Antenna-Coupled TES Arrays Development for BICEP Array CMB Experiment

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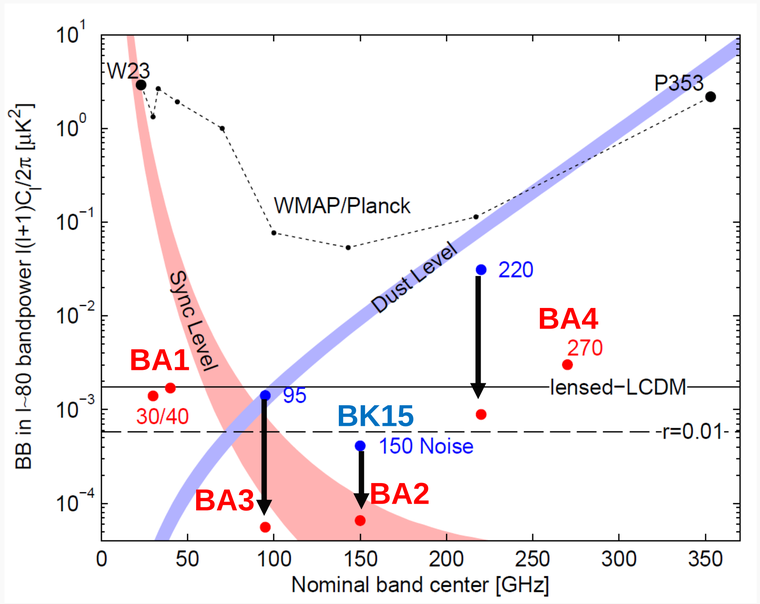
BICEP Array (BA) state of art

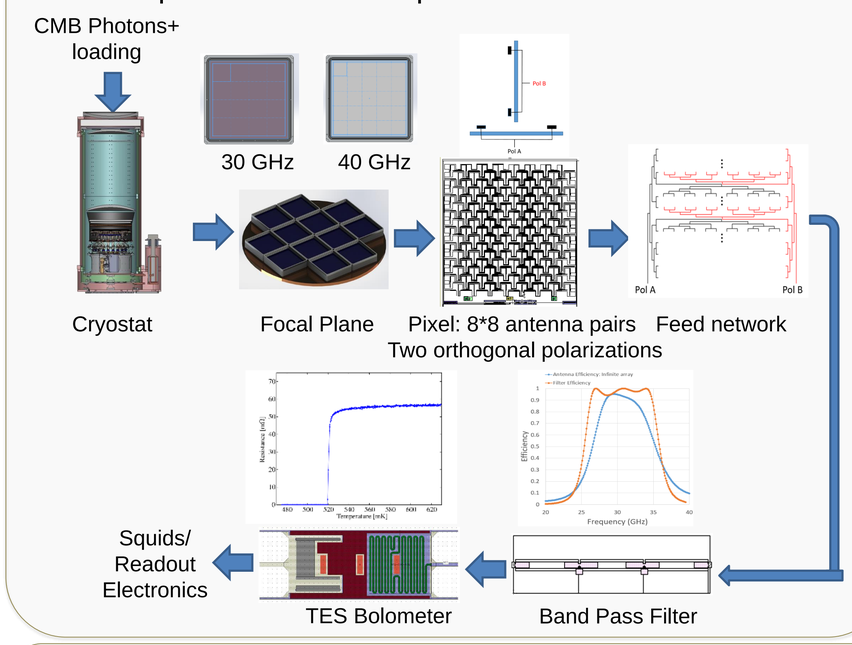
•The inflationary gravitational waves are expected to imprint a B-mode polarization pattern on the cosmic microwave background (CMB).
•Our latest BK15 paper constraints the primordial gravitational waves r < 0.07 at 95% confidence with σ(r) = 0.020.
•BICEP Array is the ongoing CMB experiment in the BICEP/Keck program that will search for the B-mode polarization with large number of background limited detectors over wide bandwidth to separate the primordial B-mode polarization signal from galactic foregrounds.
•BICEP Array will be comprised of four telescopes and expect to measure the ultimate sensitivity of the B-mode polarization signal with constrain of σ(r) = <~0.003 after deployment of 4 receivers (BA1-BA4) in 2023.
•The first low frequency receiver (BA1) is optimized to constrain synchrotron emission at 30 and 40 GHz and will deploy to the South Pole in Fall 2019.



