



Memo 79

Area Scaling for the SKA?

J. Bunton

11/06

Area Scaling for the SKA?

John Bunton
14 March, 2006

Introduction

A well known dilemma for the SKA is the necessary tradeoff for a given cost between total collecting area and the maximum operating frequency. This tradeoff exists over the full electromagnetic spectrum, with radio telescopes usually having areas measured in thousands of square metres, optical telescopes in square metres and X-ray telescopes in square centimetres. Examination of existing telescopes shows that currently the area reduces by a factor of ~ 6.6 for each decade increase in maximum operating frequency. It is suggested here that the SKA should try to follow this scaling law by having different areas in different frequency bands.

Scaling Law

For existing telescopes the area of the highest performing telescope in each frequency band decreases with frequency. The ALMA telescope [ALMA] designed to have an area of 7200 m^2 and operate at frequencies up to 10^{12} Hz , assuming an aperture efficiency of 0.7 then the effective area is 5000 m^2 . The Keck 10m telescopes has an area of 78 m^2 , or an effective area of about 67 m^2 , and at the UV cutoff at 330nm are operating at $9 \times 10^{14} \text{ Hz}$. Hubble operates above the atmosphere and is designed to reach 115nm. With a 2.4 m mirror it has an effective area of about 4 m^2 . Beyond this is the Chandra x-ray telescope [Chandra] with an effective area of 400 square centimetres at $1.2 \times 10^{18} \text{ Hz}$ (5keV) and reduced effective area at 8keV. At lower frequencies there is the proposed Deep Space Array based network with a total of 3 antenna stations each comprising 400 12m antennas [Gatti 2004]. This has a total effective area of about $10,000 \text{ m}^2$ and operates at frequencies up to $4 \times 10^{10} \text{ Hz}$. For the SKA the original specification was for an area of $1,000,000 \text{ m}^2$ [Wilkinson 1991]. The technology proposed was similar to the GMRT operating at frequencies that include the OH line. Later the upper frequency was specified as a couple of gigaHertz [Braun 1993]. This gives an effective area of $\sim 700,000 \text{ m}^2$ at $\sim 3 \text{ GHz}$. The data for these existing and proposed telescopes is plotted in Figure 1. It is seen that on a log-log plot the data is approximately linear with the area decreasing by a factor of 6.6 for every ten times increase in maximum operating frequency.

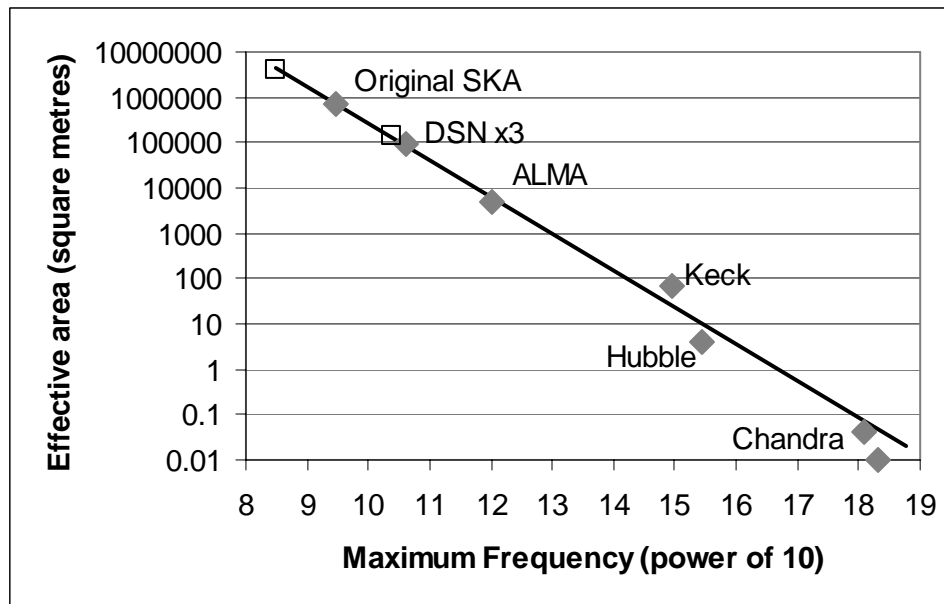


Figure 1 Effective area of major instruments as a function of maximum operating frequency. Open boxes show extrapolation of original ~3GHz SKA specification to higher and lower frequencies.

The fit is excellent over more than eight orders of magnitude. Certainly the general trend is expected but the quality of the fit seems to indicate that there may be some deeper significance to the result. Maybe it is direct reflection of the cost per square metre as a function of frequency. However in the near future significantly larger optical telescopes are expected that will lay above the line indicating that maybe the result is just a coincidence at that this point in time. Also most of the data points correspond to very different technologies. Is the trend true for a single technology over a more restricted frequency range? The ALMA and DSN data is suggestive that it might at radio frequencies.

