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(presentation only, no published proceedings)

Polarimeter Arrays for Cosmic Microwave Background Measurements.

Abstract

We discuss general system architectures and specific work towards precision measurements of Cosmic Microwave Background (CMB) polarization. The CMB and its polarization carry fundamental information on the origin, structure, and evolution of the universe. Detecting the imprint of primordial gravitational radiation on the faint polarization of the CMB will be difficult. The two primary challenges will be achieving both the required sensitivity and precise control over systematic errors. At anisotropy levels possibly as small as a few nanokelvin, the gravity-wave signal is faint compared to the fundamental sensitivity limit imposed by photon arrival statistics, and one must make simultaneous measurements with large numbers, hundreds to thousands, of independent background-limited direct detectors. Highly integrated focal plane architectures, and multiplexing of detector outputs, will be essential. Because the detectors, optics, and even the CMB itself are brighter than the faint gravity-wave signal by six to nine orders of magnitude, even a tiny leakage of polarized light reflected or diffracted from "warm" objects could overwhelm the primordial signal. Advanced methods of modulating only the polarized component of the incident radiation will play an essential role in measurements of CMB polarization.

One promising general polarimeter concept that is under investigation by a number of institutions is to first use planar antennas to separate millimeter-wave radiation collected by a lens or horn into two polarization channels. Then the signals can be fed to a pair of direct detectors through a planar circuit consisting of superconducting niobium microstrip transmission lines, hybrid couplers, band-pass filters, and phase modulators to measure the Stokes parameters of the incoming radiation.

PAPPA (Primordial Anisotropy Polarization Pathfinder Array) is a project to validate such concepts for measuring CMB polarization in a balloon flight environment. PAPPA will consist of 32 independent "polarimeters-on-a-chip" based on superconducting microstrip circuits. For laboratory characterization of microstrip components, we have designed and fabricated test circuits with a planar antenna and RF choke on thin silicon cantilevers that act as waveguide probes. The design makes possible efficient coupling of radiation between waveguide and the planar circuits, and enables S-parameter measurements to be made to characterize and refine building blocks for a "polarimeter-on-a-chip."

Authors:

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Polarimeter Arrays for CMB Measurements

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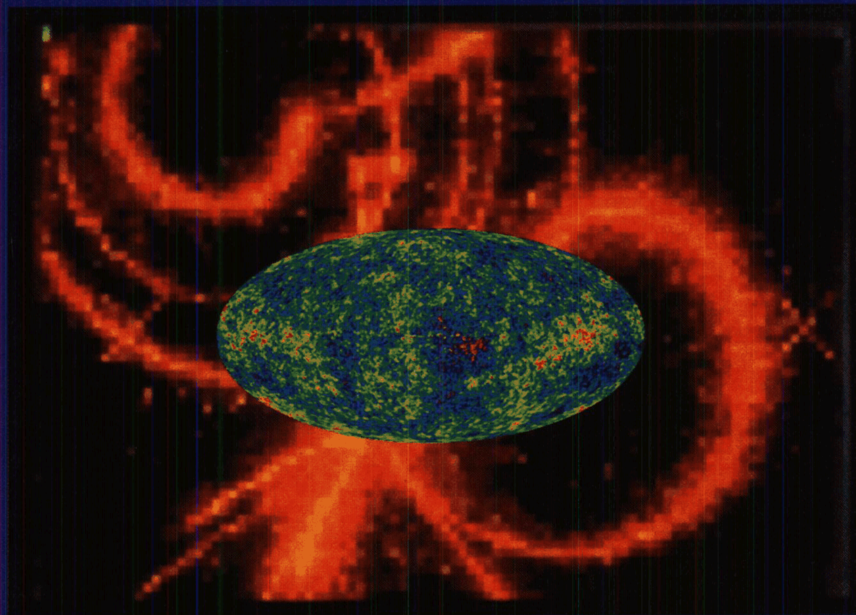
NASA/Goddard Space Flight Center

