was free to draw on all the technology and simulation projects mentioned in the Australian submission. The scores for SKAMP, on a basis of 1 to 5, are as follows.

Demonstration of pivotal and/or high-risk technology, 2-3  
 Demonstration of cost-reduction strategies, 1-2  
 Demonstration of realistic risk management for concept or system, 1  
 Likelihood of completion by end of 2008, 3  
 Likelihood of substantial added knowledge by 2006, 4  
 Realism of project plan (milestones & timescale vs budget & manpower), 3  
 Definition of appropriate milestones (suitable for ISPO monitoring) 3  
 Security of funding for the project as defined, 3-4

#### Luneberg Lens Concept

The decision to set aside further work on the LL concept, and to concentrate on concepts that offer more certain promise of a successful outcome, has led to a plan that should certainly result in practical demonstration of a number of essential aspects of SKA technology within a few years. This is a decisive step forward, and resulted from giving full attention to the dielectric loss of the LL elements, which was the basic problem. Although the attenuation of the dielectric was improved, the resulting performance was not competitive with that of reflector antennas for the high-frequency end of the SKA range. From the science viewpoint, this disadvantage was judged to outweigh the multi-fielding at centimeter wavelengths, which was a major strong point of the LL concept. Also, the dielectric loss would require the use of relatively small apertures for the individual receiving elements (a diameter of 7 m was considered in the 2003 LL white paper), resulting in increased computing load at the low end of the frequency range as discussed in SKA Memo. 49. The various reports and studies of the LL concept contain contributions to aspects of the SKA system in the areas of signal processing and distribution etc., which should be useful in development of other concepts.

#### Footnote Added by Peter Hall Regarding the New Technology Demonstrator (NTD)

At the time of final publication of this report (September 2004) it appears that the Australian SKA Consortium will now implement a revised NTD project plan involving a dish + focal plane array option. The EWG will review this proposal when details of the project plan are made available via the SKA Director.

## **EWG Demonstrator Review - Indian SKA Demonstrator**

Parbhu Patel (ASTRON, NL) and Dave DeBoer (SETI Institute, USA)

July 5, 2004

### **Introduction**

The Indian submission relating to SKA demonstrators describes the planned work to provide the proof-of-concept for the Preloaded Parabolic Dish (PPD) antenna concept. Although some aspects of the demonstrator plan are only given in brief, the proposed milestones are well defined and are achievable within the suggested timescale. Furthermore it lends itself for an easy monitoring by the ISPO, on a timely basis.

### **Answers to Questions**

*1. What is the purpose of the project?*

The purpose of the project is to produce one antenna by December 2004 and a cluster of 9 –12 telescopes by the end of phase 2, which ends in 2007.

*2. What does the project demonstrate in engineering terms?*

In engineering terms, the project will carry out the following, in phase 1:

1. PPD concept proving
2. Design and develop broadband feeds
3. Develop a versatile control system

And in phase 2, it will:

1. Produce a cluster of 9 – 12 telescope at GMRT.

*3. What is the approximate scale and duration of the project?*

Phase 1 will finish by December 2004 and the second phase by 2007.

*4. How much is the project actually funded? If there are outstanding funding applications, when will the results be known? .*

There is no indication that there is an outstanding funding application and therefore we assume that the required funds have already been approved for the second phase (2004 – 2007).

5. *Which institutions are key players?*

There is industrial participation from:

- a. Central Power Research Institute, Bangalore
- b. GD Softech, Bangalore
- c. Jog Equipment Pvt. Ltd, Pune
- d. Tata Consulting Engineers, Bangalore

6. *How is the project co-ordinated? Is the management structure straightforward or complex?*

There is no information provided on the management structure.

7. *What are the major milestones? Are the milestones tightly defined? Will it be possible for the IEMT and ISPO to track progress over the coming years?*

There are only two major milestones. One is in Dec 2004, when the following will have been accomplished:

1. PPD concept proof
2. Design and development of broadband feeds
3. Development of a versatile control system

By Dec 2007, the project will have achieved:

1. Production of a cluster of 9 – 12 telescopes at GMRT.

8. *Are the overall goals and milestones plausible given the resources available?*

Yes, assuming the resources are made available.

9. *Is it likely that the project will add substantial knowledge (e.g. about a concept) prior to the 2006 external review of SKA engineering progress?*

We believe it will, as phase 1 will finish by December 2004 and by 2006 considerable progress will have been made towards producing a large number of antennas.

10. *Is it likely that the project will deliver its major outcomes in time for selection of SKA technologies in 2008?*

It will have finished its final goal of 9 – 12 telescopes by December 2008.

11. *How well does the project address the key technology questions raised by the IEMT in its 2003 report?*

There are three further questions asked in the 2003 report. The questions which were not answered on automated, and on-site, production are particularly important as they relate to a potentially lower cost solution; the answers could put the PPD in a favourable light.

12. *How well answered are the supplementary questions raised by the IEMT in its 2003 report? Are there major outstanding issues?*

See 11.

13. *How well does the demonstrator establish scalability to SKA (including areas such as connectivity and data transfer, in the case of concept demonstrator)? Is there a clear plan in place to demonstrate the cost reduction needed to make SKA feasible?*

The PPD concept is clearly scalable to SKA, as the number of dishes can be adjusted and the processing requirements can also be adjusted to match the available funds. It shares many, if not all, the issues with the US overall design.

