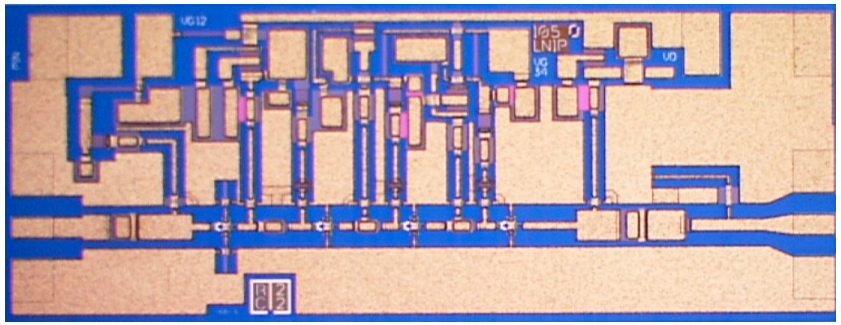
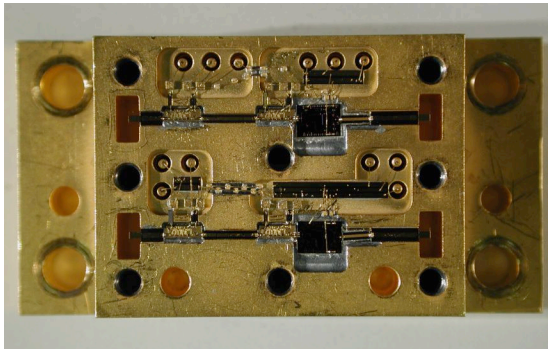
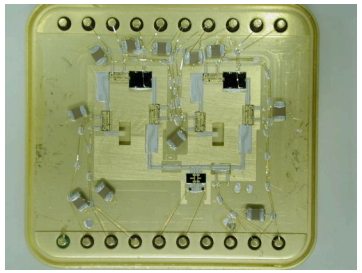
MMIC Development Path toward Integration



InP MMIC amplifiers (10 years of NASA tech investment):
Ultra-low noise operation, highly repeatable, simple integration.
Proven in observations: FCRAO, CAPMAP, Efflesberg Telescope, will go in SZA



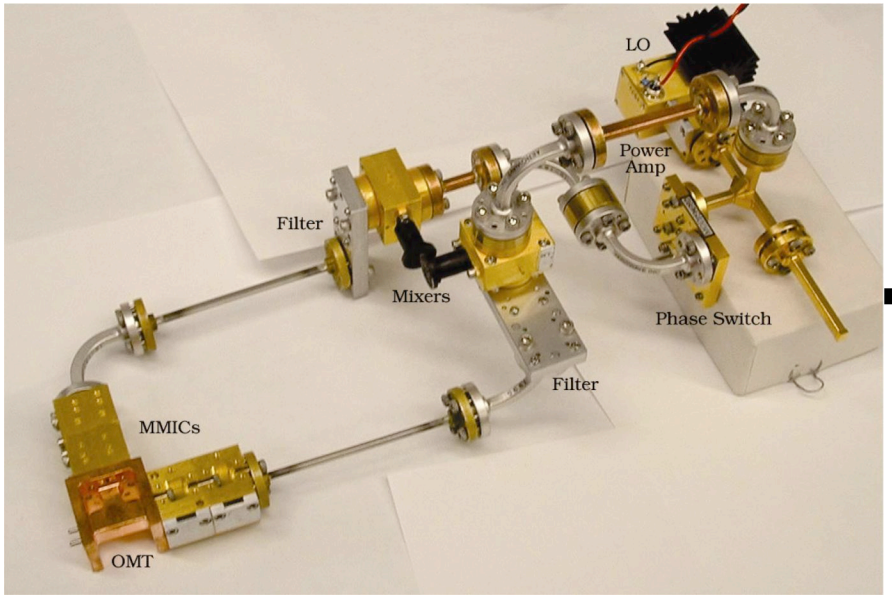
Multi-function integration:
All component chips ***already*** developed
Integration demonstrated in Planck



QUIET IC Style packaging;
Low-cost, <u>scalable</u>
Fully automated assembly

Breakthrough in MMIC Packaging makes this possible

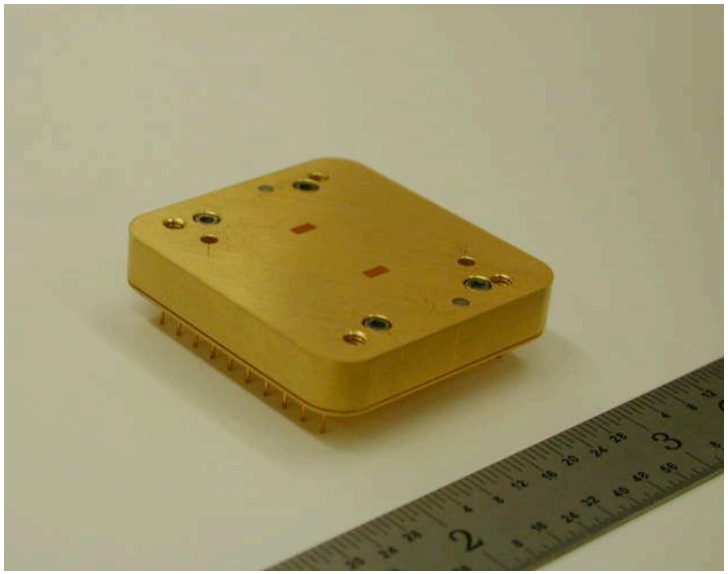
CAPMAP 90 GHz Correlation Polarimeter



X-Y Polarizer

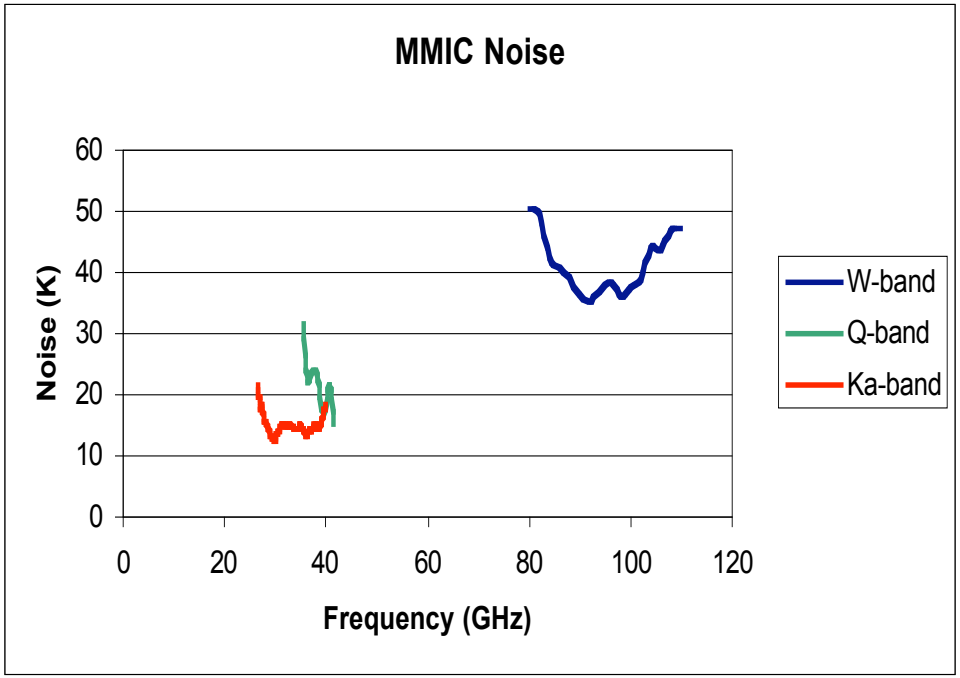
~ $40K and 50 physicist-hours for checking, characterizing, etc

