Performance of Al-Mn Transition-Edge Sensor Bolometers in SPT-3G

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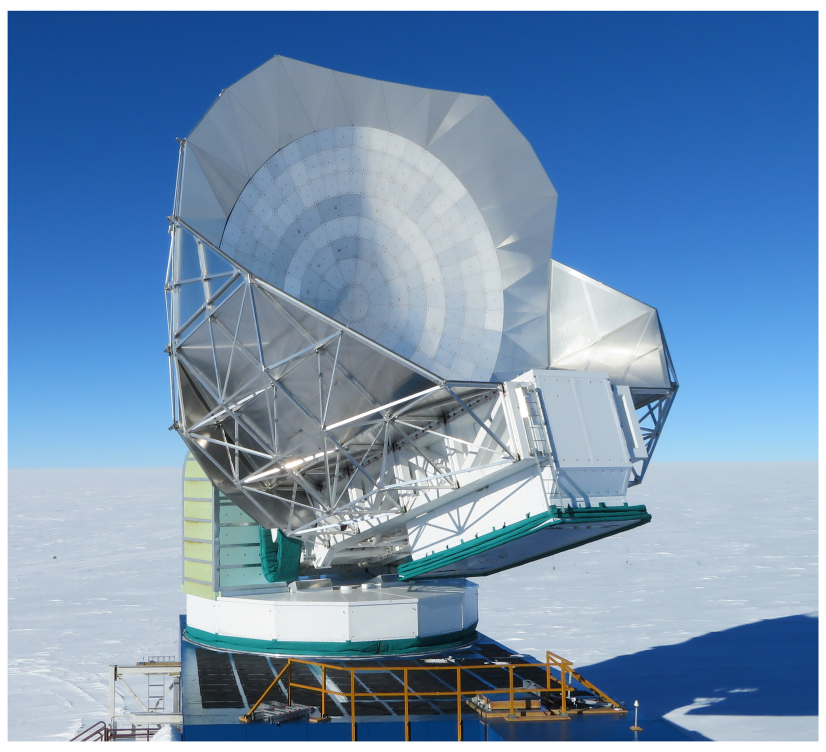
on behalf of the SPT-3G Collaboration

South Pole Telescope and SPT-3G

The 10-m South Pole Telescope (SPT) is dedicated to observing the cosmic microwave background (CMB). In 2017, we deployed a new camera called SPT-3G with 15,000 detectors observing at 95, 150, and 220 GHz using trichroic lenslet-coupled pixels. The ongoing SPT-3G survey targets broad science goals including B-modes, CMB lensing, galaxy cluster science and more.



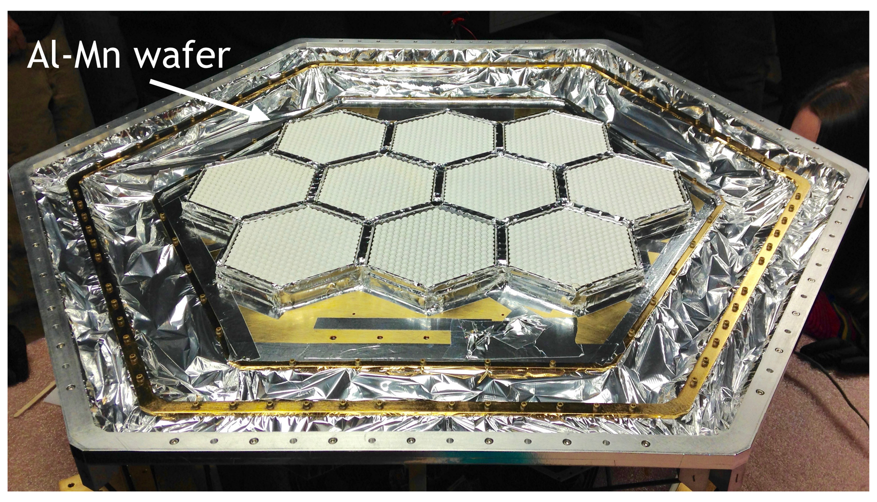


Fig. 1: ***Left:*** **the South Pole Telescope.** ***Top:*** **the SPT-3G focal plane, consisting of ten lenslet-coupled detector wafers. The detector wafer discussed here is a single wafer in the focal plane.**

