EPIC Focal Plane Design and Technology

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Messages in talk

- Cold telescope in space => Extremely high sensitivity focal plane
- Focal-plane technologies being tested now
  - Multiple viable options
  - Detailed trade-offs

EPIC-IM Bands and Sensitivities

Freq [GHz]	θ_{FWHM} [′]	4 K Telescope Option					30 K Telescope Option				
		N_{bol}[a] [#]	NET [μK√s] bolo[b]	NET [μK√s] band[c]	$w_p^{-1/2}$ [μK-′][d]	δT_{pix}[e] [nK]	N_{bol}[a] [#]	NET [μK√s] bolo[b]	NET [μK√s] band[c]	$w_p^{-1/2}$ [μK-′][d]	δT_{pix}[e] [nK]
30	28	84	84	9.2	14	83	24	83	17	26	150
45	19	364	71	3.7	5.7	34	84	70	8	12	69
70	12	1332	60	1.6	2.5	15	208	60	4.1	6.4	37
100	8.4	2196	54	1.1	1.8	10	444	55	2.6	4.0	24
150	5.6	3048	52	0.9	1.4	8	516	57	2.5	3.8	23
220	3.8	1296	59	1.6	2.5	15	408	77	3.8	5.8	34
340	2.5	744	100	3.7	5.6	33	120	220	20	30	180
500	1.7	1092	350	10	16 (140)[f]	8[g]	108	1500	170	260 (2000)[f]	140[g]
850	1.0	938	15000	280	740 (70)[f]	7[g]	110	250k	24k	40k (3000)[f]	340[g]
Total[h]		**11094**		**0.6**	**0.9**	**5.4**	**2022**		**1.5**	**2.3**	**13**

[a]Two bolometers per focal plane pixel

[b]Sensitivity for a single bolometer to CMB temperature

[c]Sensitivity combining all bolometers in a band

[d]$[8\pi\ NET_{bolo}^2/(T_{mis}\ N_{bol})]^{1/2}(10800/\pi)$

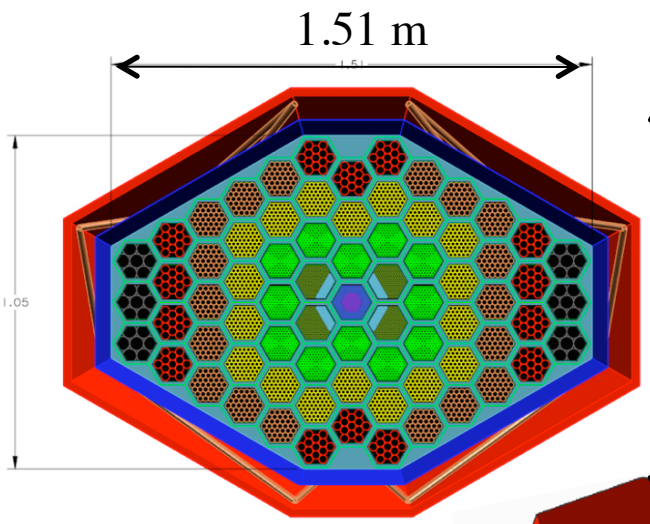
[e]Sensitivity δT_{CMB} in a 2° x 2° pixel

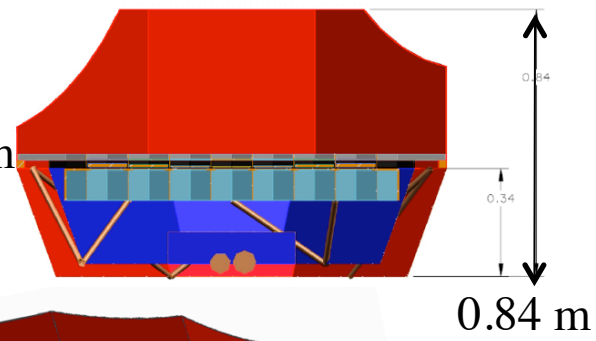
[f]Point source sensitivity in μJy (1σ) per beam without confusion

[g]Surface brightness sensitivity in Jy/sr in a 2° x 2° pixel (1σ)