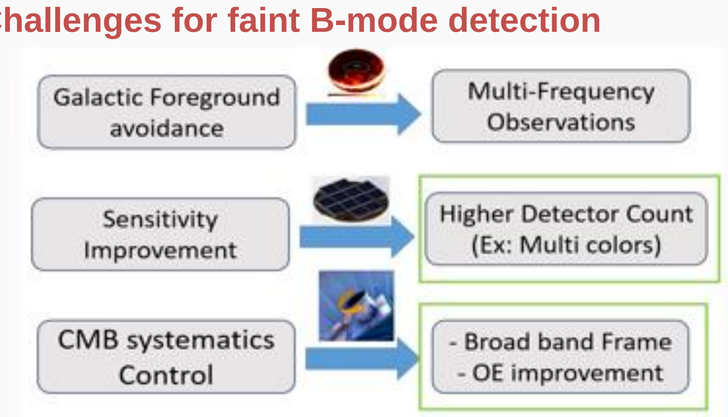
Improved Sensitivity with BICEP Array

CMB Photon Path

- BICEP Array focal plane module design is based on BICEP3 design. Each receiver contains 12 detector modules. Each module contains a 0.625mm thick silicon wafer with an array 5X5 for 40GHz and 4X4 for 30GHz.
- The CMB signal plus loading has been received through the Cryostat by the focal plane.
- Each pixel has two orthogonal polarized arrays of 8 by 8 slot antennas coupled through a summing network to a pair of Al/Ti Transition Edge Sensors (TES). An on-chip band-defining filter selects the frequency of interest with ~27% bandwidth.
- Broad-band corrugation frame (25-45) GHz is used to minimize polarizations mismatches in edge pixels.
- This current across the TES is measured by a superconducting quantum interference device (SQUID) that is coupled to an inductor placed in series with the TES .



Challenges for faint B-mode detection



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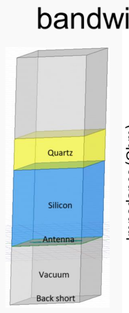
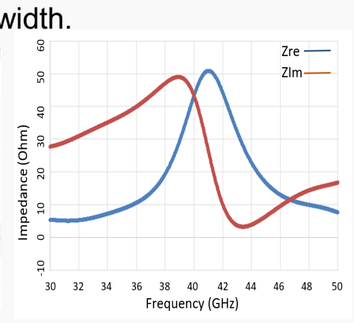
Slot Antenna Array

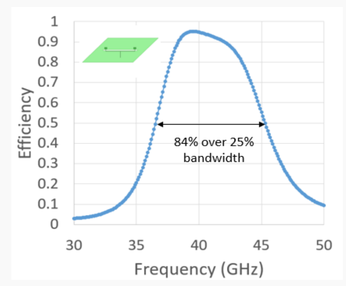
- The slot array is designed with spacing ($S \leq \frac{\lambda 0}{\sqrt{\varepsilon_r}} (1-\frac{1}{N})$), to avoid grating lobes.
- The optical performance of the antenna is characterized by optical efficiency and beam map.
- The efficiency of the antenna is about 84% over 27% bandwidth.



