Interference Mitigation Using an Array Feed

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We study in simulation the use of an array feed of electrically small elements for RFI mitigation. For a 25 meter reflector and seven element array, in the presence of an interferer, the classical max-SNR spatial filtering algorithm rejects the interferer at all interferer power levels and arrival angles. The effective sensitivity of the array feed and reflector system, with the interfering signal considered as part of the system noise, is similar to that of a simple circular waveguide feed. As the interferer moves, sensitivity fluctuates by a few dB due to a quasi-grating lobe effect.

1 Introduction

Spatial filtering techniques for RFI mitigation require multiple, spatially separated looks at the interfering signal. For a large reflector, this can be accomplished with an array feed. Array feeds have received much attention for general communications applications (e.g., [1, 2]). Within the radio astronomy community most work has involved electrically large waveguide type elements, with each element individually matched to the reflector aperture for optimal sensitivity and minimal or no signal combining between elements [3]. Existing array feed implementations of this type include the multibeam “HIPASS” receiver on the Parkes telescope. In order to obtain more complete control of the array response pattern using array processing techniques, element spacings of less than one wavelength are required, which precludes elements that are individually matched to the reflector for an efficient illumination pattern. Previous work on arrays of electrically small elements includes theoretical studies, numerical simulations, and prototypes [4]-[9].

At present, the chief technical hurdles in relation to constructing an astronomically useful array feed of electrically small elements are development of low noise amplifiers matched to individual elements, high bandwidth signal processing, and ensuring that a sufficiently high antenna sensitivity can be attained. For RFI mitigation, it also remains to demonstrate in principle that spatial filtering can be used with an array feed. In this paper, we consider the last two of these questions, and show using simulations that an array of electrically small elements in conjunction with a spatial filtering algorithm can provide reasonable effective antenna sensitivity even in the presence of RFI.

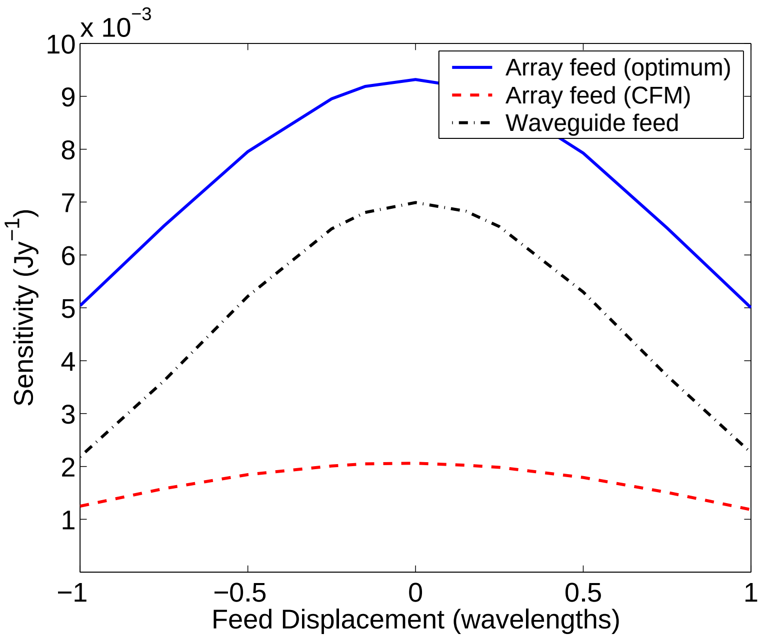

Figure 1: Sensitivity vs. feed offset distance along the paraboloid axis for a seven element dipole hex array (no interferer case).

2 Simulation Results

We first consider a hexagonal, seven element dipole array and a 25 meter paraboloidal reflector with $f/D = 0.36$, to determine the achievable antenna sensitivity without interference. Antenna patterns were computed using the GRASP8 (TICRA) package. For a receiver temperature of 15 K and 300 K background earth below the reflector, the sensitivity in Jy^{-1} obtained for the seven element array is shown in Fig. 1. The array weights were obtained by brute-force optimization of sensitivity and by making use of the max-SNR algorithm, which optimizes SNR for a given noise model. Both approaches yielded essentially identical results. For comparison, sensitivity for a circular waveguide feed with 1.3 λ diameter optimized for maximum sensitivity at 1612 MHz and the conjugate field match solution for the array are also shown. For maximum sensitivity, the aperture efficiency of the array feed at zero displacement was 53.6% and the spillover efficiency was 99%. For the conjugate field match solution, the aperture efficiency was 65.4% and the spillover efficiency was 67.7%.

