Implementing Interference Suppression:

Impacts on SKA System Design

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One Page Hit for Busy People

- **The best digital signal processing based interference suppression requires that the delays of all interferers be sampled so that *Nlags/BW > 4*Dmax/c* (3)**

- **Therefore, given a bandwidth, frequency and a certain number of frequency channels, the size and number of SKA stations are constrained if these techniques are used.**

- **As shown in Figure 1, this constraint becomes severe for high frequencies (20GHz) and small numbers of lags (Nlags ~ 300-1000) restricting station diameter.**

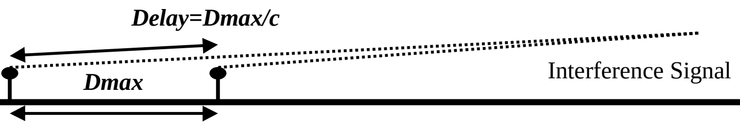
- **The 1hT small parabola based SKA prototype in its proposed configuration and any similar Luneberg lens implementation, may need up to 30,000 lags if they are to use these techniques.**

Interference Suppression Techniques

In this poster we restrict our attention to digital signal processing techniques and their potential impact on SKA system design. There is a group of “blind” techniques (including adaptive filters, null steering, sub-space tracking and post-correlation cancellers) that require:

$$\mathit{delay} < \mathit{sample\ interval} \qquad (1)$$

Interference may come from any direction, including opposite horizons. The maximum range of propagation delays across an array is ***2*Dmax/c***, where ***Dmax*** is the largest Dimension of the telescope (array) and ***c*** is the speed of light.



For a Nyquist sampled bandwidth ***BW***, the sample interval is ***1/(2*BW),*** so we have

$$1/(2*BW) > 2*Dmax/c \qquad (2)$$

Since this is very hard to achieve, many suppression systems include a number of lags ***Nlags*** over which the algorithm can search. This leads to

$$Nlags/(2*BW) > 2*Dmax/c \qquad (3)$$

SKA - Square Kilometre Array

Interference Suppression is a vital aspect of the SKA. There are other interference suppression algorithms which may not require equation (3) to hold (including channel or time sample blacking, flagging of visibilities, robust signal statistics and bandwidth decorrelation) but it remains to be seen if they can be as effective and we do not consider them any further in this poster. What impacts are there on the system design and under what conditions are algorithms that require equation (3) viable to pursue ? The relevant SKA specifications in this context are:

- Frequency Range ***f***: ***0.3-20*** GHz (4)
- Bandwidth (***BW***): ***0.5+f/5*** GHz (5)
- Number of lags (***Nlags***): ***10,000*** (6)

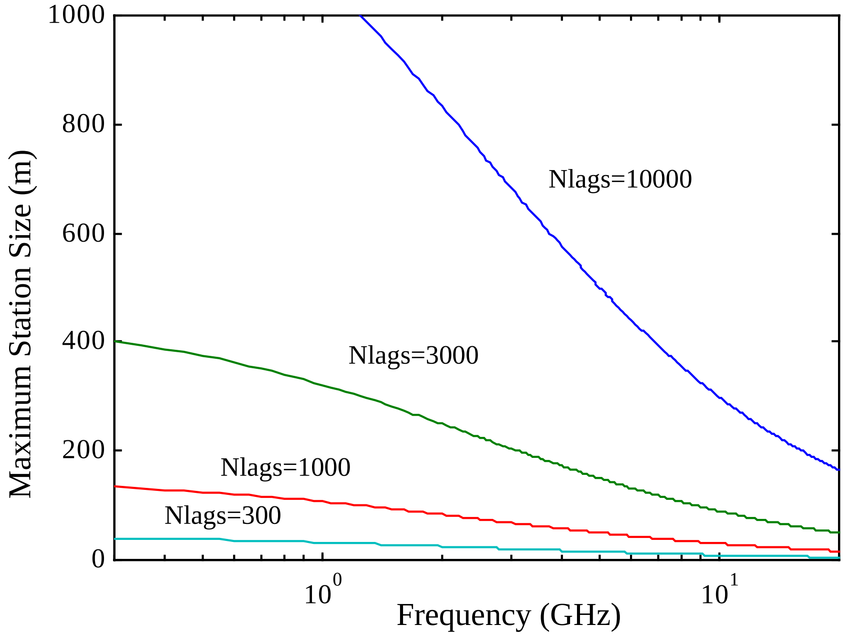
The whole SKA array does not fit equation (3). This is not surprising and can be considered an advantage because the interference does not correlate between stations. Most of the proposed technologies for the SKA envisage the SKA being made up from a number of stations from which the signals are combined to form a tied or synthesis array. A much more useful question therefore is whether equation (3) holds for individual stations ? Yes - under certain conditions.

