Multi-band Dual-polarization Pixel for CMBPOL

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

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Collaboration

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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 <u>significantly</u> lower cost mission

Disadvantages

- Requirement for T < 1 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

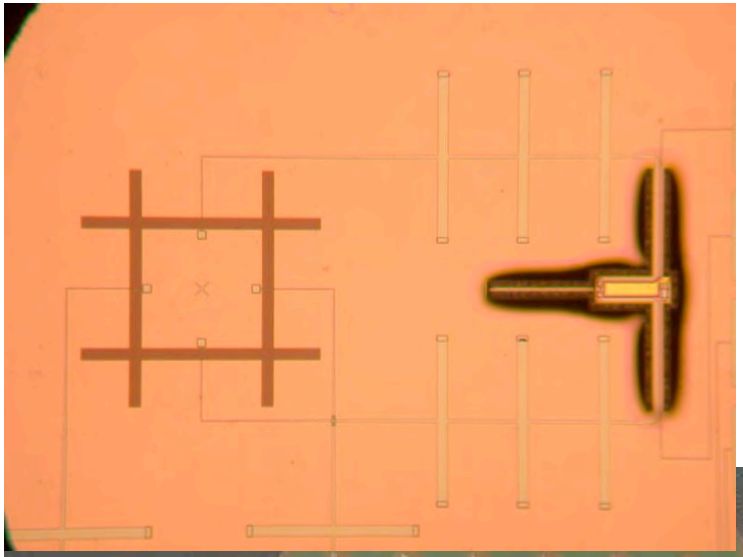
- Double-dipole: two dipoles driven in phase

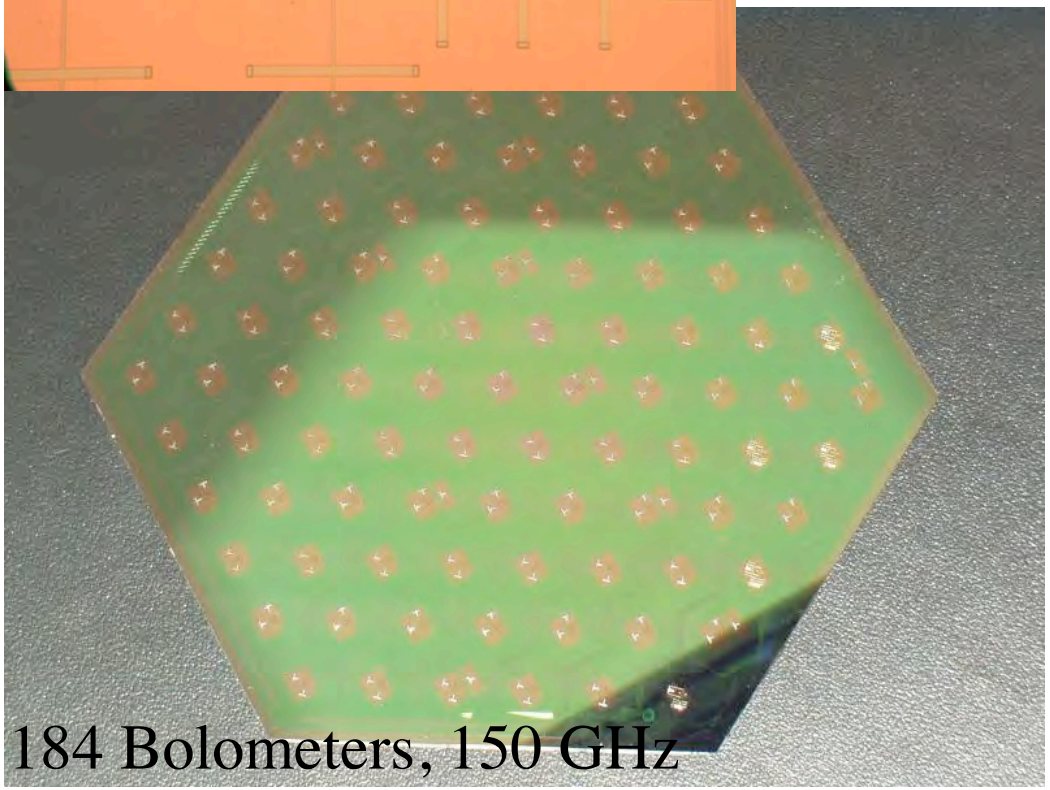
Polarbear Array

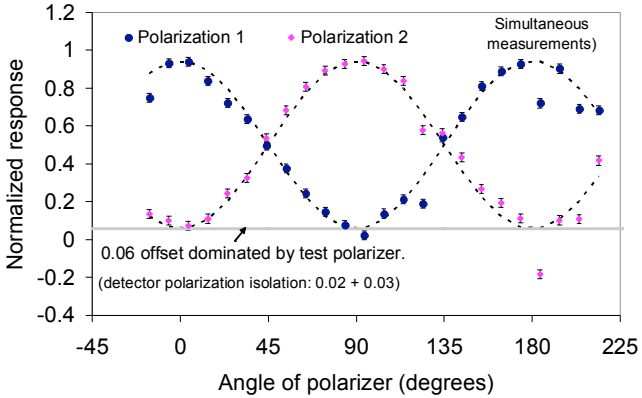
2009 Test-Phase at Cedar Flats

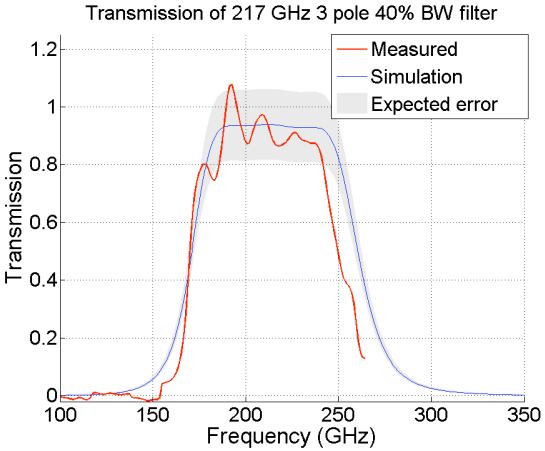
- Op. Eff. ~ 35% -> 45%

  (w/ AR coating on Si lens)