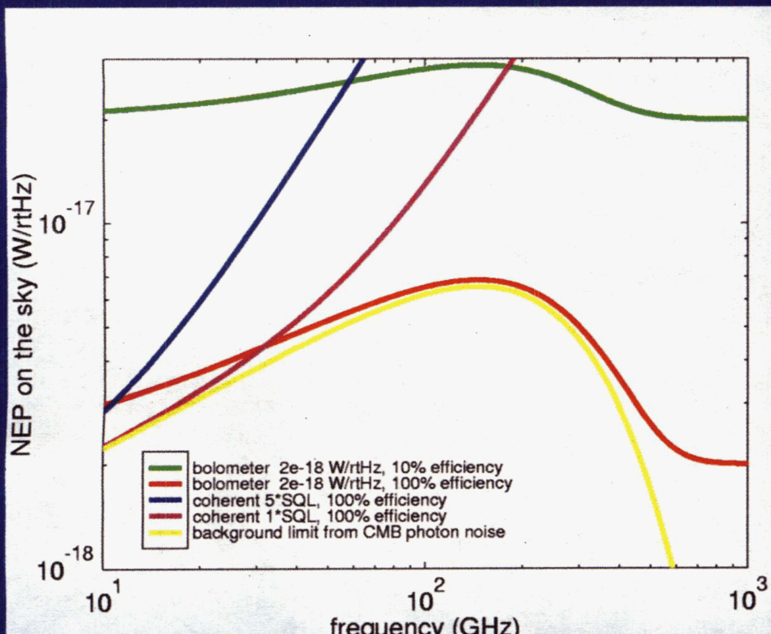
- Two challenges
- Polarimeter building blocks
- Light collection
- Modulation
- Filters
- Detectors
- PAPPA instrument
- Waveguide probe test scheme



Goal: Detect Gravity Waves from Big Bang

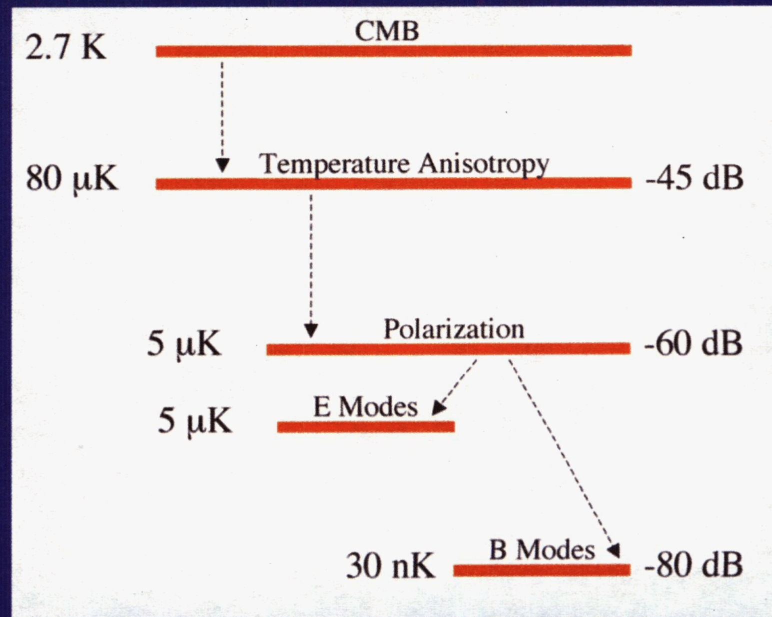
Two Challenges for CMB Polarimetry

- Background Limit:



Need concurrent measurements with thousands of (direct) detectors in array.

