CSIRO - Australia Telescope National Facility

An evolutionary approach to the development of the "Square Kilometre Array", and related generalised antenna layouts and concepts, particularly for a low-frequency facility covering the approximate frequency range 150 - 1500 MHz.

Bruce MacA Thomas
22 January 1999

1. *Introduction*

The original request from the astronomy community called for a collecting area of one square kilometre from about 150 MHz to about 1.4 GHz. As the interest by the international community grew in the SKA concept, the desired upper and lower frequency ranges rapidly expanded. The upper limit is now variably quoted as 5, 10 or 22 GHz. Unfortunately the original desire for a collecting area of one square kilometre over a limited frequency range has extended to cover the extended frequency range without any serious consideration of the impact on costs. It is proposed that a more realistic approach may be an "evolutionary" or "staged" approach, particularly given that it appears likely that two quite separate antenna/RF systems would be required to cover the desired expanded frequency range. The approach also considers existing facilities and their possible expansion prior to a major expenditure on a SKA facility, which itself may be implemented in two stages. The basis for defining each stage could be a decade expansion in collecting area, which is often considered as necessary to produce significant discoveries. A closely related issue is the need for a re-evaluation of the minimum desirable collecting area as a function of frequency to meet near-term requirements. It is interesting that if the proposed millimetre array (MMA) was specified to have a collecting area of one square kilometre, the cost would be about US$100B!

It is intended that the evolutionary approach outlined here will provoke meaningful discussions on collecting area requirements for SKA and assist the process of engineering planning.

2. *An Evolutionary Approach to SKA*

Given that in the first stage of the implementation of SKA, the proposed funding level of A$1B will only meet moderate demands of the astronomy community, it is first worthwhile to consider current planned and possible future upgrades of facilities having extensive collecting area in the frequency range of interest (22 GHz maximum).

Fig.1 shows that the frequency around 1.2 to 1.5 GHz provides a useful breakpoint for "low-frequency" (LF) and "high-frequency" (HF) facilities. If the VLA with its 25 m diameter antennas is used as a benchmark for HF facilities, an upgrade from its current collecting area with 27 operational antennas to 60 antennas (or equivalent number of smaller antennas), a collecting area similar to the GMRT would be achieved. Therefore, in the first stage of the implementation of "international" facilities with significant collecting area, an upgraded VLA operating at frequencies above 1.2 GHz would be appropriate. This could then be complemented by a LF "SKA" (LF-SKA) in which the collecting area increased with decreasing frequency as shown in Fig. 1.

This proposal is a "constant-gain" solution, which also overcomes many of the difficulties in providing appropriate antenna solutions for this band. Note that the collecting area is 1 km^2 at a frequency of 215 MHz, increasing to 2 km^2 at 150 MHz, a very desirable characteristic for many astronomy observation programs.

A later stage of expansion could be the building of the (first stage?) of an HF-SKA with a collecting area of say 2×10^5 m^2 giving an area ten times of the VLA (60) facility proposed above. To match the LF-SKA in collecting area, a low frequency limit of about 600 MHz would ideally be required. Alternatively, to maintain the same frequency limits the initial LF-SKA could be expanded by adding additional elements to increase the collecting area.

3. A General Antenna Configuration for the LF-SKA

One of the desirable requirements of SKA is that it should view a significant area of the sky and at any frequency within the operating range of the facility. Reflector antennas will not normally do this, since the antenna beam (array "primary" beam) decreases as the frequency increases. Let us first consider the "primary" or "lowest-level" pattern in the array hierarchy for the LF-SKA.

3.1 Optimum primary patterns

The primary pattern of the "lowest-level" antenna configuration should ideally cover the whole sky; ie it should have near-unity gain. Alternatively a collection of such elements which can be phase-steerable to achieve multi-beaming could be employed, but given the difficulty of achieving such a "concentrator" over a 10:1 band, this concept requires significantly more research.

To advance the overall general concept of the LF-SKA, let us take a well-known antenna which has constant moderate beamwidth and constant gain (but of course not collecting area) with frequency - the log-periodic dipole array antenna (LPDA); see Boxes A and B. This antenna, because of its frequency-independent beamwidth, satisfies a major facility requirement for simultaneous observations of an area of sky at frequencies over the design bandwidth.