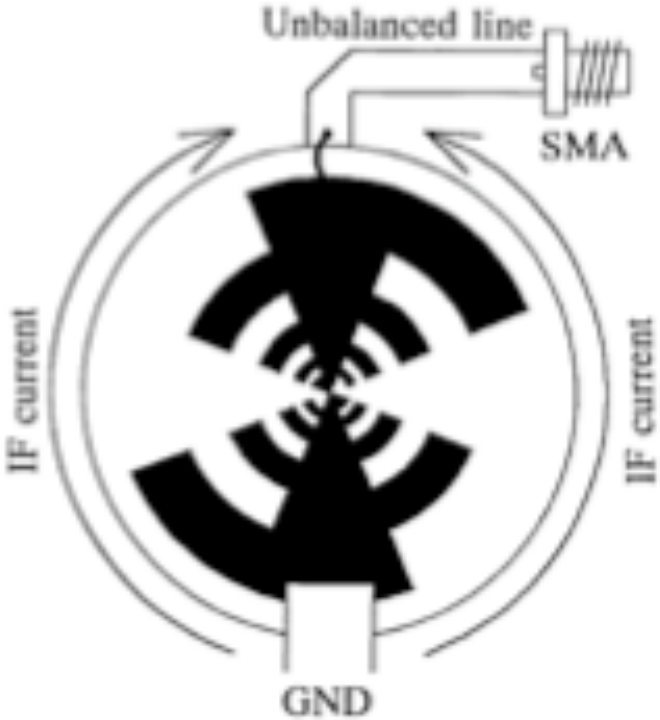






Single Pixels: Myers 05 APL, Myers 08 LTD

Classic Planar Log-Periodic Antenna



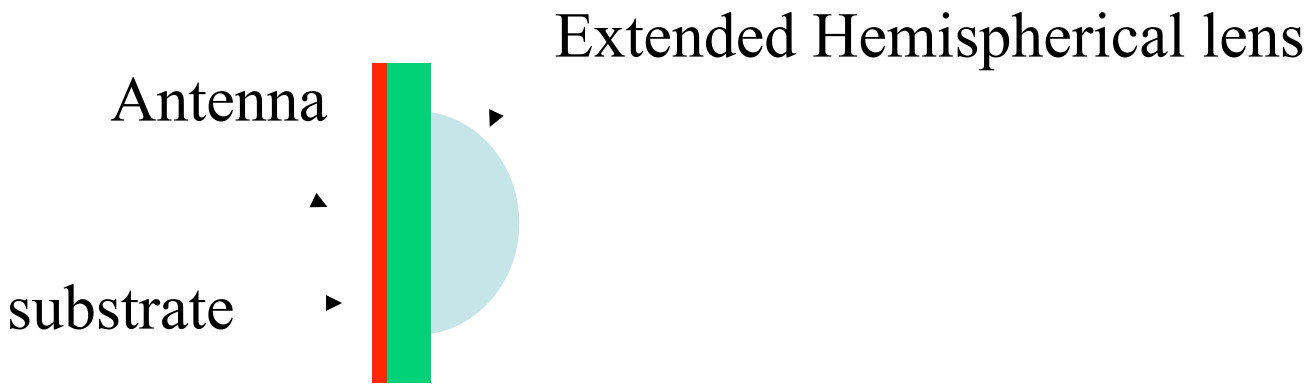
- "Teeth" resonate over narrow range of frequency

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

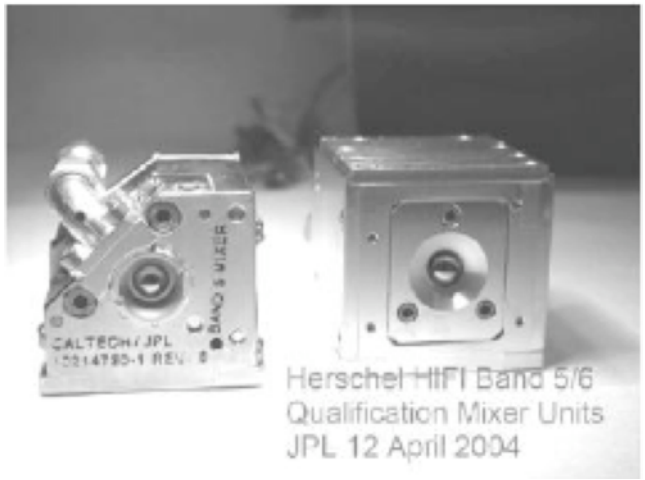


- Contacting lens focuses beam pattern
  - Surface of lens is analogous to horn aperture
- Antenna is small compared to pixel
  - Use area under lens for filters, switches, mux…
- Challenges: anti-reflection coating, mechanical alignment

Lens-Coupled Antenna Heritage

JPL/CIT

- Suborbital: CSO, SOFIA, ALMA…



JPL/CIT

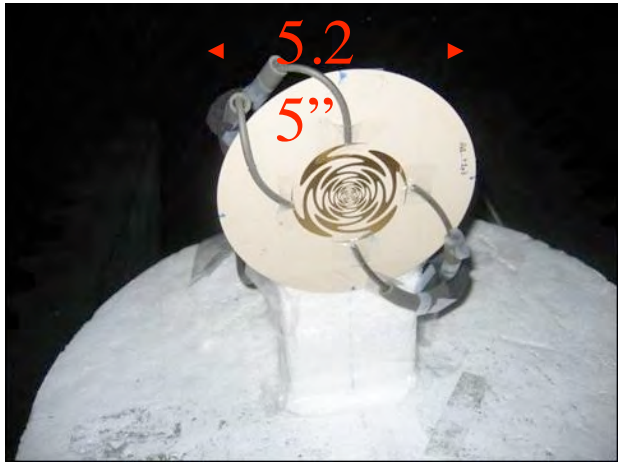
- Space qualified on Hershel

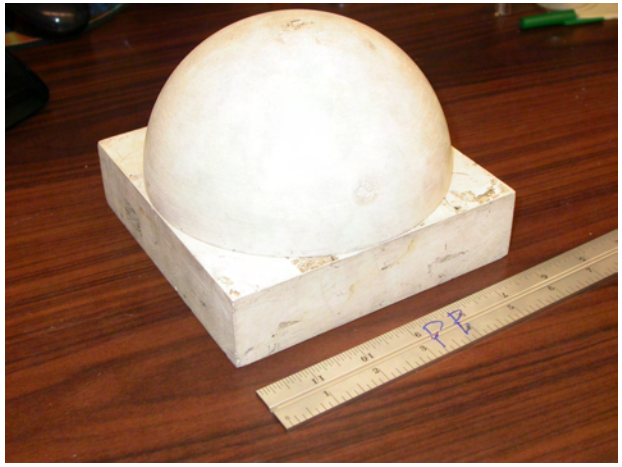
Sinuous Properties

Wire-style antenna with lens

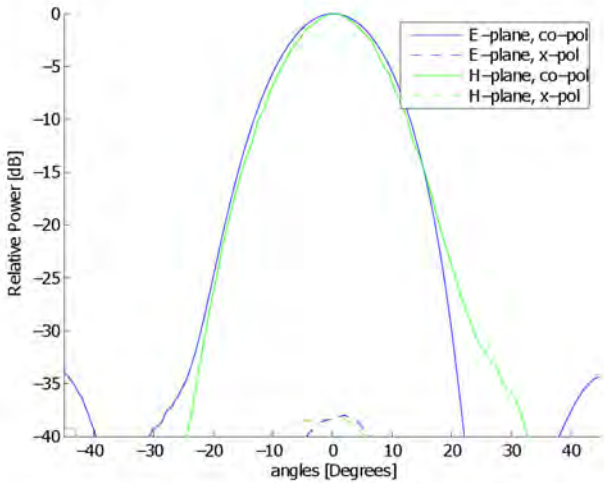
(UCSD Antenna Range)

- Fabricated on Roger's 3010 (ε=10)
- Diodes between opposite arms in center.
- Eccostock12 Lens
- 6" hemisphere; 1.5" spacer
- Operated between 5-12GHz