14. *Does the project outline a systematic approach to risk assessment and risk and risk management? What contingency options are discussed and what effect does this have on the concept or system in the SKA context?*

The risk management issues have been addressed by designing broadband feeds to cover different frequency bands, which are well known and therefore the risk attached to them are small. The horns under investigation are corrugated horn, quad-ridged horn and they will further examine trapezoidal structures also. The cryogenic system is also under development as well as the front-end receivers and the digital backend are also being systematically addressed. No mention of how the various feeds are to be used in conjunction with one another is made.

15. *Are there any software and/or computing components to the project? If so, what are the main issues addressed?*

Yes, there is a major software component to the project. They are planning a new digital back-end receiver with a capability to process a 500 MHz. Also, there is considerable embedded software being developed for the control system for tracking with a pointing accuracy of better than an arc minute.

16. *Does the plan incorporate activities for further development and review of relevant mechanical engineering and mechatronics?*

Further development of and review of relevant mechanical engineering will include the proposed study to obtain a dish diameter in the range of 12 to 18m, which will minimise the cost and provide an optimal performance in the frequency range of 0.3 to 8 GHz.

17. *Does the project include activities which demonstrate aspects of SKA infrastructure development? If so what areas are covered (e.g. remote area construction, passive climate conditioning, remote power provision, wideband data links to remote sites, etc).*

No mention of infrastructure was made. The paper included primarily the technology of the antenna concept (mount, control, feeds). Mention was made of easy on-site assembly, although the extremely low costs mentioned most likely require extremely low labour costs.

18. *Will the demonstrator do at least basic astronomical measurements and interferometry (perhaps in conjunction with an existing telescope)? Are there plans to characterize important performance aspects prior to 2008? (Such aspects might include sensitivity, bandwidth, polarization purity, pointing, beam shape stability, &..).*

There are many interesting science goals that can be performed using the proposed cluster, including:

1. Solar system studies
2. A study of the fine scale structure and statistical characterization of the turbulent gas distribution in the neutral Interstellar Medium
3. Characterization of the distribution of the low frequency recombination line emitting gas in the Milky way
4. A study of the large-scale distribution of molecules in the Milky way.
5. The cluster telescope operating in the range 3 to 8 GHz will prove to be an ideal high frequency counterpart for Simultaneous Multi Frequency Observations (SMFOs) of pulsars leading to a complete / self-contained pulsar observing set-up in India.

19. *Does the project have applicability to other SKA concepts or research efforts?*

Major items that will have applicability to other SKA concepts include:

The major positive impact of this project on SKA is likely to be derived from the cost related issues. However, the automation of the manufacturing process (question from IEMT's 2003 report) needs to be addressed in more before exact benefits can be appreciated.

20. *Are there identified links with other international SKA groups, or other major astronomy projects?*

Mention was made of using the demonstrator array to support Indian satellite operations.

21. *Are there identified links with industry participants? If so, what is the form of the industry involvement?*

There is industrial participation from:

- a. Central Power Research Institute, Bangalore, involved in the vibrational and modal analysis of the dish.
- b. GD Softech, Bangalore, consult for the mount design
- c. Jog Equipment Pvt. Ltd, Pune, Fabrication of the mount and its erection

- d. Tata Consulting Engineers, Bangalore, consultant during the installation stages.

### Quantitative Scoring

<i>Criterion</i>	<i>Rating</i>
Demonstration of pivotal and/or high-risk technology	3
Demonstration of cost reduction strategies	3-4
Demonstration of realistic risk management for concept or system	2
Likelihood of completion by end of 2008	3-4
Likelihood of substantial added knowledge by end of 2006	4
Realism of project plan (milestones & timescale vs budget and manpower)	4
Definition of appropriate milestones (suitable for ISPO monitoring)	4
Security of funding for the project as defined ?	4
Quality of responses to IEMT Oct 2003 supplementary questions 4	0

<p>0 Very poor; or very low  1 Poor; or low  2 Average  3 Good; or high  4 Very good; or very high  5 Outstanding; exceptionally high</p>
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### Some Additional Comments

The project plan is realistic with very definite deliverables and timeline.

This project has the potential to offer a very low cost solution for the production of reflectors. However, the IEMT 2003 request for further information on automated production and on-site assembly, we believe, has not been fully addressed. This information would be extremely useful to the EWG in assessing the cost impact of mass produced reflectors.

Although there is no identifiable risk strategy mentioned, we believe that the authors have deliberately chosen fairly low risk technology, leading necessarily to a low cost solution and mitigating obvious need to manage risk involved with high technology design and development tasks.

# Review of the 2004 US Demonstrator Document

Ralph Spencer, JBO  
Bruce Veidt, DRAO

September 22, 2004

## 1 Introduction

The US SKA Demonstrator document (“2004 Update on The Large-N/Small-D (LNSD) SKA Concept: Technology Development and Demonstrators”) describes planned work to refine the LNSD concept through the Technology Development Project (TDP), which has been submitted to the US National Science Foundation (NSF) in March 2004, as well as through complementary ongoing work as part of the US SKA Consortium, the Allen Telescope Array (ATA), the Deep Space Network (DSN), and the Extended VLA (EVLA).

Although the demonstrator document provides an outline of the project, many of the details discussed here were extracted from the TDP proposal sent to the NSF and is available at <http://www.astro.cornell.edu/~cordes/SKATDP>.

## 2 Answers to Questions

### 1. *What is the main purpose of the project?*

The goal of the Technology Development Project (TDP) is to produce a feasible and affordable LNSD design by focusing on critical questions listed in the next section.