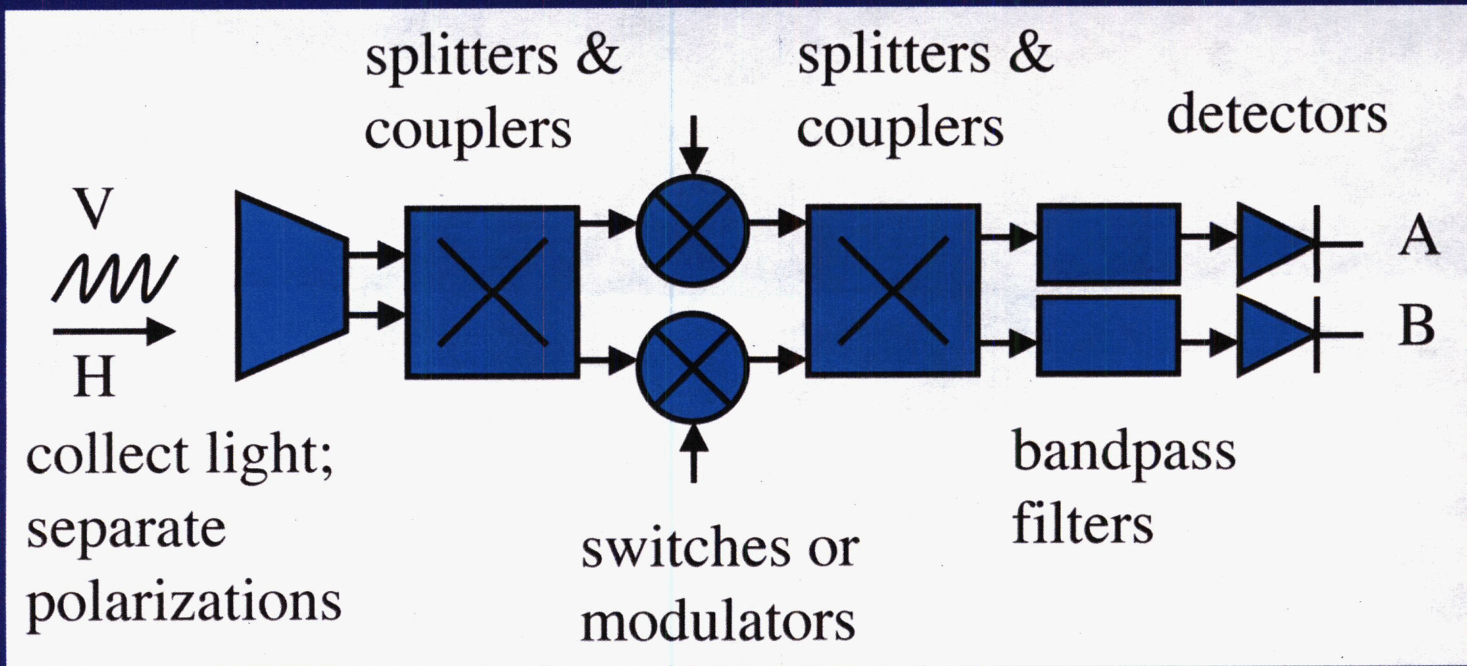
- Systematic Error Control:



Must understand and control stray light and other systematics at -80 dB level!

Polarimeter Building Blocks

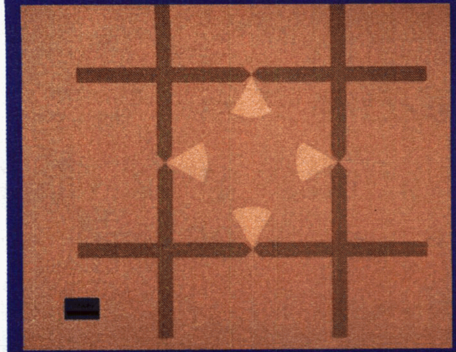
- A General Scheme (pursued by multiple groups):



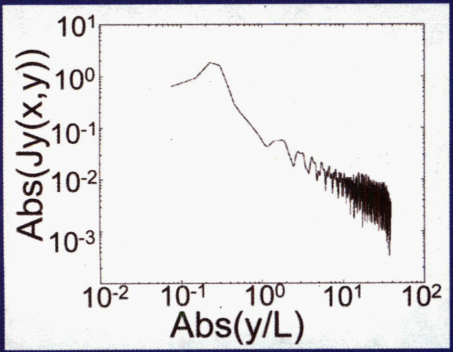
- Lossless network based on superconducting niobium microstrip
- Signal manipulation comes before direct detection (no quantum noise from amplification)

Light Collection Approaches

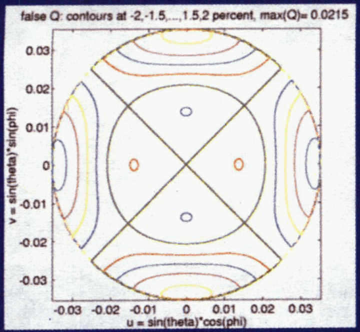
- Twin-Slot Antenna & Si lens:



Crossed twin-slot antennas



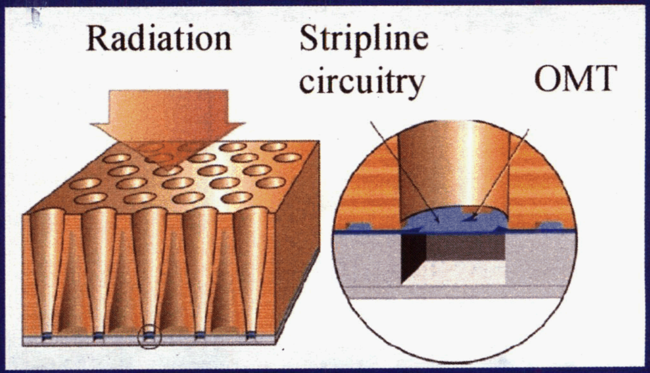
Ground plane current decays slowly with distance.