The main parameters of the LPDA used to illustrate a possible compromise solution for the LF-SKA are:

- 3 dB beamwidth: 55°
- Gain: 10 dBi
- Polarisation: dual linear
- Mount: polar

Assuming that there are 100 array-stations, the number of LPDA's is:

- No. per array-station: 6,250
- Total number: 625,000

Critical factors are the cost per unit for quantity production, and phasing techniques at the array-station level.

3.2 The array-station configuration

To avoid high-level grating lobes, the LPDA antenna elements could be arranged in a random way to minimise peak sidelobe levels (see Box C). In the limit, an indicative average sidelobe level normalised to the peak of the main beam is approximately -37 dB where each array-station consists of 6,250 phased elements.

4. Some Considerations for HF-SKA

In the design of a HF-SKA, it is currently considered that some form of reflector optics would be essential to achieve the total collecting area. Unlike the LPDA antennas used as the basic element in the LF-SKA, the reflector antenna gives constant collecting area, and increasing gain and decreasing beamwidth with frequency. The desire for constant sky coverage as a function of frequency implies sophisticated feed design. In this overview, simple symmetric cross-section reflector optics with a focal-plane array feeding is assumed.

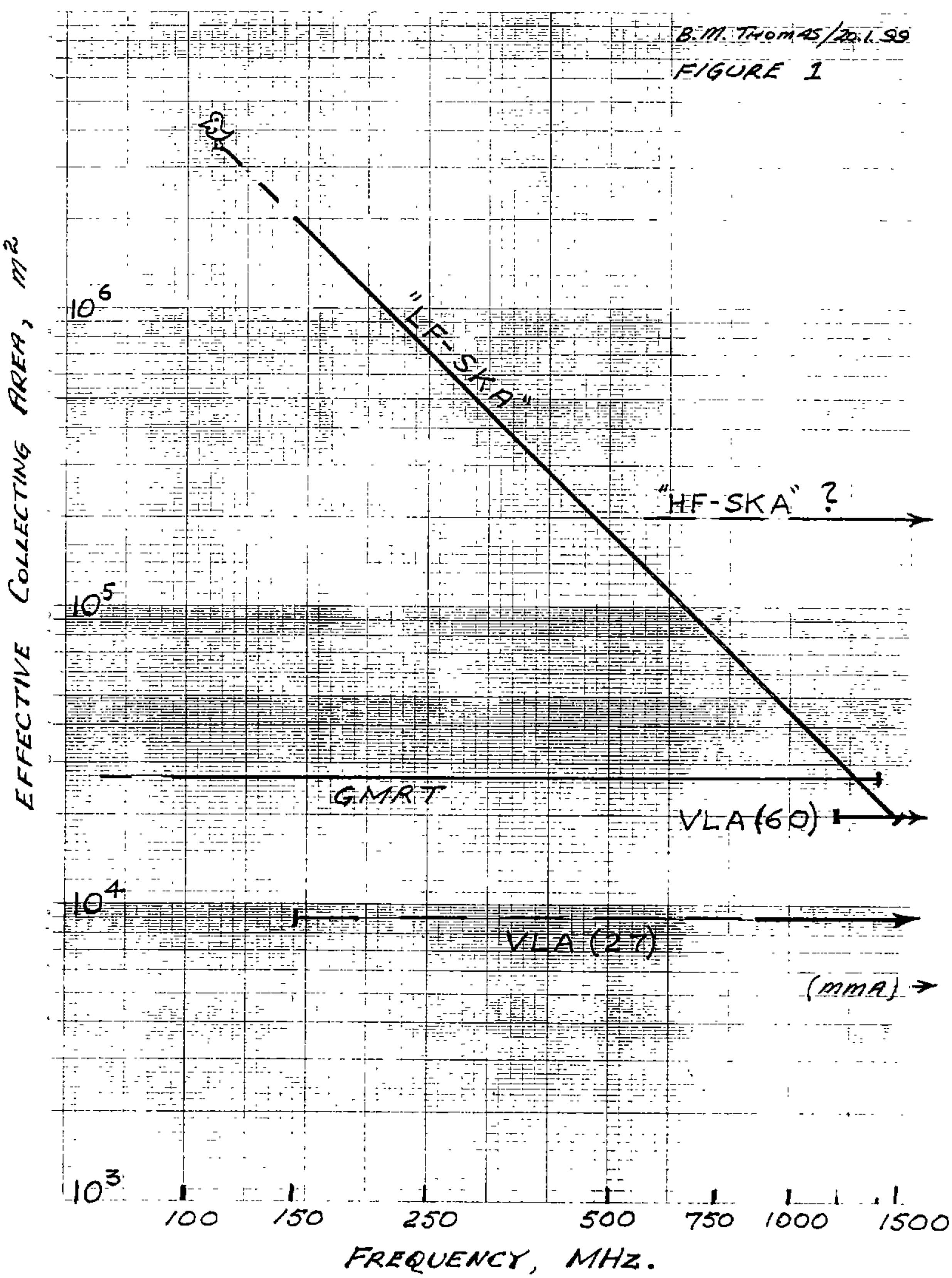
One of the requirements for the HF-SKA is to have a minimum "concentrator" (primary-pattern) beamwidth of 1.1° at 1.4 GHz, which implies a normalised reflector diameter, D/λ, of 60, ie, a diameter of approximately 12.5 m. Assuming an efficiency of 60 percent, the number of such elements, assuming an initial collecting area of 2×10^5 m^2, is 2,700, giving 27 antennas per array station (assuming 100 array stations).