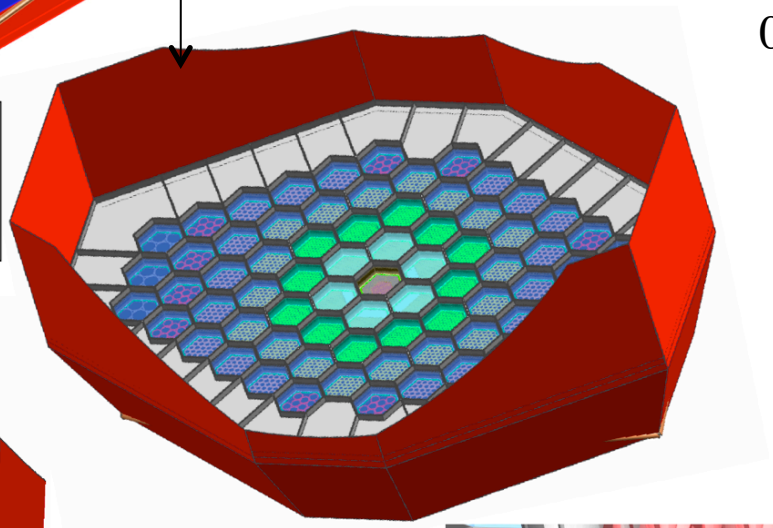
[h]Combining all bands together

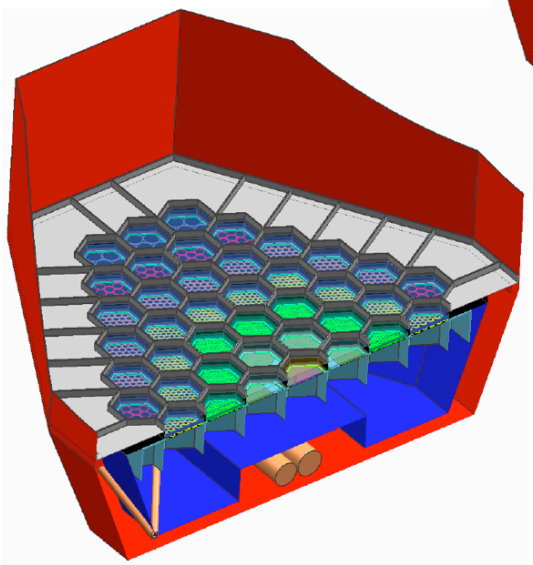
EPIC Focal Plane



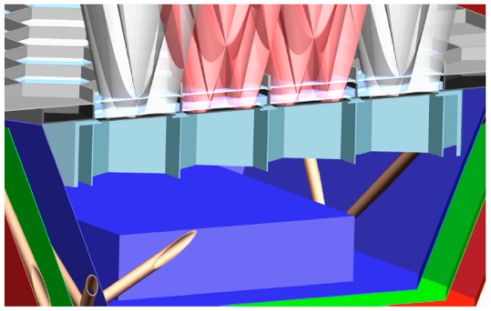


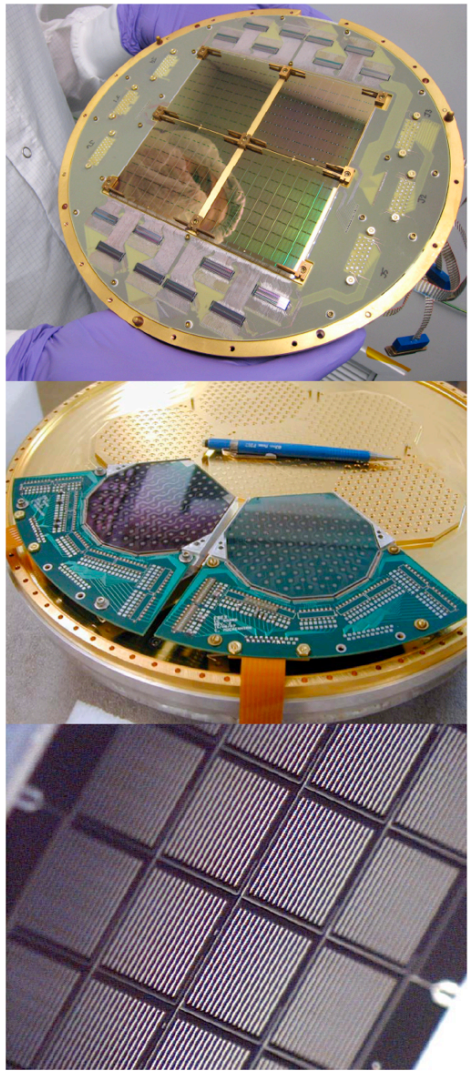
The EPIC-IM crossed Dragone telescope provides a very large focal plane, populated with detector sub-arrays operating (from the center to the edge) at 850, 500, 340, 220, 150, 100, 70, 45 and 30 GHz. The detectors are packed at 2-fλ spacing on individually multiplexed sub-arrays.