### 2. *What does the project demonstrate in engineering terms?*

The key questions that the TDP will address are:

- How do we obtain sensitivity at the lowest cost?
- How do we achieve adequate data processing throughput?
- What is the optimal diameter and costing of the antenna that takes all factors into account?
- How can we mitigate radio-frequency interference (RFI) in order to reach sensitivity goals?
- How can the LNSD design provide images with high dynamic range ( $> 10^6$ )?
- How would the LNSD concept and TDP results be used in a hybrid design for the SKA that incorporates additional or alternative antennas?

The subprojects that will work to answer these questions are:

1. Antennas and receivers
2. Signal transport and digital processing
3. System analysis and design
4. Operations and costing
5. ATA SKA Development Facility
6. Siting
7. Education and public outreach

These subprojects will make use of experience gained in other US led projects, particularly the Allen Array, the proposed DSN project and the EVLA.

3. *What is the approximate scale and duration of the project?*

The duration of the project is 5 years, to begin in 2005. About 60 people are actively involved in the SKA in the US and presumably most would be involved in the TDP.

4. *How much of the project is actually funded? If there are outstanding funding applications, when will the results be known?*

This proposal was submitted March 2004 and a funding decision is expected in October–November 2004. The requested amount of the grant is US\$32 million. Funding for related projects (the ATA, DSN, and EVLA) is ongoing.

5. *Which institutions are key players?*

Members of the US SKA Consortium are:

1. California Institute of Technology and the Jet Propulsion Laboratory
2. Cornell University and the National Astronomy and Ionosphere Center
3. Harvard University and the Smithsonian Astrophysical Observatory
4. Massachusetts Institute of Technology and the Haystack Observatory
5. National Radio Astronomy Observatory
6. University of Illinois
7. University of New Mexico
8. Naval Research Laboratory
9. SETI Institute
10. University of California at Berkeley
11. University of Minnesota
12. University of Wisconsin
13. Virginia Polytechnic Institute and State University (VA Tech)

The US SKA Consortium Executive Committee is the supervisory, regulatory and decision-making body for the TDP.

6. *How is the project co-ordinated? Is the management structure straightforward or complex?*

The US SKA Consortium is chaired by Y. Terzian (Cornell), with co-chair W. J. Welch (UC Berkeley) and Treasurer D. DeBoer (SETI Institute).

The TDP proposal has principle investigator J. Cordes (Cornell) with co-PIs R. Cappallo (MIT), P. Goldsmith (Cornell), S. Weinreb (Caltech/JPL), and W. J. Welch (UC Berkeley).

The TDP will be managed by the National Astronomy and Ionosphere Center under the direction of the US SKA Consortium. The overall structure is very flat with the Project Office communicating directly with the seven subprojects. Subproject leaders and institutional participants have been established.

Reporting of progress is to be done on a quarterly basis to the NSF, and annually to the US SKA Consortium. Individuals working on tasks report to subproject leaders, who in turn report to the TDP Project Office. Reports and white papers will be produced when requested by the International SKA Project Office.

7. *What are the major milestones? Are the milestones tightly defined? Will it be possible for the IEMT and ISPO to track progress over the coming years?*

Two major milestones for the overall project are a concept proposal to the SKA for international concept selection in 2007 and a presentation of the concept to the US Decadal Survey in 2009.

Within each subproject are a series of tasks, decision points, and milestones. Interactions between the tasks are clearly outlined in tables, flowcharts, and Gantt diagrams. Quarterly reports on progress will be made to the NSF and annual reports will be made to the US SKA Committee. This level of detail is sufficient to track progress of the project.

8. *Are the overall goals and milestones plausible given the resources available?*

Yes, given the breadth of the radio astronomy technology community in the US and the budget of US\$32 million over 5 years.

9. *Is it likely that the project will add substantial knowledge (e.g. about a concept) prior to the 2006 external review of SKA engineering progress?*

Although this is only one year into the TDP timeline, "substantial knowledge" should be available based on earlier work and work continuing at the SETI Institute/UC Berkeley on the ATA, at JPL on a new DSN design, and at NRAO on the EVLA. Since the institutions and individuals that are part of this project have had considerable experience working together on earlier SKA-related work it should not take long to commence work once funding is released.

10. *Is it likely that the project will deliver its major outcomes in time for selection of SKA technologies in 2008?*

Yes, assuming that a large fraction of the funding requested is awarded. This appraisal is based upon the large number of technical experts available in the US.

11. *How well does the project address the key technology questions raised by the IEMT in its 2003 report?*

The TDP is addressing many of the concerns and questions raised in the 2003 report.

- Three subprojects will address the problem of wide-band low-loss feeds: ATA group, Ingerson, and Professor Kildal (Chalmers). Given the importance of this component to the project, a triple-track approach is prudent.
- Cutting and joining techniques for the hydroformed reflector will be investigated, addressing concerns about transporting large monolithic objects around a continent.
- Concerns about polarization purity and calibration are a factor driving the investigation of symmetrical reflector designs, and will also be part of the evaluation of the wide-band feeds.
- There is *much* work to be done to address concerns about imaging with large-N arrays. The ATA will demonstrate large-N imaging when it goes on-line, as will LOFAR. The TDP will analyze this further through the “Systems Analysis and Design” subproject. The large-N vs. small-N controversy has not been resolved as it requires input from small-N proponents. Computing costs for large-N arrays need further study, especially in light of Tim Cornwell’s recent paper [<http://www.aoc.nrao.edu/~tcornwel/scaling-rev1.pdf>] that argues that computing costs scale with the antenna diameter to the negative-eighth power. A realistic cost equation for computing must be developed so that the overall facility cost as a function of antenna diameter can be minimized. Currently they have assigned a fixed cost for central processing and this is probably an incorrect assumption (see Fig. IV.4.1 of the TDP NSF proposal).