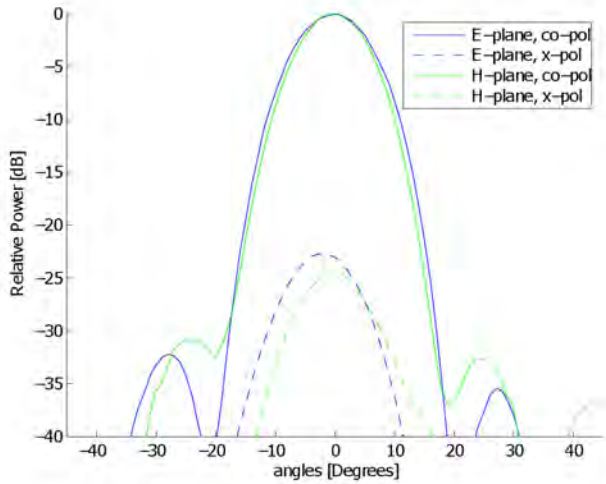




Measured beams with lens

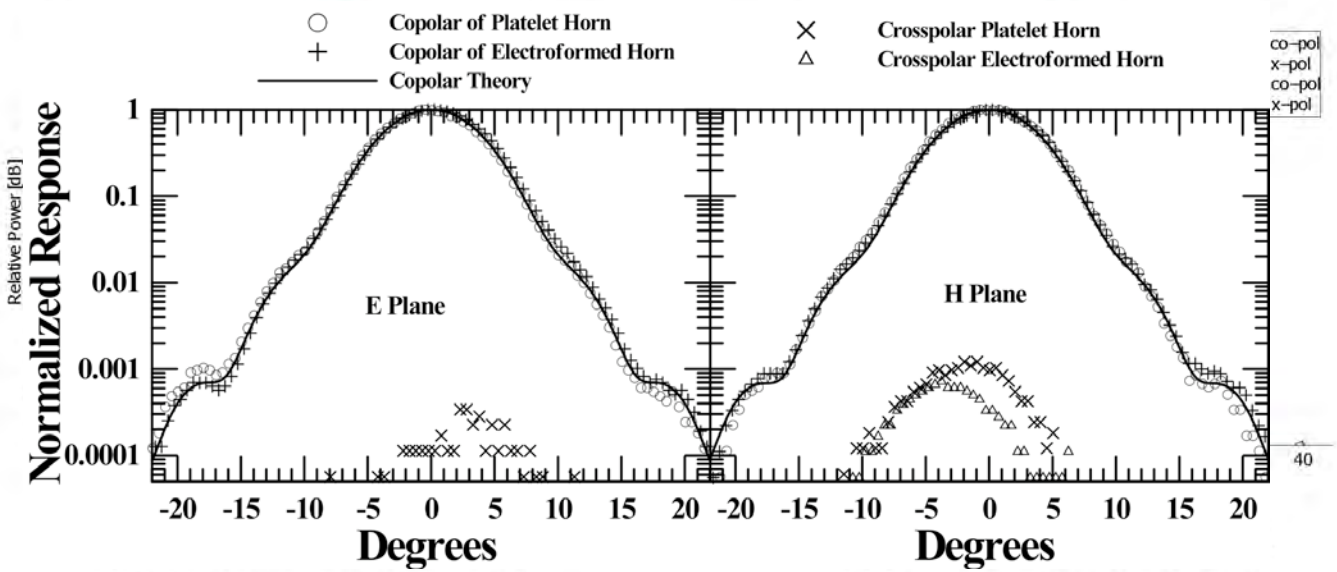


(a) 5 GHz Measured Cuts



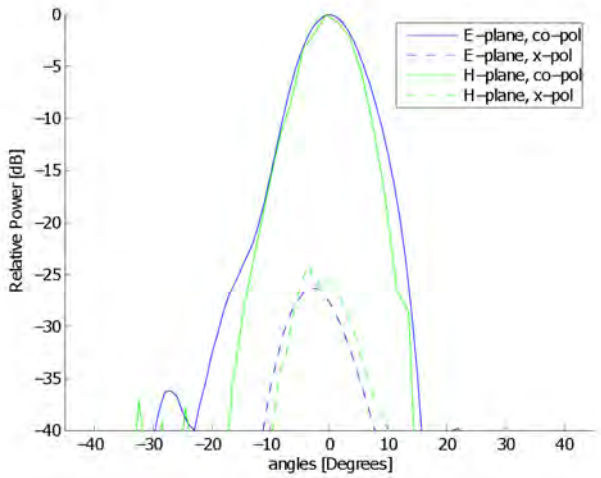
(b) 6 GHz Measured Cuts

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

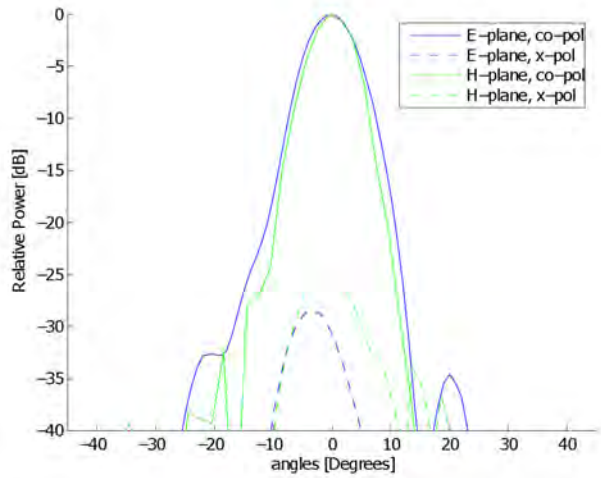


Scalar Horn (Gundersen and Wollack whitepaper)