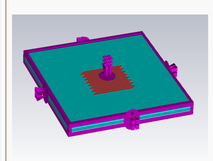
HFSS infinite Array



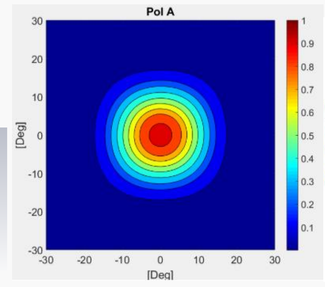
Real/Imaginary Impedance



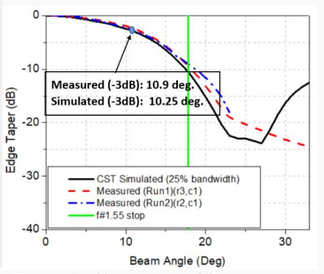
Expected Efficiency



CST Finite Array



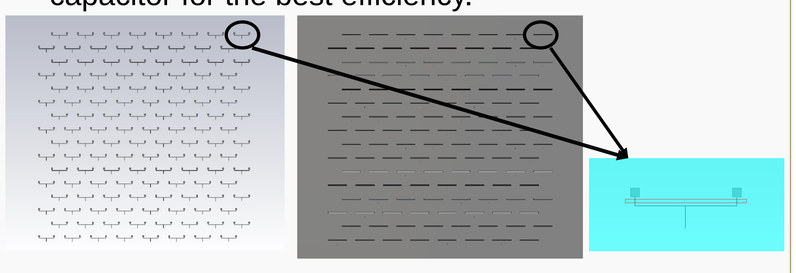
Beam map of Pol A



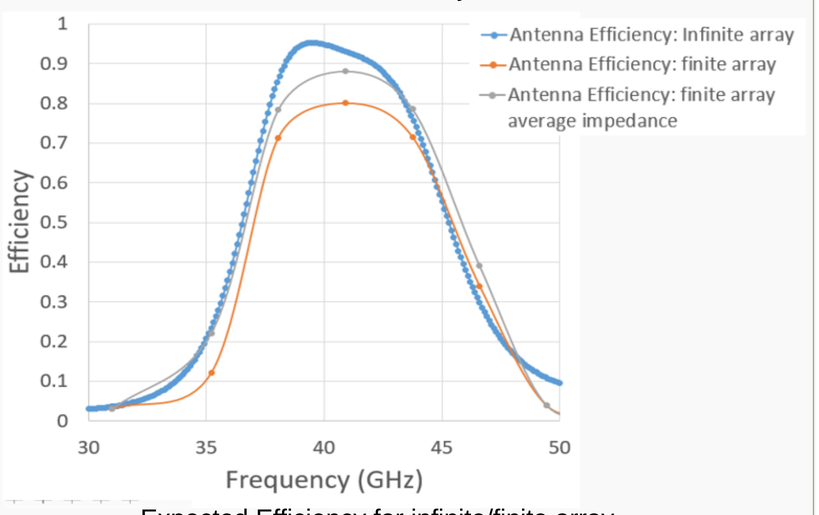
Expected/measured beam map

Optical Efficiency (OE) Enhancement

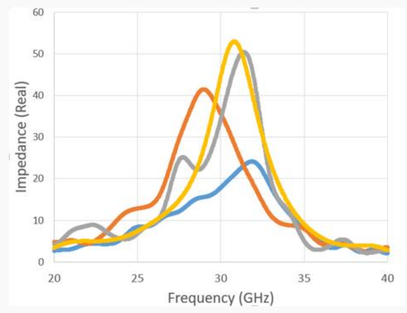
- We built the feed network in CST and it shows mismatch losses due to different impedance for edge slots vs corner slots vs middle slots.
- We tune the transmission line impedance and capacitor for the best efficiency.