In the presence of an interferer, we define an effective sensitivity,

$$S_{\mathit{eff}} = \frac{G}{T_{sys} + T_{int}} \tag{1}$$

where G is antenna gain in K/Jy, T_{sys} is the combined receiver and antenna spillover temperature, and T_{int} is the equivalent noise temperature of the interfering signal at the output of a beamformer which combines inputs from the array feed elements. We note that this definition of effective sensitivity is inherently optimistic, because interfering signals are generally not spectrally white and have a more severe impact on observations than white noise.

Using simulated array element patterns with a single, fixed point source interfering signal and the max-SNR algorithm to obtain array weights, we compute the effective sensitivity (1) as a function of interference to noise ratio (INR) and interferer arrival angle. The interfering signal was rejected for

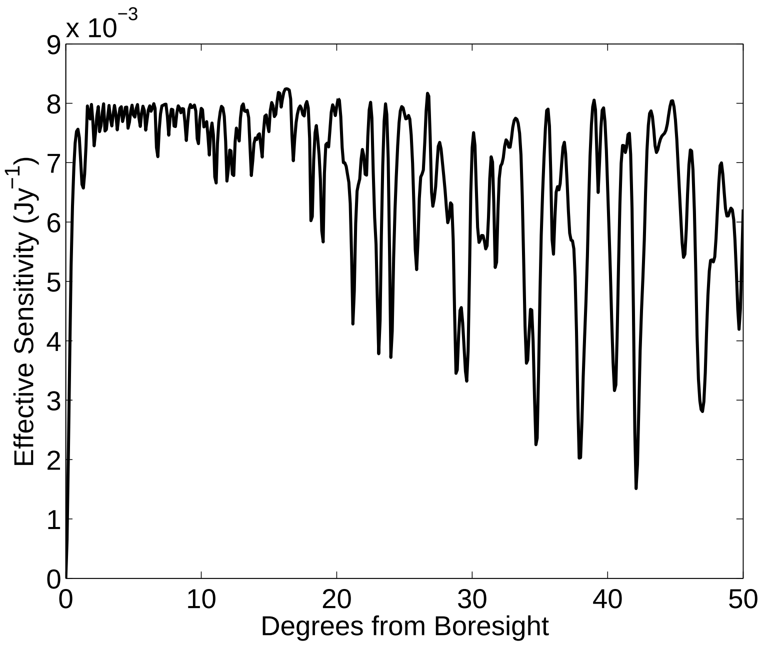

Figure 2: Effective sensitivity in the presence of an interfering signal as a function of interferer location using the max-SNR beamformer.

all INR levels and all arrival angles more than a few beamwidths away from boresight. As shown in Fig. 2, however, the effective sensitivity fluctuates as a function of interferer arrival angle by several dB. At minima of the sensivitity, the solution found by the spatial filtering algorithm leads to smaller boresight gain and admits more spillover noise than at other interferer arrival angles. At these angles, the array feed response to the interferer is nearest to the response to a signal at boresight, in the sense of the interferer and signal array response vectors having largest angle cosine, so that the effect may be viewed as a quasi-grating lobe behavior. With a larger array (19 elements), variations in effective sensitivity with interferer arrival angle still occur, but are slightly less severe, and the average attainable sensitivity over all arrival angles increases by roughly 2.5 dB.

3 Conclusions

These results indicate that array feeds offer a promising solution for RFI mitigation, since an interfering signal can be rejected using spatial filtering at all arrival angles and INR levels. The chief drawbacks are low aperture efficiency for the seven element array relative to a state-of-the-art waveguide feed, and fluctations in sensitivity with respect to angle of arrival of an interfering signal.

Because the spatial filtering algorithm used in this study yields optimal sensitivity for a given set of array element radiation patterns, neither of these problems can be overcome by making use of a different array processing algorithm. Instead, the number or placement of array elements must be modified. Displacing the seven element array away from the focal plane up to one wavelength in the boresight direction, or changing the spacing between array elements by scaling and random perturbations, did not improve performance. These results imply that the only way to achieve a greater sensitivity or more uniform sensitivity vs. interferer arrival angle is to increase the number of array elements.

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