Wideband Spline-Profiled Feedhorns for Advanced ACTPol

Sara Simon, Princeton University

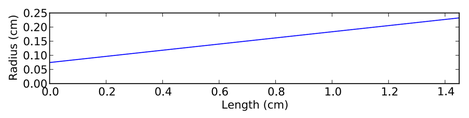
Instrument Overview

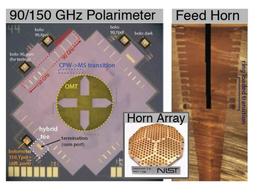
Advanced ACTPol (AdvACT) is an upgraded camera for the Atacama Cosmology Telescope that aims to measure the Cosmic Microwave Background polarization anisotropies over a wide range of angular scales. AdvACT will employ three arrays of polarization-sensitive multichroic detectors to observe in five frequency bands from 30 GHz to 230 GHz. The AdvACT arrays are designed to minimize the spacing between pixels on the array to achieve higher sensitivity, so the feedhorns for each array must have a small radial profile while maintaining efficiency.

Advanced ACTPol Feedhorn Candidates

AdvACT will feature monolithic feedhorn arrays that consist of stacked silicon wafers and are fabricated by the National Institute of Standards and Technology (NIST). An ideal horn for AdvACT would have high beam coupling efficiency with good symmetry between the E-plane and H-plane beams across the multichroic frequency bands, which is necessarily a compromise.

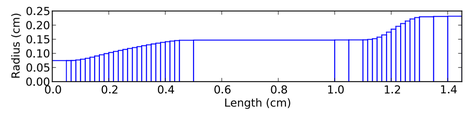
Conical: The conical horn (right) is a smooth-walled horn with the same length and aperture sizes as the spline-profiled horn. Conical horns have high efficiency but poor beam symmetry.





Corrugated: Corrugated horns can approach near ideal beam symmetry. However, for the small aperture size desired for AdvACT, the corrugations represent a significant fraction of area required by each feed, which decreases the achievable coupling efficiency. The corrugated horns in use on ACTPol's 90/150 GHz array (shown in the figure on the left) are 7 mm in diameter, but the target pixel spacing for the AdvACT 90/150 GHz array is 5.4 mm – 5.7 mm.

Spline-Profiled: Spline-profiled horns are numerically optimized by Markov Chain Monte Carlo (MCMC) techniques and represent a compromise between efficiency and beam symmetry. The 150/230 GHz spline-profiled horn is shown in the figure to the right.



MCMC Optimization of Broadband Profiled Feeds

Spline-profiled feeds are designed by numerical optimization. We have developed code that uses MCMC optimization to determine a feedhorn profile that minimizes the difference between the calculated E-plane and H-plane beams across a given range of frequencies and estimates beam coupling efficiency. The code creates a large number of random profiles and uses them to seed parallel MCMC optimizations so that the horn design can be completed in a few days. The ~20 degree field of view used for optimization is set by the Lyot stop of the instrument.

The beam symmetry is optimized by minimizing the penalty function p

$$p = \sum_{Frequency} \sum_{\theta=0}^{\theta=\theta_{stop}} (E^2 - H^2)^2$$

The beam coupling efficiency (below) is calculated to determine the horn profiles with the largest beam coupling efficiency over the observation frequencies

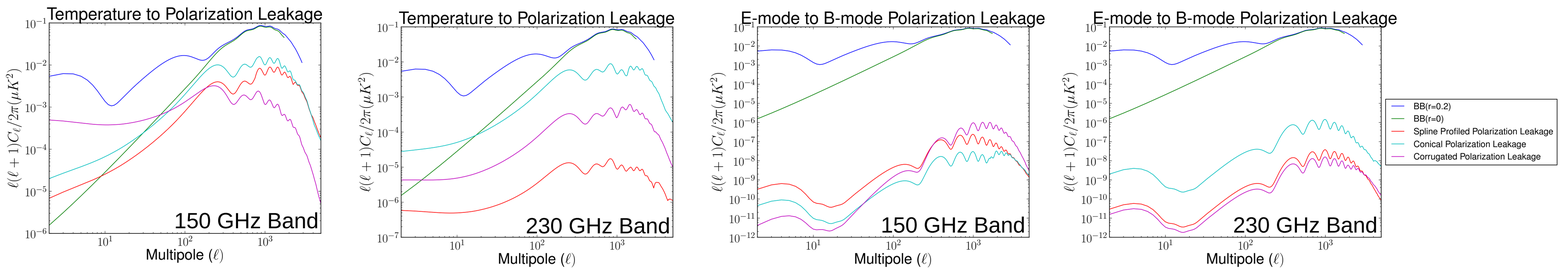
$$Beam\,Coupling\,Efficiency = \frac{\int_0^{\theta_{stop}} (E^2 + H^2) \sin\theta/2\, d\theta}{\int_0^{180} (E^2 + H^2) \sin\theta/2\, d\theta}$$

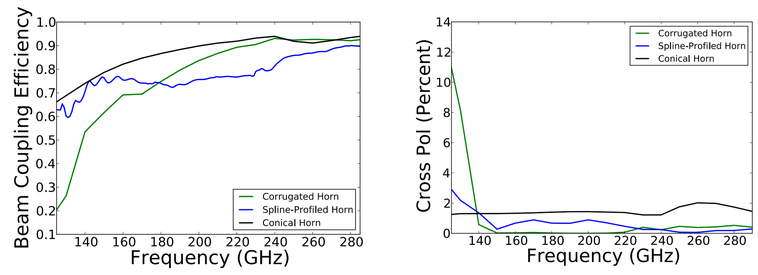
150/230 GHz Horn Simulations and Preliminary Measurements