Cross sections showing modular assembly of focal plane sub-arrays, radiation shields at 4 K (red) and 1 K (blue), low-conductivity struts, and a continuous 100 mK ADR at bottom. The sub-arrays are mounted in hexagonal cells at 100 mK (light blue). Modular blocking filters are located just above the 100 mK sub-arrays, in two stages at 4 K and 1 K. The filters are sized to not vignette the detector field of view, as shown on the right.





Examples of candidate focal plane technologies for EPIC-IM: (top) TES bolometers readout out by TDM SQUIDs; (middle) TES bolometers readout by FDM SQUIDs; (bottom) planar antenna-coupled RF-multiplexed MKIDs.

EPIC Focal Plane Technologies

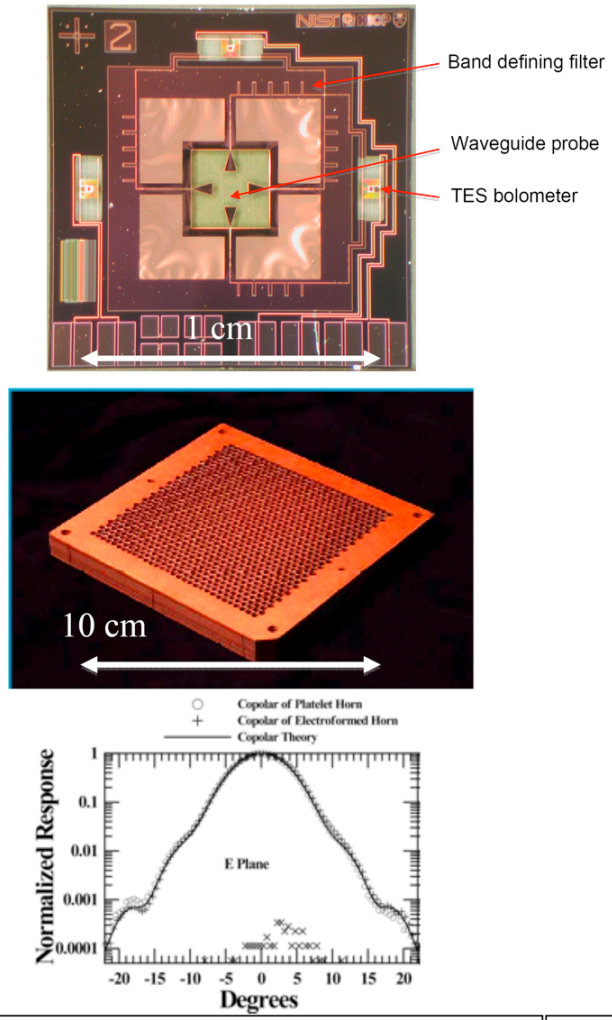


Fig. 7.4a Scalar Horn Coupling
Scalar horns have been used in many CMB experiments to date including WMAP and Planck. Traditional scalar horn-coupled instruments used hand-assembled single pixels, but new lithographic techniques are being developed for building large-scale arrays. (Top) Detector chip with waveguide probes to couple to waveguide. On-chip filters determine the frequency band, and transition-edge sensor bolometers detect power. Chip is built under a NIST/CU/KICP/Princeton collaboration. (Middle) Array of scalar horns built using stacked, lithographed "platelet" arrays. Array built by GSFC. (Bottom) Beam measurement of aluminum platelet array by U. Florida.