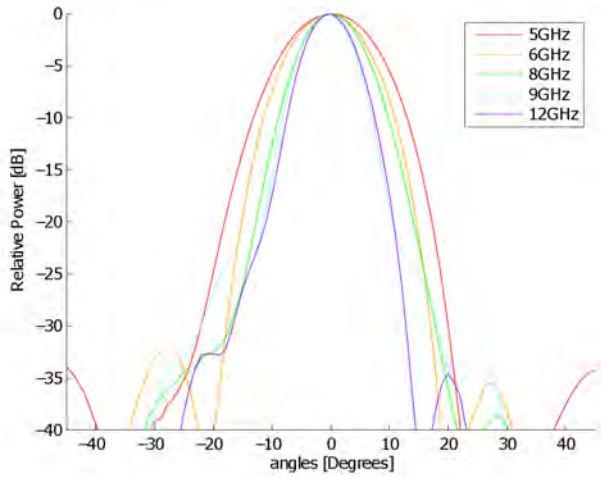
Measured beams with lens II



(e) 11 GHz Measured Cuts

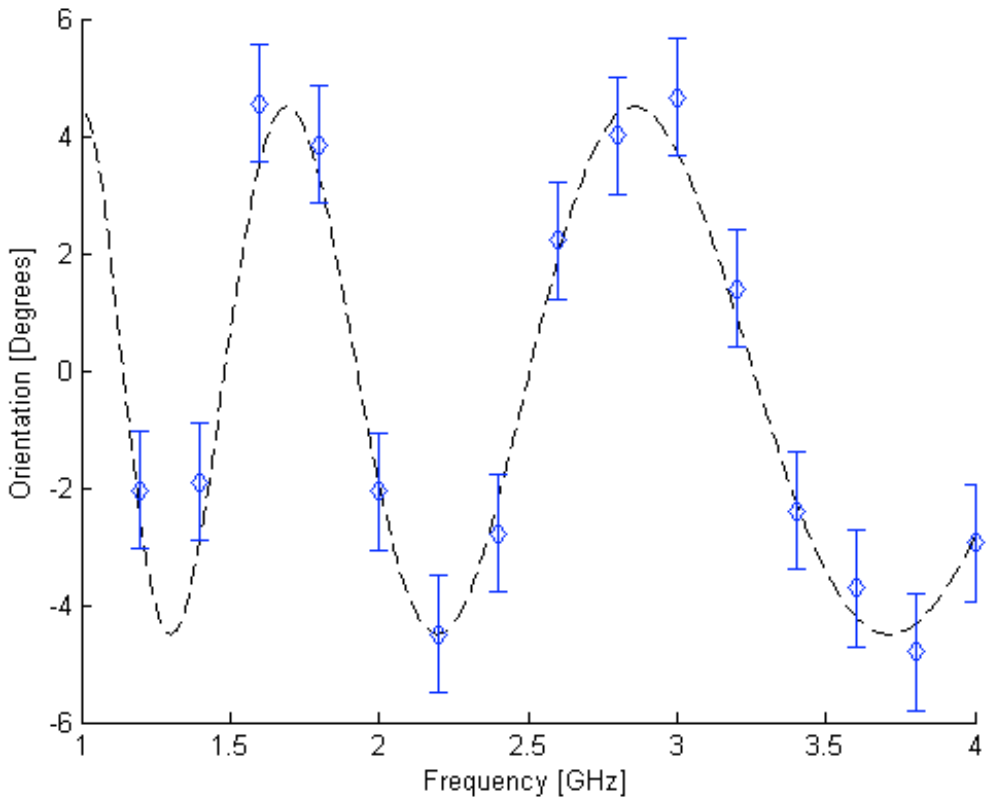


(f) 12 GHz Measured Cuts



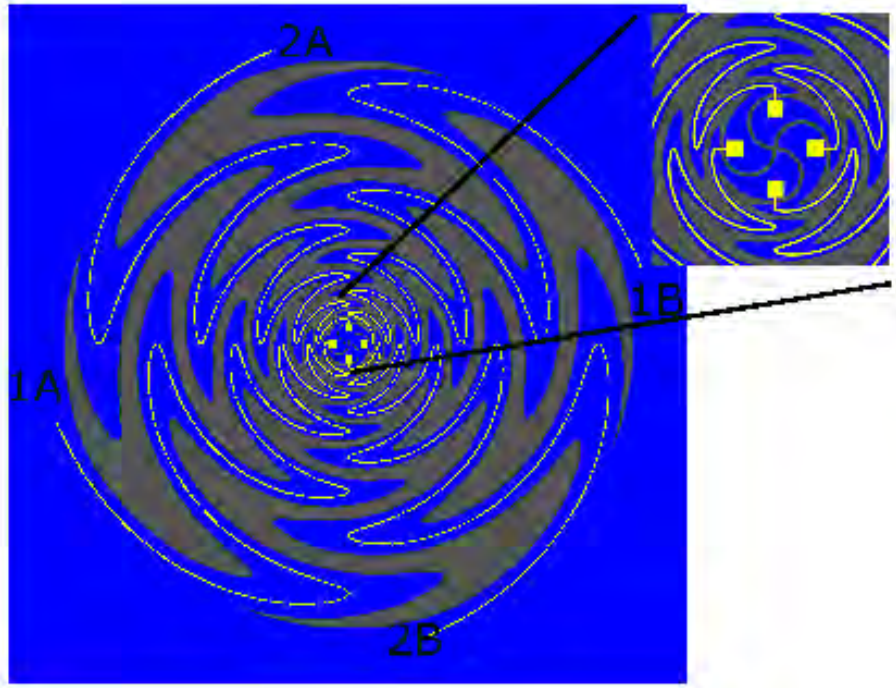
(g) Several channels of E cuts

Polarization Rotation



- Polarization angle rotates w/frequency
  - BUT, Depolarization within band ~ -27 dB (cos 5° = 0.996)
  - Each band has to be calibrated