12. *How well answered are the supplementary questions raised by the IEMT in its 2003 report? Are there major outstanding issues?*

See previous item.

13. *How well does the demonstrator establish scalability to SKA (including areas such as connectivity and data transfer, in the case of concept demonstrators)? Is there a clear plan in place to demonstrate the cost reductions needed to make SKA feasible?*

The LNSD concept is inherently scalable: the number of elements can be changed and the signal bandwidths from outer stations can be adjusted to the level available or affordable.

Concerning data transfer, the plan outlined for the TDP goes beyond paper studies and will do tests over a testbed network. These results will be complementary to fibre-transport experience from the EVLA.

Cost-reduction exercises are part of the subprojects and one subproject—“Operations and Costing”—is devoted to that issue. Throughout the life of the TDP there will be three major cost estimate milestones:

- 2005 Preliminary Cost Estimate for the international down-selection of SKA concepts,
- 2007 Enhanced Cost Estimate for the international SKA concept selection,
- 2009 Improved Cost Estimate for presentation to the US decadal review.

14. *Does the project outline a systematic approach to risk assessment and risk management? What contingency options are discussed and what effect does this have on the concept or system in the SKA context?*

Risk management seems to be handled through parallel investigations of possible designs or solutions leading to a decision point. Here are several examples:

- Risk involved in developing a wide-band, low-loss feed is reduced by considering three different ideas, the ATA feed, the Ingersen feed, and the Kildal feed.
- Although an off-axis Gregorian design is the baseline concept, other configurations, such as symmetric designs with mesh extensions are also undergoing analysis and evaluation as a potential solution to problems with polarization impurity or low-frequency operation as well as a means of reducing cost.
- Two different antenna pedestal concepts will be explored.

Note that the overall risk factor will increase if the full amount requested is not awarded and the project cannot afford investigations into alternative solutions and must concentrate on current baseline designs only.

The risk in estimating construction costs will be reduced by monitoring the “real world” experience from the construction of the ATA and the upgrade to the VLA.

Another way in which the TDP will reduce uncertainties is to construct critical components, such as the antenna, as soon as possible.

15. *Is there any software and/or computing component to the project? If so, what are the main issues addressed?*

Yes, computing is a major component of the “System Analysis and Design” subproject. The main issues that will be addressed are:

- RFI mitigation and management,
- calibration and imaging,
- development of a system simulator,
- data management and archiving,
- configuration studies,
- observing modes and impact on data transmission and signal processing.

16. *Does the plan incorporate activities for further development and review of relevant mechanical engineering and mechatronics?*

Yes, research involving mechanical engineering will take place in the following areas:

- hydroformed primary,

- telescope pedestal,
- cryogenic coolers,
- cryostat windows.

17. *Does the project include activities which demonstrate aspects of SKA infrastructure development? If so, what areas are covered (e.g. remote area construction, passive climate conditioning, remote power provision, wideband data links to remote sites, &..).*

General civil engineering requirements for SKA are not explicitly covered, however specific work for a 12-m demonstrator will be undertaken. The project will demonstrate infrastructure development in these areas:

- Land acquisition and environmental impact studies are a task within the “Siting” subproject.
- The “Signal transport and digital processing” subproject will investigate various options for long-distance data transmission using optical fibres. Experiments are planned using a continent-spanning test bed. The use of commercial, research or dedicated networks for long distance paths will be considered. Protocols for optimal high data rate transmission over established networks will be investigated. Research into the use of analogue transmission over short links as in the ATA will also be undertaken. A cost model task specifically mentions using international data to extend the model for non-US sites.

18. *Will the demonstrator do at least basic astronomical measurements and interferometry (perhaps in conjunction with an existing telescope)? Are there plans to characterize important performance aspects prior to 2008? (Such aspects might include sensitivity, bandwidth, polarization purity, pointing, beamshape stability, &..).*

By 2008, the proponents intend to demonstrate a prototype 12-metre antenna with pedestal, its surface accuracy and pointing performance. The tests will include optical characterisation of the surface accuracy, pointing accuracy using an optical telescope, and efficiency using a test receiver. Manufacturing repeatability will be demonstrated by forming at least one additional reflector.

The performance of prototype receivers will be determined by testing them on a modified ATA 6-metre antenna.

By 2009, the final demonstrator for this project is a single 12-metre antenna located at a radio observatory. This antenna will be segmented for shipping. It will be equipped with receivers and will be capable of basic astronomical and interferometric measurements.

19. *Does the project have applicability to other SKA concepts or research efforts?*

Major items that will have applicability to other SKA concepts include:

- MMIC development and fabrication,
- signal transport from stations to correlator,
- correlator architectures,

- RFI mitigation,
- configuration studies,
- calibration and imaging,
- system simulator,
- data management and archiving.

20. *Are there identified links with other international SKA groups, or other major astronomy projects?*

Links will be with:

- Allen Telescope Array,
- Jet Propulsion Laboratory,
- Extended VLA,
- LOFAR (MIT),
- Professor Kildal, Chalmers University, Sweden.

21. *Are there identified links with industry participants? If so, what is the form of the industry involvement?*

Links with industry will be made in the form of contracts for several small companies:

- hydroformed reflector (Andersen Manufacturing Company),
- wide-band feed (Ingersen, Broad Spectrum),
- reflector manufacture study (Schultz Associates)
- pedestal design (Schultz Associates)
- pedestal design (Minex, Inc.).

A number of tasks in the work breakdown structure are labeled “TBD” and could be filled through a competitive bidding process. Other tasks are labeled as “consultant”.