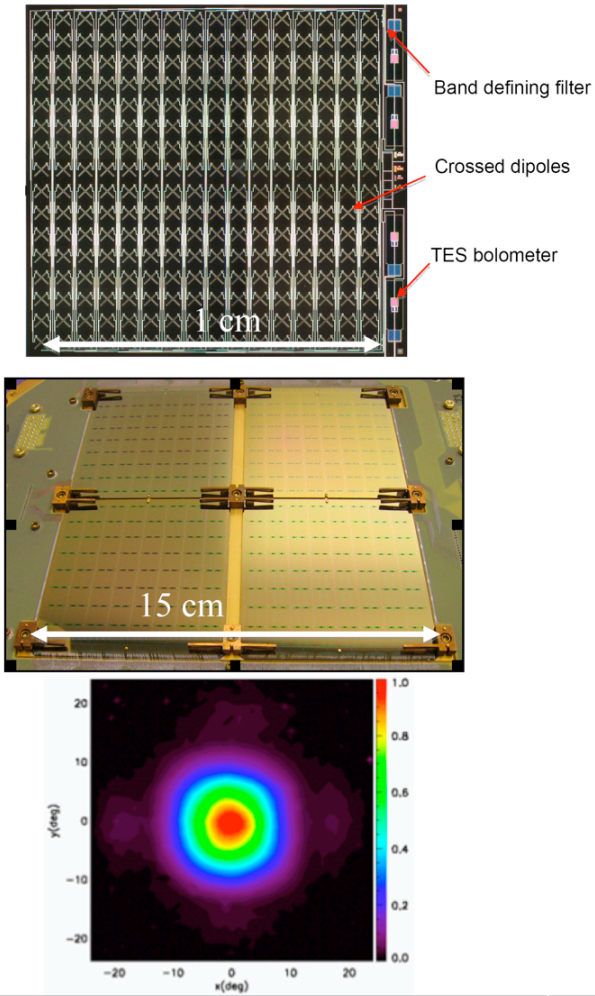


Fig. 7.4b Phased-Array Antenna Coupling
A focal-plane feed with a highly directional beam can be formed by a phased-array of wavelength-scale dipoles. This technique is common in radar and communication. (Top) Photograph of a single phased-array pixel. The "x" shapes are crossed dipoles that sense two polarization states. A transmission-line summing network connects all the dipoles. Band-defining filters and transition-edge sensor bolometers are located on the right of the chip. (Middle) Four 8 x 8 arrays of the same pixels shown at the top along with readout circuit board. (Bottom) Beam map made with a pixel such the one in the top photographs. Arrays and measurements by JPL/CIT.

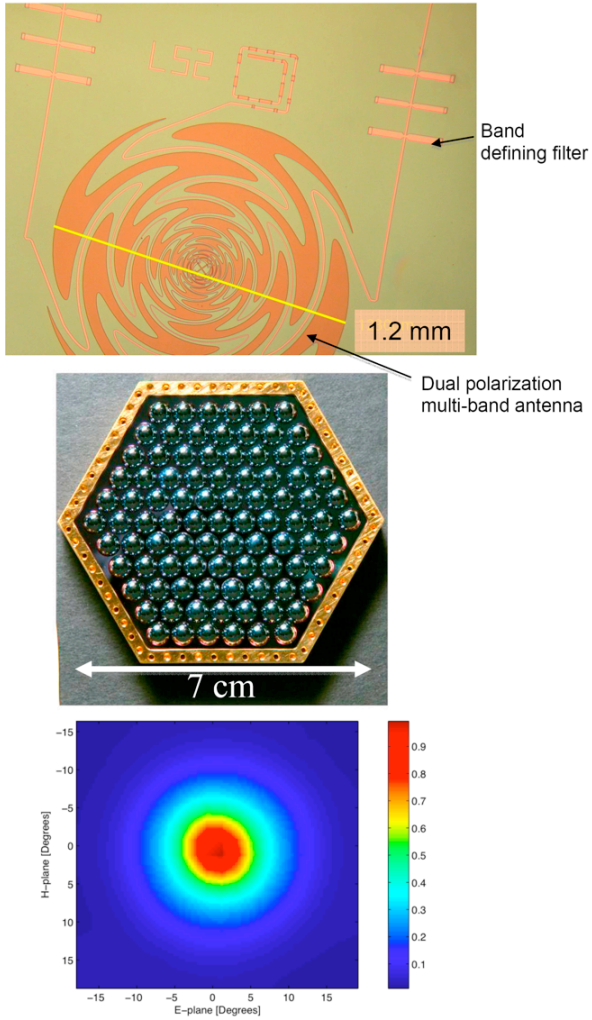
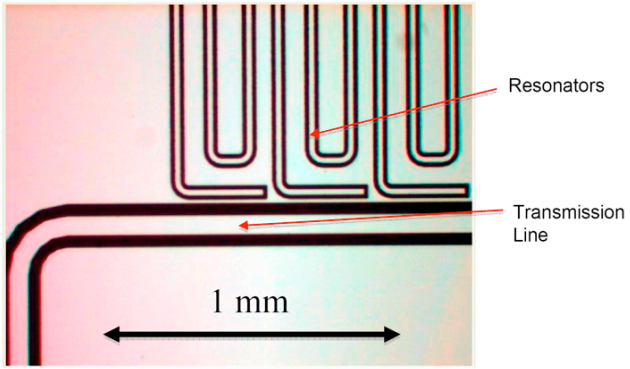