QUIET Correlation Polarimeter IC



~ $500 and automated assembly and test, completely scalable

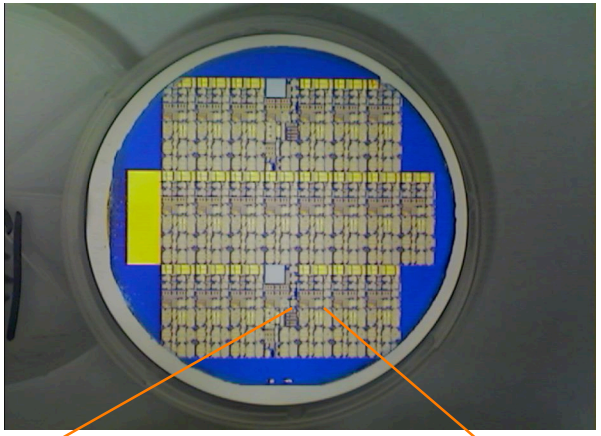
MMIC Module Noise Performance

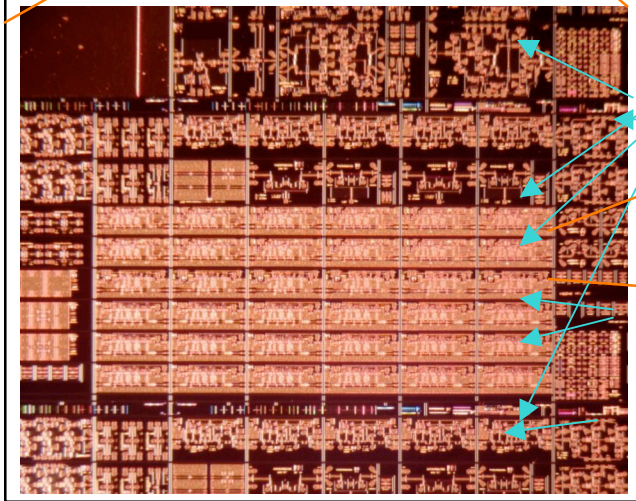


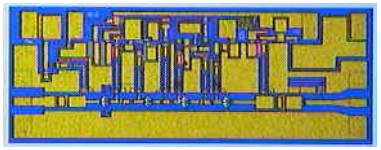
QUIET Specification

Channel	90 GHz	40 GHz
T_{sys}	50 K	20 K
BW	18 GHz	8 GHz
Gain Match	0.5 dB	0.5 dB
Phase Match	10 deg	10 deg
Detector balance	1 dB	1dB
Sensitivity on sky/mod	205 μK-sec$^{1/2}$	110 μK-sec$^{1/2}$
Cost/module (qty 1000)	<$500 (TBC)	<$500 (TBC)

Cryogenic HEMT Optimization Program





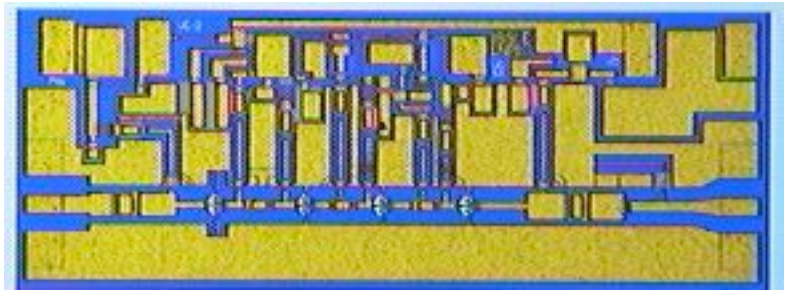


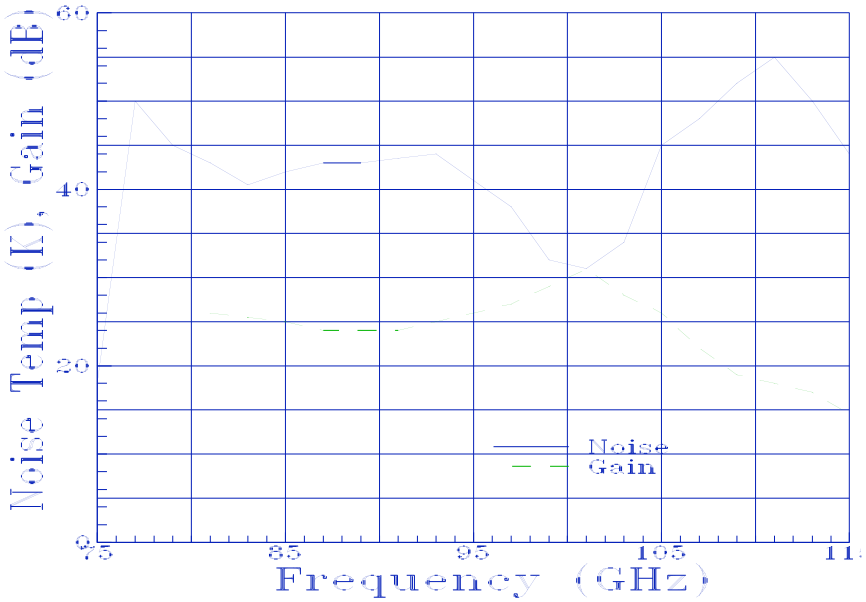
CHOP has produced thousands of low-noise InP devices which are being used for a radio astronomy including:

- UMass Sequoia Array
- 90 GHz VLBI on Effelsberg Telescope
- UCSB/JPL BEAST Telescope
- DSN
- Princeton University CMB polarization
- Planck and FIRST prototype development
- IF amplifiers for CSO, SOFIA receivers
- Amplifiers for Metsahovi Radio Obs.

TRW 4-Stage CPW 80-115 GHz Amplifier

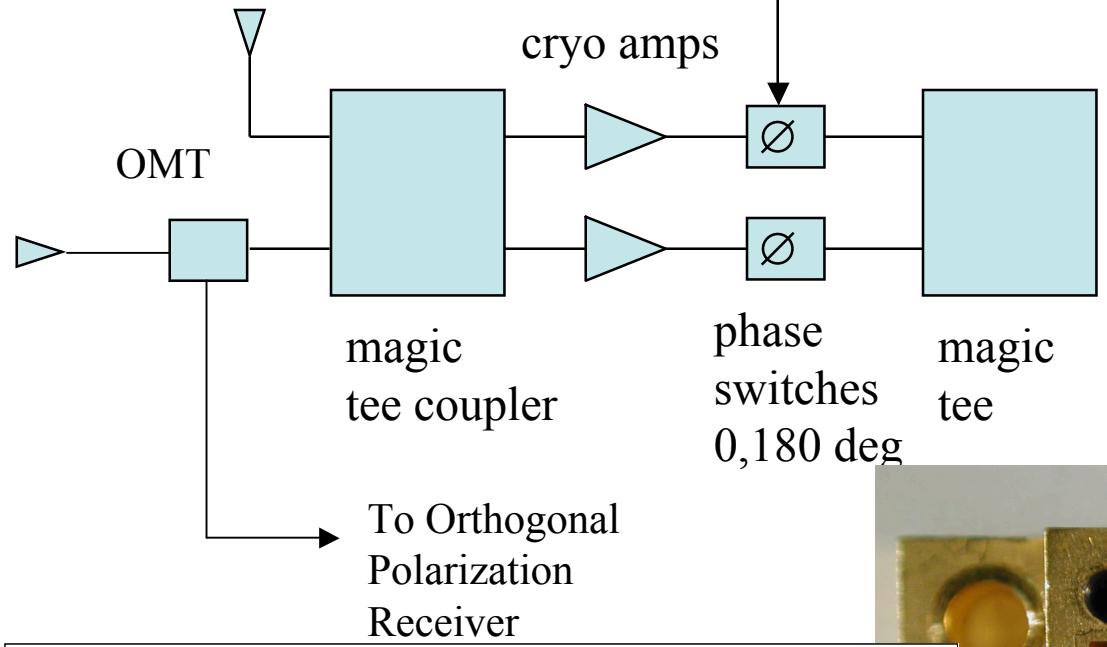
- Design by S. Weinreb
- 80-115 GHz >17 dB gain
- NF~ 3-4 dB at room temp
- Record low noise at cryo temps:
  - → < 45 K from 85-105 GHz
  - → < 40 K from 96-104 GHz
  - → 30 K noise at 100 GHz
- Yield:105 chips per wafer
- Ultra-low power operation
  - 20 dB gain at 1.4 mW
  - 15 dB gain at 0.54 mW
- Excellent Gain and Phase match (5 deg typ)