Impact on SKA Station Design

What impact does equation (3) have on the size and number of stations ?

- Taking equation (3) and specifications (4) - (6), the maximum station size as a function of frequency at which the SKA stations will operate is shown in Figure 1.
- An immediate consequence of these constraints, is the minimum number of stations (Figure 2). Here we have assumed an average filling factor of 20%.
- Taking 1000 as a realistic maximum number of stations, we see that operation up to 20GHz is feasible if we can afford Nlags> ~4000 to cover the 0.5+f/5 GHz bandwidth specification. If we desire a smaller number of stations e.g. < 200, Nlags > 10000 would be required.
- If this is not possible, the bandwidth at the higher frequencies may be reduced, or other suppression techniques used. An alternative is to move to a more complex (non-blind) suppression system that adaptively finds interfering signals (or uses prior knowledge) and then suppresses them in a limited frequency and delay space.
- The discussion so far is independent of antenna technology and applies equally to dishes, Luneberg lenses and planar phased arrays. Planar phased arrays do in principle permit a much closer packing of the antenna elements and therefore allow some relaxation of the constraints. However, there are other more serious challenges in getting the large area planar phased arrays working at these high frequencies.

Figure 1: Implications for SKA station size



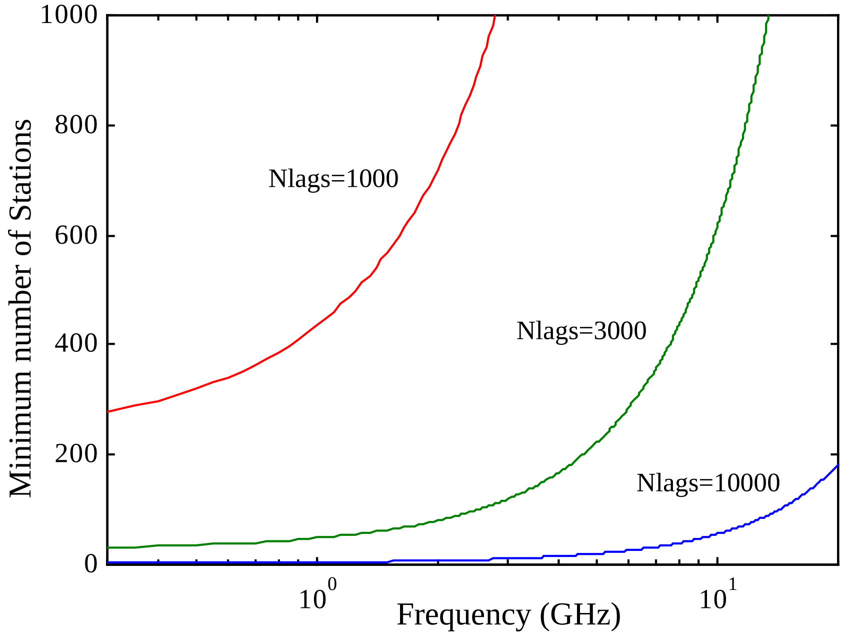


Figure 2: Implications for number of SKA stations

Spatial Filtering Impacts

The algorithms that use spatial filtering (e.g., null steering, sub-space tracking) can, in principle steer ***N-1*** nulls if the array has ***N*** elements. In an astronomical application, there is an additional requirement that the shape of the beam in the look direction should remain constant, otherwise strong astronomical sources drifting in and out of the changing beam can degrade the dynamic range of the images. From some simple LMS beam forming simulations, we estimated the maximum beam deformation (by taking the difference of the gains of the beam patterns formed with and without null steering) as a function of the number of elements in a linear array:

No. Elements	Beam Deformation
8	20%
15	3%
75	0.10%
128	0.01%

The SKA specifications require a dynamic range of 1 million in the final images. While the number of stations and imaging algorithms have substantial impacts on the dynamic range which need to be quantified, it looks likely that ~100 elements per station will be required to have sufficiently stable beam shapes.