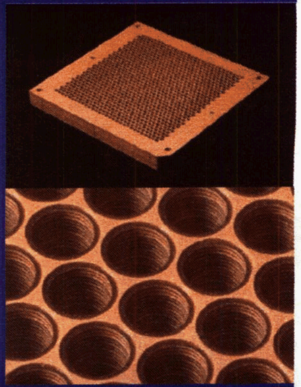
Cross-polarization from non-round beam

- large spacing to avoid crosstalk
- large lens for low cross-polarization

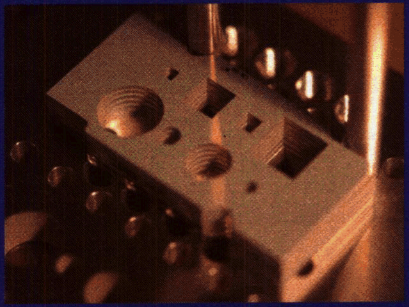
- Platelet Feedhorn & Planar OMT:



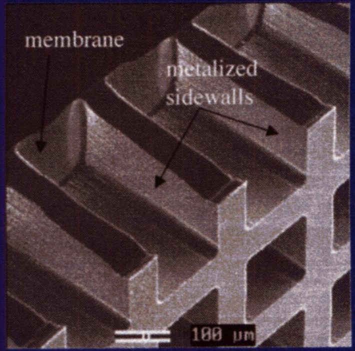
Light collection concept.



Array of 1000 metal platelet feeds.



Test of stacked thru-wafer Si waveguides.

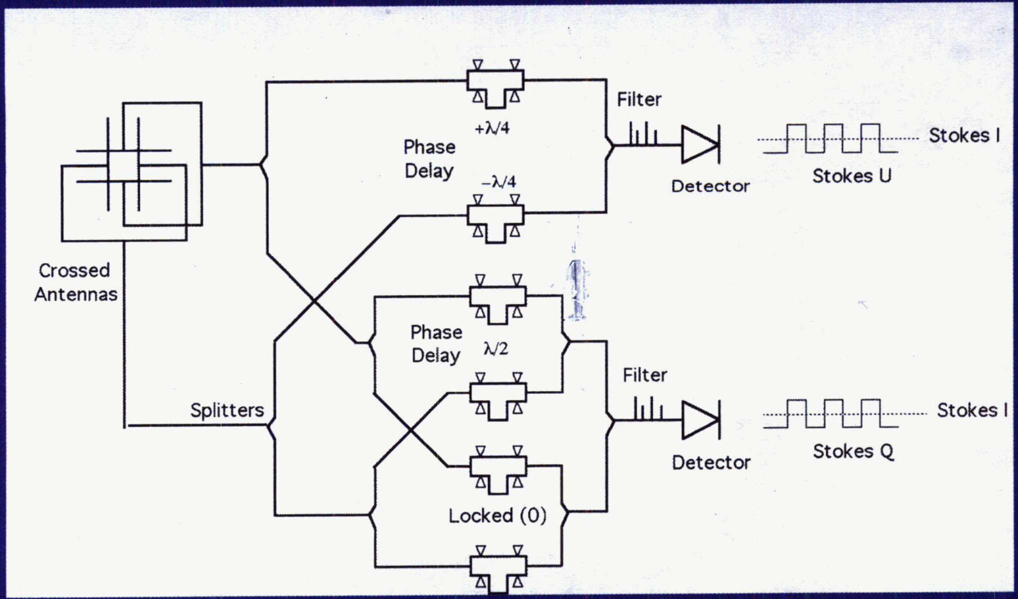


Membranes over thru-wafer waveguides.

