National Aeronautics and Space Administration

Antenna-Coupled TES Bolometer Arrays for CMB Polarimetry

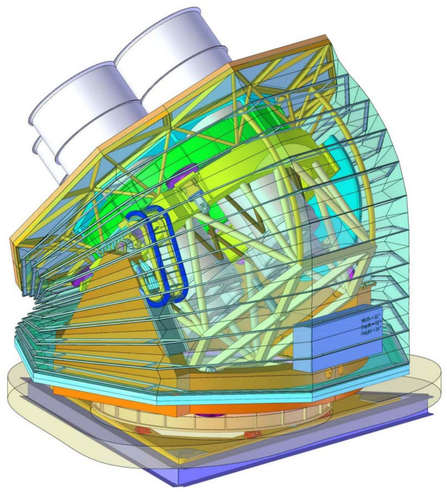
Principal Investigator: James Bock (3268)

Co-Is: Krikor Megerian (3891), Hien Nguyen (3268), Roger O'Brient (3891), Anthony Turner (3891), Alexis Weber (3891)

Program: Strategic Initiatives

Project Objective:

We are developing arrays of antenna-coupled TES (transition-edge superconducting) bolometers to demonstrate technical readiness for the Einstein Inflation Probe, a future space-borne CMB (Cosmic Microwave Background) polarization satellite in NASA's strategic plan for astrophysics. The arrays are designed to meet the requirements of balloon-borne and ground-based experiments, which provide the closest environment to a space mission. Antenna-coupled arrays offer the advantages of high sensitivity spanning the frequencies (30 – 300 GHz) required for comprehensive foreground removal. The arrays are developed to the point they are ready for demonstration in demanding scientific applications on ground-based and sub-orbital platforms.



We are demonstrating TES bolometer array technology for the new BICEP Array CMB polarization experiment. The BICEP Array (mount shown above) is deploying to the South Pole this 2019-20 Antarctic summer. When completed, it will search for inflationary polarization in high sensitivity measurements in 30, 40, 95, 150, 220 and 270 GHz frequency bands.

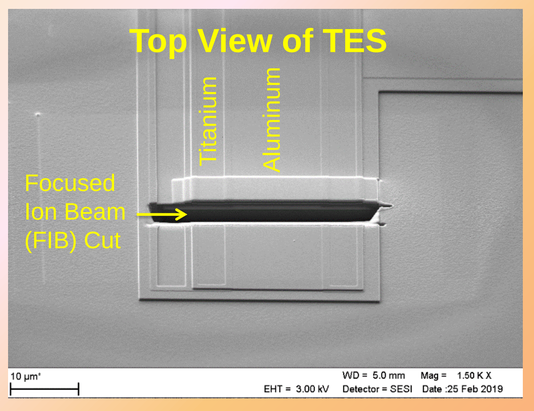
Benefits to NASA and JPL:

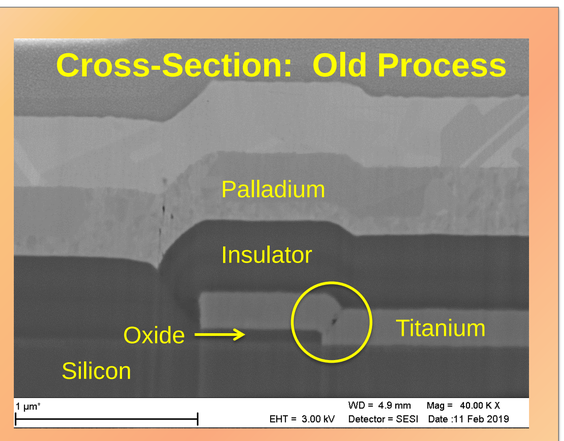
This program develops detector technology to the requirements of ground-based and sub-orbital experiments (BICEP Array, BICEP/Keck, SPIDER) where the devices operate in demanding environments to make scientific measurements that help advance the field in preparation for the Einstein Inflation Probe.

These detectors have produced the deepest CMB polarization maps, and have achieved the highest instantaneous sensitivity in the field. Ground-based measurements provide a high-fidelity demonstration in a demanding scientific environment.

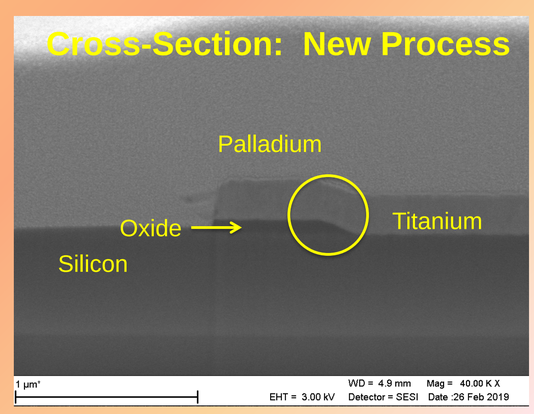
JPL is currently studying a CMB polarization satellite (PICO) for a NASA Probe study in preparation for the 2020 Decadal survey. PICO operates large-format antenna-coupled TES bolometer arrays.

