Cryogenic Measurements of CMB Polarimeters

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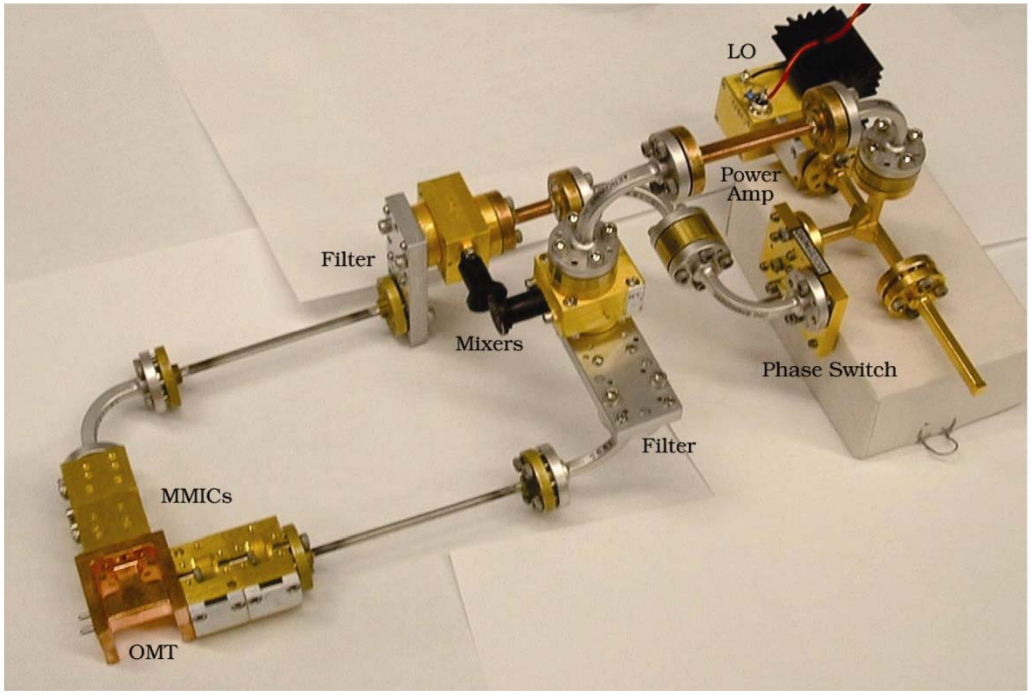
Detecting polarization of Cosmic Microwave Background (CMB) with Q, U Imaging ExperimenT (QUIET)

- QUIET experiment phase 1: 91-element array at 90 GHz and a 19-element array at 40 GHz operate for one year
- 1m side-fed Cassegrain telescope mounted on the Cosmic Background Imager (CBI) platform in Chajnantor, Chile (altitude of 5080 m)
- QUIET is an integrated approach to characterizing the CMB polarization power spectra using 20% frequency bandwidth arrays of 40 GHz and 90 GHz polarimeters
- **QUIET arrays offer the most sensitive detector technology for ground-based CMB observations at 100 GHz or below**

Detecting polarization of Cosmic Microwave Background (CMB) with Q, U Imaging ExperimenT (QUIET)

- Established techniques for controlling polarization systematic error
- Each module in the array measures simultaneously both Q and U, the linear Stokes parameters (we also included a few modules for I parameter measurement)
- Array is a self-contained unit incorporating feed optics, polarizing elements, lock-in modulation (4kHz), tunable detector biasing, and analog to digital conversion

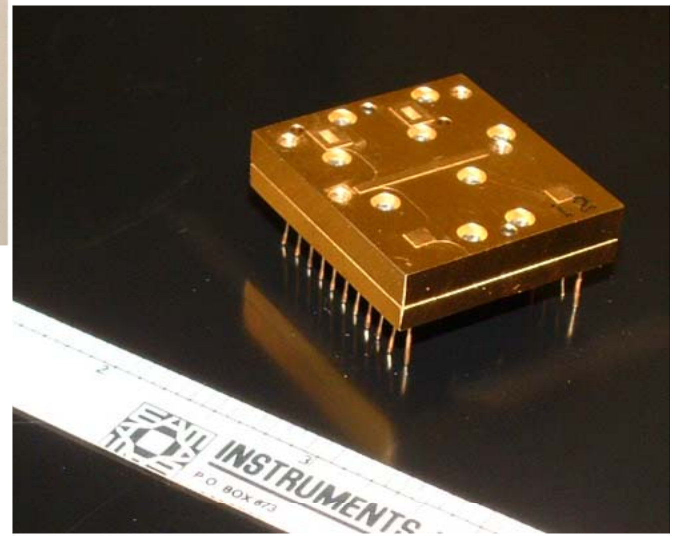
Polarimeter development at JPL reduced the size of the receiver for QUIET