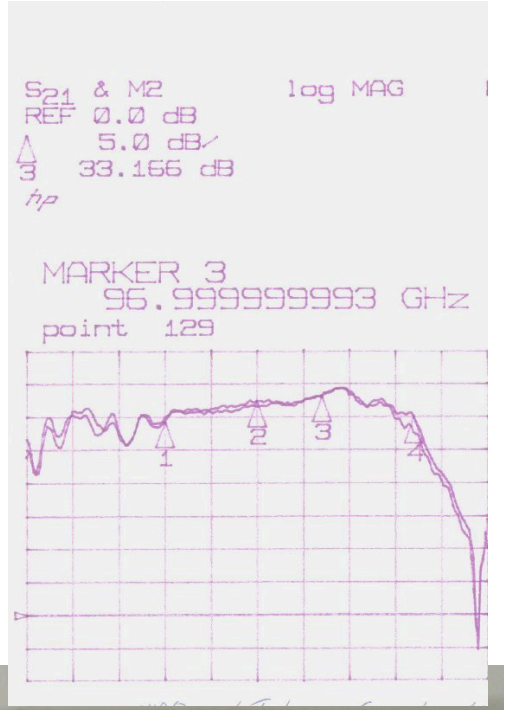


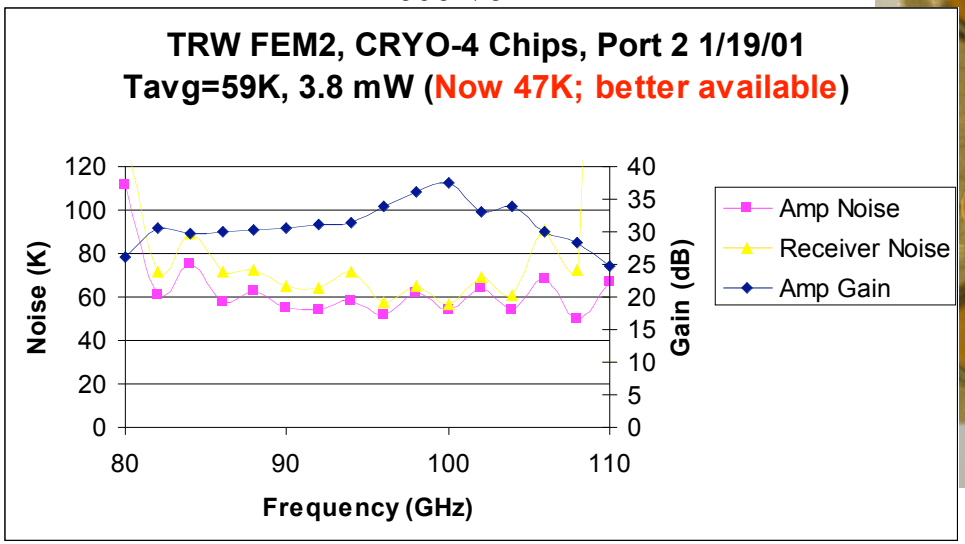


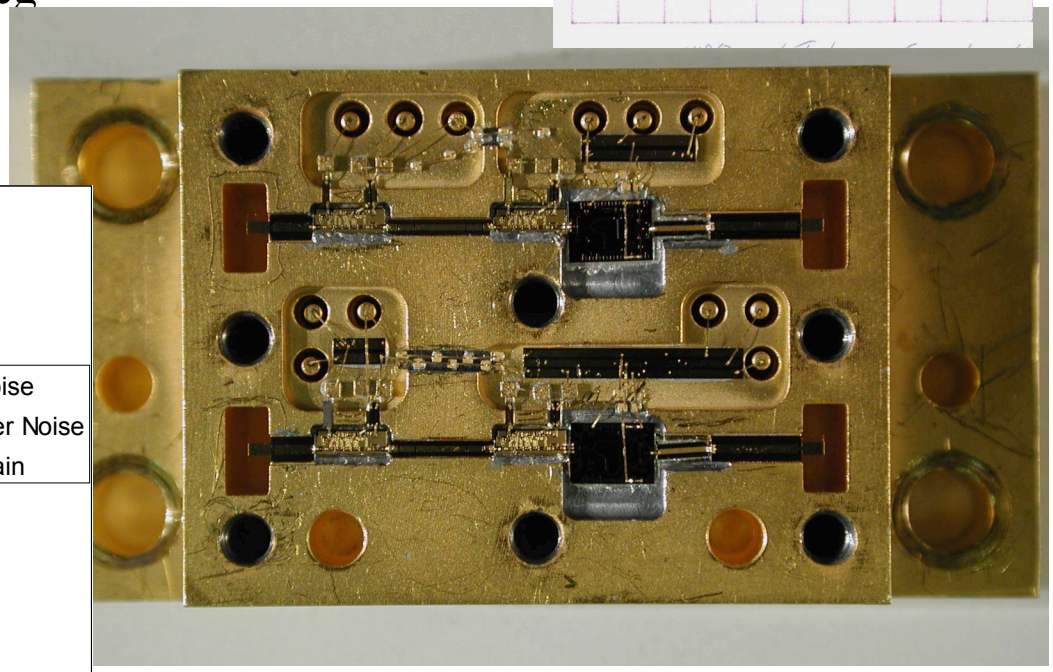
Integrated Systems

Circa 2000 Planck-LFI 100 GHz Breadboard



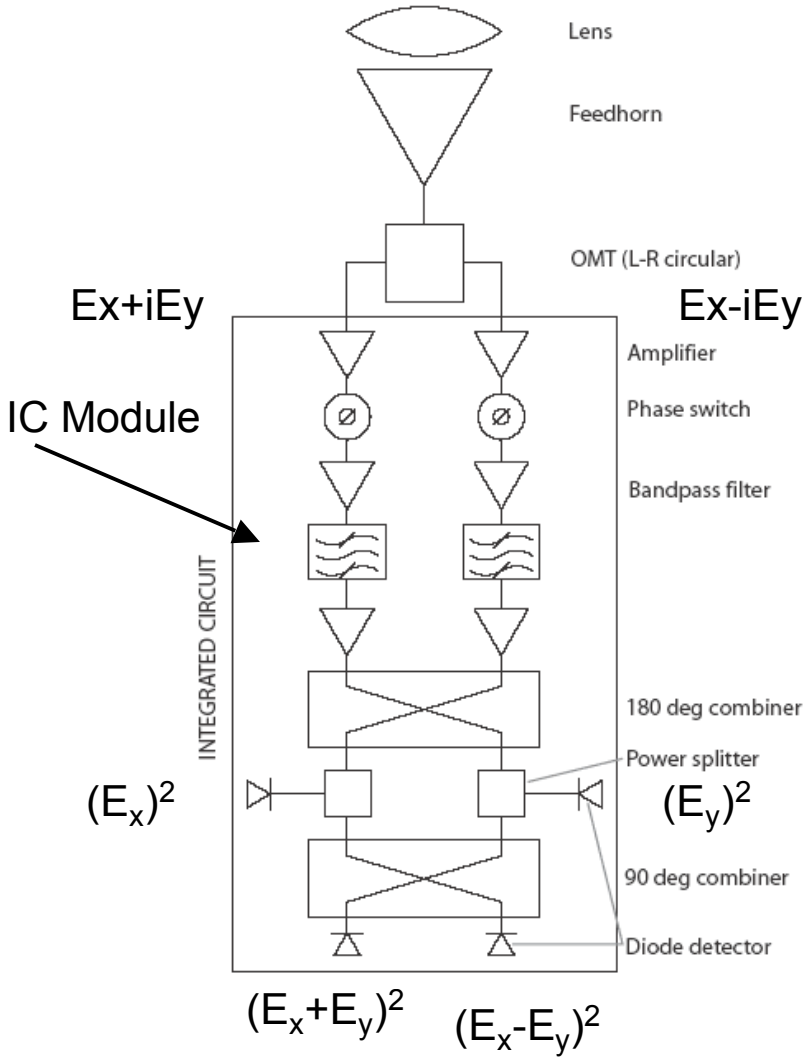


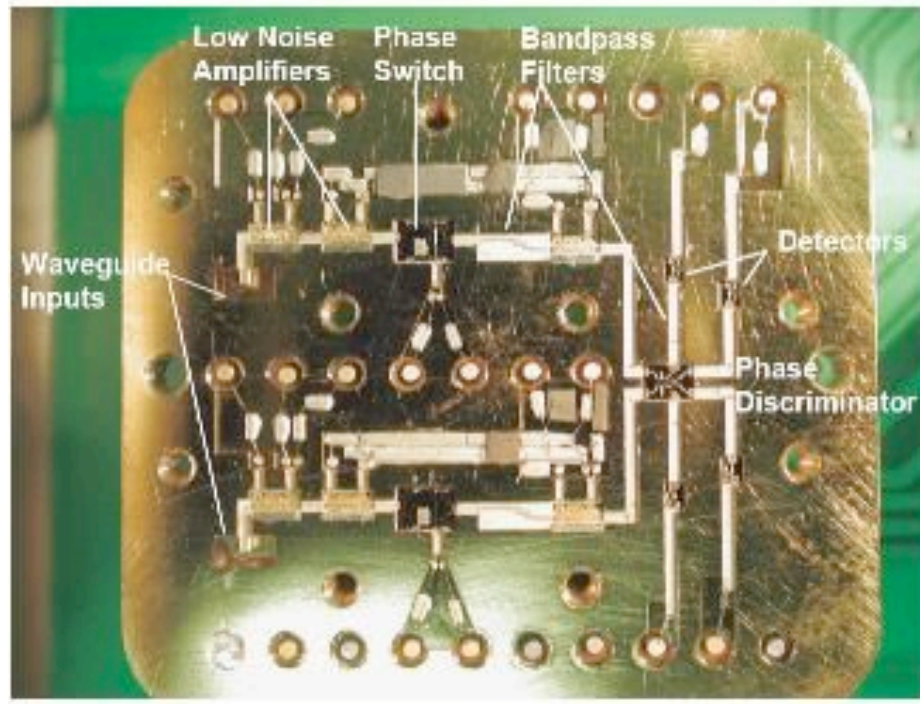




-JPL Dec 2008

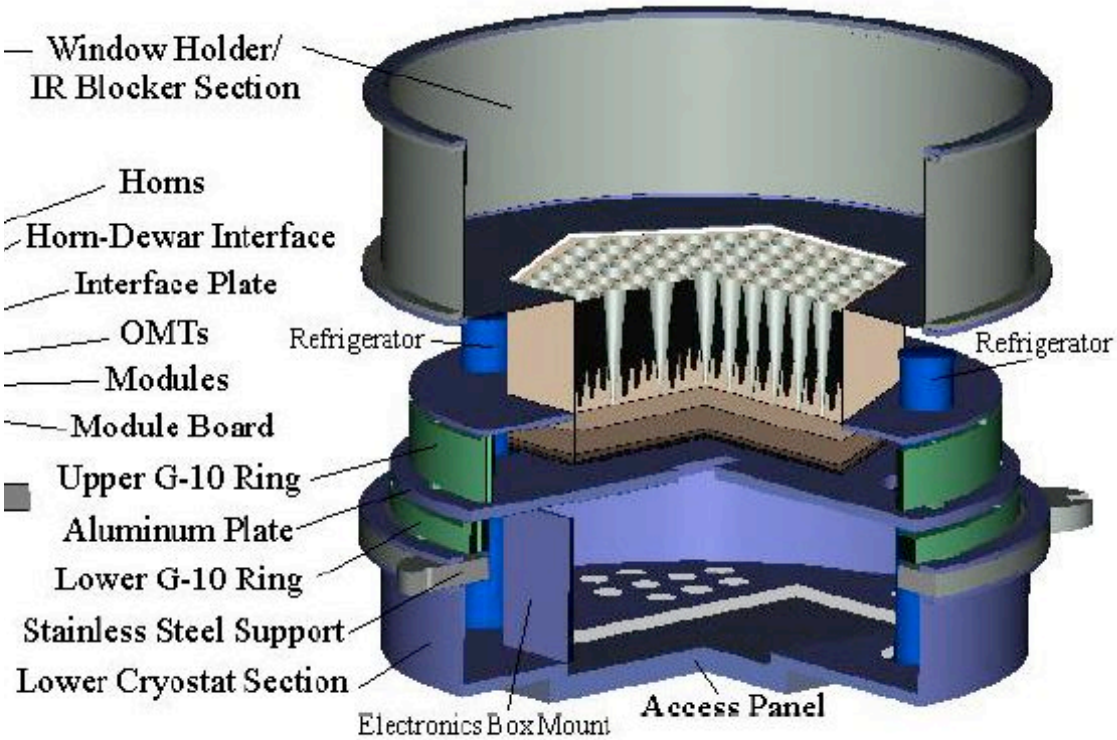
90 GHz Pseudocorrelation Receiver