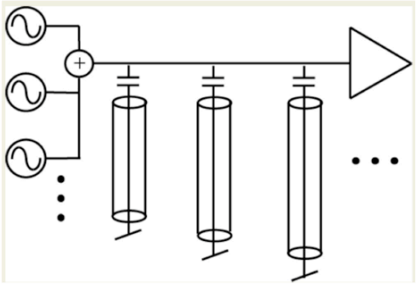
Fig. 7.4c Antenna with Contacting Lens Coupling
A dual-polarization multichroic pixel with 3:1 bandwidth can be built using a planar log-periodic antenna with a contacting lens to achieve high directivity. A focal-plane of multichroic pixels would reduce the size and weight of the focal plane, greatly reducing technical risk. (Top) Photograph of a dual-polarized log-periodic antenna with 80-240 GHz bandwidth and band-defining filters for a single band. Transition-edge bolometers (not shown) detect power. Channelizing RF filters will be used to detect 4-5 photometric bands from a single antenna. (Middle) Focal-plane array of hemispherical silicon lenses. (Bottom) Beam map of a 90 GHz pixel. Array and measurements by University of California, Berkeley.

Focal Plane Tradeoffs

- Scalar Horns
  - Low horn sidelobes
  - Low-mass design required (horns at higher T)
- Phased-Array Antenna
  - Low-mass, mechanically simple design
- Lens-coupled Antenna
  - Reduce focal-plane area by ~ 3x -> reduce design risk

EPIC Multiplexed Readout Technologies





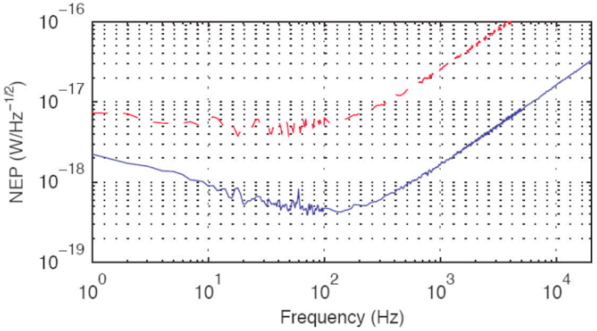
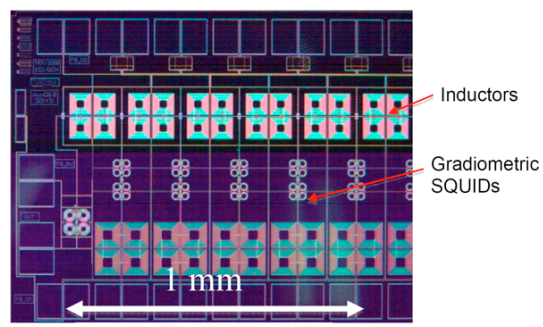
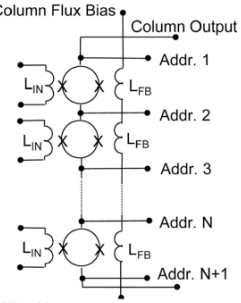


Fig 7.3a Multiplexed Kinetic Inductance Detectors

The MKIDs system features an integrated sensor and multiplexer element. Power deposited in a superconducting distributed resonator reduces it kinetic inductance and changes its frequency. A number of resonators separated by a constant-frequency intervals shunt a transmission line, and the impedance of the resonators are measured by detecting the change in transmission in amplitude or phase. (Top) Three resonators coupled to a transmission co-planar waveguide. (Middle) Schematic diagram of multiplexer. Biases are generated digitally and mixed up to GHz frequency. The signals are measured using a cold HEMT amplifier. (Bottom) Noise Equivalent Power for amplitude detection (red) and phase detection (blue). Figures and data courtesy CIT /JPL.