CapMap 90GHz Polarimeter

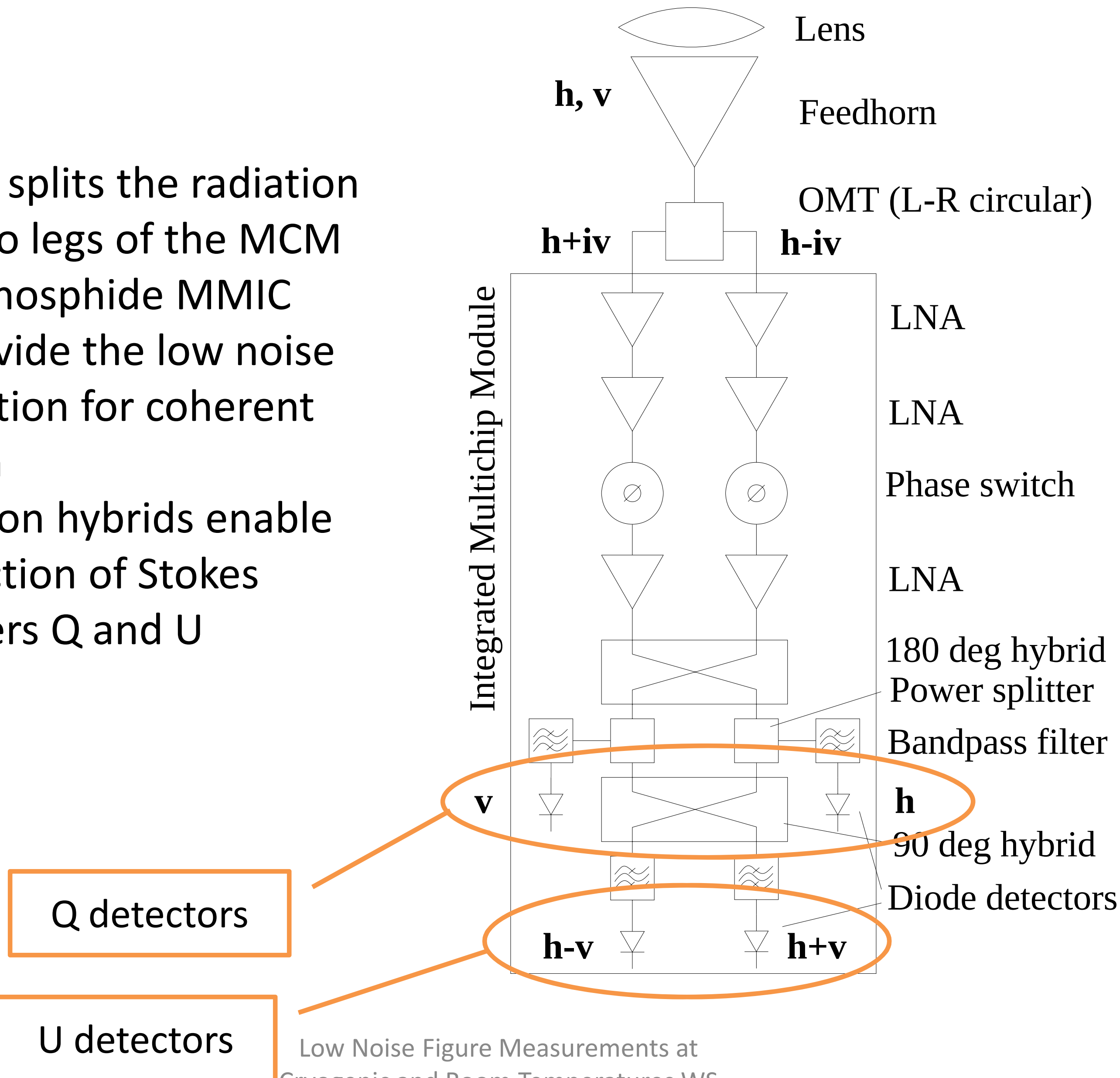
QUIET 90GHz Polarimeter

- Suitable for automated volume production
- Fits behind the feed horn



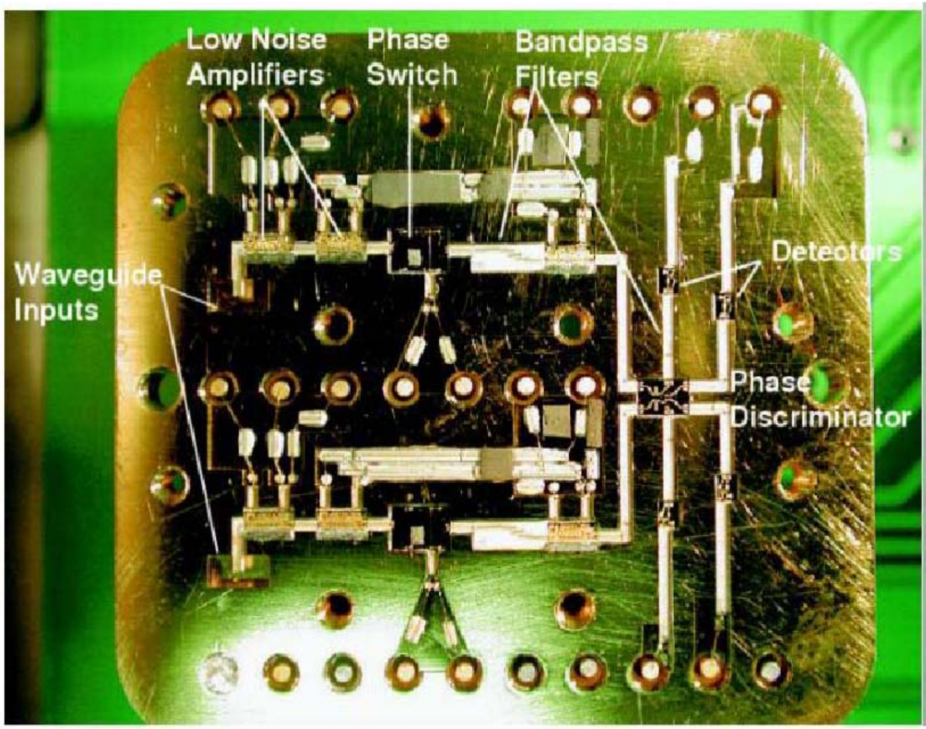
Block diagram of the polarimeter

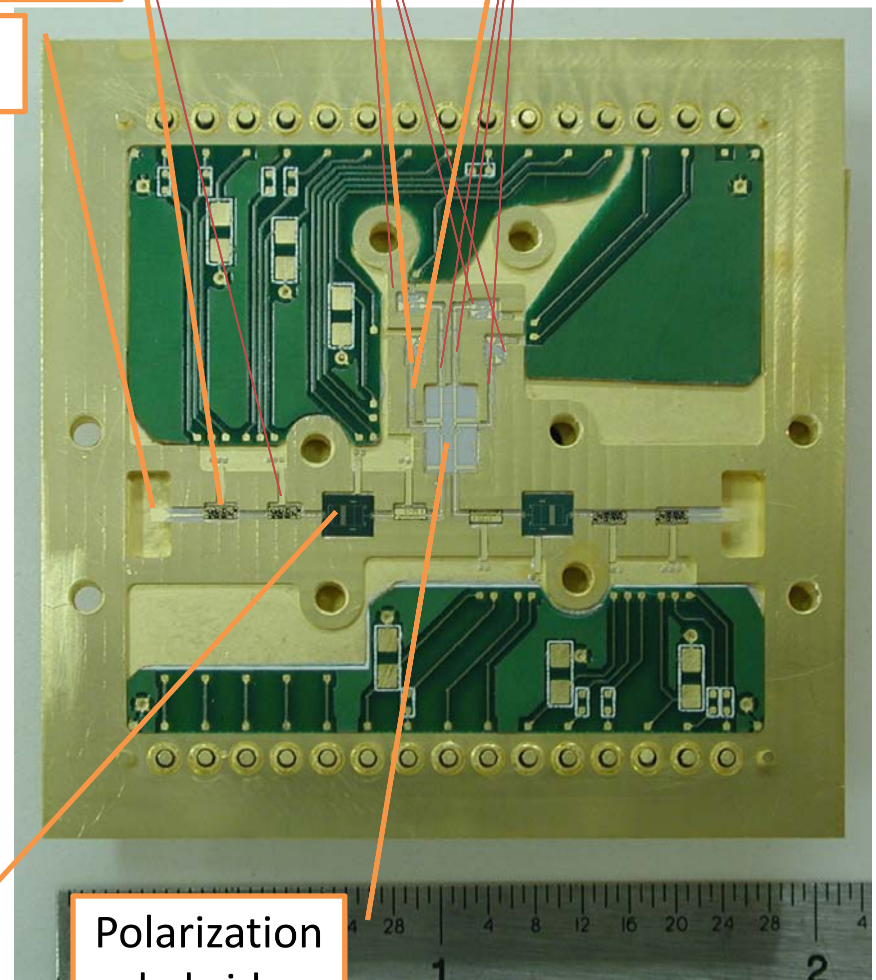
- The OMT splits the radiation to the two legs of the MCM
- Indium Phosphide MMIC LNAs provide the low noise amplification for coherent detection
- Polarization hybrids enable the detection of Stokes parameters Q and U