- large pixels also, but excellent beams

Modulation Schemes

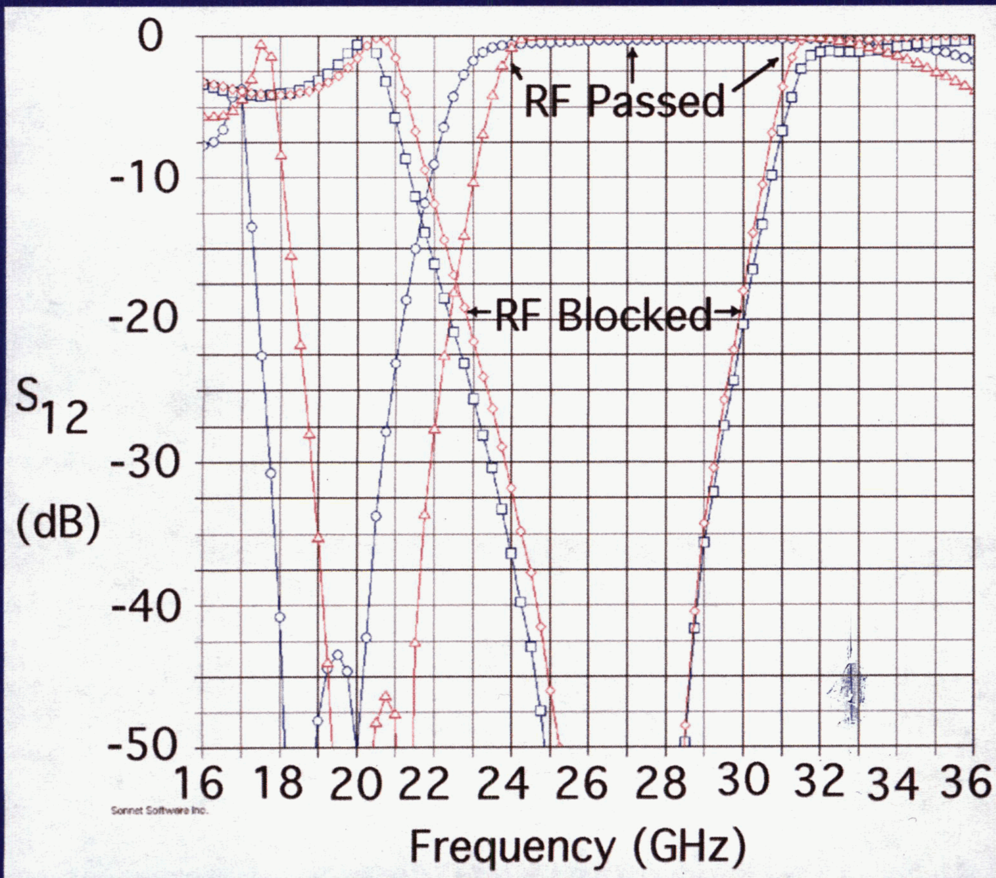
- External modulator for first demonstrations
- On-chip modulation can measure Stokes Q & U simultaneously, with residual coupling to V (not I), using all signal power:



- Phase switch elements:
  - RF-MEMS (variable *C*) - GSFC with G. Rebeiz (UCSD) and S. Barker (UVA)
  - Nb tunnel junction (variable *L*) - e.g. JPL/Caltech

Modulation Schemes

- Niobium tunnel junction switch:



Predicted switching behavior of prototype.

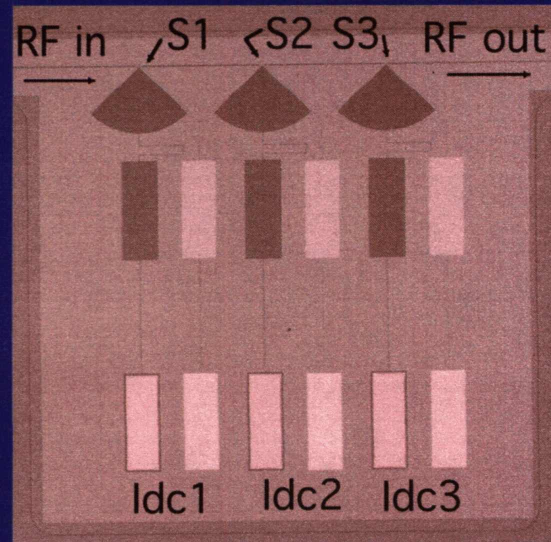
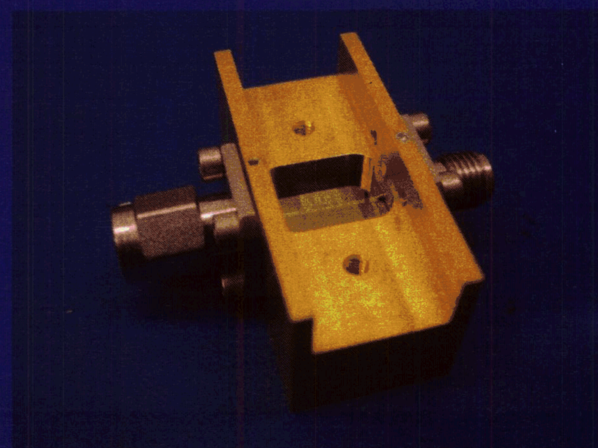


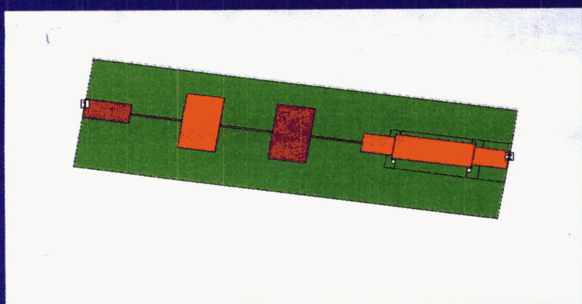
Photo of switch device.

