SKA Concept Designs (Whitepapers) – EMT Comments
P J Hall, 1 October 2002

1. General Observations

Although the Stage-1 reports vary considerably in scope and depth, they are enormously useful from the viewpoint of provoking science discussions, system engineering reviews and engineering reality checks.

A function of the EMT and ISAC working groups over the next 12-24 months will be to formulate as many common metrics as possible to assist concept proponents in the preparation of Stage-2 reports, including standard-form specifications and costings. The EMT stresses that the SKA project can only advance at the required rate if the working groups are truly functional.

The EMT agrees that May 2004 is a realistic timeframe for presentation of Stage-2 concept descriptions. While the initial documents are of great value, the effort involved in producing them was a substantial load, especially on smaller groups. With a number of (potential) foundation SKA technologies still unproven, the priority for 2003 should be achievement of key technical milestones within the various international R&D groups. The EMT will liaise with project leaders to identify milestones for each project and will ask the groups to report against these at the Geraldton 2003 meeting.

While identifying a focus of the Geraldton meeting as technical assessment, the EMT agrees that first-level updates to the Stage-1 Whitepapers can be completed by May 31 2003. These 'Stage-1a' updates need not be major productions but should instead include brief answers to points raised by the EMT and ISAC.

The EMT suggests that the SKA Director, in consultation with the EMT and ISAC, issue guidelines for Stage-2 descriptions by mid-2003.

The EMT feels that the ISSC's firm cost target of USD 1 billion will be invaluable to concept proponents in framing revised ideas. While proponents will be free to add variations, it will be useful to see what each group can achieve for the stated base budget, using common inclusions and costing metrics.

All proposed SKA designs currently cost more than USD 1 billion (including construction costs). Keeping the total cost below USD 1 billion requires de-scoping. (Note too that concept estimates are likely to increase, not decrease, with more careful costing). Areas where this might occur include effective area, frequency coverage, number of widely separated beams, and field-of-view. The final ISAC report will clearly be invaluable in framing Stage-2 proposals.

The EMT will ask that a more detailed consideration of operational costs be included in Stage-2 descriptions. Operating cost is potentially a driver in deciding between concepts, with basic comparisons relating to initial versus downstream expenditure. Again, common metrics will be needed for sensible comparisons. As yet, there is no functional 'operations' working group within the EMT or ISAC; the ISSC or SKA Director may wish to consider how the operational costs could be factored in to the Stage-2 Whitepapers.

2. Technical and System Observations

In general terms, the EMT notes that concepts divide broadly between those offering high-frequency operation (> 10 GHz) and those offering widely-separated multibeaming; no concept combines the two attributes, although the Luneburg Lense and Cylindrical Reflector systems offer a measure of compromise. While there is much development still to be done, the EMT feels that the Large-N, Small-D array and the Aperture Array Tiles are the strongest technology concepts in the high-frequency and multibeaming camps. Only the paraboloids offer operation above 10 GHz and only the phased array tiles hold the prospect of large numbers of agile beams. However, it is still uncertain whether the required phased array performance can be realized on SKA timescales; for this reason it is too early to disregard other multibeaming concepts.

The EMT stresses that all the concepts being examined have the potential to contribute to future radio astronomy, either within or outside the SKA context. The SKA(s) in final form will likely owe something to several concepts now being discussed and it is apparent that many first-level demonstrators will contribute significantly to astronomy and radio science. The EMT feels that it would be appropriate for the ISSC to write to national astronomy and radio science organizations, noting the contribution of various groups to the SKA project and stressing the importance of continued R&D.

The EMT is persuaded that independent, widely-placeable, multibeams translate into a true sensitivity gain for a radio telescope. It notes though that the concept challenges many in the astronomy community and, seemingly to a lesser extent, the radio-science community. While LOFAR and smaller SKA demonstrators are an important first step in establishing the merits of multibeaming, the EMT endorses the concept of a large (1% SKA area), cm-wave, multibeaming demonstrator. This instrument would be a vital stage in going from no multibeaming arrays to, perhaps, a multibeaming SKA. (It is of course entirely reasonable to demand that such an instrument establish the scientific credentials of multibeaming before the final step to an SKA is taken).