Planar multichip module polarimeters

QUIET 90GHz Polarimeter





QUIET 40GHz Polarimeter

Planar multichip module polarimeters

Planar modules work well in automated assembly

Polarimeter

MMICs, substrates

Epoxies

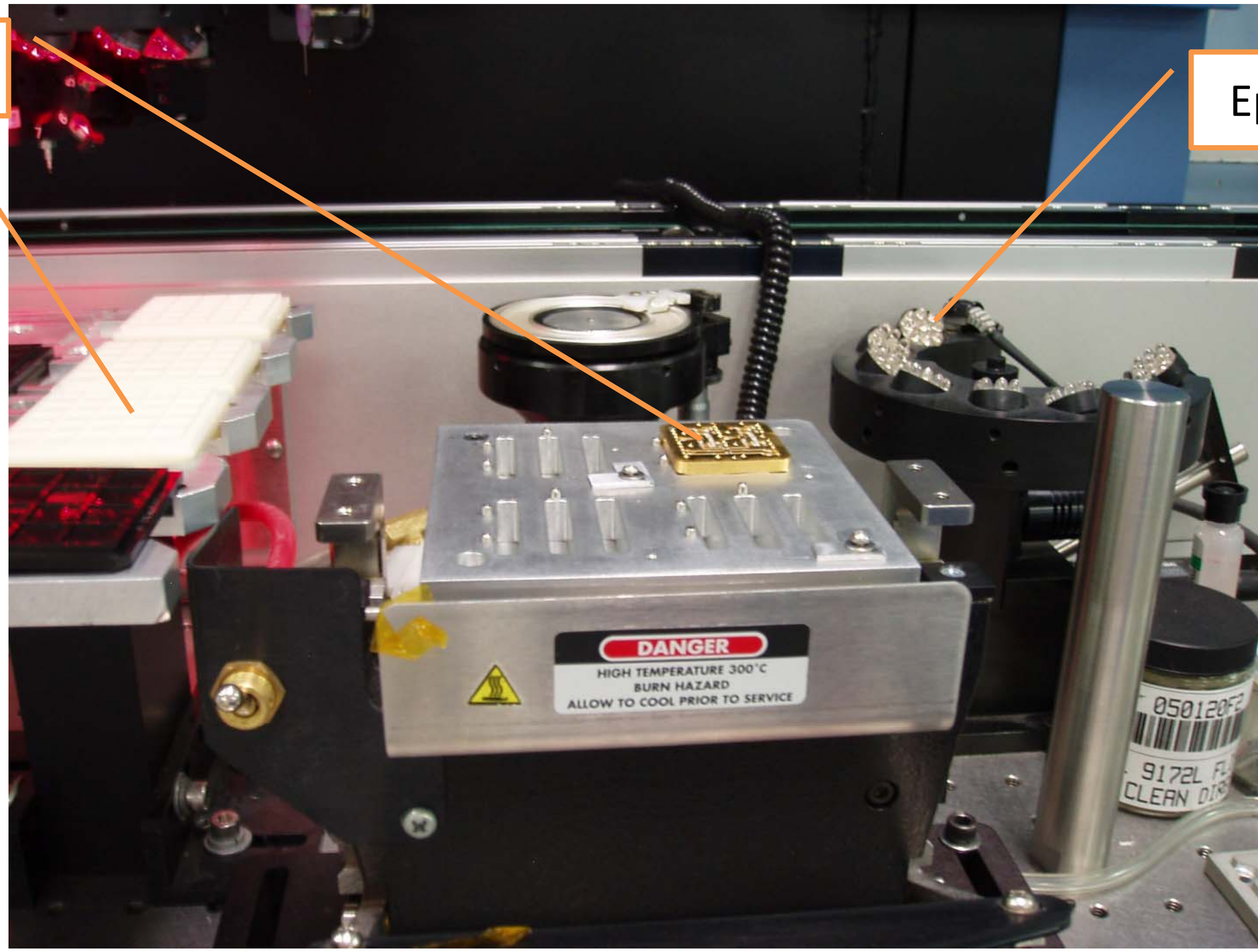
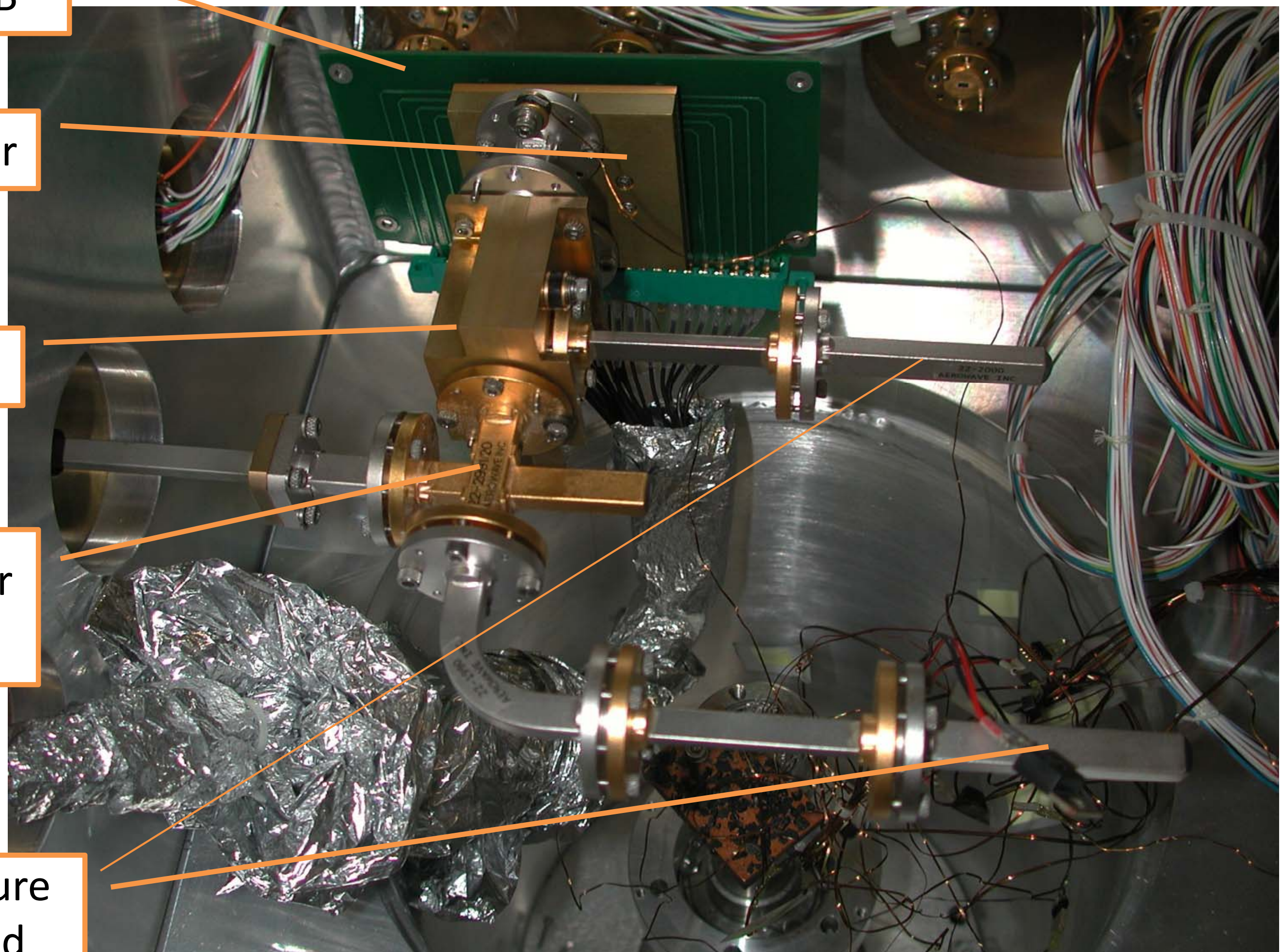