Al-Mn Sensors

In 2018 we developed a fabrication process at Argonne for Al-Mn transition-edge sensors (TESs). The Al-Mn process has several advantages over TESs based on bilayer designs:

- TES deposition performed in a single step
- Fine control of Rn using TES geometry
- Fine control of Tc using Mn doping concentration and baking of wafer at ~180 C

We fabricated an Al-Mn detector wafer at Argonne and after lab characterization, we deployed this wafer on the telescope.

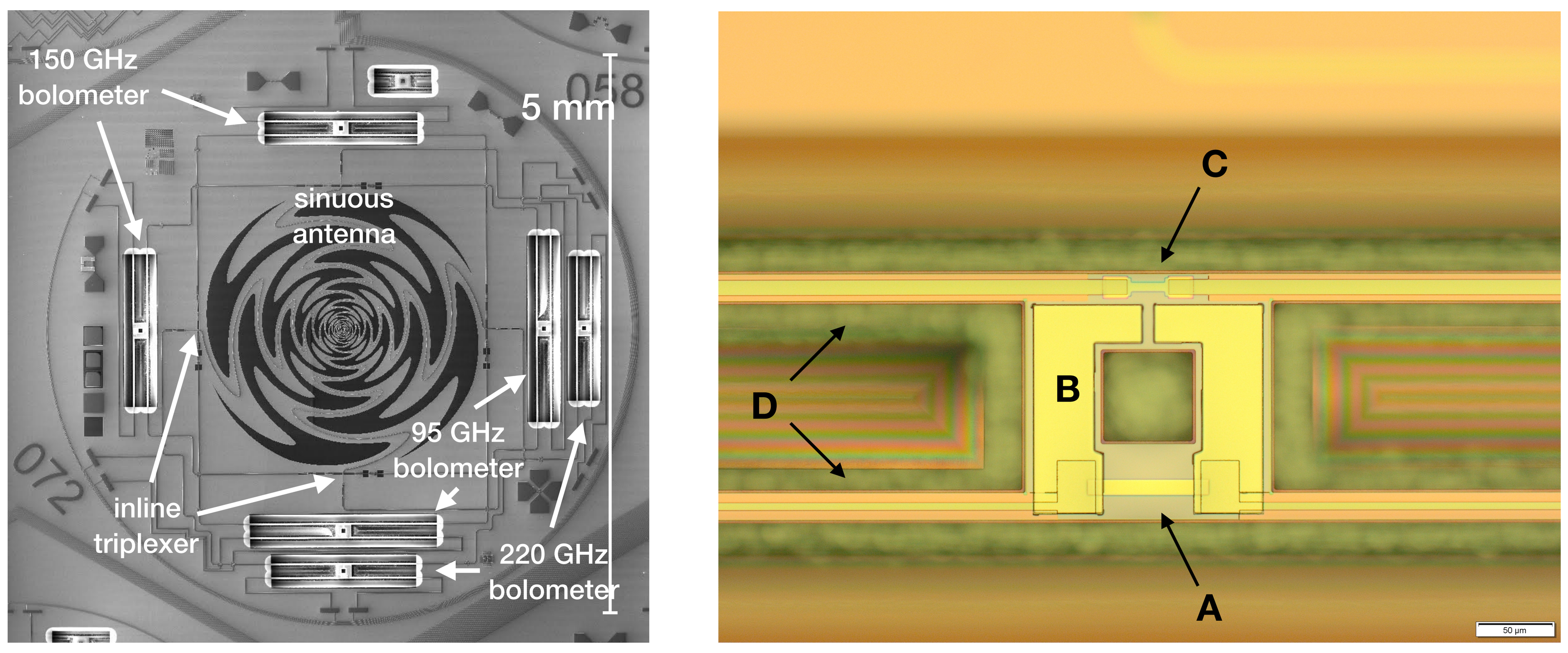


Fig. 2: ***Left:*** **Layout of trichroic SPT-3G pixel.** ***Right:*** **Al-Mn TES bolometer island, showing (A) Al-Mn TES, (B) Pd heat capacity added to the island to stabilize the bolometer, (C) 20~Ohm load resistor for signals from the antenna, and (D) SiNx legs that mechanically support the suspended island and define the thermal conductivity of the bolometer.**