The SKA timeline need not depend critically on the results from a multibeaming demonstrator. In the likely event that the case for a high-frequency SKA is found to be compelling, the two SKA directions de-couple naturally. From within the multibeaming camp, a large demonstrator – possibly allied with LOFAR – is simply a stage in a multibeaming SKA development.

With the likely split between high frequency and multibeaming SKAs, it is important to examine options such as shared infrastructure (e.g. data transmission and signal processing) for telescopes operating in the two regimes.

The EMT feels that the more detailed set of SKA specifications to be produced by ISAC will be invaluable in addressing important technical questions. Relevant topics include:
- mandatory frequency coverage
- A/T and its allowable variation with parameters such as frequency and elevation
- multibeaming and sky coverage (see below)
- brightness sensitivity (as a function of angular resolution) for a stated bandwidth-time product
- source change or slew times

More thought could be given to the relative merits of an area re-use capability (small number of widely separated beams), perhaps driven primarily by operational efficiency considerations, versus a many-beam capability driven by science. Furthermore, the acceptability of sub-arraying to give some multi-beaming ability needs to be considered.

Parameters such as the total sky coverage; instantaneously accessible sky coverage; and number, distribution and nature of beams (e.g. whether imaging or not) should be clarified on the basis of science discussions. A relevant specification is the number of beams required from array stations located at various distance scales, since the amount of information required from middle and outer stations is a significant cost driver.

It would also be useful to know the scientific value of beams which have limited motion on the sky (e.g. beams which do not track at sidereal rate) – the 'constrained' multibeaming mentioned at the Groningen meeting.

More simulation of the imaging and calibration performance of various concepts, or at least classes of concepts, is urgently needed; much effort might be saved in Stage-2 Whitepapers if e.g. small-N solutions are demonstrated to be unsustainable. The EMT recommends that its working group on software engineering take a lead role in co-ordinating activities in this area. However, it notes the need for wide scientific input to the process.

Many concepts propose some degree of mechanical movement; the EMT would like to see more complete reliability analyses and costings in Stage-2 concept descriptions. This should be based on expert mechanical engineering assessment.

Susceptibility to weather varies from concept to concept and we would like to see some degree of risk assessment for at least high winds, lightning and hail in the next-round descriptions.

The reports identify many common areas of infrastructure and technology development. These include site development, low-noise receivers (cooled and uncooled), high-bandwidth (Tb/s) data transmission, fast ADCs, wideband (GHz) signal processing, and large-volume data handling.

There are key questions pending in areas of common concern. Apart from obvious component development issues (e.g. ADCs), accurate prediction of functionality and cost for areas such as LNAs and long-haul data links is essential in framing reasonable SKA designs. A particular question relates to the predicted performance of uncooled LNAs since this is crucial in deciding whether a concentrator is necessary and, if so, what types are feasible. We note that both specialist radio astronomy and industry inputs are essential in answering these questions.

While there are many possibilities for common technology projects, the EMT and general discussions in Groningen led to four areas being identified as particularly important in the short term. These are array and station configuration studies, calibration strategies, RFI mitigation strategies and systems, and site RFI studies.

The EMT stresses particularly the importance of a global approach in framing SKA interference mitigation (IM) strategies. Many of the techniques now being developed by individual groups have substantial impact on SKA system design. Furthermore, it is quite likely that the various techniques will interact, conceivably to the point of compromising SKA data or overall IM efficacy. The brief of the EMT working group on interference mitigation is therefore broad and the group will be most effective if both astronomy and other engineering working groups interact with the IM team; this is amplified in the detailed IM report (Appendix 2).

So far, the EMT has not identified any significant latent advantages or pitfalls beyond those presented by the concept proponents or referred to in the list of technical questions (below). However, we comment that operational modes involving ‘small-D’ collecting areas in all-sky experiments (e.g., omni-directional SETI) seem to have received little attention to date. Such modes might involve independent pointings of individual concentrators, sub-arrays of concentrators, or stations. (The station case is of course applicable to large concentrators as well). ISAC may wish to consider this further.

3. EMT Questions for Concept Proponents

Cylindrical Reflector SKA

The wideband, dual-polarization, line feed is a central element of the design. Can the authors give any indication as to how the feed might be realized and what its performance might be, including its performance with hour-angle scan?

Can the authors give an indication of how the delay line RF beamformers might be realized and what performance (e.g. transmission and reflection behaviour) might be expected over the wide bandwidths envisaged?