Photo by NxGen Electronics

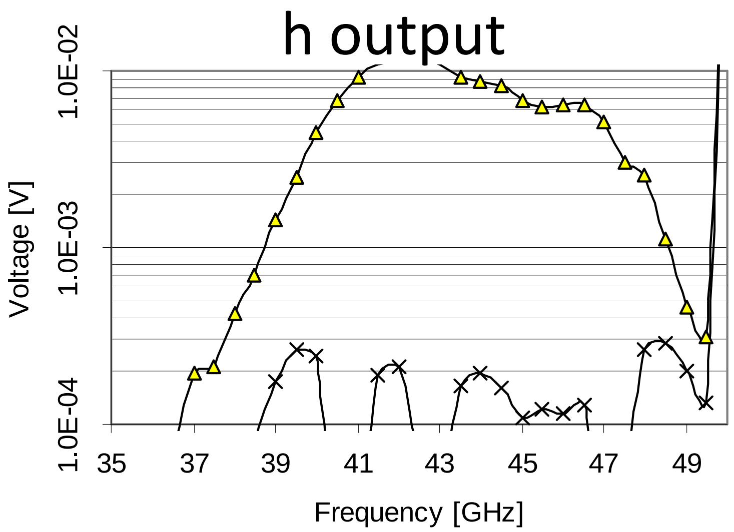
Testing of the 40 GHz polarimeters

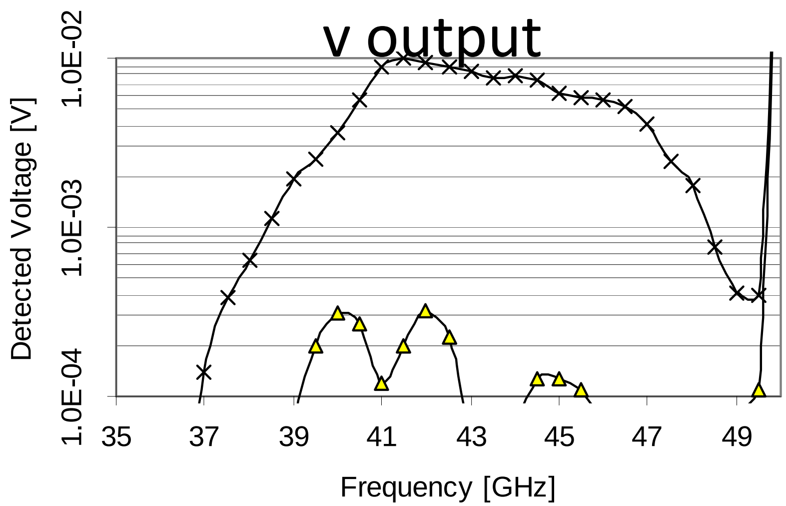


Testing of the 40 GHz polarimeters

Cryogenic measurements:

- Noise temperature of less than 25 K on best modules, 25K - 30 K typical
- Frequency bandwidth is 8 GHz
- Detector isolation > 15 dB



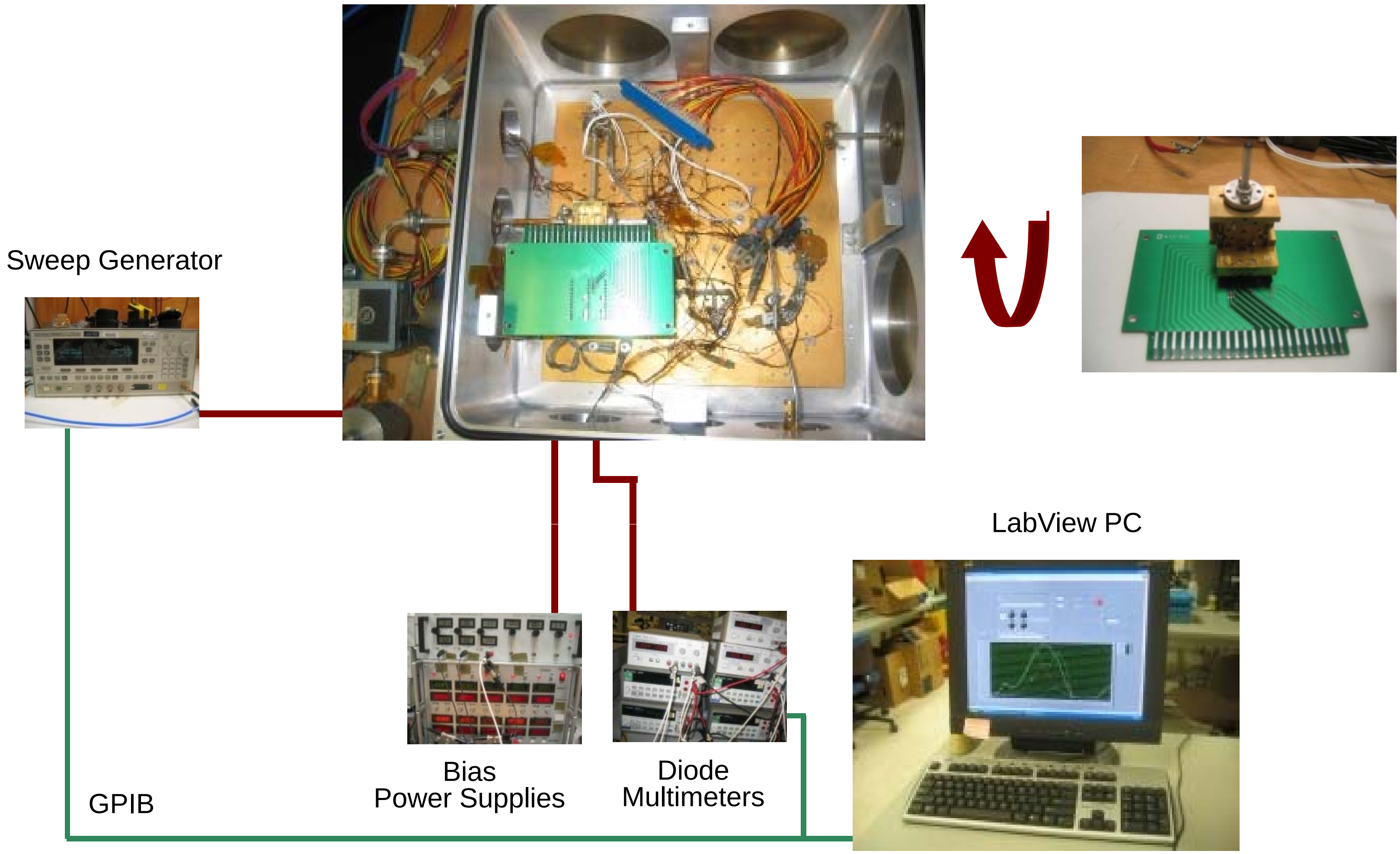


Testing of the 90 GHz polarimeters

- Aim:
  - Establish baseline performance of modules
  - Room-temperature & cryogenic (20 K)
- Practice:
  - Check basic operation of each module
    - Polarity of diodes correct?
    - Devices shorted?
    - Phase switches turn on?
  - May require several iterations
  - ‘Manually’ find ‘good’ bias values, to optimise
    - Balance
    - Isolation
  - Measure swept response
  - Measure system temperature
- Also tests to try to improve systemic problems
- And testing new module designs