Slot-Sinuous with Microstrip Feed



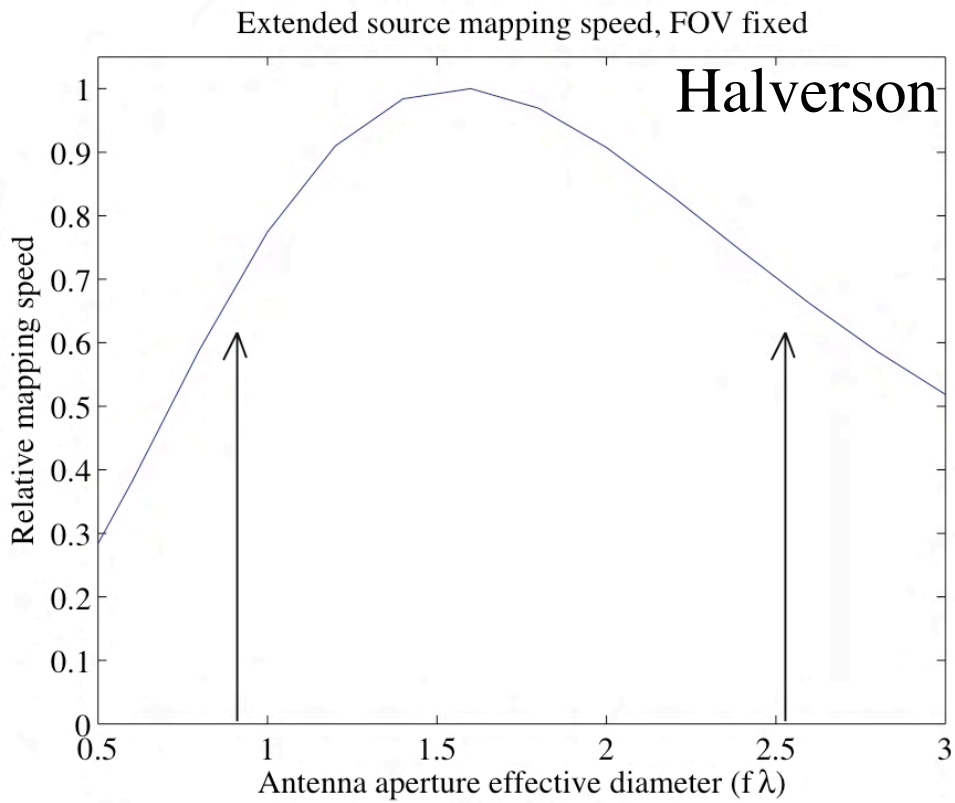
Grey-slot

Blue-ground plane

Yellow-microstrip

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

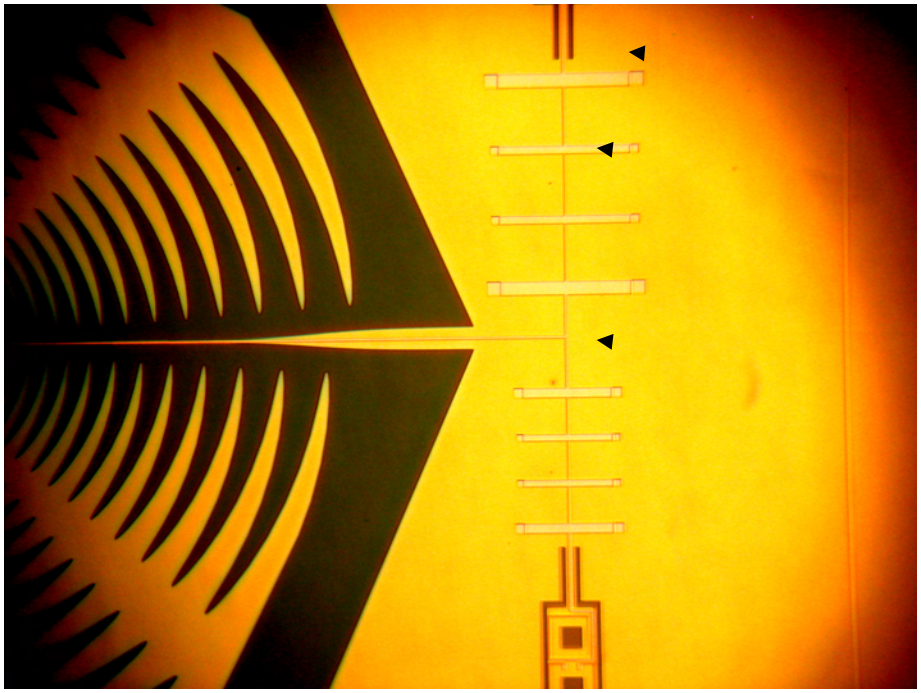
Selecting Lens Size



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

Band Definition

150-220 GHz Diplexer



- 4 bolometers
- 4-pole λ/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

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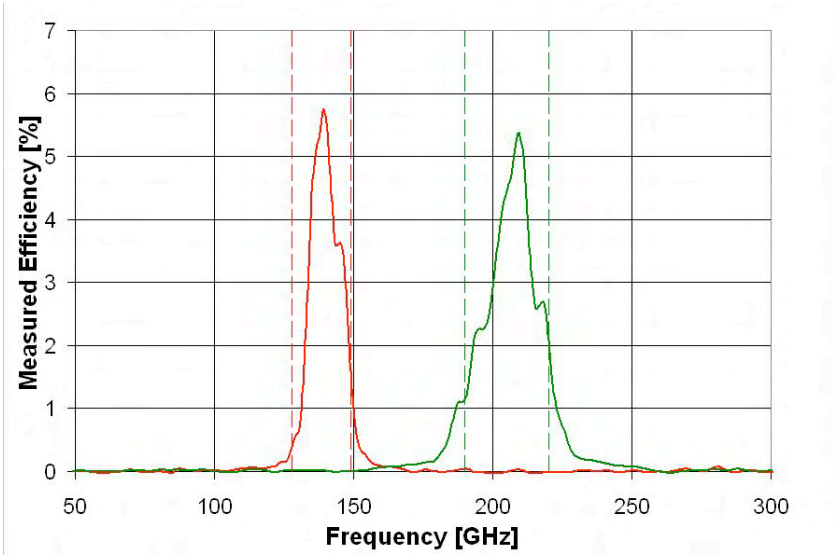
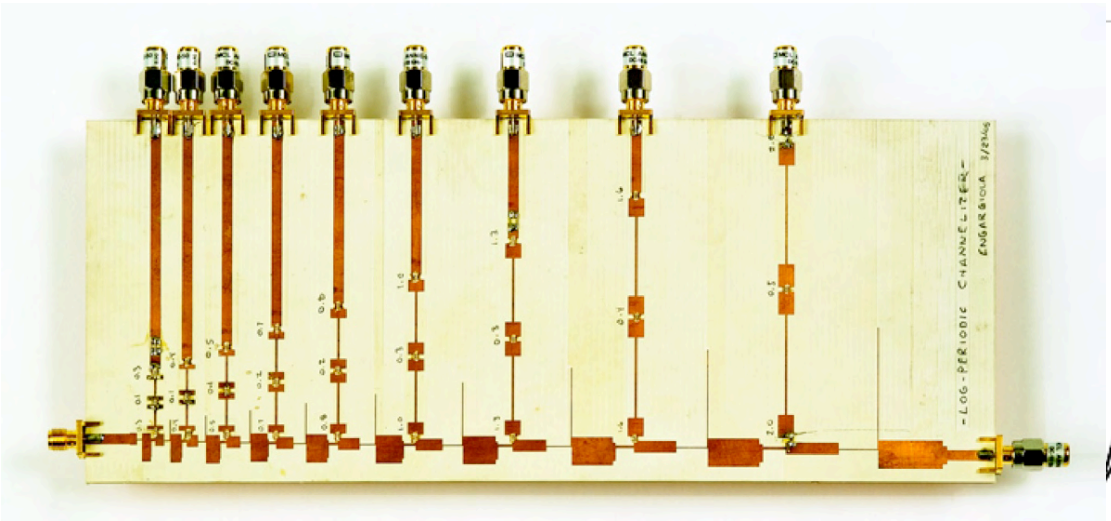
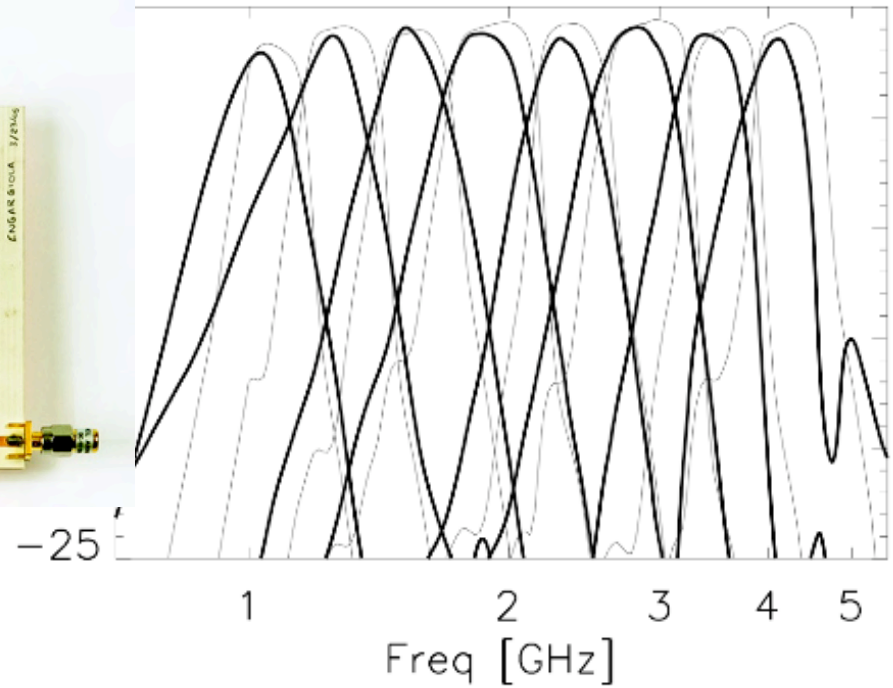