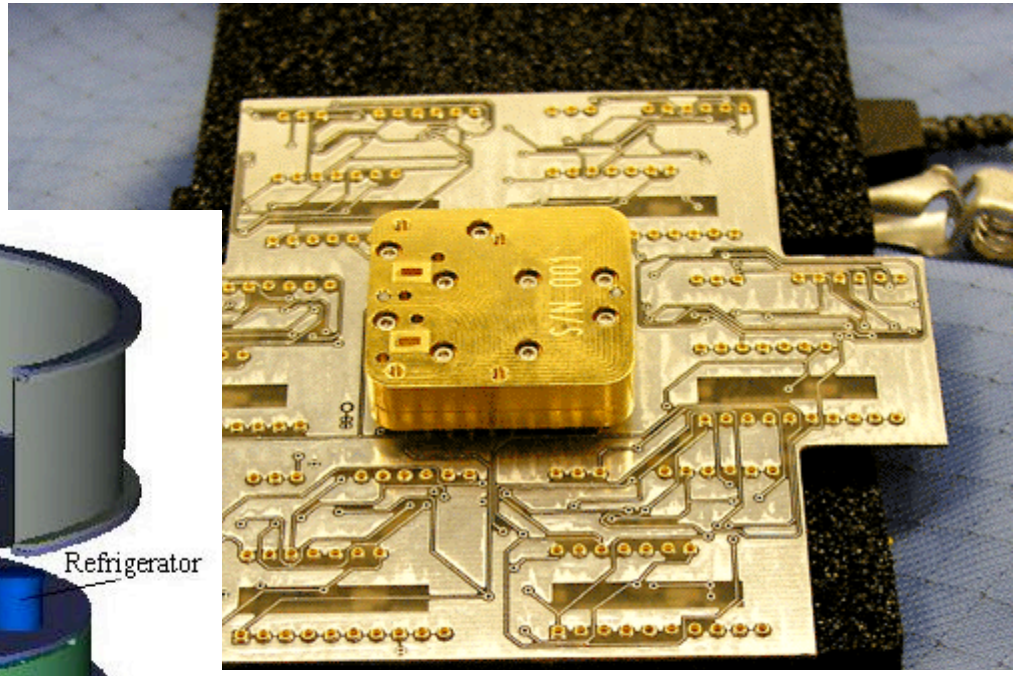




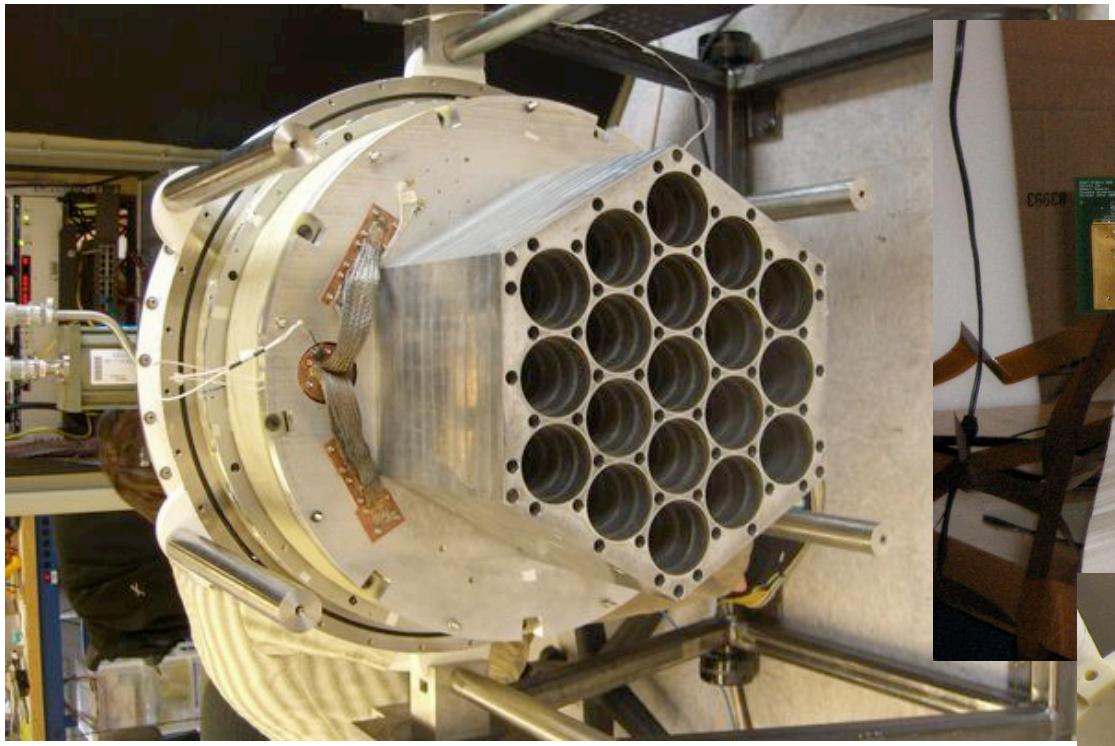
T_{sys}=~60K at cryo temps

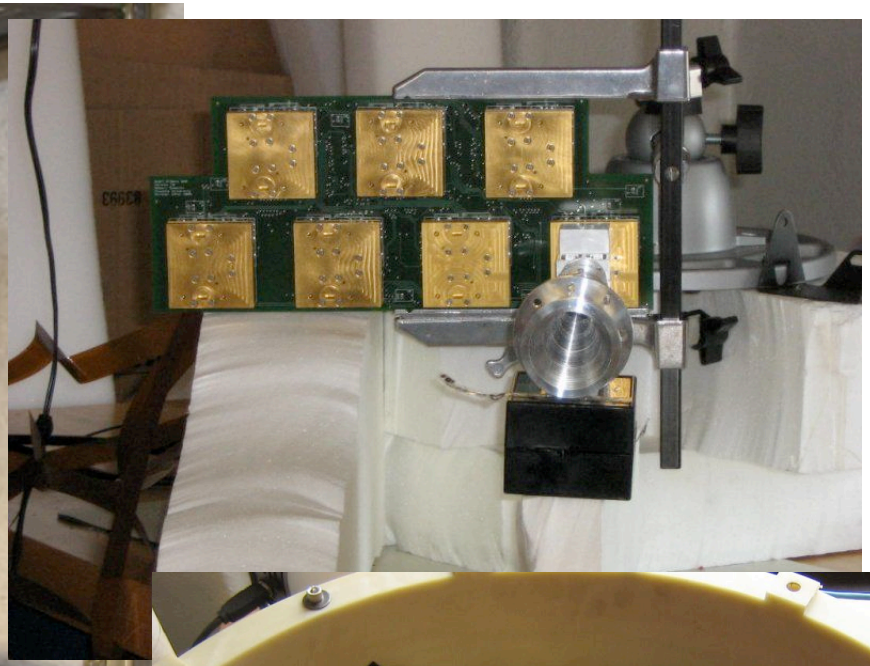
Array Integration

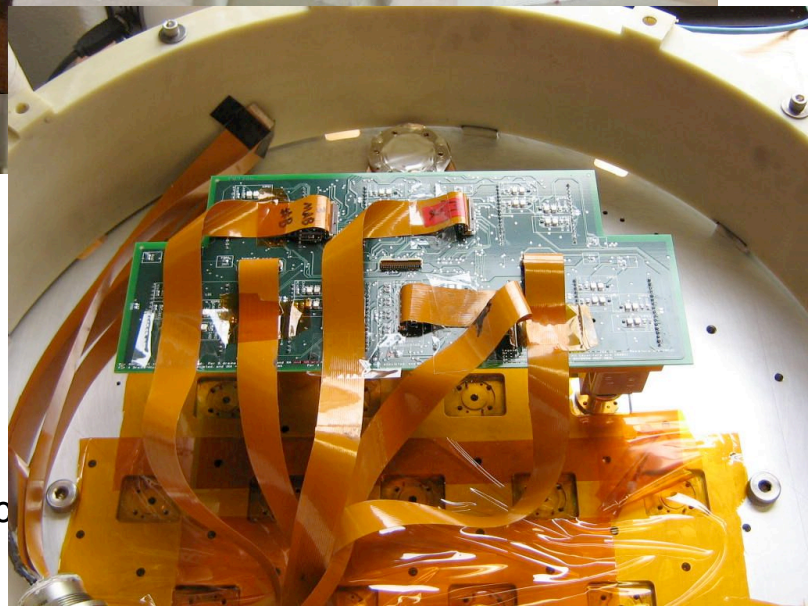




Q-Band Array



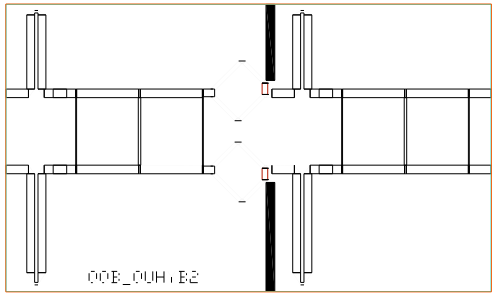


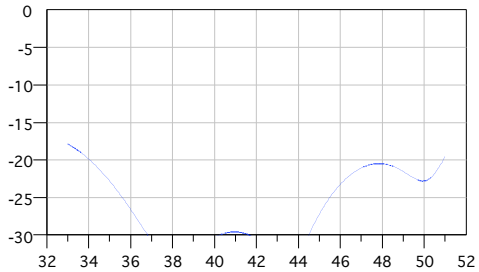


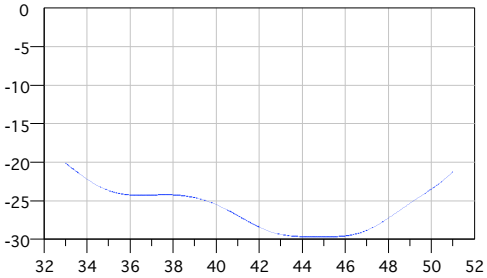
40 GHz Polarimetric Radiometer Modules