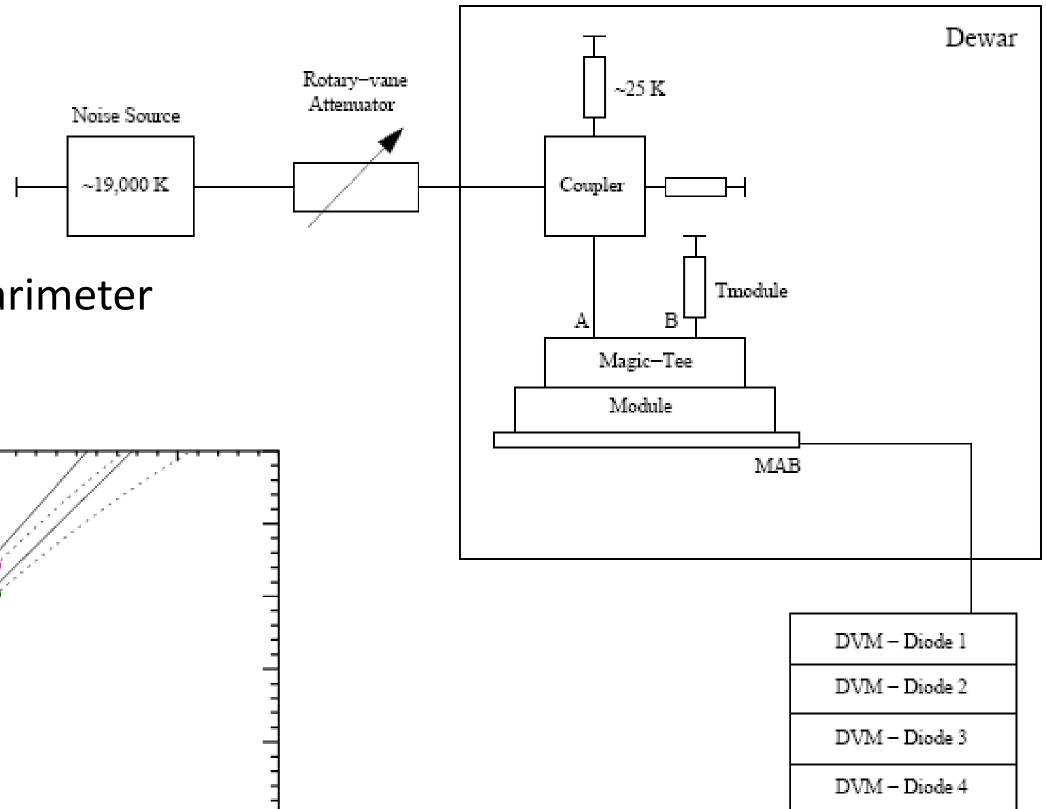
Testing of the 90 GHz polarimeters

Frequency sweep test set-up

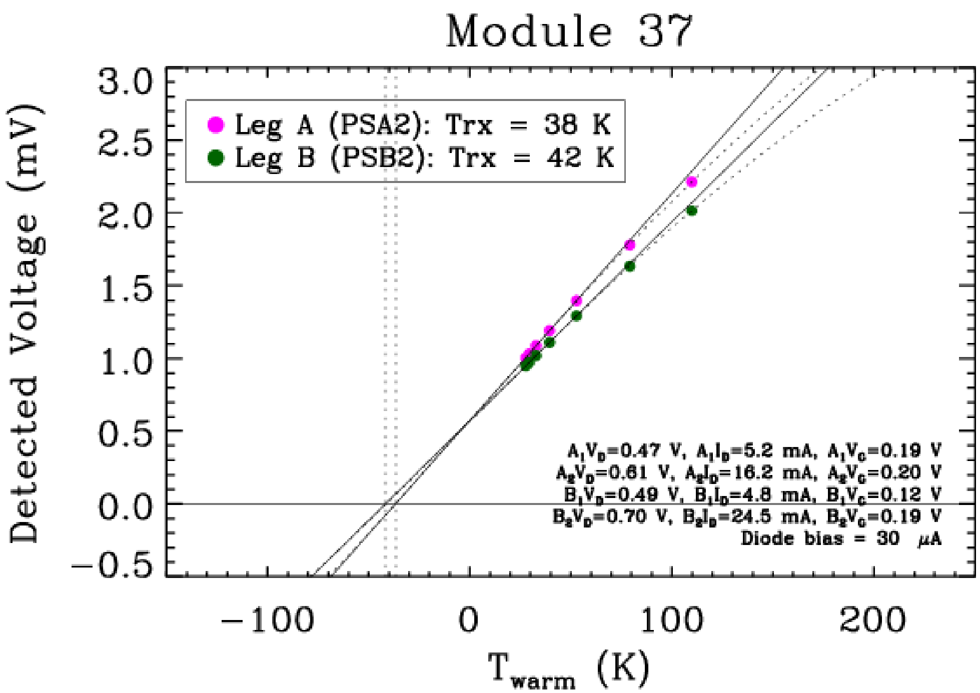


Testing of the 90 GHz polarimeters

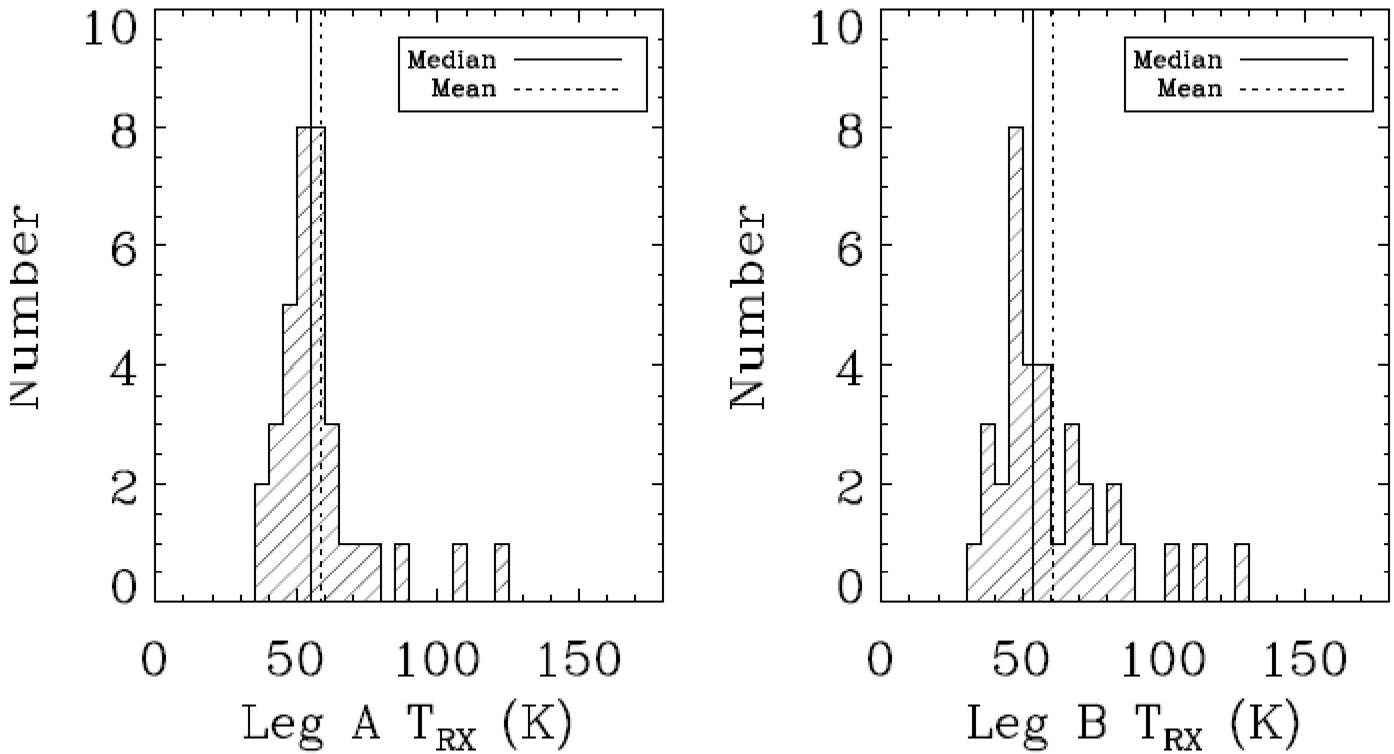
Noise test set-up



Noise obtained in a QUIET polarimeter module, at 30K ambient



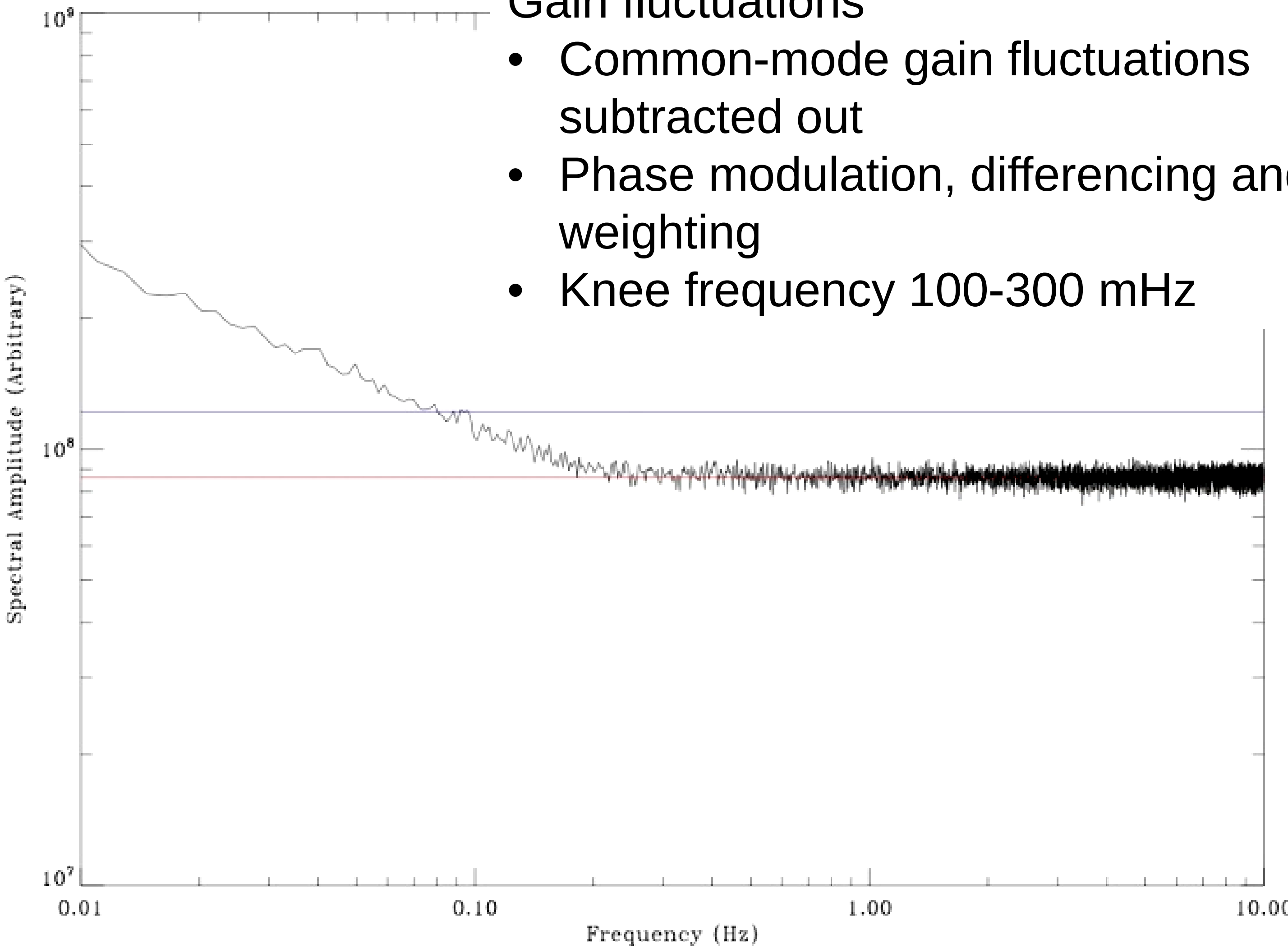
Testing of the 90 GHz polarimeters



Histogram of the receiver temperatures of leg A (left) and leg B (right) for 35 production modules, derived from a linear fit to load temperatures in the range 27-52 K. The median TRX for leg A is 55 K and for leg B is 54 K. The receiver noise temperature is the average of the noise temperatures of the two legs.

Testing of the 90 GHz polarimeters

Gain fluctuations
- Common-mode gain fluctuations subtracted out
- Phase modulation, differencing and weighting
- Knee frequency 100-300 mHz



Joey Richards & Mike Seiffert (JPL)

