The SKA: single- or multiple-antenna Array Stations?

by

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Summary
The large collecting area required for each SKA Array Station can be achieved by coherently adding the outputs of a (sparse) group of relatively small antennas. However, an Array Station comprising a single continuous aperture of the same area has a wider beam and much lower sidelobes. The SKA then has a larger synthesised field and better dynamic range.

1. INTRODUCTION

In all proposals for the Square Kilometre Array (SKA) the total collecting area is divided into a number of Array Stations. An example given in the Science Case document (Taylor & Braun, 1999) has twenty Array Stations clustered in a central 30 x 50 km zone, with a few outliers at distances up to 500 km. Subsequent proposals have more Array Stations and a greater proportion at large distances from the centre (Smolders & van Haarlem, 1999). An Array Station can be a single continuous phased array, built up from numerous contiguous phased sub-array panels. Alternatively an Array Station can comprise one or more *concentrators*. In this context, a concentrator is any type of antenna with a single feed point and a gain significantly greater than isotropic - a reflector, Luneburg lens or log-periodic antenna, for example.

If an Array Station comprises a number of small concentrators they would be connected phase coherently to achieve the required collecting area. Such a group of antennas could be arranged randomly or in a regular grid, but would necessarily be thinned (spaced) to avoid mutual interference (blockage) when the antennas are steered towards low elevation angles. In this paper we argue that for high dynamic range imaging, single concentrator or contiguous planar phased-array Array Stations have advantages over thinned designs.

2. THE EFFECTS OF THINNING ON AN ARRAY STATION BEAM

We define the thinning factor, t, to be the ratio of the geometrical area of the Array Station to the total collecting area of the antennas. For a regular array of circular paraboloids to be steered to zenith angles of ~60 degrees, the thinning factor would need to be at least 4. For a random array the thinning would need to be somewhat greater.

To illustrate the effect of thinning, we compare the characteristics of a thinned (and tied) group of antennas with those of a single concentrator of the same total area:

- The forward gain is unaffected by thinning: it depends only on the total area.
- The beamwidth is reduced by - $\sqrt{t}$
- The beam area, and hence the SKA field size, is reduced by t.
- The beam efficiency (energy in the main beam) is reduced by t.
- The tied group will have sidelobes within the primary beam of the individual antennas. All the energy lost to the main beam appears in sidelobes. Thus the energy in the sidelobes will be (t-1) times greater than the energy in the main beam.

Figure 1 illustrates some of these points for an Array Station consisting of a small number of concentrators arranged randomly with a thinning factor of 5.

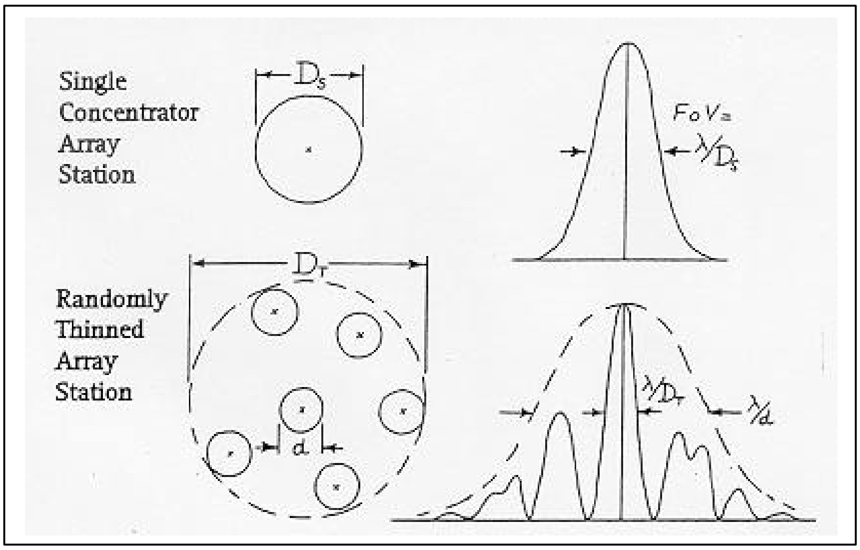

Figure 1. A schematic diagram illustrating the effect of thinning an Array Station. A single concentrator has a beam width of ~ λ/D_S. If the same antenna collecting area is distributed randomly over a larger aperture (with a thinning factor of 5), the beam width (and field of view of the SKA) is reduced by a factor of $\sqrt{5}$. Random sidelobes are formed within the primary beam of the constituent antennas. The beam efficiency of the Array Station is reduced by a factor of 5.