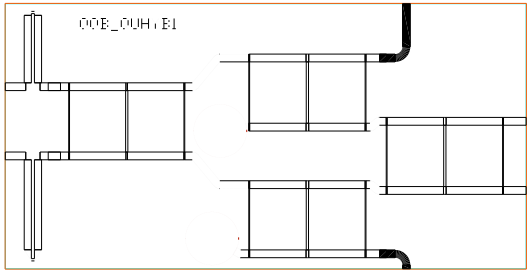
Polarizer QU hybrid

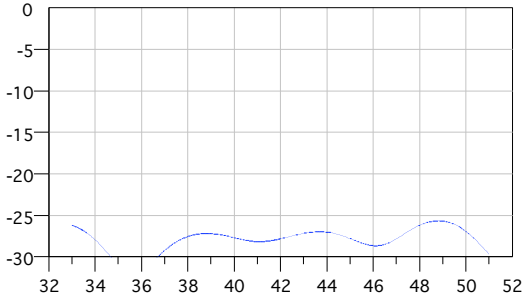
Two versions designed
on Alumina thin film technology





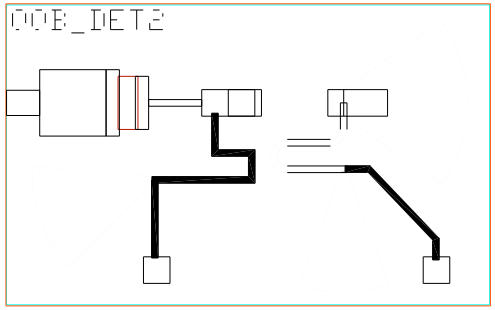


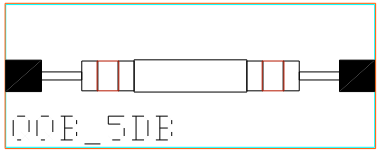




40 GHz Polarimetric Radiometer Modules

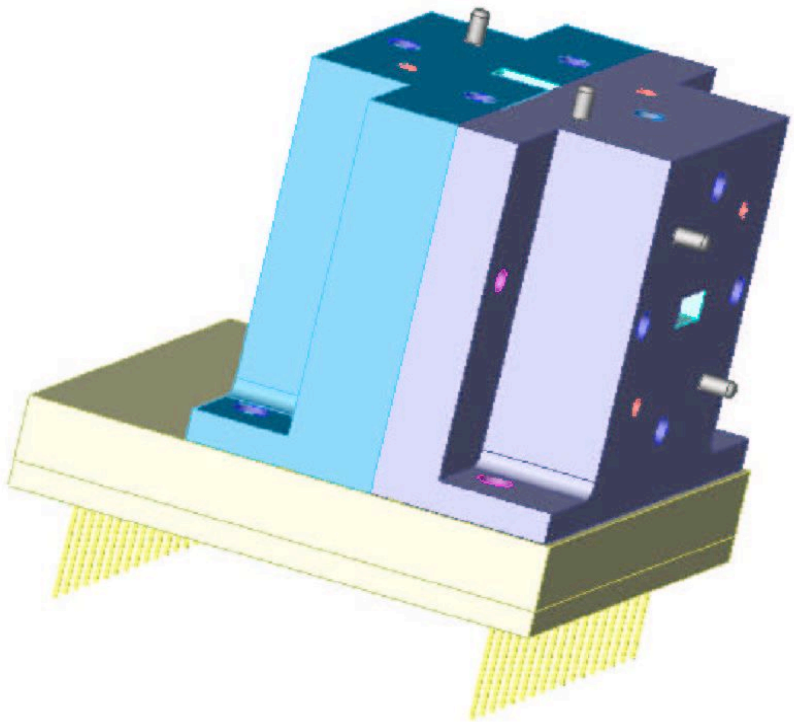
Bandpass filters, detectors, attenuator in thin film technology