### 3 Quantitative Scoring

Criterion	Rating
Demonstration of pivotal and/or high-risk technology	4 <sup>†</sup>
Demonstration of cost reduction strategies	4
Demonstration of realistic risk management for concept or system	4
Likelihood of completion by end of 2008	0
Likelihood of substantial added knowledge by end of 2006	4
Realism of project plan (milestones & timescale vs budget and manpower)	5
Definition of appropriate milestones (suitable for ISPO monitoring)	4
Security of funding for the project as defined	?
Quality of responses to IEMT Oct 2003 supplementary questions	4

<sup>†</sup>Score increased if low-frequency FPA demonstrated

0	Very poor; or very low
1	Poor; or low
2	Average
3	Good; or high
4	Very good; or very high
5	Outstanding; exceptionally high

### 4 Commentary

This is a wide ranging and ambitious project to develop and refine the LNSD design concept for the SKA. However, to accomplish its goals, it is important that the project be fully funded. The NSF decision on funding will be made public at the end of 2004. It is this uncertainty of funding makes the assignment of numerical scores difficult. In particular, the item “Likelihood of completion by end of 2008” is given a score of 0 due to the uncertainty of funding and because the work plan extends into 2009. The item “Security of funding for the project as defined” is left with a question mark because we have no insight into the thinking of the NSF or the proposal reviewers.

This project will work to reduce risks and uncertainty by analyzing several design options in parallel and then applying selection criteria to choose one. This is certainly a good approach (it mirrors the approach taken by the SKA community to discover an affordable SKA concept) but it is contingent upon full funding of the project. Partial funding would likely force the abandonment of this parallel approach, making the attainment of milestones on schedule less certain. However, incomplete funding may provide the impetus to seek international partners.

The earliest that funding could be awarded is early 2005. We feel that the project could ramp up activity quickly given that many of the individuals have worked on various SKA-related activities in the past.

Although the proposal does not mention of project tracking by the ISPO, this should be possible with little additional effort by the TDP Project Office since such material will be produced for the NSF and the US SKA Committee. This material should also be made available to the ISPO. A number of hard deadlines are established and many milestones and decision points are clearly laid out, facilitating tracking. A series of meetings and workshops are planned and these face-to-face meetings are another venue for project tracking.

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The biggest difficulty in project tracking is likely to be the breadth of the project, which extends from antennas to public outreach.

The IEMT and ISPO need to decide what information is required for proper project tracking and how often must it be submitted.

We must also remember that other related ongoing projects, namely the EVLA, ATA, and DSN array, will provide important information on many concerns of the LNSD concept including fibre optic communications, large-N imaging, operation costs, and element construction costs.

## EWG Demonstrator Review – Chinese FAST Demonstrator

S.Ananthakrishnan and Graeme James, 28 June 2004  
(Updated 13 September, 2004)

The main purpose of the project is to produce a SKA technology demonstrator as well as a stand alone telescope at the low frequency end of up to 2000 MHz, with possible extension to 5 GHz.

In engineering terms, it is a total concept and will demonstrate those facets of the KARST which exclude synthesising of apertures, correlator backends etc. In view of its modern design, the KARST demonstrator (FAST), which is modelled after the Arecibo telescope, will have a much better declination coverage.

The scale of the FAST project has two components. While the reflector overall dimension is 500 m in diameter, the actual area used at any one time is 200-300 m. However, the sophisticated engineering involved in the feed design and the adaptive reflector tiles entails considerable labour and effort. If we combine the two, the scale appears to be ~5% of SKA project effort. The total cost of the project is estimated to be ~USD 60M, of which the Chinese astronomers have obtained a funding of USD 2M, which is being used for making a 1:10 scale model of FAST by the autumn of 2005. It is not clear from the report whether and when the remaining budget will be sanctioned. The key institution is the National Astronomical Observatory, China (NAOC) of the Chinese Academy of Science (CAS) and has involved 30 Chinese institutes and two foreign institutions. The coordination is fully controlled by NAOC.

The main strengths of the FAST project are that of (i) large reflector size giving high sensitivity and hence easy total flux measurements; (ii) low RFI in the KARST region and (iii) low labour costs in China.

The weaknesses mentioned in our earlier review remain, namely that KARST concept has too few antennas for the SKA configuration, Galactic Centre may not be covered, frequency coverage may be limited to 2-3 GHz, etc. Further, while the building of a FAST prototype will be a great achievement for NAOC, the proponents need to specify tighter time limits for completing the project. The software issues related to the FAST and later KARST have to be worked out (even if they are not major issues); the detailed costing remains to be done; the industry involvement has not been spelt out in any detail.

Although all the basic concepts of FAST are being tested in the laboratories, in the field and via simulations, what is being built is only a “Demonstrator of the Demonstrator” (DoD), for which too specific milestones need to be spelt out. Again, although the DoD will clarify a number of concepts involved in the FAST project, it will not be sufficient from the IEMT point of view for scaling the DoD to the level of SKA, or to be able to take any final decision regarding the use of such reflectors for the SKA configuration, unless dramatic progress is made on the FAST project between the years 2006 and 2008.

The report has not specifically addressed the various issues raised in the previous IEMT reports. However, serious efforts have been made by the proposers to study the working of the focal plane assembly and much experience has been gained by them. The FoV is also being increased from a few minutes of arc to half a degree by adopting the Aperture Array Technology and multi beam concepts are being explored.

In summary, the reviewers have reservations in considering the DoD as a scalable model for SKA, within the time frame of technology decision making process.