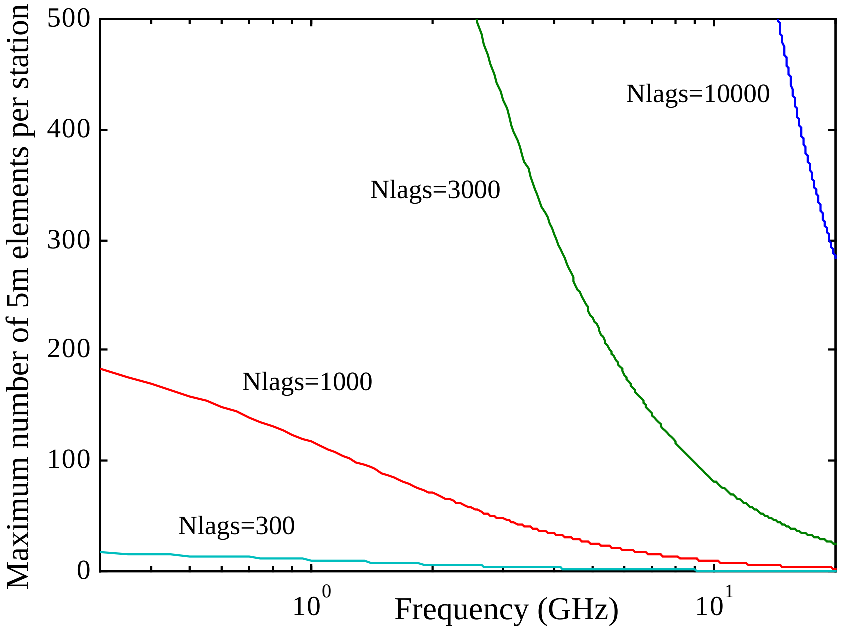
Number of Elements per Station

Given the station size estimates in Figure 1, we can estimate the maximum number of 5m elements per station (Figure 3). Again we have assumed a filling factor of 20%. Operation at the highest frequencies (10-20 GHz) begins to become impractical if we have Nlags < ~ 5000 because we have too few elements to form stable beams. We take 5m elements, because elements smaller than this cannot meet the low frequency specification (0.3 GHz). If the elements are larger, it will only be harder attain enough elements for the spatial filtering algorithms to work effectively.

If the SKA stations were restricted to Nlags ~1000 and a maximum operating frequency of 1.4 GHz, this would require ~600 stations whose size is < 100m, with each station probably having enough elements per station to allow effective operation of spatial filtering algorithms.

The available number of lags (Nlags) that can be afforded for interference suppression techniques is therefore a key question in the SKA system design, with far reaching consequences.

Figure 3: Implications for number of 5m station elements



SKA Core and the 1hT

SKA Core

- Some proposals suggest ~50% of the collecting area be in a dense core.
- From equation (3) we estimate that this would require Nlags > 100000 for operation up to 20GHz for 20% filling factor.
- This may be too expensive, requiring the central core to be made from stations !
- A planar phased array (25% filling factor) with a maximum operating frequency of around 1.4 GHz could squeeze 50% of the required collecting area into a physical area small enough to satisfy equation (3) if it had Nlags ~16000.

1hT

- The 1hT SETI prototype of the SKA is likely to have some 500-1000 five to ten metre paraboloids spread over a physical area of 1 square kilometre. It will have an operating bandwidth of 9GHz running from 1-10GHz. If equation (3) is to be satisfied, the required number of lags (Nlags) is shown as a function of the filling factor in Figure 4.

Figure 4: Implications for 1hT interference suppression