Noise Testing of the 40 GHz polarimeter array

Cryogenic measurements:

- noise testing setup at Columbia University
- two zotefoam loads LN2 (77K) / LO2 (90K)

Module	NT: 77-90	NT: 300-77	NT: 90-300
9	36.17 K	44.62 K	46.2 K
23	34.71 K	35.68 K	35.86 K
25	19.39 K	26.1 K	27.48 K
26	26.69 K	24.63 K	24.24 K
27	33.59 K	38.02 K	38.85 K
28	21.63 K	25.9 K	26.77 K
18	– K	– K	– K
7*	33.67 K	46.28 K	48.71 K
14*	26.59 K	30.46 K	31.21 K
12	22.51 K	27.54 K	28.55 K

Noise Testing of the 40 GHz polarimeter array

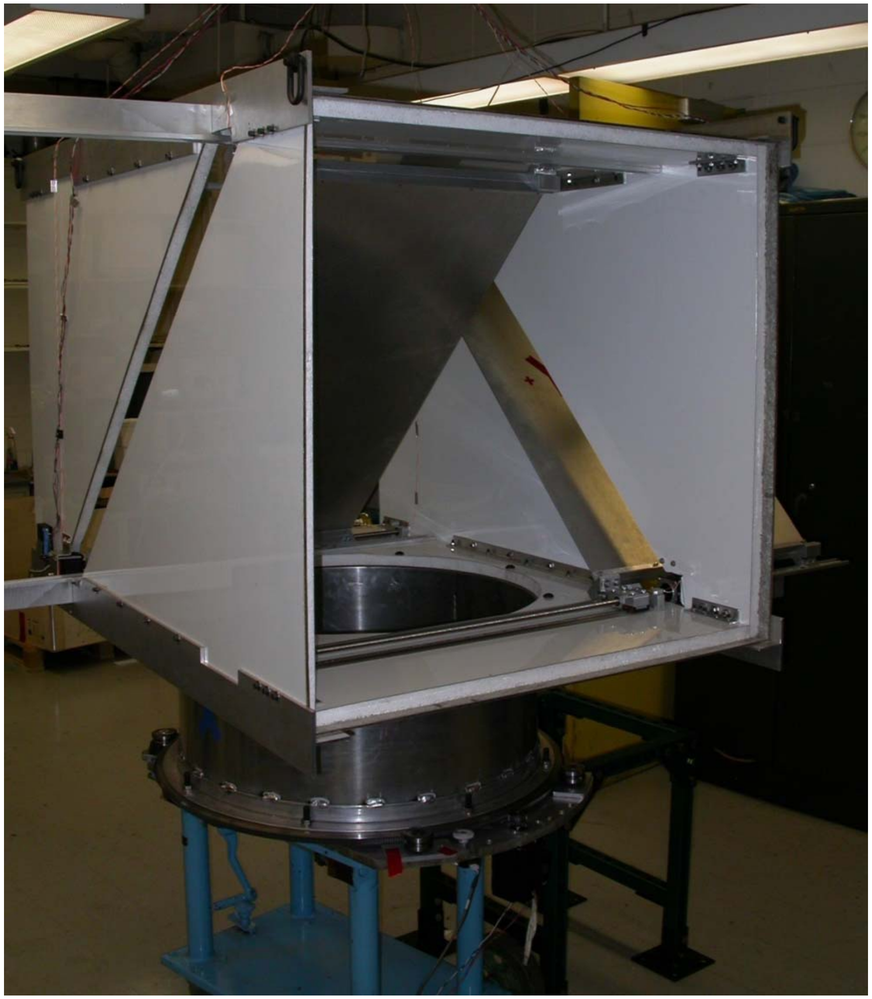
Frequency sweeps

Module	+Q (GHz)	-Q (GHz)	+U (GHz)	-U (GHz)	+Q Isolation	-Q Isolation
9	7.1	–	7.1	7.2	87.09 dB	52.88 dB
23	7.7	–	7.2	7.6	12.09 dB	16.09 dB
25	8.0	–	7.4	7.9	45.96 dB	25.98 dB
26	6.7	–	6.9	7.3	39.53 dB	13.12 dB
27	7.6	–	7.3	7.5	31.13 dB	19.08 dB
28	7.7	–	7.1	8.5	60.45 dB	56.72 dB
18	–	–	–	–	–	–
7	7.0	–	6.4	6.8	11.59 dB	30.07 dB
14	7.7	–	8.5	6.9	28.92 dB	16.75 dB
12	7.6	–	7.0	8.5	24.36 dB	21.98 dB