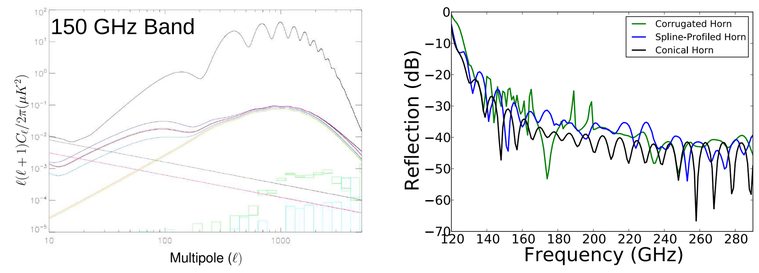
We model the feedhorns for the high frequency array with an electromagnetic finite element method solver called High Frequency Structure Simulator (HFSS). We calculate the beam coupling efficiency, cross polarization, reflection, and leakage into the polarization spectra. The polarization leakages in the power spectra assume a pair differenced detector pair, which is an extreme test of the performance since in AdvACT the half-wave plates will provide significant mitigation of the systematics. Furthermore, accounting for beam asymmetries in analysis could further decrease the polarization leakage and cross-linking in the maps helps identify and quantify the polarization leakage.

Horn Design	Beam Coupling Efficiency		Cross Polarization	
	150 GHz	230 GHz	150 GHz	230 GHz
Corrugated	56.0 %	89.6 %	1.8 %	0.3 %
Spline Profiled	72.4 %	82.2 %	1.1 %	0.4 %
Conical	77.7 %	91.9 %	1.3 %	1.6 %

Simulated



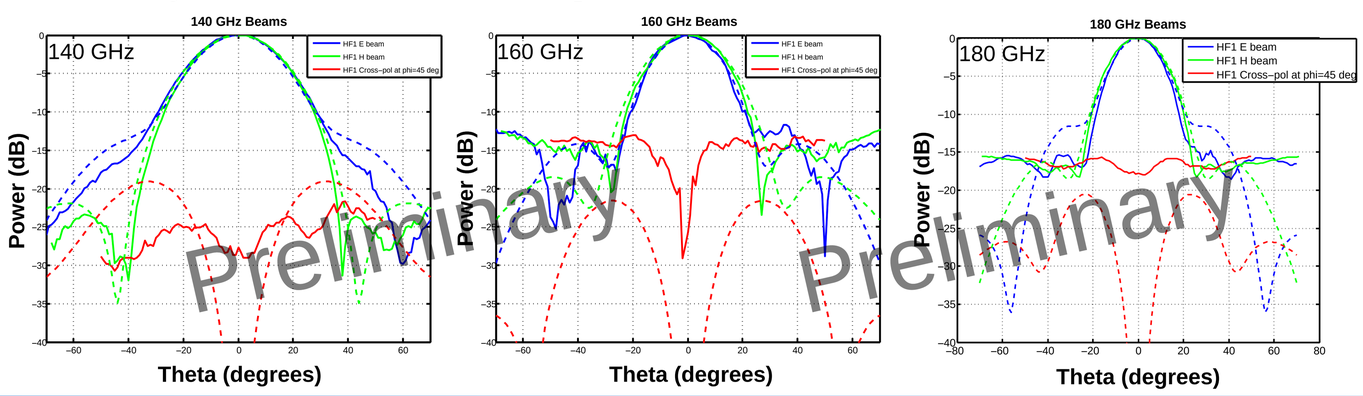




MCMC simulations modeling the leakage of the 150 GHz band are shown in the bottom left figure. The green boxes indicate the E-mode leakage from the feedhorn, and the cyan boxes indicate the B-mode leakage. The B-mode leakage is completely from the MCMC realization noise, which indicates that the temperature to polarization leakage from the feedhorn goes solely into E-modes.

Measured

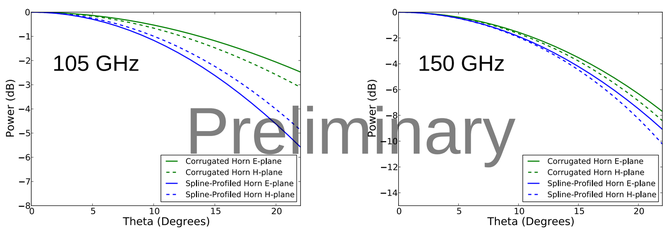
Preliminary Measurements of an Interpolated 150/230 GHz Horn:



The actual 150/230 GHz horn design will have sections with a 167 um step size. A test horn was fabricated using the same profile of the 150/230 GHz horn but interpolated to a step size of 250 um for quick fabrication. Dashed lines are simulations and solid lines are measurements.

Future Work

The 150/230 GHz wideband spline-profiled feedhorn that we have developed for AdvACT has good beam symmetry while retaining a high beam coupling efficiency. It improves the mapping speed of the array by a factor of ~1.75 over the original corrugated design. Once the fabrication of the monolithic 150/230 GHz feedhorn array is complete, we will perform further characterization measurements. Preliminary modeling of the 90/150 GHz and 28/41 GHz designs is underway, and the designs will be completed once the aperture sizes are finalized. Some preliminary beam simulations from the 90/150 GHz horns are shown on the right.



Acknowledgements

This work is supported by a NASA Space Technology Research Fellowship. This work is supported by the U.S. National Science Foundation's Mid-Scale Innovations Program. ACT operates in the Parque Astronómico Atacama in northern Chile under the auspices of the Comisión Nacional de Investigación Científica y Tecnológica de Chile (CONICYT).