8-Band Channelizer





- 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

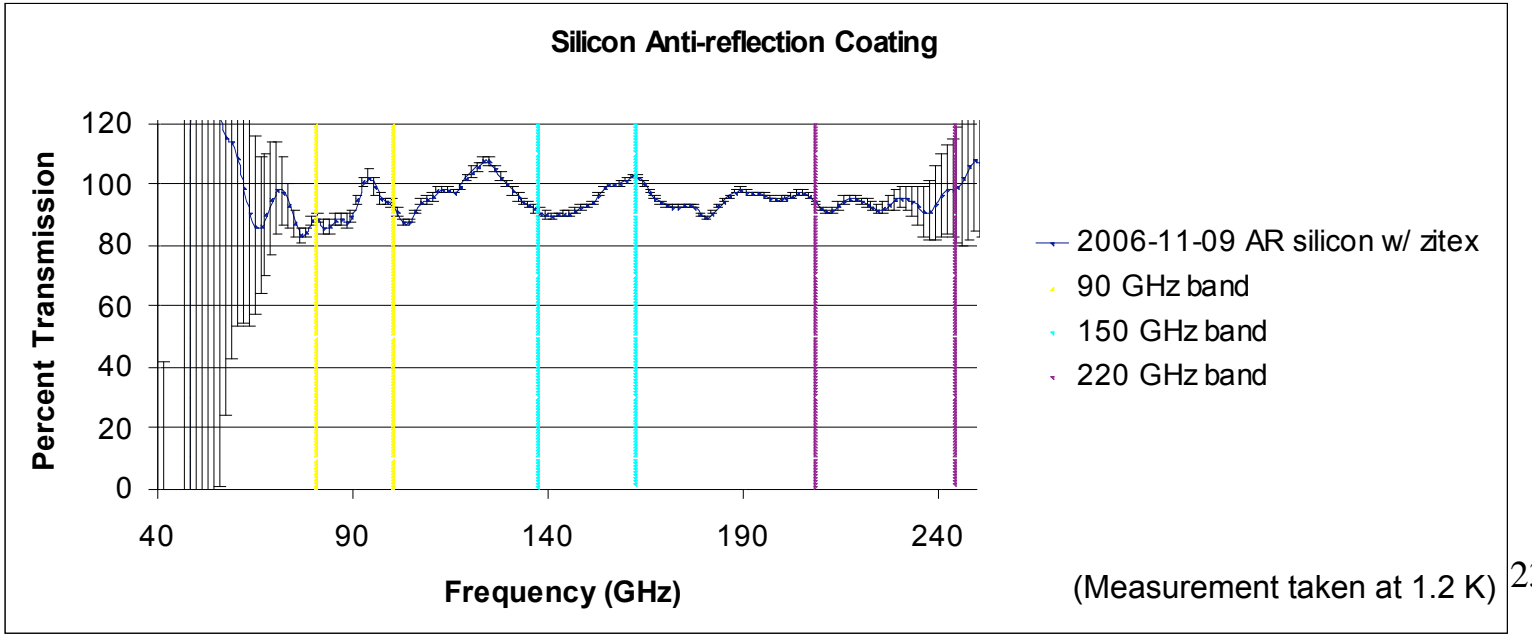
Broadband anti-reflection coatings

Erin Quealy

Multi-layer TMM Chebyshev coating on hemisphere

TMM 3 (e_r =3.27),
TMM 4 (e_r =4.5),
TMM 6 (e_r =6.0),
TMM 10i (e_r =9.8)

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



(Measurement taken at 1.2 K)

Mechanical Alignment of Lenses

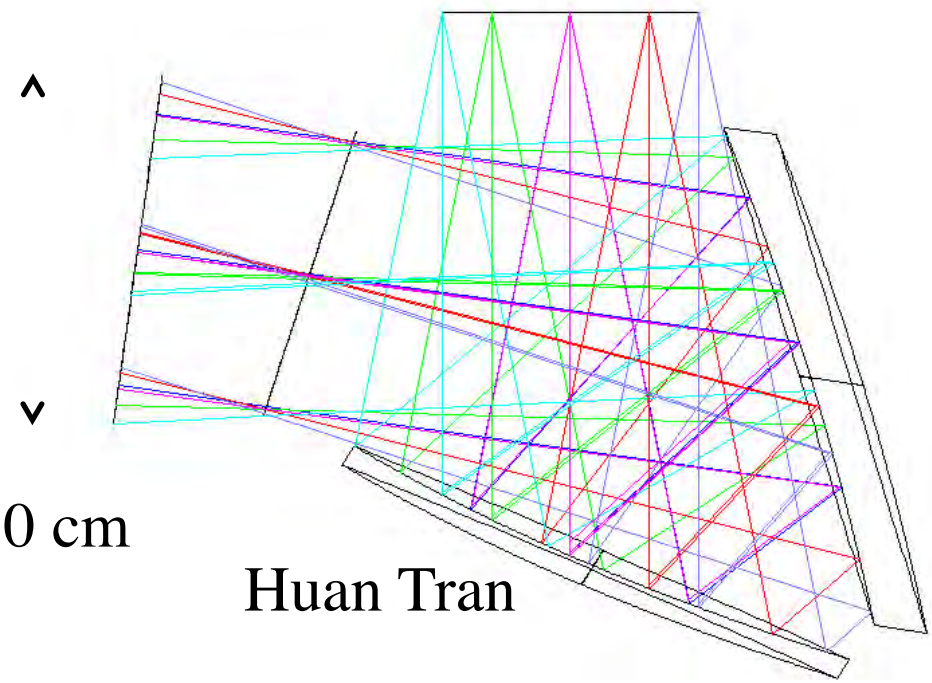
- Lateral alignment requirement $\lambda/10 > 100\ \mu\text{m}$
- Lithographic seating wafer
  - ~ 10 μm accuracy
- Wafer-wafer alignment marks
  - Use IR light

Needed Work for TRL 5-6

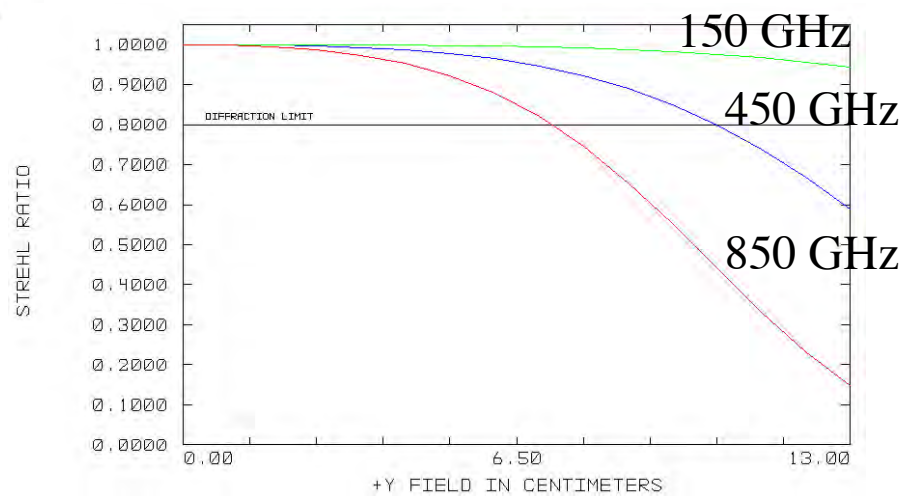
- A few cycles of: simulation and scale model <-> cryogenic antenna testing
  - Measure:
    - Beam patterns
    - Polarization properties
    - Efficiency
    - Band Definition
- Lab test broadband antireflection coating
- Lab test log-periodic channelizer
- Test in suborbital experiment e.g. Polarbear, EBEX, or SPT

Low-cost Mission Concept enabled by Multi-band Pixels

Cartoon high throughput single small aperture

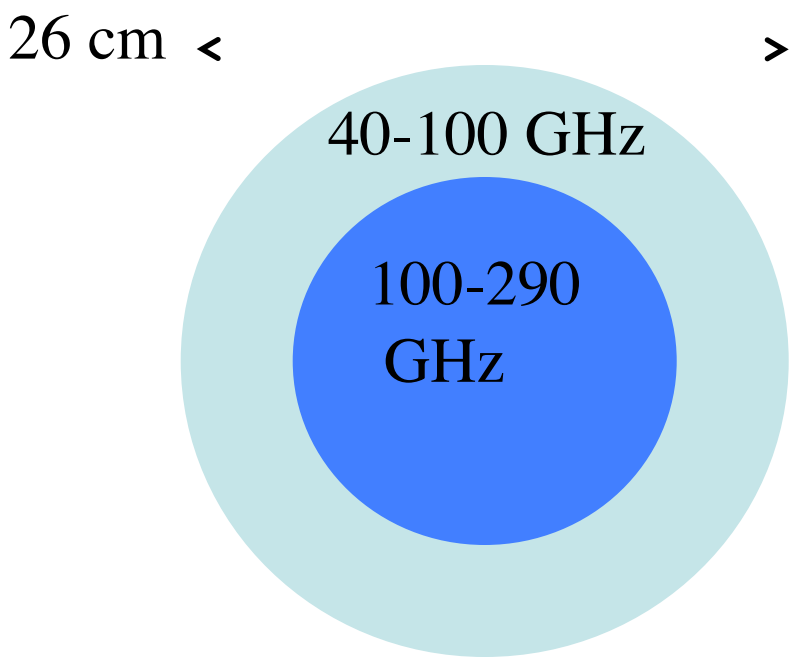


Huan Tran



- 4K Crossed-Dragone
  - 30 cm aperture
  - 26 cm focal plane

Cartoon high throughput single small aperture II



- 650 Pixels (5400 bolos)
  - 500 Pixels: 100, 130, 170, 290
  - 150 Pixels: 40, 60, 80,100