Thus the data in Figure 1 generates an interesting result whose application to the SKA is uncertain but for of this memo it will be assumed that the scaling law is true. It will generate some interesting result but they must not be considered definitive. However it is hoped that the results will further stimulate the debate as to what form the SKA will take.

A Three Band SKA

It would seem that the original SKA proposal that calls for a total area of 1,000,000 m² at ~3 GHz falls close to the line extrapolated through the other data. The increase in maximum frequency to 25 GHz, using an area scaling of 6.6 per decade in frequency, would predict that the area should be reduced to about 200,000 m².

On the assumption that the area scaling is valid, it's no wonder that the SKA is having trouble meeting its cost target. With the large frequency coverage proposed for the SKA the area scaling suggests that a number of different frequency bands are needed with the area increasing with decreasing frequency.

Attempts to have the area vary with frequency are already happening. There is now a growing consensus that below ~0.3 GHz broadband dipoles similar to those used by LOFAR, MWA-LFD, and LWA be used [ISPO 2006] and the scaling law suggest that the area could be as much as 6,000,000 m². This is not entirely unreasonable as the target antenna cost for the LFD is \$44/m² excluding electronics. At higher frequencies methods of achieving an area variation with frequency include hybrids [Veidt 2004] and the 12-16m dish proposal [Shultz 2005]. In the 12-16m dish concept the inner 12m is solid and has an area of 113m² around this is a 2m wire-mesh annulus that increases the area to 200m² at frequencies below 3 GHz. The scaling law suggests that an even more extreme design is needed such as one where the inner 7m is solid and the wire-mesh annulus is 4.5m wide giving a 7-16m dish. The cost of a 7-16m dish will be less than that of a 12-16m dish leading to a concept with increased area below 3 GHz but possibly reduced area at higher frequencies.

With such a dish and broad band dipoles at low frequencies it may be possible to have an SKA where the total area scales as follows:

Low Band	below 0.3 GHz	6,000,000 m ²
Mid Band	0.3 to 3 GHz	1,000,000 m ²
High Band	3 to 25 GHz	200,000 m ²

The low and high band specifications are plotted in Figure 1 as open boxes and the mid band specification is equal to that in the original SKA proposal. It is seen that in conjunction with ALMA the three band approach follows the area scaling rule over a 3000:1 frequency range.

The three band solution is suggested here only as a starting point for discussion. However it is reasonably equitable in terms of point source sensitivity. The high band system will use cooled receivers giving an A/T_{sys} of about 8,000 m²/K at frequencies between 3 to 10 GHz decreasing to 5,000 m²/K at 25 GHz. For the low frequencies band sky noise predominates and the sensitivity is about 7000 m²/K at 0.12 GHz. The mid band system has the same sensitivity at 0.3 GHz. The sensitivity peaks at ~20,000 m²/K, if uncooled receivers are used on the mid band system.

Conclusion

The proposed area scaling for the three frequency bands has high sensitivity over a 200:1 frequency range and a large effective area at low frequencies. When considered in the light of other existing instruments it would seem that the proposed area scaling is a fair way to apportion area. The 7-16m dish plus broadband dipoles demonstrates one of many possible methods of achieving the proposed area variation.

However, the validity of the scaling law is uncertain so at best the area scaling for the SKA should be considered as another starting point in the current debate as to the form the SKA should take.

Bibliography

Braun, R., 1993, 'A Next Generation Radio Observatory: The Square Km Array', URSI General Assembly, Kyoto, Japan, Aug. 22 - Sept. 2

ALMA www.alma.nrao.edu/info/

Chandra cxc.harvard.edu/proposer/POG/html/HRMA.html#chap:hrma

Gatti, M.S., 'The Deep Space Network Large Array' in Yuen J.H., (Ed) The Interplanetary Network Progress Report, Vol 42-157, 15 May, 2004.
http://ipnpr.jpl.nasa.gov/progress_report/42-157/title.htm

ISPO, 'SKA Reference design', SKA Memo 69, Jan. 2006, www.skatelescope.org

Shultz, R., 'USSKA Antenna Development' SKA Memo 63, June 2006,
www.skatelescope.org

Veidt, B., 'EWG Comments on Hybrids', SKA 2004, Penticton Canada, 18-22 July 2004.

Wilkinson P. N., "The Hydrogen Array", Radio Interferometry: Theory, Techniques and Applications IAU Colloquium 131, ASP Conference Series, Vol. 19, 1991. T.J. Cornwell and R.A. Perley (eds.), pages 428-432.