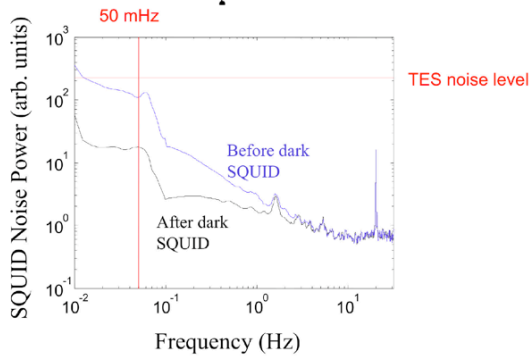
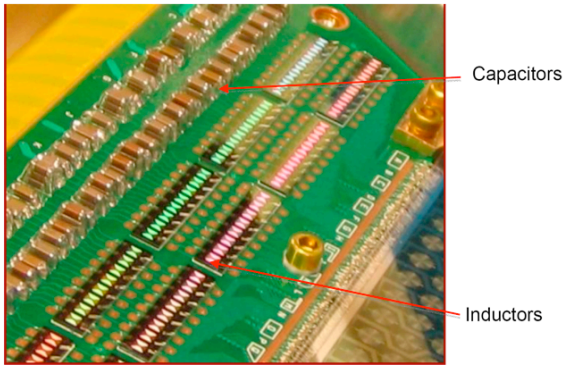
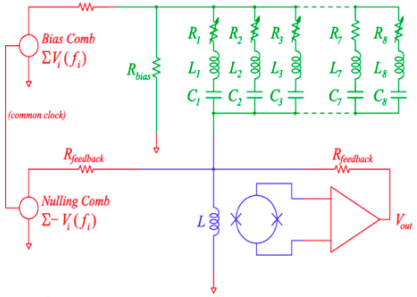


Fig. 7.3b Time Domain Multiplexed TES

The time-domain multiplexer uses SQUIDs as switches to sequentially sample a set of TES bolometers. Common address lines are shared between columns resulting in a low total wire count. (Top) Photograph of a 32-channel multiplexer chip. (Middle) Schematic of time-domain multiplexer. The TES bolometers are connected to the input inductors, and when the bolometer is read out when the associated SQUID is in the on condition (Bottom) Noise power for a time-domain multiplexer, which is lower than TES noise for f > 10 mHz. Figures and data courtesy NIST.





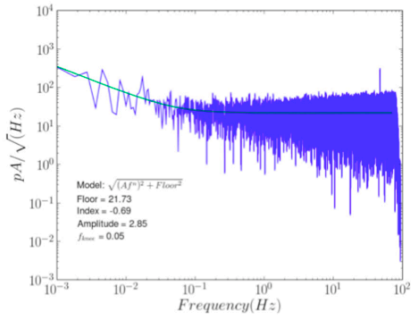


Fig. 7.3c Frequency Domain Multiplexed TES

The frequency-domain multiplexer uses a sinusoidal bias for each TES bolometer with a unique, identifying frequency for each bolometer. The signals for a set of bolometers are read by a single SQUID and the amplitude modulated signals are recovered at room temperature. (Top) Photograph of bolometer array with lithographed inductors and surface mount capacitors. (Middle) Schematic of multiplexer circuit. (Bottom) Noise plot for two differenced bolometers (as would be done in EPIC). The noise level corresponds to an NEP of ~ 3 x 10^{-17}. All the Figures and data courtesy University of California, Berkeley.

Multiplexer Power Dissipation

Temp	4 K Telescope Option			30 K Telescope Option		
	TDM	**FDM**	**MKIDs**	**TDM**	**FDM**	**MKIDs**
300 K	150 W	264 W	100 W	75 W	53 W	20 W
20 K	0	0	100 mW	0	0	20 mW
4 K	375 μW	540 μW	0	85 μW	108 μW	0
1 K	0	0	0	0	0	0
100 mK	1875 nW	20 nW	20 nW	420 nW	4 nW	4 nW

Further Sensor/Readout Tradeoffs

- System Interactions
  - Wiring Requirements
    - TDM = 5,277 wires, FDM = 694, MKIDs = 11 coax
  - Magnetic Shielding
  - Sensor Temperature Sensitivity
    - Detector differencing greatly beneficial
  - RF sensitivity

Summary

- Much recent progress in focal plan tech.
  - TES/MUX currently deployed on ground/balloon
    - TRL-5 soon
  - Monolithic polarization arrays
    - TRL-5 by mid-decade
- Multiple Sensor/Readout Combinations
  - Tradeoffs in power and implementation
- Multiple Optical Coupling Methods
  - Scalar Horn => low sidelobe power
  - Phased-array antennas => low mass/pixel
  - Multi-chroic antennas => ~3x mass reduction