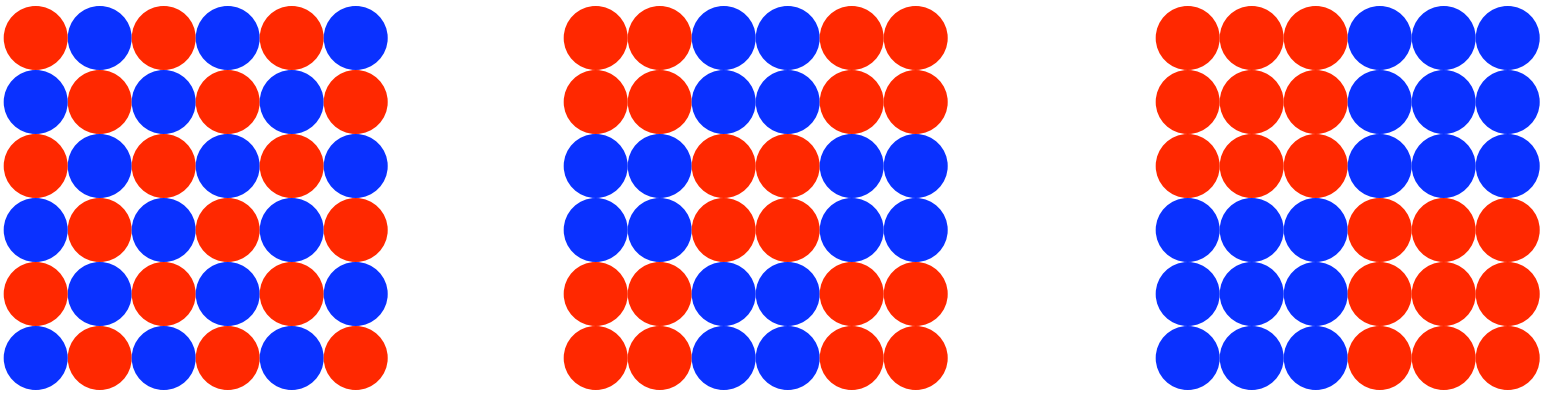
Conclusions

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

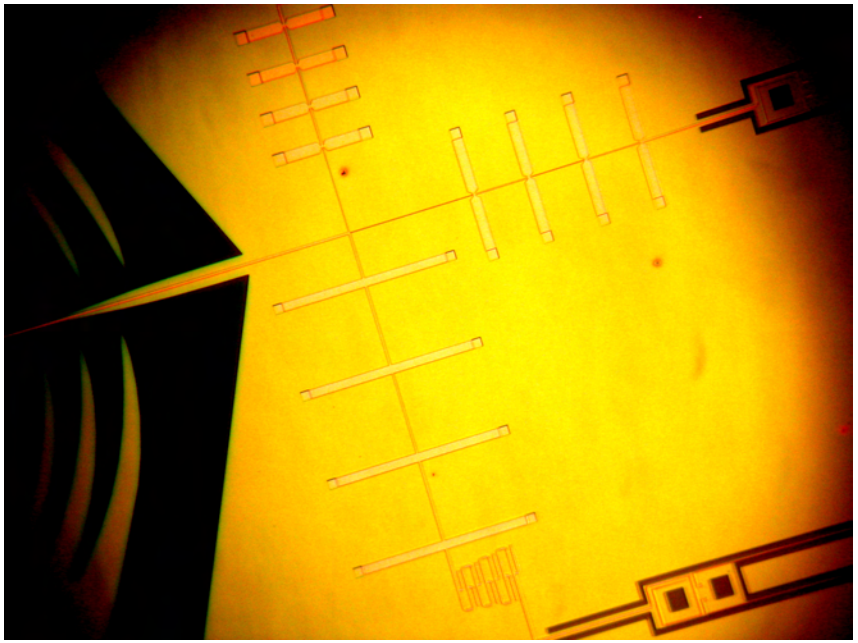
Phase Array of Lensed Pixels



300 GHz 150 GHz 100 GHz

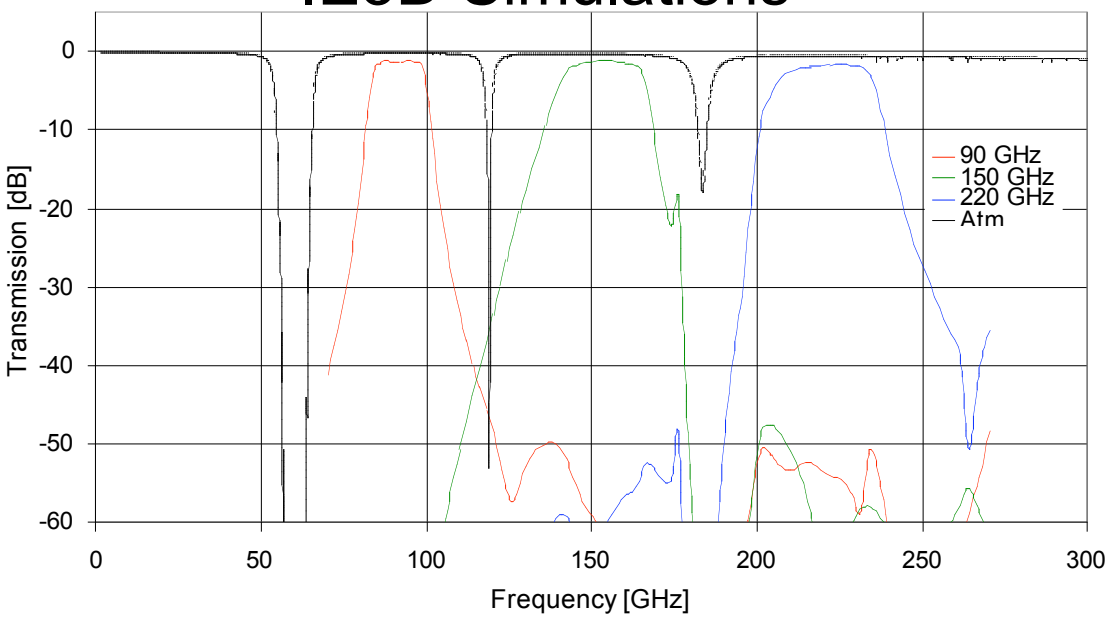
- Phase array lensed pixels: keep ~const beam size
  - Separate frequencies, then add RF