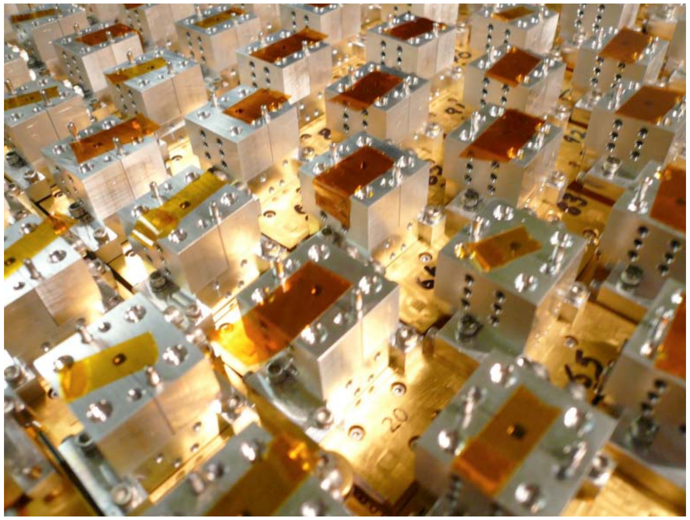
Polarised testing of the 90 GHz Array

Testing set up at University of Chicago

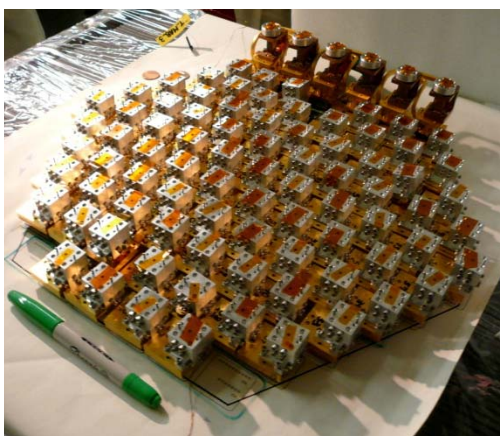
- Reflector rotates above the cryostat
- Enables automated optimisation of the modules
- The signal is provided by a rotating 1% polarising wire grid in front of a 77K target
- Amplitude of the signal is roughly ~1K