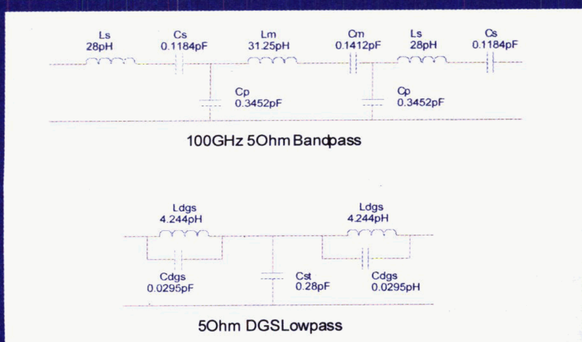


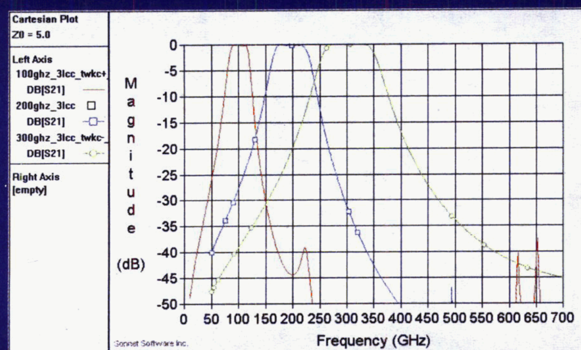
Chip in test package.

Bandpass Filters

- Multiple measurement bands required for foreground modeling
- Implement with niobium microstrip
- Challenges:
  - high frequency leakage < -40 dB up to niobium cutoff at 700 GHz
  - low radiation loss up to 300 GHz
  - sharp enough roll-off to avoid atmospheric emission lines

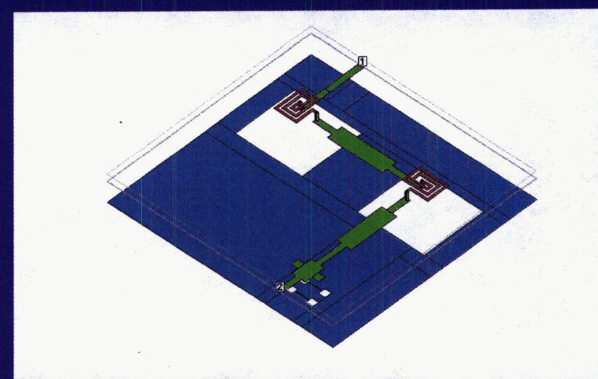






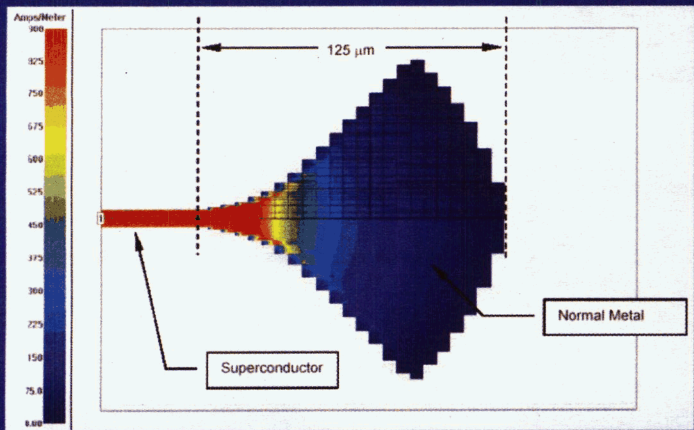
S21 for three filters (100, 200, 300 GHz)

- Low Z_0 solution to spur problem



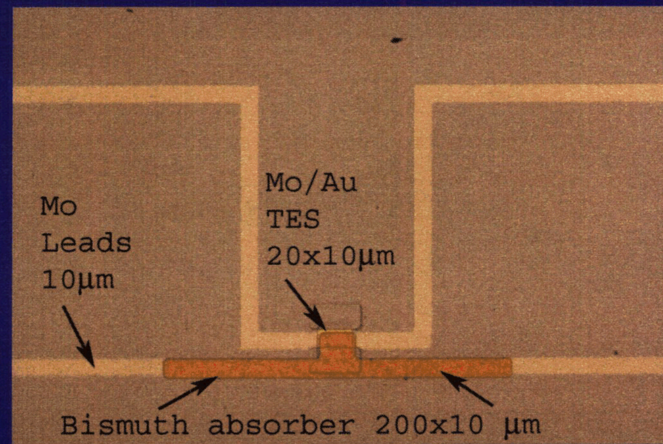
- Choose orientation of stages to reduce radiation loss

