

Review of the Canadian LAR Development and Demonstrator Plans

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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 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 believed to extend 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 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 be 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_{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_{sys} of ~150 K at L band with a 40K LNA).

Frequency	1	3	10	GHz
T_{sky}	8	5	6	K
T_{spill}	10	10	10	K
Feed	12	21	38	K
LNA	23	34	45	K
T_{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 LAR 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 this Demonstrator would provide will not be available on the schedule currently planned for the SKA technology selection process. The dramatic scale of the proposed Demonstrator, with its concomitant costs, presents substantial risk of schedule delay for the Demonstrator beyond the date of 2014 when the LAR group estimates the Demonstrator will have been able to validate the LAR design for full-scale SKA development.

Scalability of Demonstrator

The large LAR Demonstrator 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 LAR 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 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). This Demonstrator 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.

The LAR “demonstrator” 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 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 demonstrator and would depend on (planned) testing of prototype areas of the more accurate reflector panels.