Quantitative Scoring (on the basis of proposal as submitted, and assuming operation at frequencies < 5 GHz)

<b>Criterion</b>	<b>Rating</b>
Demonstration of pivotal and/or high-risk technology	3-4
Demonstration of cost reduction strategies	2
Demonstration of realistic risk management for concept or system	3
Likelihood of completion by end of 2008	0, 4 <sup>(a)</sup>
Likelihood of substantial added knowledge by end of 2006	4
Realism of project plan (milestones & timescale vs budget and manpower)	1-2
Definition of appropriate milestones (suitable for ISPO monitoring)	1-2
Security of funding for the project as defined	?
Quality of responses to IEMT Oct 2003 supplementary questions	1

Notes:

a. Higher score refers to 30 m “demonstrator of demonstrator”

Key:

- 0 Very poor; or very low
- 1 Poor; or low
- 2 Average
- 3 Good; or high
- 4 Very good; or very high
- 5 Outstanding; exceptionally high
- ? Indicates critical funding outcome still unknown
- NR = no response received

## Review of the Canadian LAR Development and Demonstrator Plans

John W. Dreher and A. Richard Thompson  
September 2004

This review is based on the document *Project Plans for the Development of the Large Adaptive Reflector – Development-to-Demonstrator* by the LAR Group at HIA, DRAO, NRC, and Penticton, dated April 28, 2004, hereafter denoted as the *Plan*.

The Large Adaptive Reflector (LAR) involves a wider combination of technologies than any of the other SKA concepts. A number of these, such as the aerostat suspension for the feed, and the wide range of automatic adjustment of the surface panels, are outside of the range of devices which are widely used and well understood on radio astronomy. Progress has been made in many areas and plans for the period 2004-2009 cover all of the major elements involved. Staff at a number of universities—McGill, Laval, University of British Columbia—are involved in specific detailed studies. A five year development plan from Fiscal Years 2004/5 to 2008/9 is outlined and covers all of the major areas involved. Building of a 300 to 350 meter demonstrator (denoted CLAR) could begin following completion of this plan, and would take an estimated 2 to 3 years. Funds for development through FY 2004/5 are now available, but those for the following years have yet to be secured. The cost of major parts of the demonstrator is not known well enough to make a detailed cost estimate of the demonstrator at this time. The frequency range covered by the demonstrator would be 100-1800 MHz, although the frequency range of the technology, as it might be applicable to the SKA, is planned to be extended toward 22 GHz, using smaller adjustable panels to improve the overall reflector accuracy. An impressive list of astronomical projects within the 100-1800 MHz range is given for testing and confirming the performance of the CLAR demonstrator. This demonstration phase of the project would probably not be completed before 2014.

### Proposal for Demonstrator

This section is organized along the review guidelines suggested by the SKA International Project Engineer.

### Questions Raised by the IEMT

Several critical enabling technologies for the LAR concept were identified in the IEMT Report of October, 2003. For convenience these points are cited below (in italics) followed by review comments based on the current Plan.

*Focal plane arrays: Large FPAs covering relatively wide bandwidths are required. Arrays of Vivaldi antennas are currently favored. Resistive loss, wideband match to amplifiers and the possibility of cryogenic cooling all need study. The performance requirements for the array are complex. All of the following need to optimized in a*

*variable way as pointing changes: aperture illumination, nulling of spillover on the ground, cross polarization correction by combining the signals from orthogonally polarized array elements, possible RFI nulling.*

This is, in the reviewers' opinion, the key technology development required for the LAR concept; the Plan reflects this importance by allocating the most funding to this subtopic of research. The development work on the focal plane arrays is leveraged from the extensive work done for the Aperture Array concept that have shown that closely-spaced Vivaldi array elements can support large bandwidths at relatively low cost. Working with academic and industrial partners, the LAR team proposes to develop a fully operable prototype array section by 2007-2008. This development work seems well-suited to reduce the risks associated with this subsystem, but three important factors are not (explicitly) addressed in the Plan:

1. The LAR concept whitepaper assumes system temperatures in the range 20-30 K. To obtain this performance will require cryogenic cooling of all ~9,000 "front ends" of each focal plane array. Implementing such a large-scale cryogenic system within the space, weight, power, and budget constraints will be extremely difficult. It is unlikely that a cryogenic cooling system could be "tacked on" to a room temperature design after the fact. If cryogenic cooling of the LNAs proves impractical, the system temperatures attained by a LAR station are likely to be 2-3 times higher than assumed in the whitepaper, with a dramatic effect in cost and/or performance of the SKA. The table below provides a rough estimate of  $T_{\text{sys}}$  based on Weinreb's assessment of future LNA noise, spillover calculations by the LAR group, and an estimate of 0.3 dB loss at 3 GHz in the feed and transmission line structures ahead of the LNA (based on work done for the ATA balun and on a reported 0.5 dB loss for a measured Vivaldi feed; The current AA prototype (THEA) reports  $T_{\text{sys}}$  of ~150 K at L band with a 40K LNA).

Frequency	1	3	10	GHz
$T_{\text{sky}}$	8	5	6	K
$T_{\text{spill}}$	10	10	10	K
Feed	12	21	38	K
LNA	23	34	45	K
$T_{\text{sys}}$	53	70	98	K

2. The LAR whitepaper cost estimate assumed 3 focal plane arrays to cover 0.1 to 22 GHz, which implies a bandwidth ratio for each array of at least six. The Plan, however, seems to be focused on arrays with a bandwidth ratio of only two, which would require 8 focal plane arrays to cover 0.1 to 22 GHz. Since roughly half the cost of a LAR station was estimated to be in the focal plane arrays, any increase in the number of such arrays that are needed would increase costs substantially (and also have undesirable operational consequences).