TES Fabrication Development

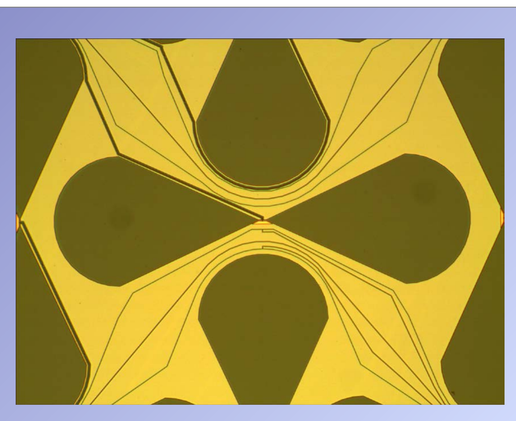


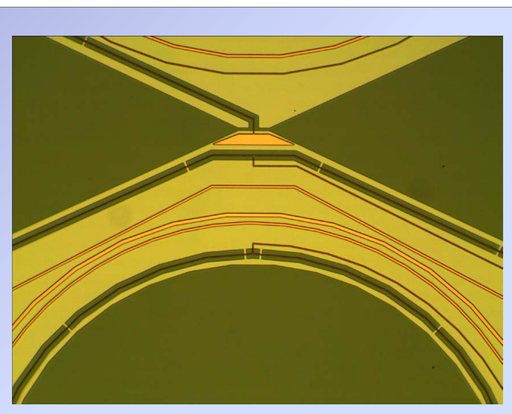


Based on non-ideal TES behavior on 6" wafers, we developed a new TES process for large arrays. *Top*: We sectioned the TES and contacts area using a focused ion beam. *Upper Right*: The cross-section view shows a coverage gap in the titanium TES. We developed a process to taper the oxide step which largely eliminated this gap and improved the electrical properties of TES arrays. *Lower Right*: The new process tapers the oxide layer so that the titanium can go over this step without a coverage gap, resulting in improved electrical performance.

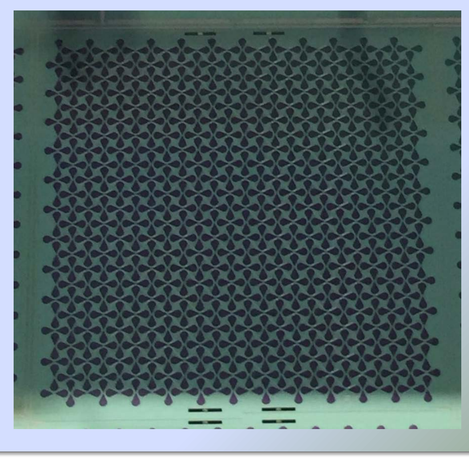


Dual-Band Antenna Design

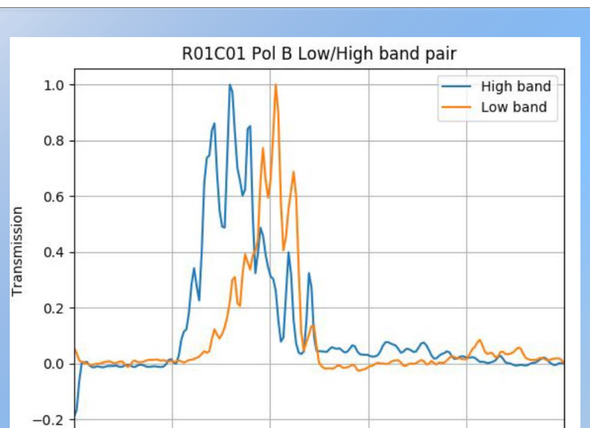


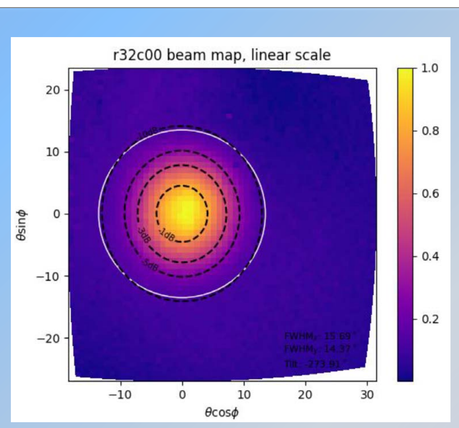


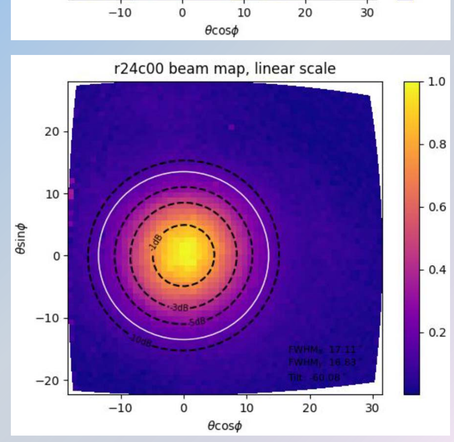
We developed a new design to increase the bandwidth of the antenna. *Lower Right*: Rather than using an array of slots, we use an array of slot "bowtie" antennas. *Top Left*: In this individual bowtie, the shiny gold areas are covered with niobium ground plane, the brown areas are the bowtie opening in the ground plane. There are two arrays of bowties shown, coupling horizontal and vertical polarization simultaneously. The feed network controls the phase and amplitude, to synthesize the desired beam shape. *Upper Right*: Each bowtie is coupled at the center into a feed network using coplanar waveguide to match impedance.