Yield

	Passing detectors	Reasons for losses
Total	1572 (100%)	N/A
+ Nominal warm pinout	1442 (91.7%)	on-wafer shorts and opens, wirebonding defects
+ Resonances detected	1413 (89.9%)	open channels in readout
+ Routinely operated	***1248 (79.4%)***	optical responsivity requirement

Table 1: Cumulative number of detectors meetings various yield requirements. ***Nominal warm pinout*** **excludes detectors with abnormal resistances measured at 300K.** ***Resonances detected*** **are detectors that correspond to resonances visible in a network analysis of multiplexing readout LC chips.** ***Routinely operated*** **includes detectors that were operated in-transition during observing in June 2019.**

Electrothermal Properties

Saturation powers, normal resistance, and critical temperature were measured in a dark cryostat and deployed on the telescope. Uniformity and agreement with fabrication targets is excellent.

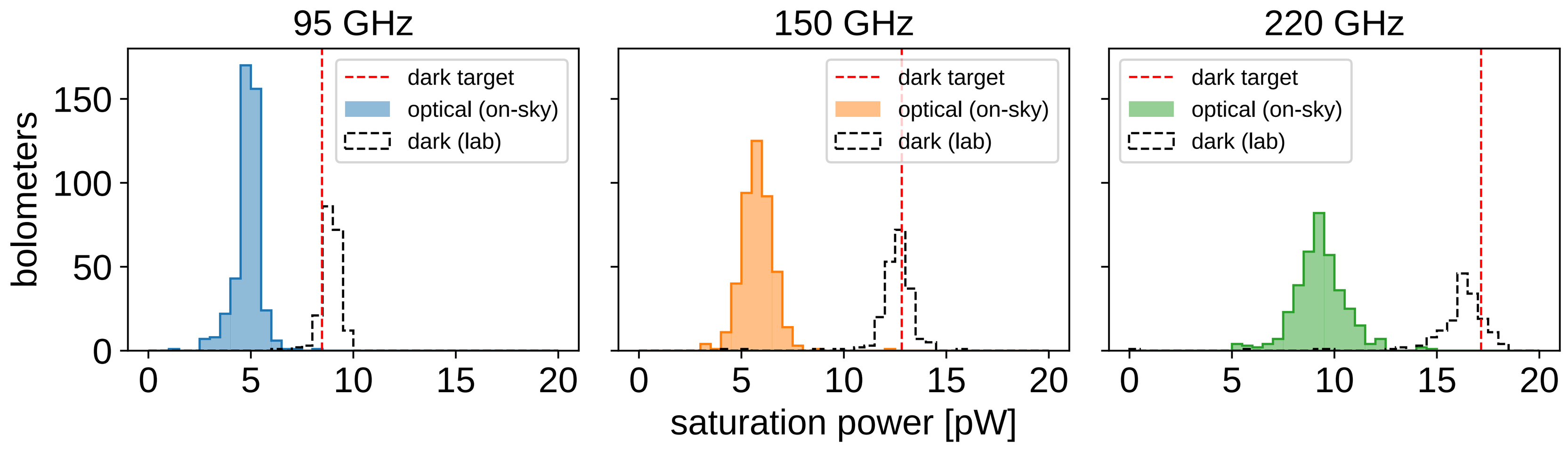
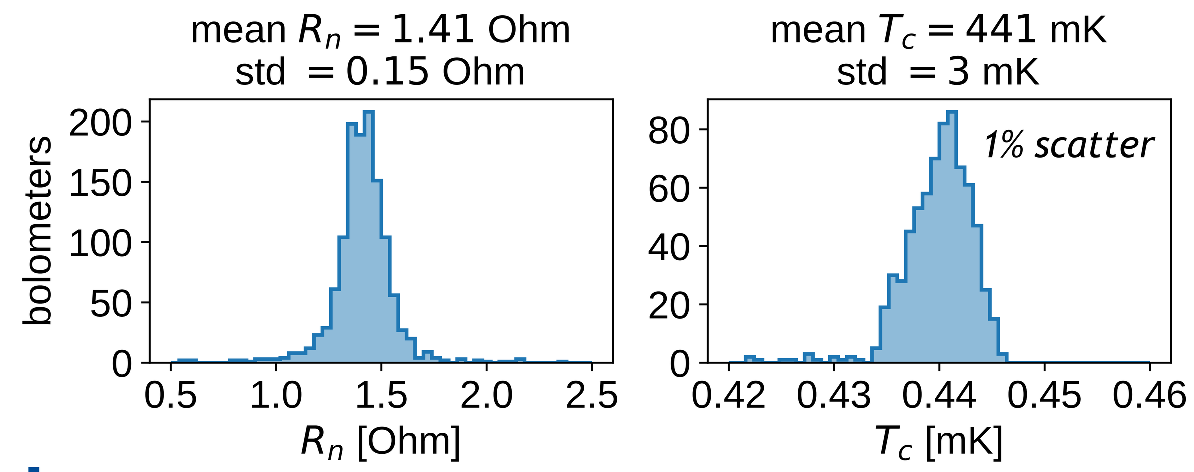


