IEMT Demonstrator Review – European Aperture Array SKA Demonstrator (EMBRACE)

Preliminary Draft by Peter Hall, 25 June 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^2 (equivalent to a 25m dish), EMBRACE will be the first dense aperture array able to do meaningful radio astronomy.

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 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, I would strongly suggest that they consider incorporating full polarization into the main EMBRACE project; the demonstration of astronomical capability will be less than convincing without this capability. Pursuing a dish analogy, a factor of two trade-off in collecting area reduces the dish diameter from 28 m to 20 m: still a useful size for astronomical characterization.

Having said this, the authors are to be commended for defining such a challenging project: to get a new type of instrument functional, in a form able to do astronomy, and to demonstrate the required cost reduction factor, will be a very substantial contribution to radio science. 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 a dual polarization main array. The demonstration of what will presumably be fairly modest-rate data links is interesting but is surely one level below that of realizing a full-capability main array.

The limited instantaneous bandwidth (40 MHz) may be a function of the need to use existing technology (e.g. at the WSRT?) 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. While the decision to process a segment of the available bandwidth is not greatly detrimental to the engineering demonstration, it might be worth exploring whether collaborations with other groups (including those outside Europe) could yield a wider bandwidth EMBRACE backend.

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 IEMT 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, of which EMBRACE is a part. 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 July.

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 twodimensional 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 are 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):

Criterion	**Rating**
Demonstration of pivotal and/or high-risk technology	4
Demonstration of cost reduction strategies	5
Demonstration of realistic risk management for concept or system	3?
Likelihood of completion by end of 2008	3-4
Likelihood of substantial added knowledge by end of 2006	4-5
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

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