Could the authors clarify the instantaneous sky coverage available and the allowable range of multibeaming within this coverage? Beyond survey work, can the authors expand on other science applications which might justify the complexity of a distributed feed in order to get a constrained multibeaming ability?

Are there lessons which can be learned from existing (or past) cylindrical reflectors in terms of mechanical reliability issues? Are there any new mechanical arrangements envisaged for the SKA implementation?

Refracting Concentrator (Luneburg Lens) SKA

Compared with filled aperture, large-D, proposals, the instrument outlined has somewhat reduced surface brightness sensitivity for low spatial frequencies. Can the authors quantify the brightness sensitivity at various array scales and mention how the reduced sensitivity might affect the science done with the instrument?

Can the authors give an indication of how the protective skin on the lenses might be implemented, noting that a fairly thick skin may be necessary to prevent hail damage in certain sites? What implications does a thick skin have for scattering of ground radiation into the feeds? How effective will the skin be in preventing moisture ingress into the lens?

The authors favour an 8-bit signal transport and processing (including correlation) arrangement. Relative to existing radio astronomy systems, this could be something of an over-design. Although the relative costs of 8 and 4-bit correlators are mentioned in Appendix G, could the authors expand on their reasons for preferring the higher-resolution processing and summarize the incremental costs incurred?

While the authors adhered to the original notion of omitting site development costs from the concept document, can they now outline any special factors which might affect such costs and note whether the amounts suggested in some other documents (e.g. the US paper) are roughly applicable?

Can the authors give an example of how the low and high-band station processing/transmission bandwidths might be used with likely receiver combinations?

In the comparison of costs between cooled and uncooled receivers (Section 15-2), can the authors expand on the choice of cooled low-band receivers as the comparison point?

The Large Adaptive Reflector (DRAFT Document)

Can the authors outline their reasoning of how the "small-N" LAR SKA implementation might achieve the specified dynamic range for the SKA? The comment (p. 5) regarding the focal plane array and the small individual cluster beam size playing a part in achieving the required performance could be expanded.

With the favoured Vivaldi feed arrays, some of the benefits conferred by a 'clean' optical path are negated, especially in polarization studies. The high cross-polarized sidelobes caused by the offset primary parabola will be variable in time as the offset angle changes. Can the authors outline what level of polarization performance they might expect?

The requirement to change feed packages in order to change observing bands could be a significant constraint for observations requiring frequent band changes. Can the authors provide an estimate of the total time for a feed package change, the amount of manpower required at each antenna to accomplish the task and the expected number of different feed packages required to cover the total frequency range?

Presumably the LAR concept is subject to the same costs as e.g. Luneburg lenses or small-D dishes when it comes to transporting raw or beamformed data from stations. A filled field-of-view is only retained if all the station cluster beams are transmitted. Would the authors quote their estimates for data transmission from stations and, if their concept requires data to be discarded (e.g. by not transmitting all station beams), could they outline a representative arrangement for signal transmission across the array?

Hydraulic rams (including the types mentioned on p. 37) operating in hostile environments need attention in areas such as seal replacement. Are the actuators envisaged suitable for use in a range of potential SKA sites or might there be problems in e.g. very sandy (gritty) environments? What level of maintenance might be needed and does this look feasible for perhaps 10,000 long-stroke units?

Can the authors expand on the statement (p. 17) that the cost of linear actuators is approximately proportional to throw? If the system is a hydraulic one, would not the need for larger diameters in the cylinder, piston and connecting rod assembly (to resist lateral loads and buckling forces) lead to a steeper cost dependence law?

Can the authors give an indication of typical source-change times, bearing in mind the composite performance of the various mechanical systems?

At the top of p. 22 (in two places) should f = 2.5 be f/d = 2.5?

In the final document version, can the authors provide a bibliography for the references?

Kilometer-Square Area Radio Synthesis Telescope – KARST

Can the authors give their reasoning of how the "small-N" KARST SKA implementation might achieve the specified imaging dynamic range for the SKA?

The KARST concept as presented falls well short of the SKA target of 1 deg^2 field-of-view at 1.4 GHz. With a 200 m reflector, the beam area is around 0.01 deg^2 and at least a hundred beams would be necessary to meet the target. Would such a system be feasible in the existing design, given the reflector optical parameters and the implications on e.g. the weight at the focus? Would the authors speculate on the cost of extending KARST using focal-plane arrays?