3. The ~500 m height of the focal plan array will offer line-of-sight paths to transmitters at ground level within about ~80 km, and roughly double that to very tall broadcast

transmission towers. As a consequence very strong RFI may be anticipated at the feed elements at the lower end of the SKA band, perhaps as high as  $-30$  dBm. In addition, less-powerful but very numerous mobile interferers can be expected in the cellular and DME service allocations. The Plan does not address the constraints that this RF environment will place on the RF signal path (including the digitizers). Should it be necessary to place adaptive analog RFI mitigation ahead of the digitizers, the complexity and cost of the focal plane arrays would be increased. Also, if the samplers and associated digital systems are located in proximity to the focal plane array, a high degree of RF shielding will be required, which in turn may adversely affect the weight and budget for the focal plane apparatus.

*Aerostat control: Precision control of the aerostat position by control of the tensions in the six tethers is required.*

Flight operations with the existing one-third scale aerostat should be very useful in developing the tether/winch control system. By 2007-2008 the experience gained, which will include a six tether system, should allow the design of the full-scale system needed for the 300 m LAR demonstrator to proceed without excessive risk; however the results with this full-scale aerostat will not be available in time for the currently scheduled SKA technology selection process.

*Feed plate: The feed plate must be light weight and mounted on controllable actuators to keep it at the optimum orientation as a function of pointing angle.*

This subsystem is presently less developed than other LAR subsystems, but the proposed development plan should be able to produce a viable design within a few years. It is planned to build a (1/3) to (1/2) scale prototype during 2007-2008. The design of the feed plate is inextricably combined with that of the focal plane array itself – hence all issues related to the focal plane array, including the cryogenics, must be well understood before a realistic prototype feed plate can be designed.

*Inertial platform: Mention is made of the possible use of an inertial platform to provide the final level of support for the short wavelength receivers, but it is not yet clear if this technology is required.*

The feed plate prototype mention above is planned to include an “actuated perturbation system” which we interpret to be the former “inertial platform”.

*Wide-bandwidth data transmission: The data received by all of the elements in the focal plane array must be brought down to ground level for beam formation. This data rate may exceed the data rate that is transmitted back to the central SKA correlator.*

The development of the data transmission subsystem is included as part of the development effort of the focal plane array; in the development plan this work is largely to be performed by an industrial partner. This design will, of course, depend on the

solutions to the focal plan array bandwidth and RFI problems. The cost constraints on the signal path are severe.

## **Demonstator and SKA System Design**

The proposed 300-350 m CLAR would be a most impressive demonstration of the station concept. It would not directly demonstrate the desired high-frequency capability, but the plan for tests of this capability might be adequate. The main problem is that the valuable design, implementation, and operational experience that the CLAR would provide will not be available on the schedule currently planned for the SKA technology selection process. The dramatic scale of the CLAR, with its concomitant costs, presents substantial risk of schedule delay beyond the date of 2014 when the LAR group estimates the CLAR will have been able to validate the LAR design for full-scale SKA development.

## **Scalability of Demonstrator**

The large LAR demonstrator (CLAR) will not *per se* illuminate SKA scaling issues such as connectivity and data transfer.

## **Science and Interferometry with the Demonstrator**

With ~10% of the value of  $A_{\text{eff}}/T_{\text{sys}}$  of the full SKA, the CLAR “demonstrator” would be the an extremely powerful astronomical instrument in its own right, well able to “jumpstart many of the science goals of the SKA” as noted in the Plan. It would certainly be used in conjunction with other large telescopes for VLBI and other interferometric applications.

## **Activities and Milestones for the Demonstrator**

The Plan outlines a full development program for all aspects of the LAR station, culminating in the 300-350 m LAR demonstrator (CLAR) working in the 0.1 to 1.8 GHz band (with the ability to perform tests to 22 GHz using a portion of the reflector and a test focal plane array). CLAR might be complete by ~2011, resources permitting, with a subsequent five-year operational period to complete all technical and scientific goals.

The development plan includes major subsystem prototypes/demonstrators, roughly on the following schedule:

- Prototype of reflector section with 2 levels of actuators 2005
- (1/3) scale aerostat with 6 tethers 2006
- Small feed array prototype 2006
- Prototype LNA, RF/optical link 2007
- (1/3) scale feed plate 2008

- High frequency panel tests

2008

## Resources

The Plan indicates a 5 year development program running from 2004 through 2009 with a total cost projected at ~9.3 M US\$ and a total effort of ~57 person-years. About 10% of this is presently funded, with the remainder subject to approval by the sponsors (National Research Council, Canada Foundation for Innovation, Natural Sciences and Engineering Research Council, Industry). The small average staffing level of ~11 FTE should produce a very cost-effective effort; on the other hand with such a small team and so many innovative solutions to be determined, the risk of schedule slip must be considered high. (For comparison, the cost and time of the ATA R&D effort were comparable, but the scope of the ATA work was substantially smaller – even so the ATA effort has had difficulty maintaining the planned schedule.)

Reduction of the field of view specification for the SKA would substantially reduce the cost of the LAR station, since this reduction would allow for a smaller focal plane array.

The CLAR is a **major** research instrument, the cost of which is likely to exceed 70 M\$ and which will take at least 2-3 years to build. The LAR team characterizes it as “a goal, which has the support of a large segment of the Canadian radio astronomy community.”