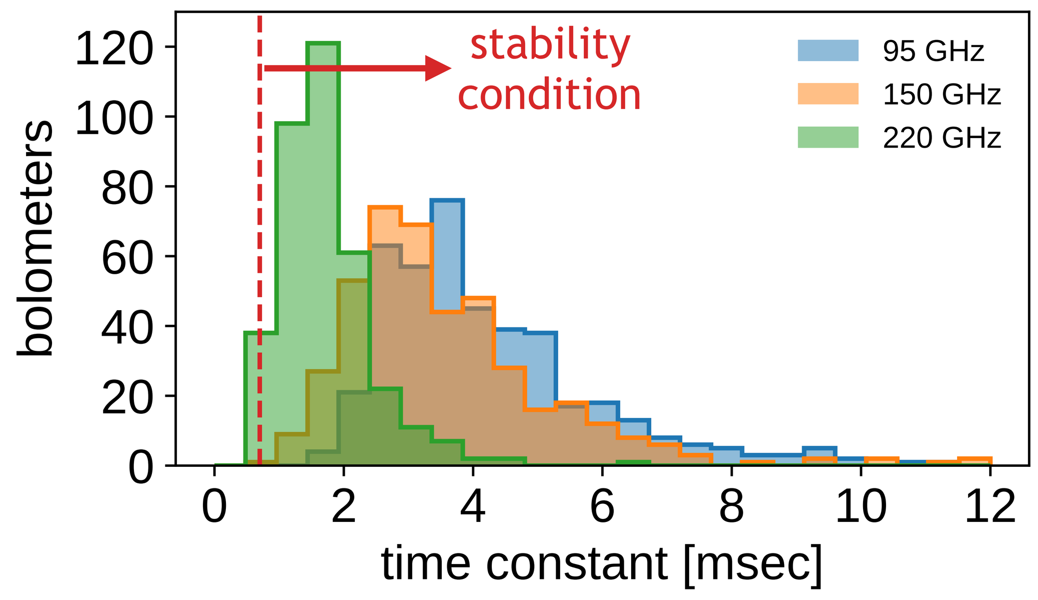
Fig. 3: ***Top:*** **Saturation powers by band, measured in dark cryostat and on the telescope.** ***Right:*** **Normal resistance and critical temperature.**