The lowest operating frequency mentioned is 300 MHz but presumably the antenna can operate down to 100 MHz with suitable feeds. Could the authors confirm that size and weight constraints at the focus permit the use of larger feeds?

The authors nominate a suite of narrowband receivers for KARST. Do they feel that contemporary wideband receivers and feeds may have a role in simplifying the proposed antennas?

Can the authors give an indication of typical source-change times, bearing in mind the composite performance of the various mechanical systems?

Aperture Array Tiles

Can the authors indicate how the multi-band operation might be implemented with the Vivaldi tile? Noting the comments on p. 35, we believe that there are in fact three separate arrays. However, nothing in the main text illustrates the layout of such arrays.

On the same theme, it is unclear how much information (e.g. number of beams) is transmitted from a station and how the costed station data transmission resources relate to the astronomical capability of the SKA (e.g. in terms of number of beams available from stations at various frequencies or baseline lengths). Could the authors give an idea of their thinking in this regard?

The authors correctly note that the cost of steel does not reduce with time – unlike electronics. However, would they give some indication regarding the cost of laminate used to make the array feeds? Our first estimates indicate that the cost of this material for 2 square kilometers of physical area could be several hundred million dollars.

The question of scan blindness is not raised. Are there ways of preventing this effect over the frequency range mentioned or do the authors propose ways of working around it (e.g. by scheduling observations appropriately)?

Could the authors clarify what they are proposing regarding mechanical positioning? We assume that the 15 degree tilt illustrated in Fig. 7 could be permanent.

We do not understand the statement in the caption of Fig. 7 regarding the average sensitivity of tiles versus paraboloids. How can fixed tiles (subject to geometrical foreshortening effects) beat steerable paraboloids?

Could the authors comment on the robustness of the polarization calibration given the raw polarization response of the Vivaldi array?

Could the authors comment on the shape and variability (e.g. with frequency) of the Vivaldi element pattern? How do these factors influence the "ideal" (cos ZA) case plotted in Fig. 7?

We feel that the justification for the performance of uncooled LNAs (Appendix A) is somewhat cursory given the importance of the projections on built area (and cost). Could the authors discuss the commercial trends which they feel will drive CMOS technology to achieve the <20K noise equivalents shown in the graph?

The dynamic range specification in Table 1 is incomplete. Should Table 3 indicate mechanical scan in elevation?

Pre-loaded Parabolic Dish

Can the authors give an indication of how the dish manufacturing process might be automated?

Could the authors quantify further the advantages which lightweight dishes confer in terms of mounts and drives?

Can the authors discuss whether this technique could be used to fabricate off-axis paraboloids?

Large N – Small D Array

Compared with filled aperture, large-D, proposals, the instrument outlined has somewhat reduced surface brightness sensitivity for low spatial frequencies. Can the authors quantify the brightness sensitivity at various array scales and mention how the reduced sensitivity might affect the science done with the instrument?

With 15 m minimum spacing, the 12 m antennas will be closely packed. Would the authors clarify the low-elevation shadowing situation? What is the minimum un-shadowed elevation?

The 12 m dishes are shaped for efficiency. Have the authors considered the effects on the off-axis performance and the implications this might have for any future retro-fit with focal plane arrays?

Can the authors give any more details of the dish mount and its likely mechanical performance (including reliability)?

Have the authors had any further thoughts on the form of the "swing away" arrangement for the prime focus receiver ?

Could the authors outline further the operation of the new-generation cryo-coolers and the commercial drivers for the assumed cost reductions?

In the ATA, cooling to ~ 80 K is considered to be adequate and it appears that the path to cheap, reliable, pulse tube coolers is clear. Could the authors comment on the technologies and tradeoffs involved in cooling to 15 K in their proposed design?

Could the authors clarify the feed proposals for the highest frequencies? Are ATA-style feeds a possibility, both in terms of electrical performance and mechanical mounting arrangements for e.g. internal cryostats? Given the possible applicability of the TRW feed to many SKA concepts, are the authors able to supply any further details at this stage? If the TRW feed proves unsuitable, can conventional feeds be used in the available space near the Gregorian focus? Could the authors outline the cost and operational consequences of using conventional feedhorns above 10 GHz?