90-150-220 GHz Triplexer



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

IE3D Simulations



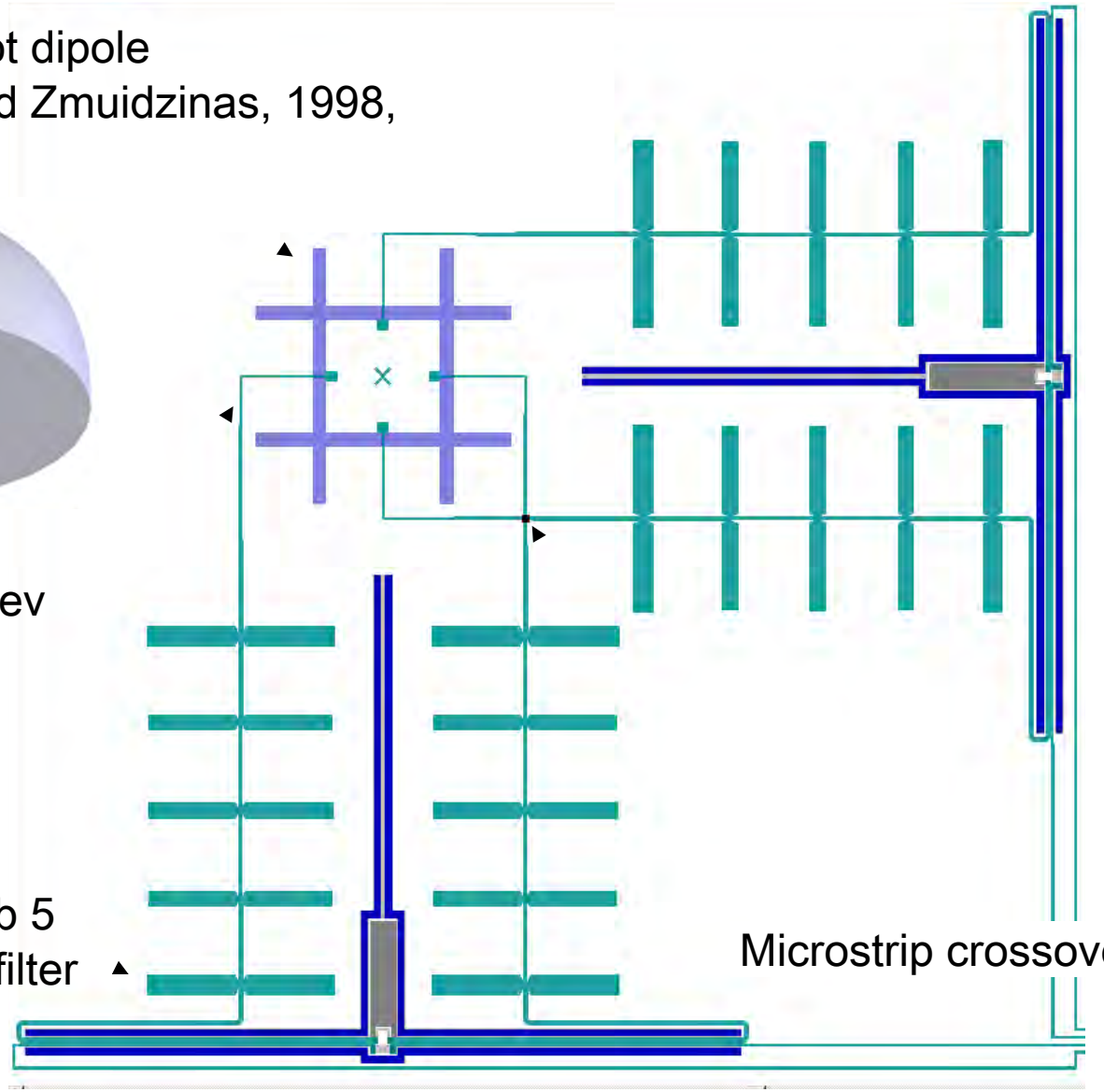
Single-color pixel design

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

Si lens

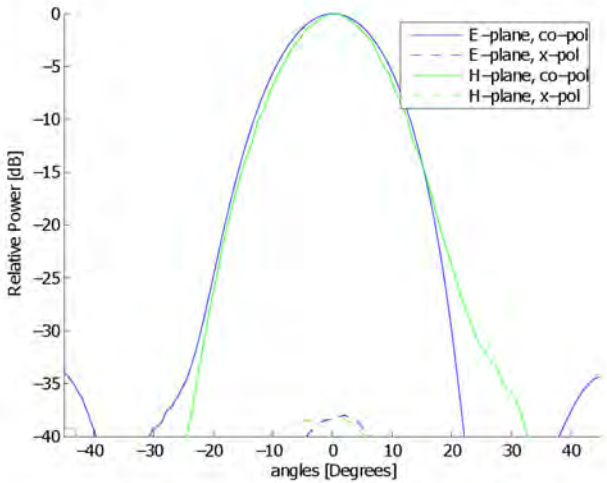
Dolph-Chebyshev microstrip transformer (McGinnis and Beyer, 1998)

Shorted λ/4 stub 5 pole microstrip filter

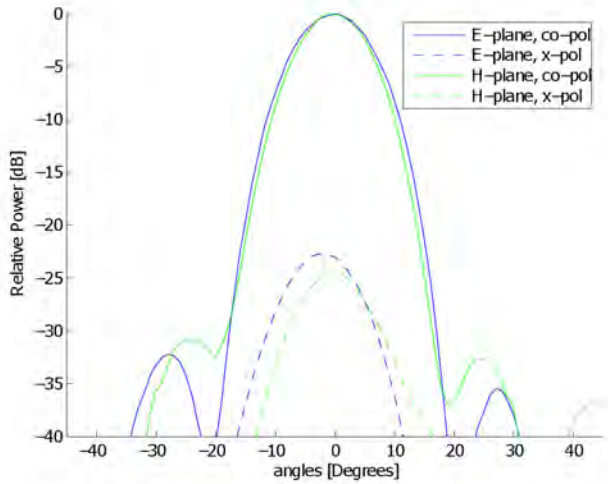


Microstrip crossover

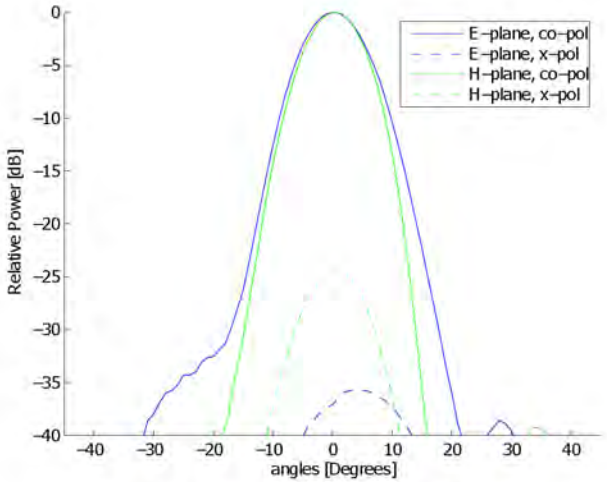
Measured beams with lens



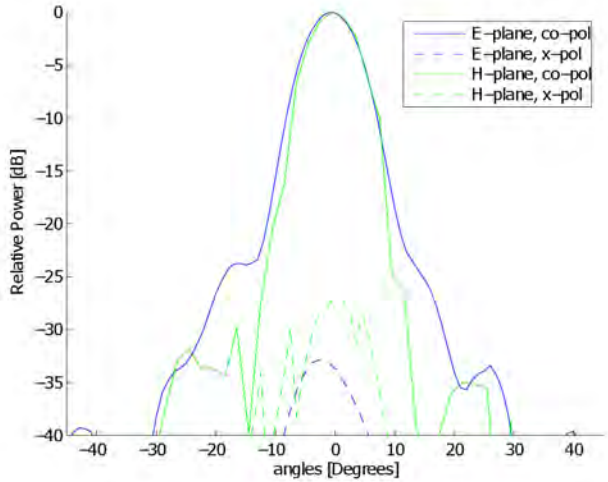
(a) 5 GHz Measured Cuts



(b) 6 GHz Measured Cuts



(c) 8 GHz Measured Cuts



(d) 9 GHz Measured Cuts

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