Performance Analysis of a mm-Wave Phased Array Feed for the Green Bank Telescope

Junming Diao[1], Richard Black[1], Karl Warnick[1], Brian Jeffs[1], and Neal Erickson[2]

[1] Department of Electrical and Computer Engineering
Brigham Young University, Provo, UT, USA
diaojunming@gmail.com
[2] Department of Astronomy
University of Massachusetts, Amherst, MA, USA

Phased array feeds (PAFs) offer the capability for wide-field imaging and increased survey speed for large reflector antennas used for astronomical observations. Wide-field phased array feed receivers have been demonstrated successfully at L-band, and efforts are underway to develop PAFs for higher frequencies. Due to the small element pitch, millimeter-wave band arrays require significant advances in miniaturized electronics and micromachining. The University of Massachusetts Radio Astronomy group is fabricating a low-noise 8×8 mm-wave cryogenic wideband PAF system, with calibration, beamforming, and digital signal processing power in development at BYU. The feed will be mounted for initial tests on the Green Bank Telescope (GBT) 100-meter reflector in late 2015.

In preparation for field experiments, we have extensively modeled the signal and noise performance of the feed using a full-wave finite element model of the array. The model approximates the GBT optics using a single reflector with opening angle equal to that of the GBT secondary reflector. We have found that the computational load in the digital back end can be significantly reduced by using only a small number of elements per beam, while maintaining high sensitivity for each formed beam. This reduction destroys the regularity of the beamforming operation, and therefore comes at the cost of increased software complexity.

We have also studied the achievable efficiency and sensitivity of wideband array feeds over frequency. For a wideband feed, the nature of formed beams changes significantly from the low to high end of the operating bandwidth. At low frequencies, one element is sufficient to illuminate the secondary reflector aperture. At high frequencies, the radiation pattern realized by the elements are discontinuous, and the array feed begins to operate in so-called cluster feed mode. To achieve ultrawideband operation, an array feed must span the between single feed, array feed, and cluster feed regimes. At the transition frequency between the “array” and “cluster” modes, aperture efficiency unavoidably decreases at the frequency where the nulls of the Airy pattern of field focused by the reflector in the plane of the array feed lie on the location of elements in the array. Based on this effect, a physical bandwidth limit for high-sensitivity PAF operation can be obtained. Considerations on the design of future array feeds that overcome this limit are given.