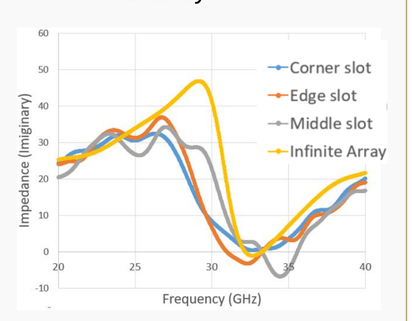
Feed network/slot arrays/unit cell in CST



Expected Efficiency for infinite/finite array



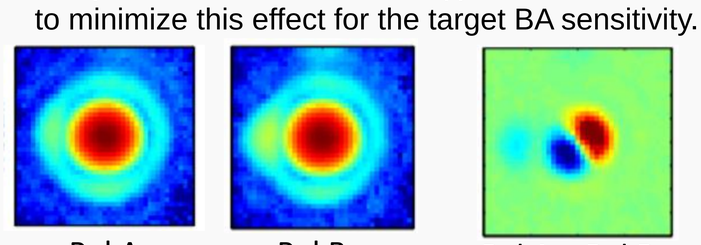
Real Impedance



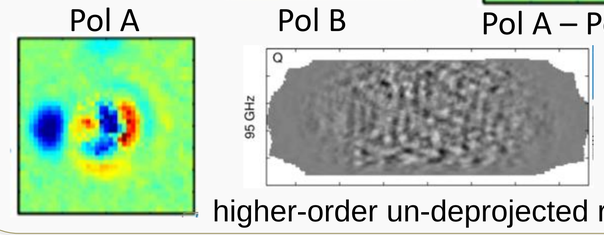
Imaginary Impedance

Problem Definition

- In our recent BK15 paper, we have a temperature to polarization (T → P) leakage due to higher-order un-deprojected residuals in the measured differential beam maps (beam mismatches).
- The residual after differential pointing is deprojected to be Δr = 0.0027 +/- 0.0019, which is currently not comparable to our constrain σ(r) = 0.020. We still need to minimize this effect for the target BA sensitivity.



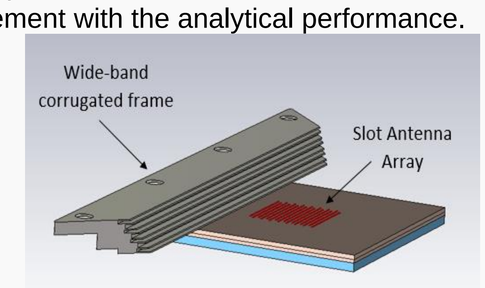
Pol A | Pol B | Pol A – Pol B



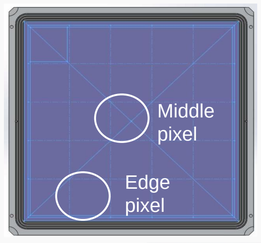
higher-order un-deprojected residuals

Broad Band Corrugation Measurements

- Broad band corrugation frame is optimized to minimize differential pointing between both polarizations of the edge pixels. The measurements show that a very good agreement with the analytical performance.