Terminations and Detectors



Ultra broadband normal metal termination for 20 ohm Nb microstrip

Membrane-supported TES bolometer with transverse metal bars for noise suppression (J. Staguhn, *et al.*, GSFC)



Other detector options include:

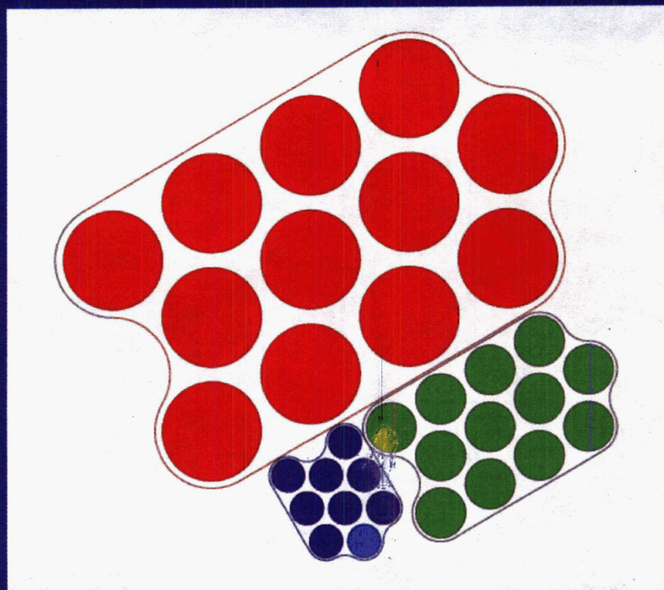
- THM (above) - S. Ali *et al.* (Univ. Wisconsin and GSFC)
- RF-STJ - J. Teufel *et al.* (Yale University)
- MKID - J. Zmuidzinas *et al.* (Caltech/JPL)

Primordial Anisotropy Polarization Pathfinder Array (PAPPA)

- Balloon experiment to measure CMB polarization using candidate technology for Inflation Probe mission
- NASA (Kogut), U. Pennsylvania (Devlin), NIST (Irwin), and U. Virginia (Barker)

Quantity	Value
Target Patch Dimensions	$20° \times 20°$
Target Patch α	
Target Patch δ	
Band 1 ν	100 GHz
Band 2 ν	200 GHz
Band 3 ν	300 GHz
Band 1 $\Delta\nu$	30 GHz
Band 2 $\Delta\nu$	60 GHz
Band 3 $\Delta\nu$	90 GHz
Angular Resolution (Band 1)	0.5°
Angular Resolution (Band 2)	0.25°
Angular Resolution (Band 3)	0.17°
Field of View	
Primary Mirror Illumination	0.42 m
Focal Plane Maximum Diameter	4 inches
Cross-polarization limit	20 dB
Primary Mirror Diameter	0.6 m
Number of pixels (Band 1)	12
Number of pixels (Band 2)	12
Number of pixels (Band 3)	8
Target ADR Cooling Power	20 mW
Target ADR Temperature	0.15 K
"Buffer" around each feedhorn	$\lambda/2$

