Focal Plane Arrays & SKA

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Today:
- SKA and antennas
- Phased arrays and SKA
- Hybrid SKA possibilities
  » A hybrid based on AA + SD/FPA
- FPAs, AAs and SKA

Tomorrow:
- Politics and collaboration
- Re-useable deliverables in SKA demonstrators
SKA Challenges

- Technology
  - Wideband, efficient antennas
  - Fast, long-distance, data transport
  - High performance DSP & computing hardware
  - New data processing and visualization techniques

- Project Management
  - Evolving science goals
  - High levels of technical risk
  - International politics
    - Possible funding phase slips
  - Ambitious delivery timescale
  - Industry liaison
    - Pre-competitive alliances
Main Technology Drivers

- Frequency range
- Field-of-view
- Number of independent fields-of-view
- Balance between survey and targetted instrument

See EWG whitepaper reviews + demonstrator evaluations
Range of possible solutions
- Aperture phased arrays
- Flux concentrators (dishes)

Need at least two antenna types to meet current spec
- Cost effective high-frequency solutions don’t provide enough area at low frequencies
- Want good efficiency at high frequency AND multi-fielding (or at least wide field-of-view) at low frequency
- The “hybrid” approach

SKA concepts have different antennas BUT much post-antenna
Originally:
- Phased FPAs for very large concentrators (dish, cylinder) to get ‘reasonable’ FOV (~1 deg² at 1.4 GHz)
  » Small N concepts
- Aperture arrays with very small RF-phased elements (‘patches’)
  » Large N concept

Now:
- All of the above
- Wide-field cylinder (> tens of deg²)
- Small dish (~12m) + FPA to get wide FOV below ~2 GHz
  » (tens of deg²)
- Digital AA concept feasible?

Phased arrays are (almost) ubiquitous in the SKA
- Central to (almost) all wide-field concepts
Story So Far

- Concept whitepapers and EWG/SWG reviews
  - Rounds 1 and 2

- Demonstrator EWG reviews and ranking
  - Including initial risk (performance + economic) assessment

- Combining versatile wide-field concentrator with FPA may be attractive
  - Concentrator = small dish?
  - Captures some (cost?) benefits of dishes with some wide FOV advantages of phased arrays
  - No whitepaper at this point
    » But interesting to think what overall SKA performance and budget might be achievable
  - Low filling factors (~0.1) but versatile mosaic modes conceivable

- Recognize compelling case for aperture array sub-300 MHz
A Hybrid SKA?

> 2 GHz

Via SD/FPA?

< 2 GHz

Courtesy ASKACC

Courtesy S. Weinreb, Caltech

Courtesy ASTRON
Phased Focal Plane Arrays

- **Distinguished from “multi-feed” systems by:**
  - Elements combined in a beamformer
  - Element spacing chosen to fully-sample the focal field information

- **For radio astronomy:**
  - Bandwidth: >2:1
  - Low noise

[Diagram of phased focal plane array]

[Amplitude and phase weighting]

[Overlapping far field beams]

[Conceptual beamformer architecture]

*Courtesy Scitech*
Plain Person’s View of FOV Expansion

FOV vs Concentrator Diameter

- FOV (0.3 GHz)
- FOV (0.7 GHz)
- FOV (1.4 GHz)
- FOV (3 GHz)
- Req'd 0.7 GHz FOV

P J Hall, 6/05, v2
FPAs and SKA

- Much commonality between AA and FPA development work
- But different optimizations
  - Physical (mechanical/weight/…, operating temperature, …)
  - Electrical (e.m. properties, beam-forming arrangements, …)
- Expect play-off between AA and SD/FPA for < 2 GHz SKA
  - Can putative cost benefits of SD/FPA be realized?
  - Does the SD/FPA win over just having more (smaller) dishes?
    » Depends partly on level of DSP/correlation needed for SD/FPA to meet demanding SKA cal and imaging specs
    » 6 m dish → ∼300 MHz lower limit
  - Can maturity of AA be sufficiently demonstrated?
  - What are the science trade-offs for each approach?
Example SKA Hybrid