It is also desirable to have a near-constant imaging area over the bandwidth, so that observations can be made at widely spaced frequency intervals of the same area of sky. This implies that as the frequency is increased, the number of beams generated by the feed system should ideally increase from say one at the lowest frequency, to a cluster of beams which covers the same area of sky. Such an ideal system requires a complex focal-plane array with wideband capability. Research along these lines has commenced at the Royal Melbourne Institute of Technology under the direction of Dr. Rod Waterhouse.

The general requirements for an optimum feed system will be the subject of a later ATNF Technical Document.

5. Site and SKA Expansion Issues

One of the factors in establishing a site for SKA, is to ensure that the basic infrastructure and services are designed to take into account both a LF-SKA and HF-SKA, and their future expansions. One of the key issues here is the location of the array-stations for both systems. Maximum commonality in locating these will lead to overall long-term reduced costs.



B.M. THOMAS/20.1.99
FIGURE 1
"LF-SKA"
"HF-SKA" ?
GMRT
VLA (60)
VLA (27)
(MMA)
EFFECTIVE COLLECTING AREA, m^2
10^6
10^5
10^4
10^3
100
150
250
500
750
1000
1500
FREQUENCY, MHz.

Box A

General Properties of a Typical Log Periodic Dipole Array (LPDA) Antenna for SKA

Frequency Range: 150 - 1500 MHz

3-dB Beamwidth, E-and H-planes: 55°

Gain: 10 dBi

Effective Area (A_e): 0.8 λ^2 (λ = wavelength)

(ie, $A_e = 3.2\ m^2$ at 150 MHz, and

$A_e = 0.032\ m^2$ at 1500 MHz).

Antenna Polarisation: dual-linear

Antenna Structural Parameters:

- Approximate length: 4 m
- Longest element (rear element): 1.1 m
- Semi-angle: 6.5°
- Number of elements (one plane): approx. 35

Box B

No. of LPDA Antennas; Array Configuration

Assumptions:

- Collecting area at 150 MHz: 2 km^2
- Number of array-stations: 100

Number of LPDA Antennas:

- Total: 625,000
- Number per array-station: 6,250
- Minimum spacing in array-station: 2.5 m approx.

Drive System:

- 2-axis with polar mount
- Sky coverage: 20° - 90° elevation

Box C

General Characteristics of Thinned Arrays

The following summarises the major characteristics of the thinned arrays:

- For a given frequency and fixed number of elements, the peak gain, G, remains constant and is independent of the antenna element distribution.

  In general, $G = 4 \pi N A_e/\lambda^2$

  Where N is number of elements, A_e is the effective area of an element.

  If A_e/λ^2 of an element is constant, the gain of the array is frequency independent when N is held constant.

- For a given number of elements, N, the beamwidth of the main beam and the beam efficiency decreases as the overall diameter D enclosing the elements increases. The energy contained in the sidelobe region therefore increases.

- For given N and D, the distribution of the antenna elements determines the peak sidelobe levels, but the mean level remains constant. For example, a periodic array will give high-level grating lobes, but if the elements are randomly spaced, the sidelobe energy is smeared nearly uniformly in space.

- In the limit of a highly thinned array, the average sidelobe level, **L**, normalised to the main beam peak, is approximately 1/N. For example,

  $L \cong -37$ dB if $N = 6,250$

  (corresponding to an array-station for the example given in Box B)

  If the array-station consist of ten separate arrays (10 "concentrators"), each consisting of 625 elements, L for each concentrator is, in the limit, -27 dB.