Multi-band Dual-polarization Pixel for CMBPOL

“Focal plane area is the most precious thing we have” H. Moseley talk

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Advantages

• Dual-pol Pixel with 3:1 BW ratio and 5-7 bands
  – Gives Some Combination of:
    • Lower Size/Mass Focal Plane
    • Larger Frequency Range
    • More Frequency Bands
    • Higher Total Sensitivity

=> Potential for a significantly lower cost mission
Disadvantages

• Requirement for $T < 1\ \text{K}$ aperture stop
  – Possible to eliminate requirement
• Slightly elliptical ($< 5\%$) beams may require:
  – Accurate characterization
  – Mitigation via modulation or obs. Strategy
• Currently at low TRL
Planar Antennas

• Double-dipole: two dipoles driven in phase
Polarbear Array
2009 Test-Phase at Cedar Flats

- Op. Eff.  $\sim 35\% \rightarrow 45\%$
  (w/ AR coating on Si lens)

184 Bolometers, 150 GHz

Single Pixels: Myers 05 APL, Myers 08 LTD
Classic Planar Log-Periodic Antenna

- “Teeth” resonate over narrow range of frequency
Sinuous Antenna

• Four arms -> Dual polarization
• Opposite arms couple to linear polarizations
• Adjustable parameters: Geometric scaling factor, arm opening angle
• Self-complimentary: Constant impedance, “wire” or “slot” operation
Lens Coupling
Antenna w/Contacting Lens

- Contacting lens focuses beam pattern
  - Surface of lens is analogous to horn aperture
- Antenna is small compared to pixel
  - Use area under lens for filters, switches, mux…
- Challenges: anti-reflection coating, mechanical alignment
Lens-Coupled Antenna Heritage

- Suborbital: CSO, SOFIA, ALMA...

- Space qualified on Hershel
Sinuous Properties
Wire-style antenna with lens
(UCSD Antenna Range)

- Fabricated on Roger’s 3010 ($\varepsilon=10$)
- Diodes between opposite arms in center.
- Eccostock12 Lens
- 6” hemisphere; 1.5” spacer
- Operated between 5-12GHz
Measured beams with lens

- X-pol < -23 dB
- Consistent with simulations
- Beams narrow with increasing frequency

Scalar Horn (Gundersen and Wollack whitepaper)
Measured beams with lens II

(e) 11 GHz Measured Cuts
(f) 12 GHz Measured Cuts

(g) Several channels of E cuts
Polarization Rotation

- Polarization angle rotates with frequency
- BUT, Depolarization within band \( \sim -27 \text{ dB} \) \( (\cos 5^\circ = 0.996) \)
- Each band has to be calibrated
Slot-Sinuous with Microstrip Feed

- Microstrips:
  - cross slots in center
  - via to ground
- Planar & scalable
- ADS Momentum simulations
- Simulation: $S_{11}<-15\text{dB}$ if microstrip $Z=40\Omega$

Grey-slot
Blue-ground plane
Yellow-microstrip
Selecting Lens Size

- One lens covers factor 3 frequency range
  - Effective pixel size spans range of $D/(f \lambda)$
  - Factor 0.65 (optimum) in mapping speed over full range
- Phase arraying of lensed antennas gives $\sim$ const beam

[Graph showing extended source mapping speed, FOV fixed]
Band Definition
150-220 GHz Diplexer

- 4 bolometers
- 4-pole \( \lambda/4 \) shorted-stub filters define bands
- Impedance & length of input lines chosen so one filter looks open in the other’s band.

- End-to-end receiver FTS measurement
8-Band Channelizer

- Each channel “drops” from backbone
- Bands are contiguous (good for space)
- “loss” at peaks is largely sharing btw channels
  - Reflection loss < 10%
Lenses and Antireflection Coating
Broadband anti-reflection coatings

Erin Quealy

Multi-layer TMM Chebyshev coating on hemisphere

TMM 3 ($\varepsilon_r = 3.27$),
TMM 4 ($\varepsilon_r = 4.5$),
TMM 6 ($\varepsilon_r = 6.0$),
TMM 10i ($\varepsilon_r = 9.8$)

TMM layers on flat silicon (with expanded teflon top layer):

Silicon Anti-reflection Coating

(Measurement taken at 1.2 K)
Mechanical Alignment of Lenses

- Lateral alignment requirement
  \[ \lambda/10 > 100 \, \mu m \]
- Lithographic seating wafer
  \ (~ 10 \, \mu m \text{ accuracy} \)
- Wafer-wafer alignment marks
  - Use IR light
Needed Work for TRL 5-6

• A few cycles of: simulation and scale model <-> cryogenic antenna testing
  – Measure:
    • Beam patterns
    • Polarization properties
    • Efficiency
    • Band Definition

• Lab test broadband antireflection coating
• Lab test log-periodic channelizer
• Test in suborbital experiment e.g. Polarbear, EBEX, or SPT
Low-cost Mission Concept enabled by Multi-band Pixels
Cartoon high throughput single small aperture

• 4K Crossed-Dragone
  – 30 cm aperture
  – 26 cm focal plane
Cartoon high throughput single small aperture II

26 cm < 40-100 GHz

- 100-290 GHz

- 650 Pixels (5400 bolos)
  - 500 Pixels: 100, 130, 170, 290
  - 150 Pixels: 40, 60, 80, 100
Conclusions
Dual-pol multi-band Pixels
Summary

• Advantages:
  – Enables much less expensive CMBPOL design

• Disadvantages:
  – May (not must) require sub-K aperture stop
  – System design must allow beam ellipticity (< 5%)

• Significant work needed to reach TRL 5-6
  – Knowledge, facilities in place
END
Phase Array of Lensed Pixels

- Phase array lensed pixels: keep ~const beam size
  - Separate frequencies, then add RF
90-150-220 GHz Triplexer

- 6 bolometers on triplexers
- Design principles generalize to three or four channels

IE3D Simulations

[Graph showing transmission characteristics for different frequencies]
Single-color pixel design

Crossed Double slot dipole
(Chattopadhyay and Zmuidzinas, 1998, Myers et. al., 2005)

Si lens

Dolph-Chebyshev microstrip transformer
(McGinnis and Beyer, 1998)

Shorted $\lambda/4$ stub 5 pole microstrip filter

Microstrip crossover
Measured beams with lens

- X-pol < -23 dB
- Consistent with simulations
- Beams narrow with increasing frequency