Appendix 1. Summary of Key Points from Groningen EMT Working Group Meetings

By Peter Hall

(i) Antennas

Principal Concerns

- LAR: Feed design, especially the need for > 2:1 bandwidth feeds
- KARST: Feed bands are too narrow, re-design for fewer feeds
- LL: Demonstration of manufacturing needed
- CR: Linefeed (especially the required bandwidth and dual polarization)
- LN-SD: Confidence in extending from 6 m to 12 m diameters; transportation to site of > 6 m reflectors
- AAT: More justification of cost reduction (Moore's law vs time vs frequency); variation of polarization properties with scan; reduction of power consumption

Possibilities for Collaboration

- Phased arrays as feeds for other designs
- USA and India to discuss common reflector issues (including paraboloid mounts)
- Utilize advanced Chinese mechanical design capability (e.g. mounts)
- CR design to factor in Indian expertise in mechanical and line feed areas

Key SKA Specifications – Need for Clarity from Antenna Designer's Viewpoint

- Standard definition of A/T (e.g. at spot elevation angles, standard Galactic noise models, …)
- More info needed on slewing rates, band-change times, operating and maintenance costs, uv coverage, and A/T versus frequency
- Standard definition for multibeaming; quantify advantages of multiple FOV
- Determine how far EVLA, ALMA goes to fulfilling high frquency SKA requirements

(ii) RF Systems

- Continuing evaluation of new low-noise transistors from commercial foundaries
- Prototype amplifiers with targets:
  –Uncooled; 0.7-1.5 GHz; T_n < 15 K (cost <$1)
  –Uncooled; 0.15-1.5 GHz; T_n < 15 K; wide dynamic range
  –Uncooled; 0.5-5 GHz; T_n < 25 K
  –Cooled (80 K); 0.5-11 GHz; T_n <10 K
  –Cooled (40 K); 10-35 GHz; T_n <15 K
- Need experience with new technology refrigerators (pulse tube, cooling, thermo-electric)
- Need wideband, low-noise, active, baluns for log-periodic antennas
- Need site RFI spectral data to design front-ends
- Monitor CMOS radio-on-chip prospects

(iii) Signal Distribution

- Many emerging developments to connect with, e.g.
  –Technology, political, commercial
- Consider data transmission in regimes of own communications network, rented dark fibre and public network
- Establish network topology and high-level signal distribution architecture
- Need to look at SKA data transmission needs on various array scales
  –Including *local* networks (backplanes)
- Consider overheads and advantages flowing from data formatting and 'frame store' (cf baseband buffer) for alignment of time-tagged samples
  –Experience from new VLBI networks
- Define conceptual business model(s) to apply to networks
  –Open hybrid network, telco networks etc
- There are political advantages for telcos in sharing SKA network in remote areas

(iv) Signal Processing

- Review of whitepapers:
  - Signal processing defined as everything from digitization through signal detection
  - Luneberg lens proposal and Large N-Small D proposal contain the most detail about signal processing
  - LL proposal involves digitizing and transmitting full receiver band (5 GHz) but processing less bandwidth
  - Large N-Small D proposal is based on what's practical in *present* technology (including current limitations in quantizing, transport and processing)
  - Disagreement on quantization requirements (number of bits)
  - LAR, KARST proposals contain very little on signal processing (but perhaps less is needed because these are small-N arrays)

- Common to all concepts:
  - Wide agreement on FX architecture for correlation in large-N systems but XF could be feasible for small or medium-N
  - Most concepts require a large correlator, so common development makes sense
  - All concepts need high speed signal transmission

- Specifications needing clarification:
  - Number of independently tuneable channels (and allowable constraints)
  - Total processed bandwidth; is 0.5+ 0.2 f_c GHz still appropriate?
    (results in a large cost penalty for high observing frequencies; we can't meet this bandwidth specification today)
  - Number of "beams"
  - Simultaneous pointing to widely separated sky positions is not required for most known science (in this sense, one beam is enough)

- Multiple beams within primary beam are certainly needed (but how many?)