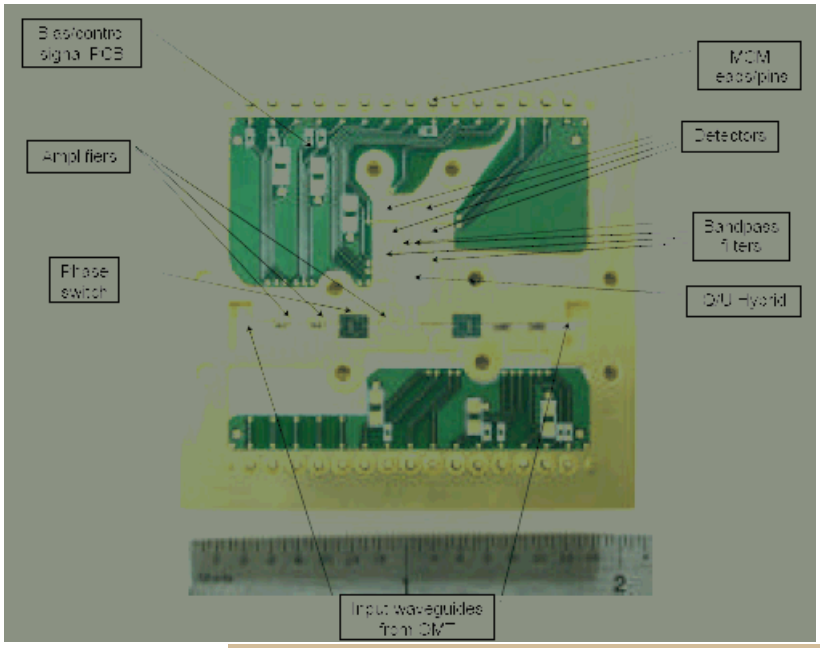


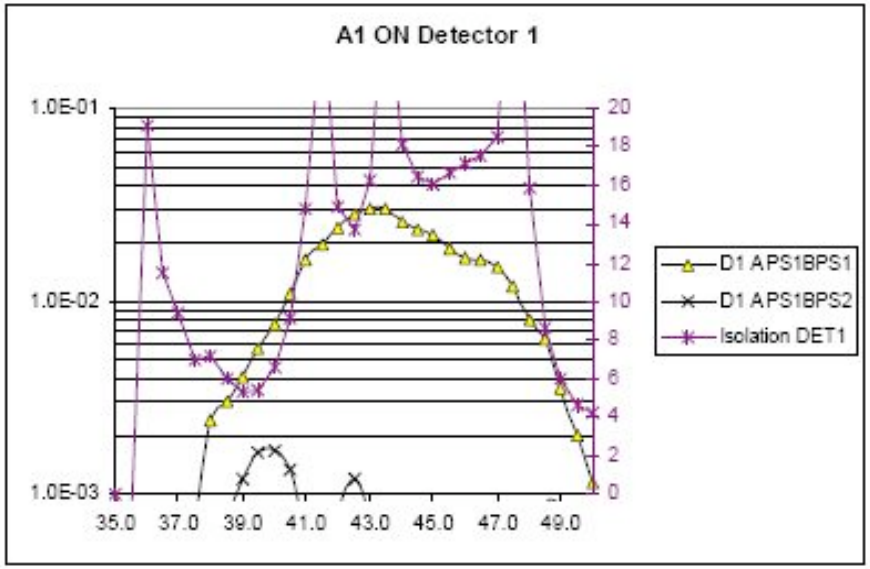
40 GHz Polarimetric Radiometer Modules

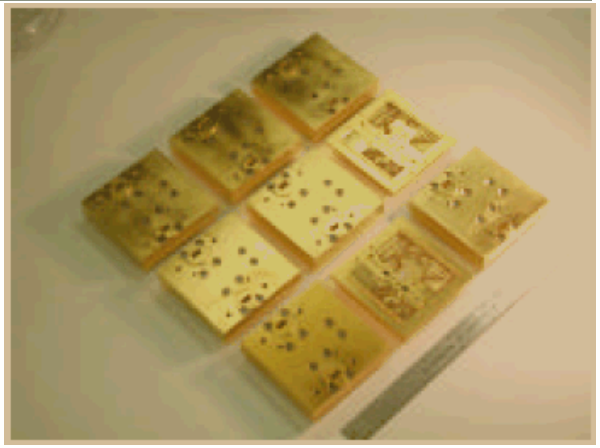
Module to be tested with a custom Magic-T



40 GHz Receivers-25 K noise, 7 GHz BW







Issues and Concerns (High level)

- Device level:
  - » No one recipe for all apps
  - » Device repeatability becoming more of a concern
  - » No support from NASA
- Module level:
  - » Loss of optimal performance with mass production
  - » Testability (too much integration?)
- System level
  - » Design for low systematics (FPA vs Interferometer)
  - » Bias Electronics- Deviated from original concept

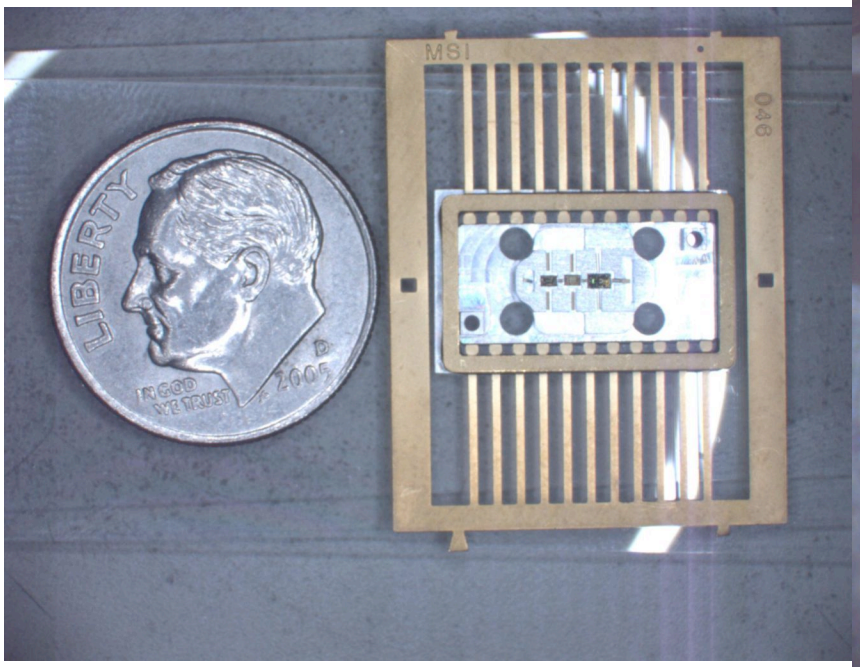
Issues and Concerns (Nuts ‘n Bolts)

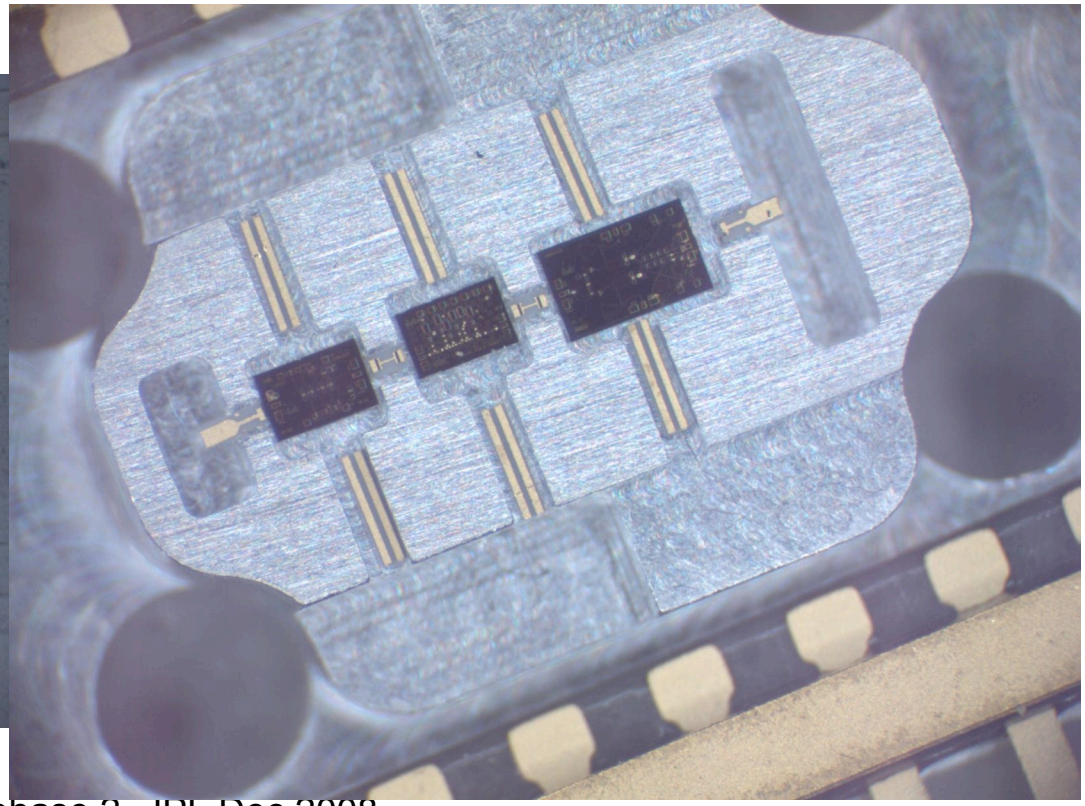
- Module yield out of assembly ~50%
  - Die attach issues
  - Wire bonding human factors, design issues
  - Occasional cracking
- Device yield
  - Wafer lot dependent
  - Pre/post backside differences
- Parts nearly exhausted- Diodes, phase switches, good MMIC amps