Dual-Band Antenna Results

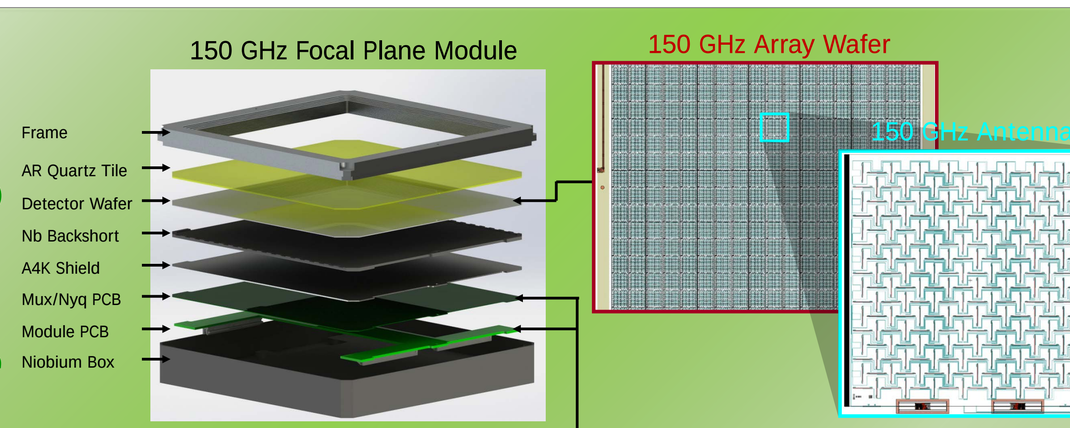


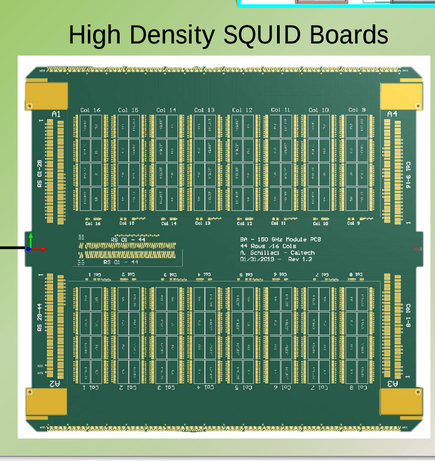




Measurements of the dual-band antenna. The dual-band antenna increases focal plane density by combining two bands into a single pixel. *Top*: Spectral response in the low-frequency and high-frequency detectors, which show a band-averaged optical efficiency of 27 % (high-frequency band) and 35 % (low-frequency band), which includes all losses in the detectors, testbed filters and windows. *Right*: Beam maps in the high-frequency (top) and low-frequency (bottom) bands, which closely match the predicted beam shape.

150 GHz Array Design





We have started designs for a high-density array incorporating 648 detectors operating at 150 GHz on a 6" wafer. By reducing the focal ratio and the chosen edge taper, we have increased the density by 2.25 from Keck Array focal planes. The detector wafer uses pixels based on dual-polarization planar slot-array antennas. The SQUID and Nyquist board presents an engineering challenge due to its high trace density, and the requirement for superconducting traces. We have developed a multi-layer PCB design that is just within commercial fabrication capabilities.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Selected Publications:

S. Hanany et al. 2019, "PICO: Probe of Inflation and Cosmic Origins", arXiv 1908.07495H.

K. Young et al. 2019, "Optical Designs of PICO: A Concept for a Space Mission to Probe Inflation and Cosmic Origins", SPIE 10698E, 46Y.

B. Sutin et al. 2018, "PICO – The Probe of Inflation and Cosmic Origins", SPIE 10698E, 4FS.

A. Soliman et al. 2018, "Design and Performance of Wide-Band Corrugation Walls for the BICEP Array Detector Modules at 30/40 GHz", SPIE 10708, 2GS.

BICEP2, Keck Array Collabroations et al. 2018, "BICEP2/Keck Array X: Constraints on Primordial Gravitational Waves using Planck, WMPS and New BICEP2/Keck Observations through the 2015 Season", Physical Review Letters, 121, 1301B.

PI/Task Mgr. Contact Info: James Bock, 4-0715
James.Bock@jpl.nasa.gov

Poster No. RPC-019