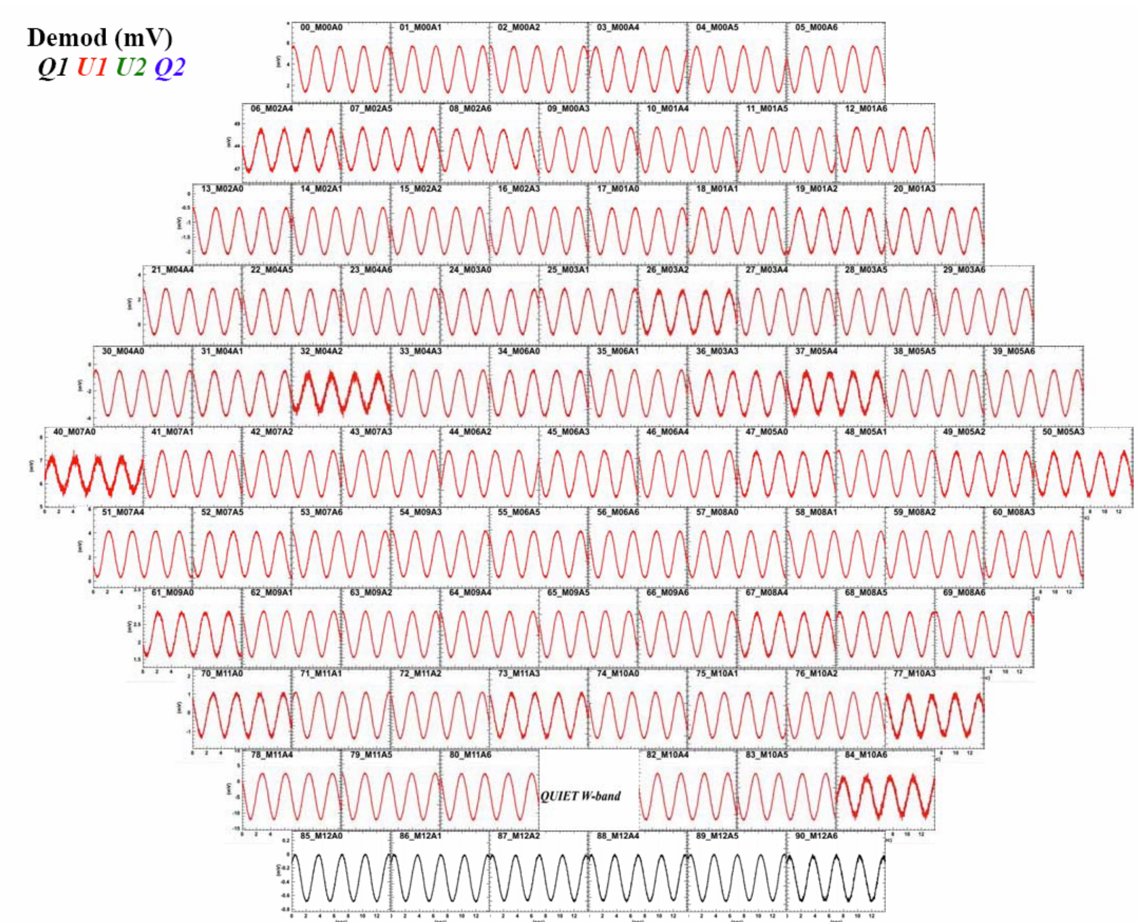
Polarised 90 GHz Array testing



QUIET 90 GHz array assembled

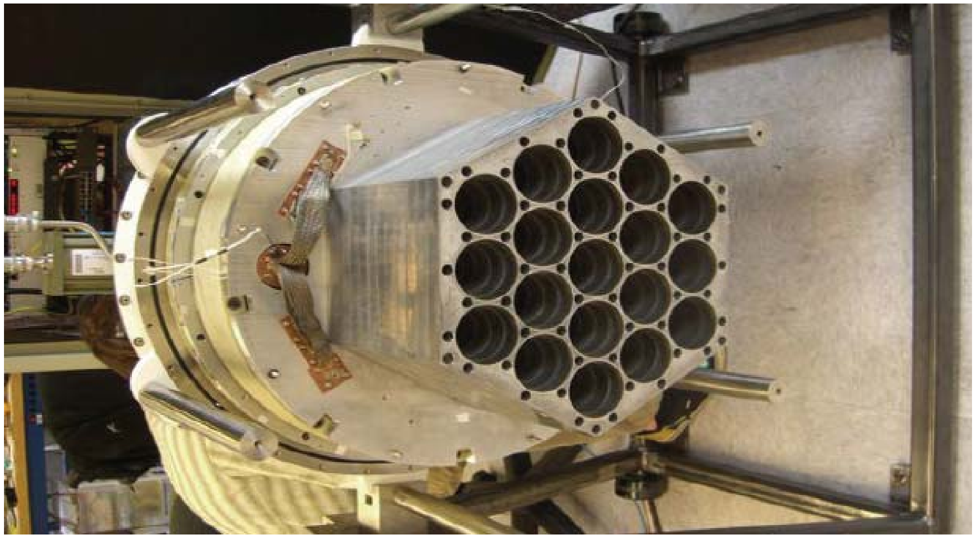


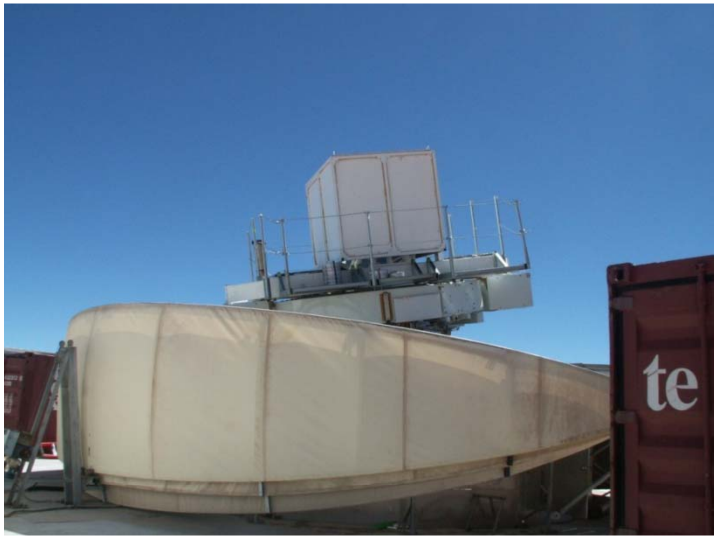
Plot of a time series of data of all 91 receivers on the 90 GHz QUIET array
The bottom row in black are I sensitive receivers.



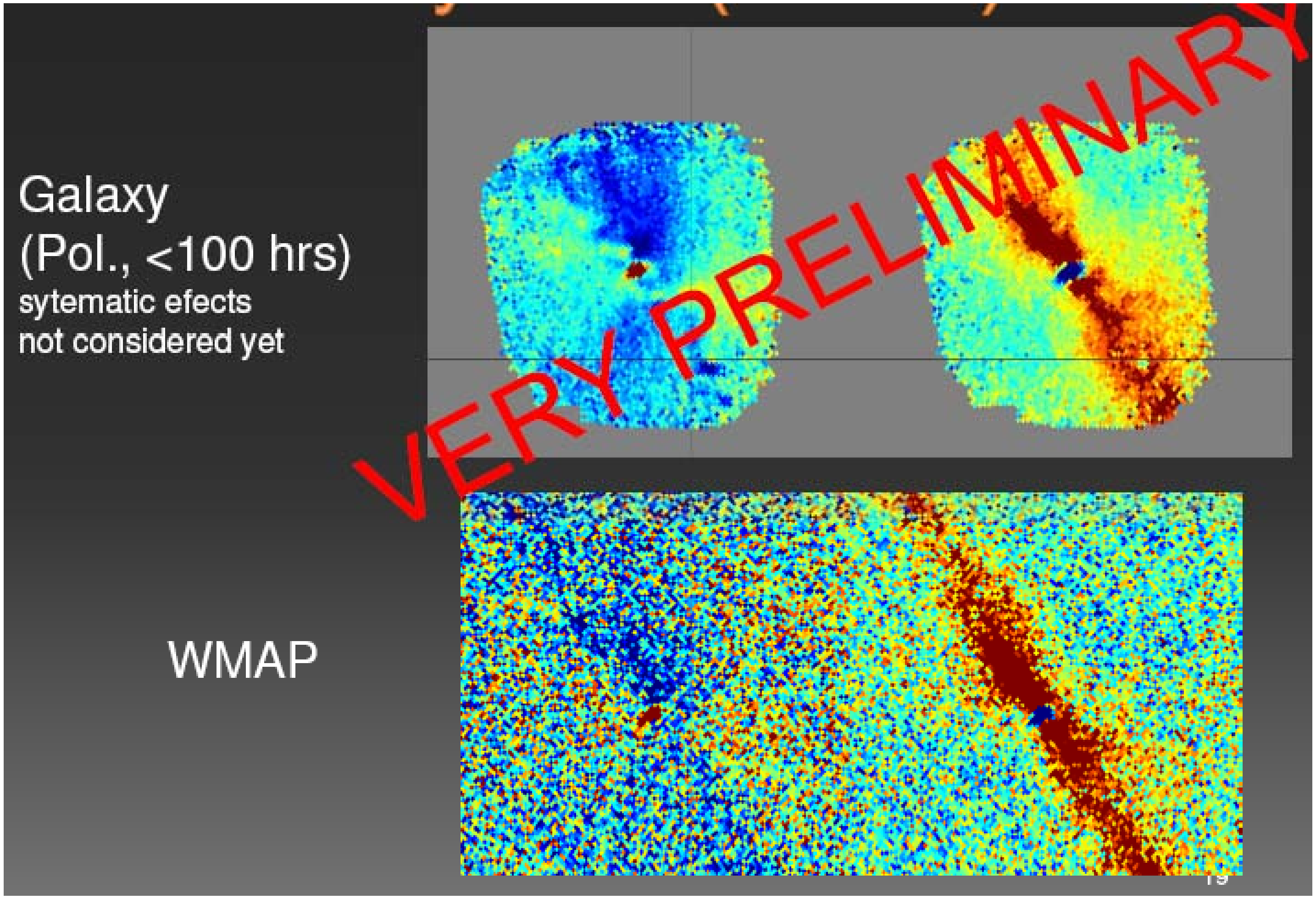
Instrument integration and operation

QUIET 40 GHz array integration and on-site with ground screen assembled





CMB observations – initial results



QUIET capabilities

Component	ν_{center} [GHz]	FWHM [′]	FOV [°]	N_{feeds} Pol	N_{feeds} Temp	T^{a}_{sys} [K]	$\Delta\nu$ [GHz]	Q+U Sensitivity[b] Per Feed [$\mu K\,s^{1/2}$]	Q+U Sensitivity[b] Array [$\mu K\,s^{1/2}$]
QUIET Phase I									
1 m	40	41	11	17	2	27	8	159	39
1 m	90	18	12	83	8	54	18	248	27
QUIET Phase II									
2 m	40	23	13	166	16	27	8	159	12
7 m	40	9	6	83	8	27	8	159	17
2 m	90	10	12	714	80	54	18	248	9
7 m	90	3–8	5	357	40	54	18	248	13

[a] Antenna temperature units, based on field-tested MMIC amplifier noise + 2.73 K + NRAO model atmosphere at 45° elevation.

[b] Thermodynamic units, including both Q and U from correlation polarimeter, with normalization $Q = (T_x + T_y)/2$

QUIET II has 3–4 times better polarization sensitivity than Planck at 100 GHz!

Slide: C.R. Lawrence (JPL)

Conclusions

- Successfully completed build and test of over 100 polarimeters
- Automated assembly and array optimization was applied (current production rate about 20 units/month)
- Module noise temperatures were about 20% higher than amplifiers tested individually
- Two cryogenic (20K) arrays integrated
- QUIET has completed phase I Q-band observations and starting phase I W-band observations

Acknowledgement

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We would like to acknowledge the work done by all members of the QUIET collaboration (5 countries, 12 institutions, ~32 people) http://quiet.uchicago.edu/team

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