Issues and Concerns (Technology concerns)

- Diodes are not ideal- MMIC zero-bias would be better
- Phase discriminator could be improved
- Bias has gotten very complex
- Design for testability

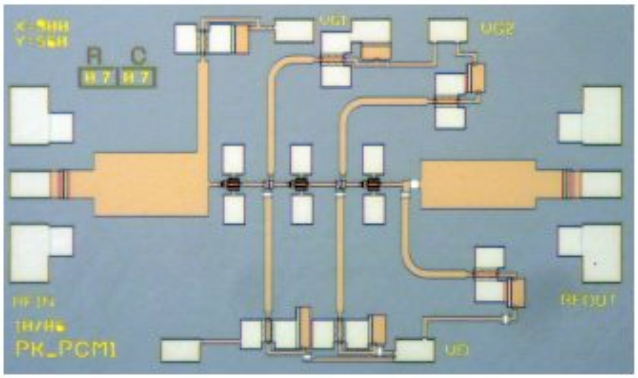
MIMRAM 180 GHz Modules

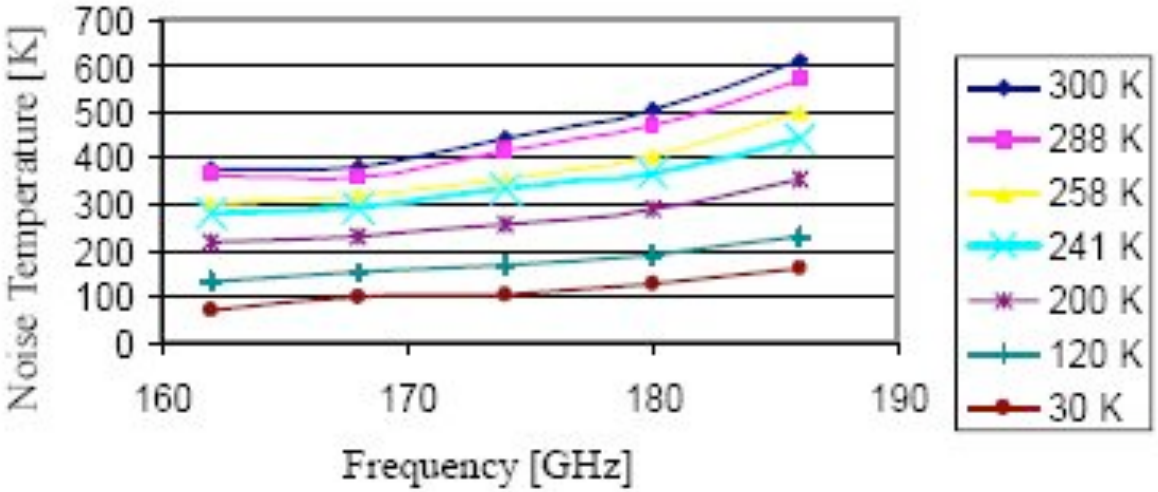


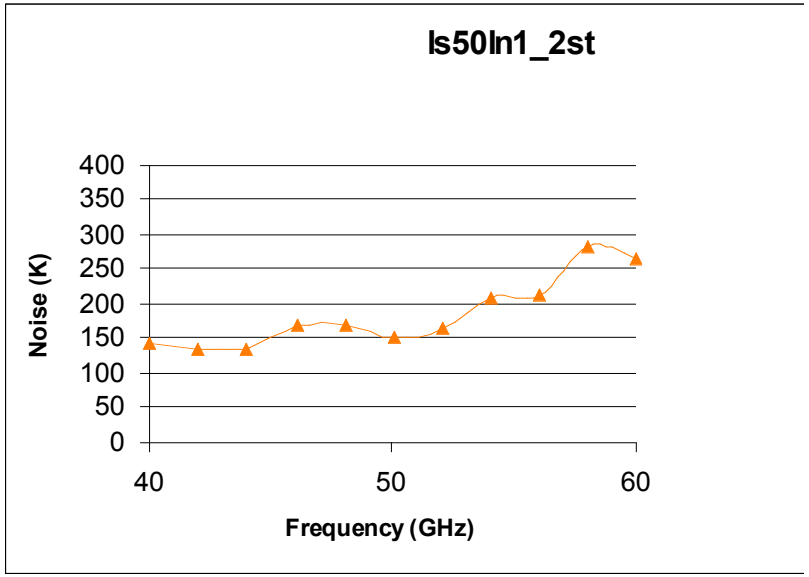


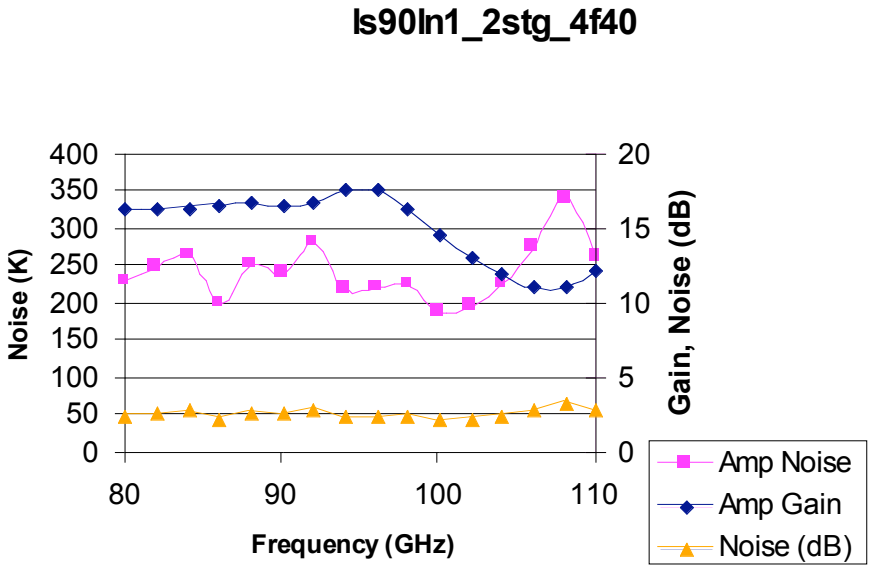
Prospects for better transistors?

35 nm InP:

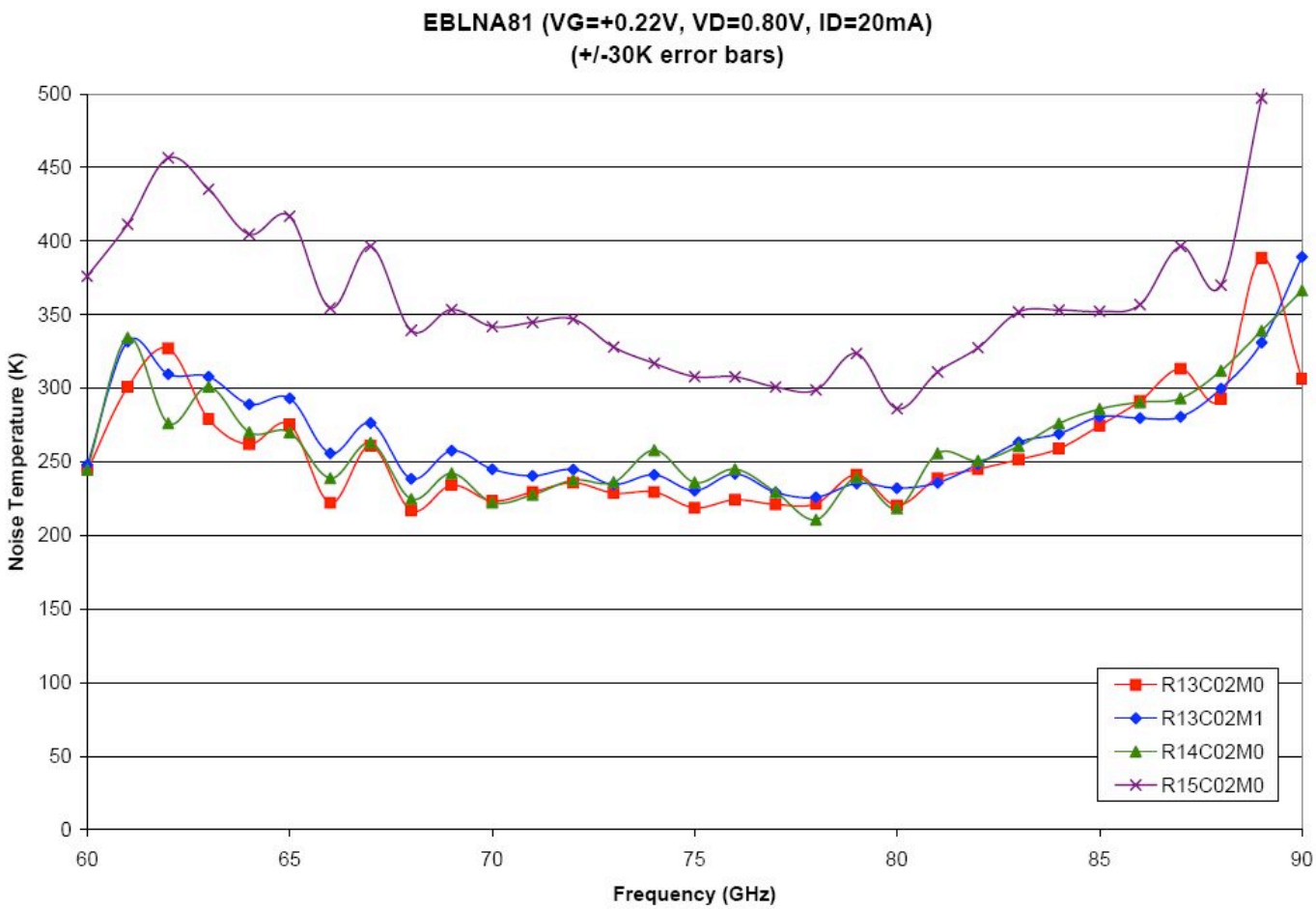






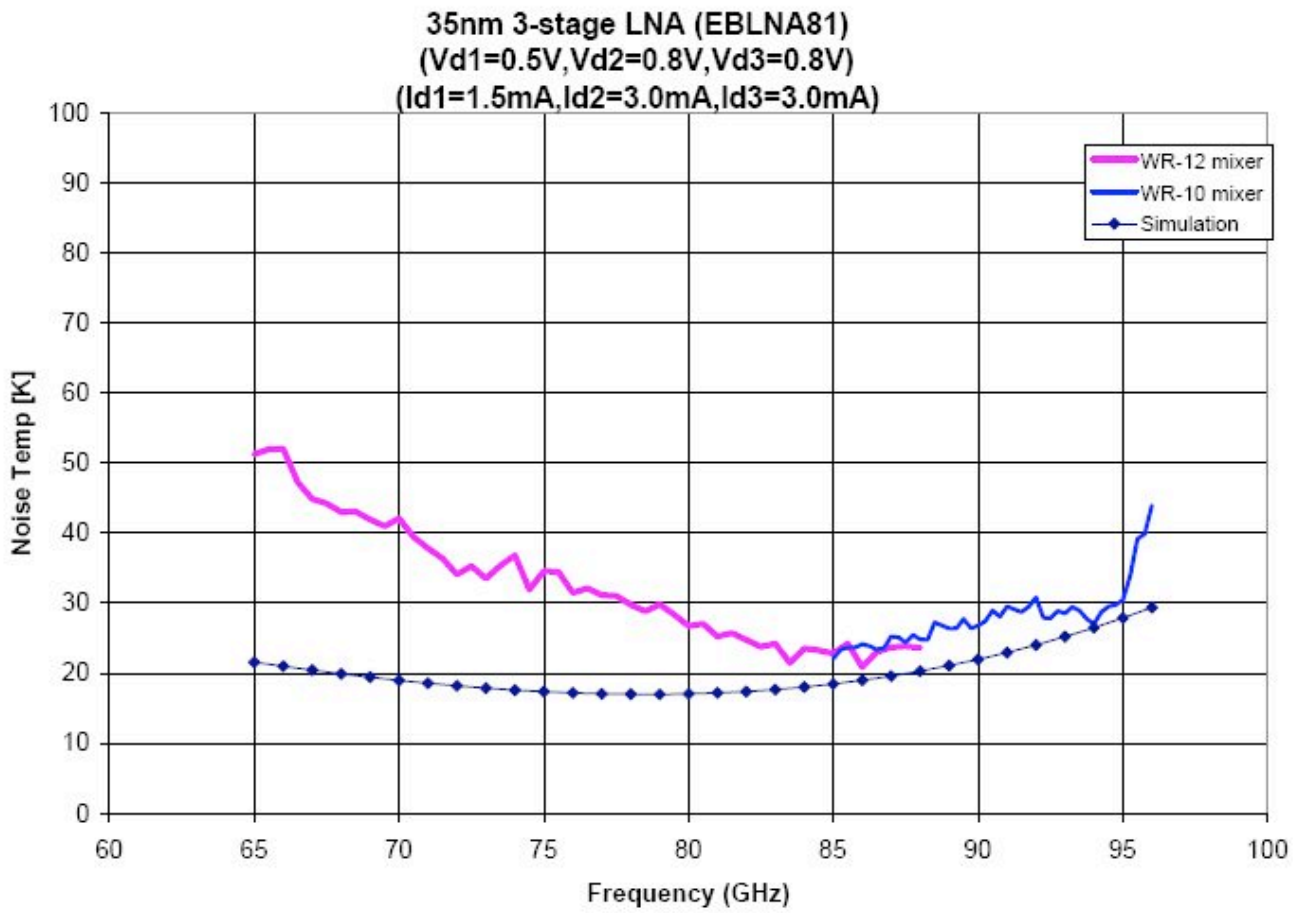


NRAO MMIC Design on NGST 35 nm Process



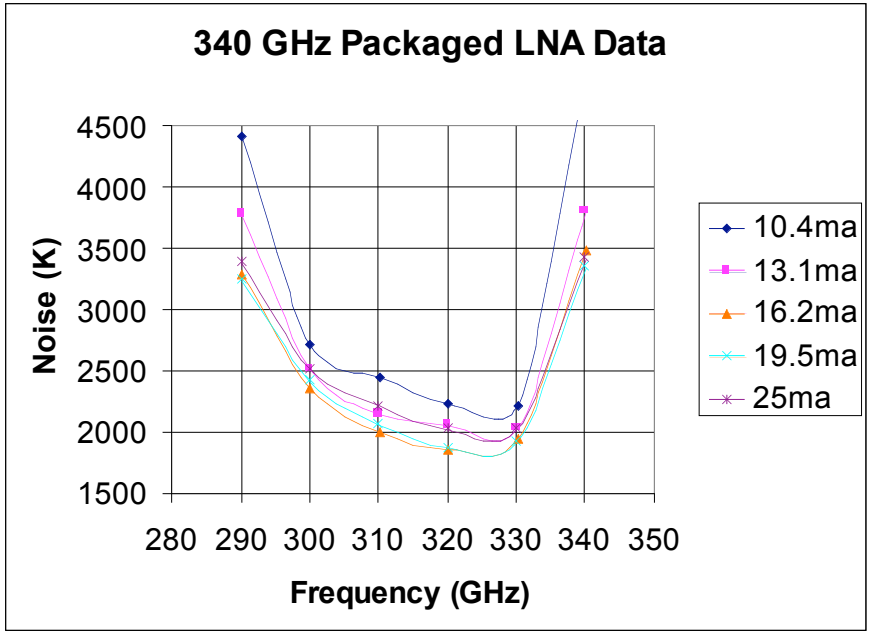
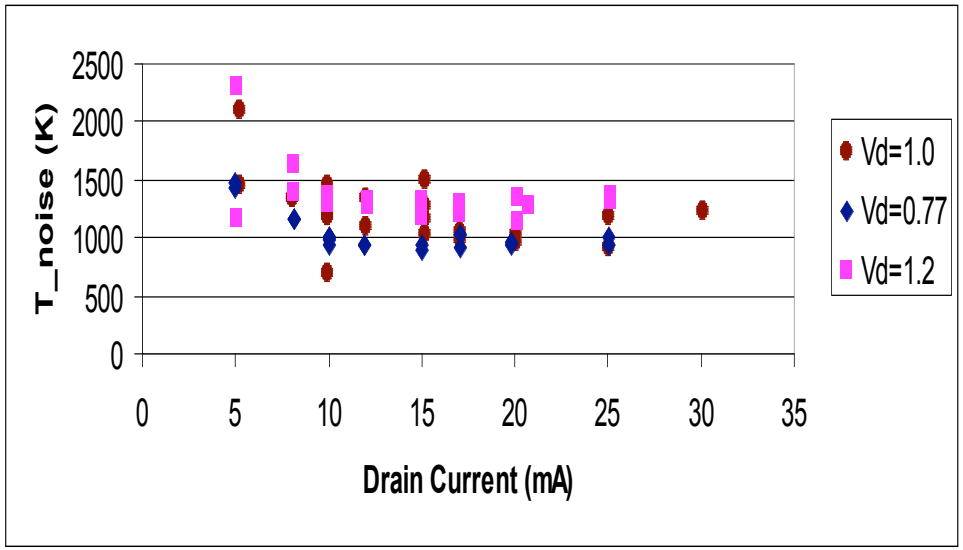
Courtesy E. Bryerton, M Morgan

NRAO MMIC Design on NGST 35 nm Process



Courtesy E. Bryerton, M Morgan

Results beyond W-band



283 GHz Die level measurements