- Issues needing work:
  - Quantization and Processing Accuracy. How many bits is enough? (Each concept should estimate its *processed* SNR, including quantization noise. Concerns that "cheap" DSP is poor value since increased noise forces expensive collecting area increase or T_{sys} reduction)
  - In estimating costs, should Moore's law be used? (If so, we need to agree on a common "Moore factor"?)
  - More details of phased array beams needed (including number of beams, relationship of phased array and station beams, and scientific useage)
  - More details of likely RFI mitigation algorithms needed (A simple cost-benefit analysis might give indicative reasonable spending for interference mitigation)
  - Functional simulations of new FX architectures are needed (only have pure mathematical analyses at this point)

(v) RFI Mitigation

- Concepts need more analysis re RFI vulnerability
  - Descriptions of representative RFI environments will be available to designers
  - But no common metrics yet
- IM evolving rapidly
  - Need tight communications with signal processing groups
  - Could lead to re-assessment of site selection criteria
- Science working groups need to assess and state their RFI vulnerability
- Additional signal processing requirements for IM may be large
  - Hardware and software implications
- Many opportunities for common sub-systems and complementary R&D
- Many operational issues arise in order to have flexible response to varying RFI environments (e.g. co-ordination with satellites)

(vi) Software Engineering

- Many SKA calibration problems should be solved by EVLA, LOFAR, ALMA
- Calibration imposes constraints (N, station sensitivity, station configuration)
  - Need details from concepts after guidance from science community
- Need to minimize systematic instrumental errors (important design metric?)
- Very large post-processing requirements for all SKA concepts
  - Need more information from each group
- Extend system boundary to include:
  - Post-processing and pipelined calibration
  - Storage, archiving and export
- Functional simulation needs to be under SE working group
- Better cost estimates needed for both development and operational software

- Better cost estimates needed for computational hardware (special and general-purpose)

Appendix 2. Detailed Report from Interference Mitigation Working Group

By Frank Briggs

RFI Mitigation Working Group Meeting held Groningen, Thursday 15 August, 2002.

Attendees:
W. Baan
A.-J. Boonstra
F. Briggs (Acting Chair)
H. Butcher
R. Ekers
P. Fridman
J. Lazio
B. Peng
B. Thomas
D. Thompson

The instructions for the group (as given by the EMT to the breakout session chairs) were:

- follow the major science/system discussions and lead EMT breakout sessions in considering important issues
- highlight SKA specifications that are still unclear (or only partly resolved) by Thursday
- look for areas (technical and scientific) that have been poorly dealt with in Stage-1 whitepapers
- look for, and record, any new ideas or emphases
- look for opportunities to provide common sub-systems, performance metrics and costings for Stage-2 concept descriptions
- assess opportunities for collaborative projects. Highlight complementary R&D, and identify areas where resource allocation could be more rational
- decide on priorities for continuing working group activity
- distill and record major outcomes from breakout discussions, and pass summaries to Peter Hall (in time for summary/discussion in the afternoon plenary session)

(i) Overview of the RFI Working Group Discussion

In general, the whitepapers have given the issue of RFI Mitigation secondary status in the discussions of the SKA designs. This is unfortunate since one of the principal challenges facing a next generation radio telescope will be how it can function in an increasingly populated radio spectrum and still perform the scientific studies that form the main science drivers.

The continuing technical studies for each of the designs need to pay increasing attention to how the entire system will be able to cope with the RFI backgrounds applicable to each of the SKA sites. These include vulnerability of the antenna design; RF, IF and digital electronics design; signal processing; and operational issues related to scheduling and coordination with other spectrum users. In fact, many developments in RFI Mitigation are shareable among the whitepaper telescope concepts, so there is ample opportunity for common sub-systems and complementary R&D.

(ii) Recommendations

- Future comparisons of SKA concepts would benefit from elaboration of the pros and cons of the designs with regard to their RFI vulnerability or their systemic advantages in RFI mitigation.
- An "RFI environment template" that provides a basis for appraising RFI vulnerability could be constructed. This would give a statistical description of the time and frequency behavior of the ambient RFI background, and it could possibly be based on a site-study such as that coordinated by Bruce Thomas for Western Australia.
- We will need a mechanism for communicating the rapidly evolving ideas on RFI mitigation so that they can be incorporated into SKA designs. (The ATNF RFI Mitigation Webpage could be used to archive and distribute information. http://www.atnf.csiro.au/projects/SKA/intmit/ Current maintainer is Daniel Mitchell)
- There is a clear need for regular communication between scientists (who must judge the impact of various kinds of RFI on their science) and the system designers. Are certain frequency bands judged more important than others -- in order to cover certain redshift ranges for certain atomic/molecular transitions? (This might affect site selection as well as system design.)