## Demonstrator completion

While the subsystem demonstrators are projected to be complete within the currently accepted SKA technology selection timeframe of 2007-2008, the large demonstrator (CLAR) will not have begun construction. At the time of selection of the SKA technology the concept development of the LAR concept should be completed. This would include feasibility analysis and some test hardware for each of the major subsections of the overall design as noted in previously. For example, the characteristics of the test aerostat (1/3 the size of that required for an SKA element) should be well understood, and extrapolation using a performance model could provide estimation of the performance at full-size. However, there would be no demonstration of a completed full-scale system, and thus no actual operating experience. Under such circumstances it will clearly be difficult for the LAR to compete with other concepts for which the performance demonstrations are more advanced, or for which the design depends largely upon technological approaches that are well proven in conventional radio telescopes. Advantages that the LAR offers for the technology of the SKA include the possibility of covering the frequency range from 100 MHz to 20 GHz in one instrument. This capability would not, however, be verified by the CLAR and would depend on (planned) testing of prototype areas of the more accurate reflector panels.

## Quantitative Scoring

(On basis of < 1.8 GHz major demonstrator)

Criterion	Rating
Demonstration of pivotal and/or high-risk technology	3
Demonstration of cost reduction strategies	2
Demonstration of realistic risk management for concept or system	1
Likelihood of completion by end of 2008	0, 2-3 <sup>(a)</sup>
Likelihood of substantial added knowledge by end of 2006	4
Realism of project plan (milestones & timescale vs budget and manpower)	3
Definition of appropriate milestones (suitable for ISPO monitoring)	5
Security of funding for the project as defined	?
Quality of responses to IEMT Oct 2003 supplementary questions	4-5

Notes:

a. Higher score refers to 'demonstrator of demonstrator'

Key:

- 0 Very poor; or very low
- 1 Poor; or low
- 2 Average
- 3 Good; or high
- 4 Very good; or very high
- 5 Outstanding; exceptionally high
- ? Indicates critical funding outcome still unknown
- NR = no response received

## APPENDIX 2

### SKA Demonstrator Evaluation by the IEMT – Guidelines for Reviewers

Peter Hall, 23 April 2004

#### 1. Introduction

This document sets out some guidelines for IEMT members reviewing the SKA demonstrator plans due for submission to the Director on 30 April, 2004. Reviewers should feel free to add additional commentary. I anticipate editing and combining the reports in a format similar to the IEMT's 2003 report; the composite document would then be made public via the Director and the ISSC.

The second part of this document contains a pro-forma for scoring demonstrator projects against various criteria. This is an exercise internal to the IEMT although the Committee may, after discussion, choose to make the results available more widely.

#### 2. Questions for Reviewers

1. What is the main purpose of the project? SKA technology demonstrator, SKA pathfinder science instrument, or other? Some projects will have several purposes and it would be appropriate to give the reviewer's feeling on primary and secondary motivations.
2. What does the project demonstrate in engineering terms? A whole concept, major subsystem(s), critical component(s), infrastructure, other?
3. What is the approximate scale and duration of the project? Financial and manpower summaries, together with an overall plan, should have been provided by authors.
4. How much of the project is actually funded? If there are outstanding funding applications, when will the results be known?
5. Which institutions are key players?
6. How is the project co-ordinated? Is the management structure straightforward or complex?
7. What are the major milestones? Are the milestones tightly defined? Will it be possible for the IEMT and ISPO to track progress over the coming years?
8. Are the overall goals and milestones plausible given the resources available?
9. Is it likely that the project will add substantial knowledge (e.g. about a concept) prior to the 2006 external review of SKA engineering progress?
10. Is it likely that the project will deliver its major outcomes in time for selection of SKA technologies in 2008?
11. How well does the project address the key technology questions raised by the IEMT in its 2003 report?
12. How well answered are the supplementary questions raised by the IEMT in its 2003 report? Are there major outstanding issues?
13. How well does the demonstrator establish scalability to SKA (including areas such as connectivity and data transfer, in the case of concept demonstrators)? Is

- there a clear plan in place to demonstrate the cost reductions needed to make SKA feasible?
14. Does the project outline a systematic approach to risk assessment and risk management? What contingency options are discussed and what effect does this have on the concept or system in the SKA context?
  15. Is there any software and/or computing component to the project? If so, what are the main issues addressed?
  16. Does the plan incorporate activities for further development and review of relevant mechanical engineering and mechatronics?
  17. Does the project include activities which demonstrate aspects of SKA infrastructure development? If so, what areas are covered (e.g. remote area construction, passive climate conditioning, remote power provision, wideband data links to remote sites, .....).
  18. Will the demonstrator do at least basic astronomical measurements and interferometry (perhaps in conjunction with an existing telescope)? Are there plans to characterize important performance aspects prior to 2008? (Such aspects might include sensitivity, bandwidth, polarization purity, pointing, beamshape stability, .....).
  19. Does the project have applicability to other SKA concepts or research efforts?
  20. Are there identified links with other international SKA groups, or other major astronomy projects?
  21. Are there identified links with industry participants? If so, what is the form of the industry involvement?

### **3. Quantitative Scoring**

In the table below, rate the project on the following numerical scale:

0	Very poor; or very low
1	Poor; or low
2	Average
3	Good; or high
4	Very good; or very high
5	Outstanding; exceptionally high

IEMT Evaluation Table for Demonstrator Project

Project:

<b>Criterion</b>	<b>Rating</b>
Demonstration of pivotal and/or high-risk technology	
Demonstration of cost reduction strategies	
Demonstration of realistic risk management for concept or system	
Likelihood of completion by end of 2008	
Likelihood of substantial added knowledge by end of 2006	
Realism of project plan (milestones & timescale vs budget and manpower)	
Definition of appropriate milestones (suitable for ISPO monitoring)	
Security of funding for the project as defined	
Quality of responses to IEMT Oct 2003 supplementary questions	