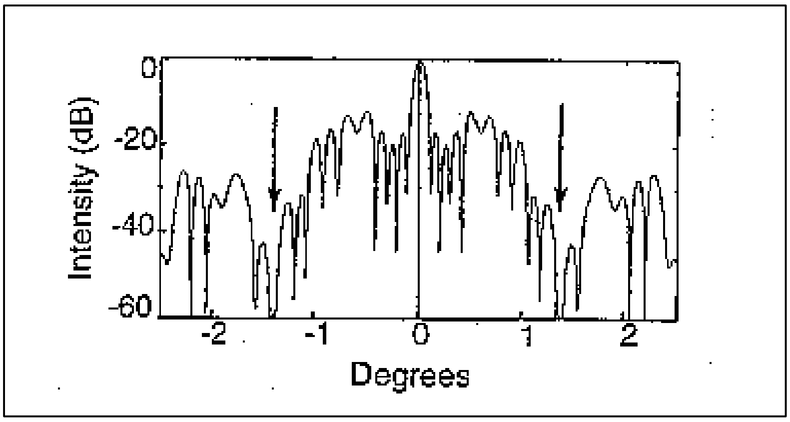

Figure 2. The computed sidelobe pattern of a partly ordered Array Station. In this example 25 circular antennas are arranged in two rings, with one antenna at the centre. The antennas are located as close as possible consistent with an unblocked view to an elevation of 30 degrees, giving a thinning factor of about 4. Arrows indicate the first nulls of the individual antennas. Strong, partly ordered sidelobes are apparent outside the narrow main beam.

Although the total energy in the sidelobes depends only on the thinning, the sidelobe structure depends on the way in which the individual antennas are arranged in the Array Station:

- If the concentrators are arranged in a regular pattern, the sidelobes are evenly spaced grating *lobes*.
- If the concentrators are located randomly within the Array Station, the sidelobes are random with an rms level of -10logN dB. (Mailloux, 1994).
- To the extent that the pattern of the concentrators is ordered, the sidelobes have an ordered structure. The computed response of a partly ordered Array Station is shown in Figure 2.

3. THE EFFECTS OF THINNING ON THE SKA PERFORMANCE

3.1 The field of view of the SKA

The field of view of the SKA is essentially the beam of the individual Array Stations. Thus thinning the Array Stations by a factor t reduces the field area by the same factor. For some astronomical programs (eg. VLBI a small field is quite adequate, but for most it would be detrimental. Table 1 compares the SKA field of view for single- and multiple-concentrator Array Stations. In this example there are 250 Array Stations. Thinning by a factor of 5 reduces the field of view at 1.4 GHz from 144 to 29 square minutes of arc. In principle the field can be increased by mosaicing, but that implies a much longer observation time or the formation of multiple Array Station beams.

	Single concentrator	**Thinned group t = 5**
Array Station diameter	**72 metre**	**160 metre**
Field of view (1.4 GHz)	**0.20°**	**0.09°**
Relative energy in FoV	**100%**	**~20%**

Table 1. Comparison of a "single concentrator" and "thinned group" Array Station. In this example each Array Station has an effective area of 4000 m^2 and 250 Array Stations are required to make a total of 10^6 square metres.

3.2 The dynamic range of the SKA

Thinning the Array Stations puts a lot of energy into sidelobes. For example, if the thinning factor is five (a realistic value) the sidelobe energy will be 4 times the main beam energy. Although these sidelobes lie outside the SKA synthesised field they are directed towards the sky, and inevitably give rise to spurious correlations. If the antennas within Array Stations are randomly distributed, and the Array Stations are randomly located the dynamic range (due to sidelobe confusion) will be roughly -10logN dB. Here N is the total number of antennas in the SKA (ie the number of antennas in each Array Station multiplied by the number of Array Stations). While some mitigation could perhaps be achieved by careful arrangements of the individual antennas and Array Stations, the effect on the synthesized image can be determined only by simulation of particular configurations. However, it is hard to believe that, with so much energy in sidelobes, the dynamic range in the synthesised image could even approach the 10^6 specified in the Science Case (Taylor and Braun, 1999)

3.3 Self-calibration.

If an Array Station comprises a number of tied antennas, then it is not possible to apply self-calibration techniques to correct the phase of individual antennas. How important this limitation is depends on the phase stability of the communications within the Array Station and the ionospheric path variations over the size scale of an Array Station. A thinned array is more vulnerable than a continuous aperture, as it is extended over a bigger area.

4. CONCLUSIONS

Any proposal for an SKA with a total collecting area of 10^6 square metres implies a large collecting area at each Array Station. An attractive option would appear to be to configure each Array Station as a tied group of concentrators, necessarily thinned to avoid mutual obscuration. Unfortunately, the thinning throws a large fraction of energy into sidelobes, with a deleterious effect on the dynamic range of the synthesized image.

We consider it unlikely that the specified dynamic range of the SKA can be achieved with Array Stations configured as thinned groups, although we have no quantitative data. There is a need to carry out simulations to investigate the relationship between SKA dynamic range and Array Station thinning.

4. ACKNOWLEDGMENTS

The authors gratefully acknowledge helpful discussions with Prof. Lawrence Cram and Dr. James Caswell. One of us (M.I.L) also acknowledges the financial support provided by the ATNF under the Australian Government's Major National Research Facility funding program.

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