PAPPA specifications

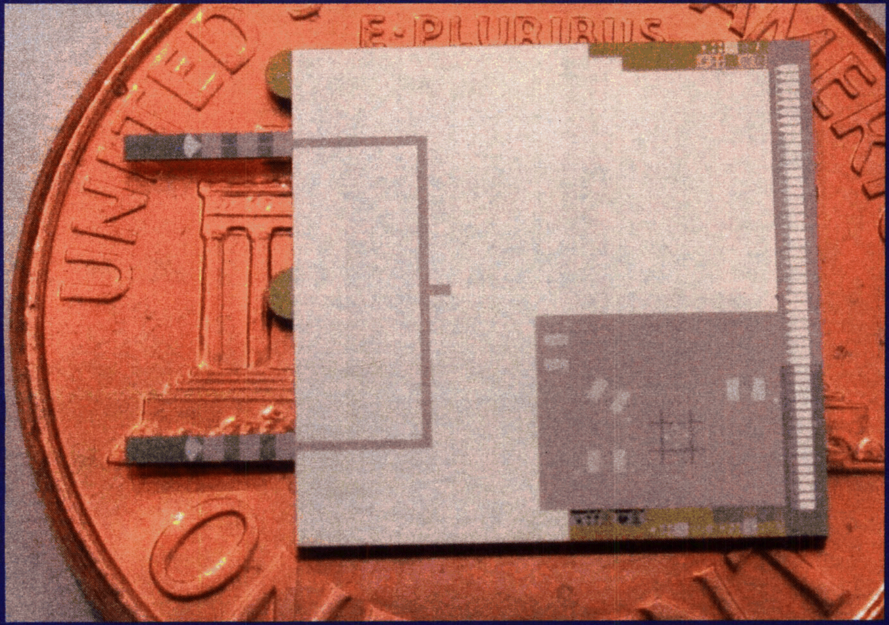


Focal plane layout

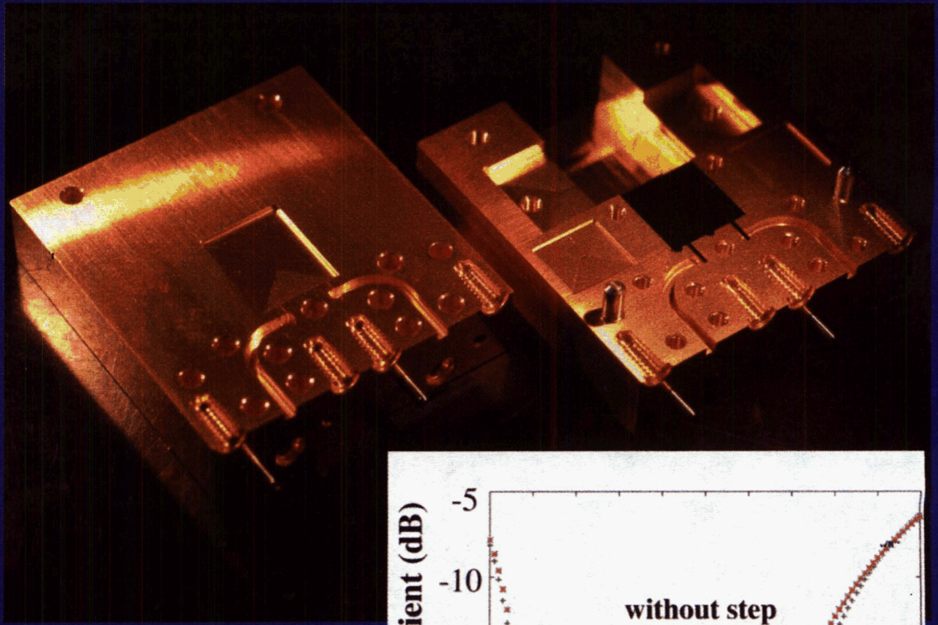
Telescope and cryostat concept

Waveguide Probes for Component Tests

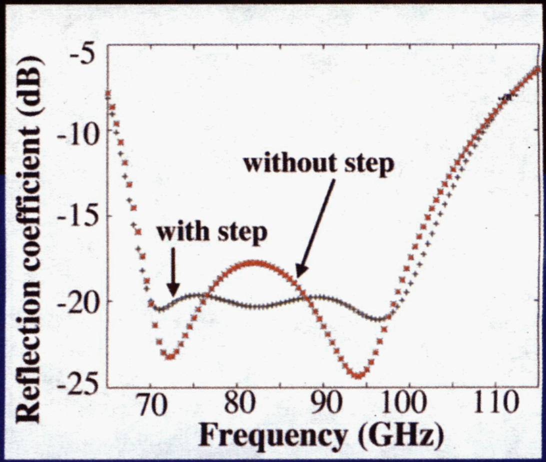
- cantilever probes sculpted by DRIE support niobium antennas
- design follows that of J. Kooi, *et al*. (2003)
- enables measurements of complex S_{ij} with VNA up to 300 GHz



Waveguide probe chip for 100 GHz (above), and predicted coupling (far right).



Split-block mounting package.



Conclusions and Outlook

- Many approaches to polarimeter building blocks are under development that address scalability to arrays and control over systematic errors.
- Waveguide probe chips offer detailed characterization of the performance of superconducting millimeter-wave planar circuits for development in the laboratory.
- GSFC/NIST/U. Pennsylvania/U. Virginia will test the polarimeter technology with balloon flights: PAPPA = "Primordial Anisotropy Polarization Pathfinder Array."