Time Constants

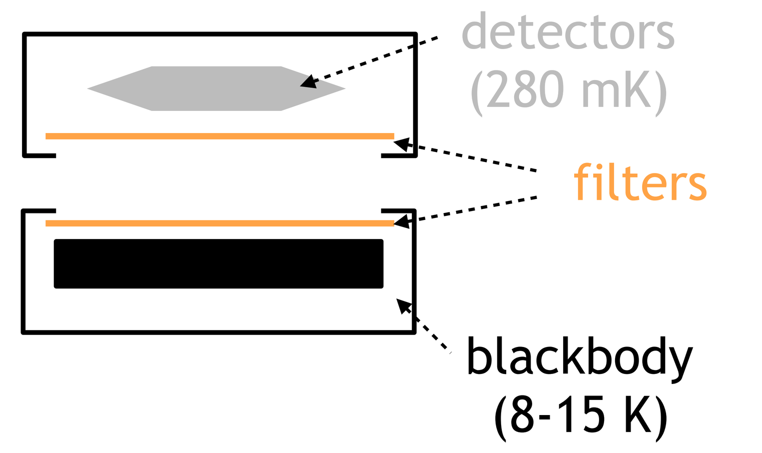
Optical time constants are measured *in situ*, using a chopped thermal source in the middle of the SPT secondary mirror. Given the SPT-3G scan speed and elevation, f_{3dB} corresponds to angular multipoles of 30,000 to 90,000—well above the scales resolvable by the telescope.

Fig. 3: Median optical time constants measured on the telescope during June 2019. Stability condition is estimated from bandwidth of resonance in multiplexing readout electronics. Detectors are safely above the stability condition, but still fast enough to resolve small scales.



Optical Efficiency

Optical efficiency is measured with a blackbody source in a dark cryostat. We control for systematic effects including parasitic resistance, stray inductance in the bias circuit, filter transmission, triplexer transmission, and wafer heating. Pixel efficiencies are high (73-83%) with good uniformity.



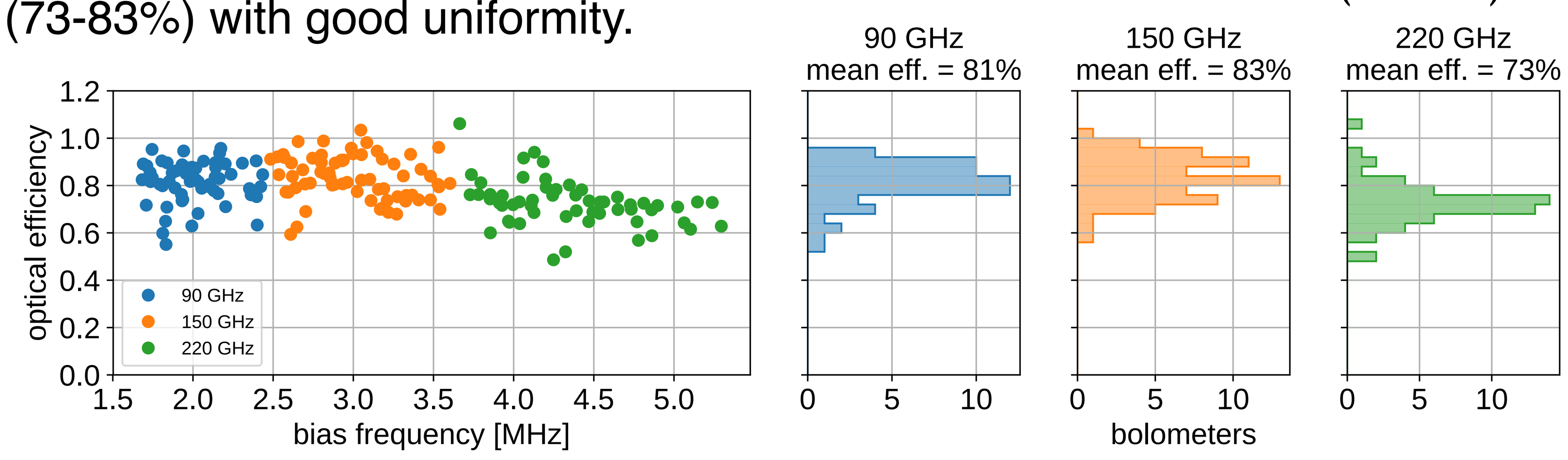


Fig. 4: Optical efficiency by band and as a function of bias frequency. There is minimal residual bias-frequency dependence in the left panel within each band, indicating that parasitic reactances in the readout circuit have been controlled to an acceptable level.

Still curious?

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