(iii) General Discussion

A broad range of issues surfaced.... Here we simply summarize the range of topics that were either mentioned in the whitepapers themselves or were raised in the breakout session.

Issues touched somewhere in at least one of the whitepapers... as work in progress...

- Site studies with current and projected RFI levels
- Self-generated RFI: shielding, circuit/chip design...
- Digital quantization/# of bits needed to contain RFI signal without losing astronomy
- Rx saturation/headroom
- Cancellation techniques (but relegated to future, where mentioned in whitepapers)
- Null-steering + algorithm development for imaging when station beams are continually distorted (updated) by null-steering

Issues not raised in whitepapers, but arising in breakout session...

- Vulnerability of different design concepts to RFI? (For example, do large telescopes with feeds high in the air have greater vulnerability? Can the RF properties of feed systems/supports be designed in order to shield them (or preferentially reflect rfi signals back from whence they came..."inverse-stealth" without causing unacceptable deterioration of system sensitivity)

- What are additional costs of adding RFI mitigation?
  - What are the added costs / computational overhead required for null-steering, both real-time steering AND post-processing image formation
  - Does effective nulling require a minimum number of receiving elements?
  - What are the added costs for cancellation techniques? (It would need a substantial parallel receiving system committed to processing the RFI itself in preparation for subtraction) (more bits? separate reference sensors?)
- Which kinds of mitigation can be combined and/or run sequentially? Which techniques (non-linear excision, for example) preclude use of other techniques (requiring extremely linearity, for example)?
- How much operational effort must go towards continual, ongoing characterization/monitoring of the RFI environment? Need for a Library of RFI statistics (frequencies, power levels, duty factors, times of day, etc) in a form that telescope scheduling can be optimized (possibly fully automated decision making with regard to scheduling) (the LOFAR RFI data base might be a good example of how to start...contact= A-J Boonstra)
  - neural nets for rfi identification and classification
  - overall system flexibility to take advantage of temporarily free bands
  - compatibility of system with rapid response to transients and externally triggered observations
- What degree of sophistication is required of the built-in RFI monitoring system?
- Tracking moving sources/automated classification/source location?
- Trade-off in specifications for LNAs and antenna gain in vulnerability to RFI...
- Feeds may be more exposed in big dish BUT the astronomical signal is amplified relative to RFI...
- How to keep interesting astronomical transients from being thrown out with the variable RFI ...
- Site evaluation... how to format/catalog information (such as Bruce Thomas' report) for maximum usefulness (either in evaluation of sites -or- as a reference for testing design concepts)?
- Site evaluation... ordinarily prefer mountain valleys for their shielding capability; but Rick Fisher's studies show that mountains create strong, complex backscatter with a wide range of delays, perhaps greatly increasing the task of RFI cancellation.
- Will advances in RFI mitigation lead to re-appraisal of ITU `levels harmful for radio astronomy'? This may need continual revisitation during the coming years...

(iv) Operational Issues

There is a range of topics that fall in the broader category of "operational issues" related to RFI mitigation. Some of these concern the mechanics of coordinating and scheduling the telescope... others concern tasks and studies that need to proceed in concert with the design studies leading up to construction.

The creation and maintenance of a radio-quiet or radio-coordination reserve is a multi-facetted task. On the local and national levels, there must be negotiations leading to a concrete (legal) commitment that will permit the confident design and construction of the array. Negotiations and understandings on an international level (suitable for coordinating use of the radio spectrum with defense and satellite services, for example) require opening new lines of negotiation/understanding through the regulatory agencies. Questions remain concerning whether coordination is possible with aircraft communications. Some see a close working agreement with other users as a win-win situation, since the other users might benefit from radio astronomy databases and monitoring.

Are there legal issues surrounding either (1) publicizing databases of spectral usage, or (2) simply receiving and monitoring spectral use in band allocated to possibly classified users? In some countries there are laws governing whether radio bands may be monitored.

What are "costs" of maintaining radio quiet reserve?

Dynamic queuing is an operational issue, along with maintenance and effective use of an RFI data-base.