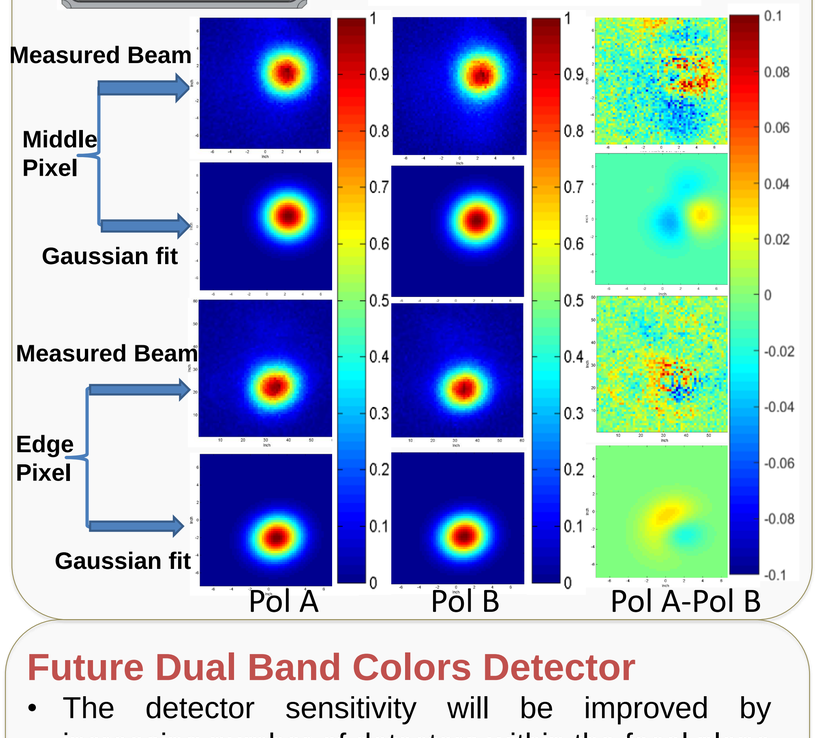


The slot arrays with the corrugated frame in CST



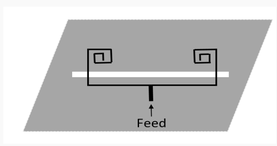
We fit the measured beam to Gaussian function to extract the differential pointing parameters.

$$B(\mathbf{x}) = \frac{1}{\Omega} e^{-\frac{1}{2}(\mathbf{x}-\boldsymbol{\mu})^T \Sigma^{-1} (\mathbf{x}-\boldsymbol{\mu})}$$

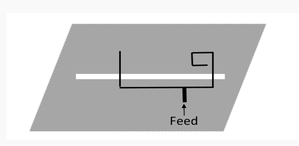


Future Dual Band Colors Detector

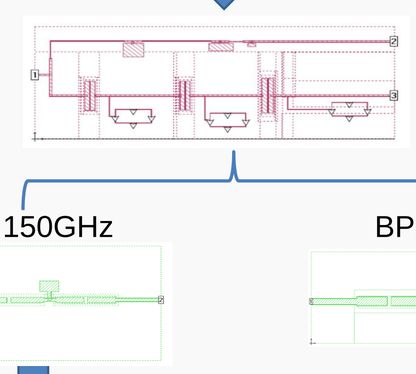
- The detector sensitivity will be improved by increasing number of detectors within the focal plane.
- The feed network of the narrow band antenna can be optimized to cover 150 GHz and 220 GHz bands.
- The diplexer is used to split the power of the antenna for the two 3rd order Chebyshev band pass filters to define our band of interest and to reject the Oxygen and water lines at 118 GHz and 183 GHz.

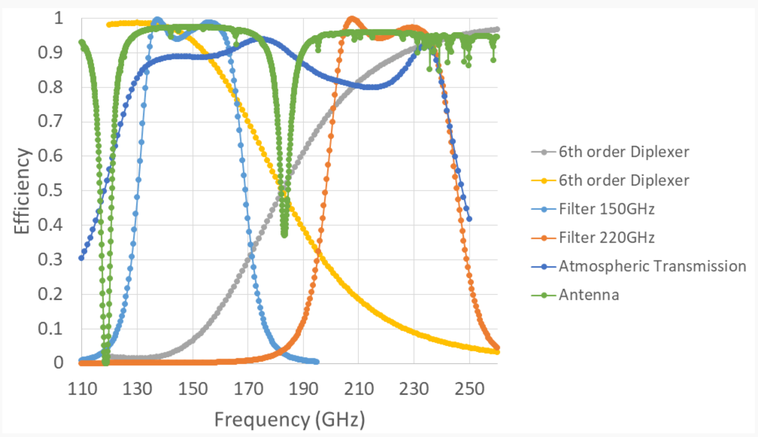


Antenna#1: Symmetric feed unit cell



Antenna#2: Anti-Symmetric feed unit cell





Antenna/filters/ diplexer/Atmospheric transmission spectrum.