- **Assume:**
  - Frequency range ~0.1 to ~ 3 GHz
  - Budget remains at ~ 1B $/€
  - Need to design a survey instrument from Day-1
    - Biases some resource allocation in design

- **Acknowledge the insight of Jaap Bregman**
  - See forthcoming EXPA papers
A sky-noise limited aperture array covering 0.1 – 0.3 GHz
- 33 tiles, each, 1.8 m square per aperture (12 m dish equiv.)
- Each tile: 2 x 2 bow-tie elements spaced at 0.9 m
- 2900/cos(θ) deg² FOV at 0.17 GHz; scales with λ²
  » 33 beams per FOV; multiple FOVs possible
- Const A_{eff} to ~ 0.2 GHz (dense array)
  » Above 0.2 GHz A_{eff} scales with λ² (sparse array)

A small dish/FPA array covering 0.3 – 3+ (?) GHz
- 4000 x 12 m dishes; F/d ~ 0.5
- 8 x 8 FPAs (Vivaldi notch elements)
  » 3 bands: 0.3-0.7 GHz, 0.7-1.6 GHz, 1.6-3.6 GHz
- A_{eff}/T_{sys} per beam ~ 9000
  » A_{phys} = 452 000 m²; A_{eff} = 272 000 m²; T_{sys} ~ 30 K
- Acknowledged issues of FPA co-location or switching (translation)
0.3 – 3 GHz

0.1 – 0.3 GHz
A SD/FPA Fly-Over

Visualization by Scitech
Performance Snapshot

- **For 0.1 – 0.3 GHz array**
  - $A_{\text{eff}} \sim 1 \text{ km}^2 \text{ at } < 0.17 \text{ GHz}$
  - 7 sr sky survey in 1.5 days with 5 hr integration per field (reaches thermal noise sensitivity, assumes full u,v coverage in 5 hrs)

- **For 0.3 – 3 GHz array**
  - $A_{\text{eff}}/T_{\text{sys}}$ per beam $\sim 9000$ (cf 20 000 current SKA target)
  - 25 % fractional bandwidth target met or exceeded
  - 0.7 GHz survey: $2 \times 10^{18}$ units (cf $1.5 \times 10^{19}$ target)
  - 1.5 GHz survey: $8 \times 10^{17}$ units (cf $3 \times 10^{17}$ target)
    - Survey LF sensitivity reduced because of FOV and A/T shortfall
    - Maybe gain factor of $\sim 2$ with less conservative BW assumptions
  - FOV approx frequency independent within each band
    - 130 deg$^2$ at 0.7 GHz
    - 25 deg$^2$ at 1.5 GHz
    - 5 deg$^2$ at 3 GHz
Ball-Park Costing

- Infrastructure: 20%
- Computing: 20%
- LF Array: 10%
- HF Array: 20%
- Electronics: 30%
Aperture Arrays v. SD/FPA

- **AA upper freq limit looks firm at ~1.6 GHz**
  - Primarily economics

- **Sky coverage, field agility and TRUE MULTI-FIELDING are real AA advantages**

- **AA is innovative, high risk, technology**
  - But *no less* demonstration in SKA context than cheap dishes + FPAs
    - By no means certain that one can make a 12m dish, mounts, drives, plus 3 FPAs for $100k per antenna
    - However, AA is *very* sensitive to per-unit component and manufacturing costs

- **Analog (RF) beamforming stages limit current AA concepts (e.g. in number of FOVs)**
  - Digital tiles (e.g. 2-PAD) are ultimate technology which overcome RF B/F limits
  - Might they be viable on a 2015 timescale?

- **Digital tiles are also key to SD/FPA approach**
  - Economic viability on ~2015 timescale is critical

- **Substantial calibration and related issues to be resolved for both AAs and SD/FPA**
Closing Thoughts

- SKA technology selection based on demonstration
  - FPA-based demonstrators will play a key part
- Technology shortlisting 2007; selection 2009
- SKA international funding proposals (2009) rest on credible technology proposals
  - Delayed or impaired technology demonstration will sink the SKA as a next-decade project
- Collaboration is a way of maximizing the likelihood of quality demonstrators
- A favourable industry reaction to SKA will be central to funding success in Eu, Aust, SA ....
  - Virtue in early industry links at regional and international level