(v) Near Term and Ongoing Operational Tasks

RFI monitoring at candidate sites needs to be accomplished in a uniform way so that fair comparisons can be made.

The view was expressed that host countries should be responsible for conducting their own site surveys (including financing)... (although there lurks the danger that we could miss out on a prime location by not making a relatively small investment now)

An ongoing assessment of "tolerable levels of RFI" (relative to current ITU official levels) should be made, as methods of RFI mitigation develop. These would not replace the current well determined levels, which are accurate for simple total power receivers and arrays that operate in conventional modes; instead there would be a new category of level for "RFI-mitigation-equipped systems".

Results of site surveys need to be made available to the technical concept designers for inclusion in their design evaluations. These might be of a statistical nature, rather than the complete database recorded during the survey. In fact, some thought should go into how best to “pre-digest” the information to make it most useful for the designers. (Albert-Jan Boonstra has indicated that the LOFAR database, which is currently being constructed, is an example of how to get started.)

Daniel Mitchell is taking over maintenance of the ATNF RFI Mitigation Archive.
The exploder had been disabled, due to security reasons. Perhaps it is time to reactivate some formal distribution in the form of an occasional newsletter.
(http://www.atnf.csiro.au/projects/SKA/intmit/)

Appendix 3. Detailed Report from Antennas and Feeds Working Group

By Graeme James

(i) Some Brief Overall Comments on the Various Designs

LAR (Canada):
- feed design is the major problem to be solved;
- should the receivers be cooled?;
- bandwidth of at least 2:1 desired but better if higher at around 5:1.
- Overall, LAR is the most expensive option. Does this represent realistic costing?

KARST (China):
- feed bands are unnecessarily narrow;
- small FOV;
- limited by suitable sites.

Luneburg Lens (Australia):
- a lens prototype built from the newly-developed artificial dielectrics required as a demonstrator;
- question of lens loss at higher frequencies;
- this solution only viable if multi-beaming is seen as a major feature of the SKA.

Cylindrical Reflector (Australia):
- the main problem to be solved is the line feed;
- problems of polarization and bandwidth with the line feed to be overcome.

Parabolic Reflector (India):
- antenna design only considered;
- can approach be extended to dual-reflector configurations and especially off-set designs?;
- question of the uniformity of the materials;
- how much does the manufacture depend on local knowledge?

Gregorian/Prime Focus Reflector (USA):
- question of confidence in being able to scale-up from SETI 6m design to a 12m using current hydro-forming techniques;
- transportation of 12m diameter antennas to remote sites is not a trivial problem.

Aperture Array Tiles (Europe):
- limited to 1.5 GHz;
- highly reliant on Moore's Law to bring the cost within range. It would be useful to have an estimate of cost v. frequency v. time;
- what are the power consumption requirements?;
- what protection against lightening strikes is necessary?

- What is the variation of polarization performance on scan?

(ii) Possible Collaborations

- The European aperture array tiles are potentially a very useful enabling technology for the feed designs in all the other concepts. Already Australia and The Netherlands are cooperating on the tile technology for array feed design. Such cooperation should be encouraged with at least the LAR and KARST concepts.
- The USA and India should be encouraged to collaborate to see if the Indian low-cost design concepts can be extended to the USA reflector design.
- The Chinese innovative mechanical systems should be studied by all designs where mechanical movement is required.
- The cylindrical reflector designers should talk to the operators and designers of the Ooty cylindrical antenna radio telescope.

(iii) Clarification and Consistency of SKA Specifications

There was a need expressed to clarify and have consistency in specifying the requirements for the SKA, in particular:

- some standard terminology needs to be adapted for defining multi-beaming as there was considerable confusion and differing interpretations during the workshop when talking about this topic
- for similar reasons, a standard definition of A_{eff}/T and its relation to elevation angle is required
- there should be a standard galactic background model adopted
- a clearer definition of what is meant by stated frequency ranges
- a clearer specification of uv coverage

Associated topics included the need for a wider representation of advocates for the science case at the next conference and to address the issue as to what degree the EVLA and ALMA can meet the high-frequency requirements.

(iv) Issues to be Addressed in Stage-2 Whitepaper Proposals (due May 2004)

- estimates of operating costs over a 20 year period
- estimates of slewing rates and the time taken to change frequency bands
- plots of A_{eff}/T v. frequency