Novel Technology for Ultra-Sensitive Cosmology Instruments

G. Yassin

University of Oxford

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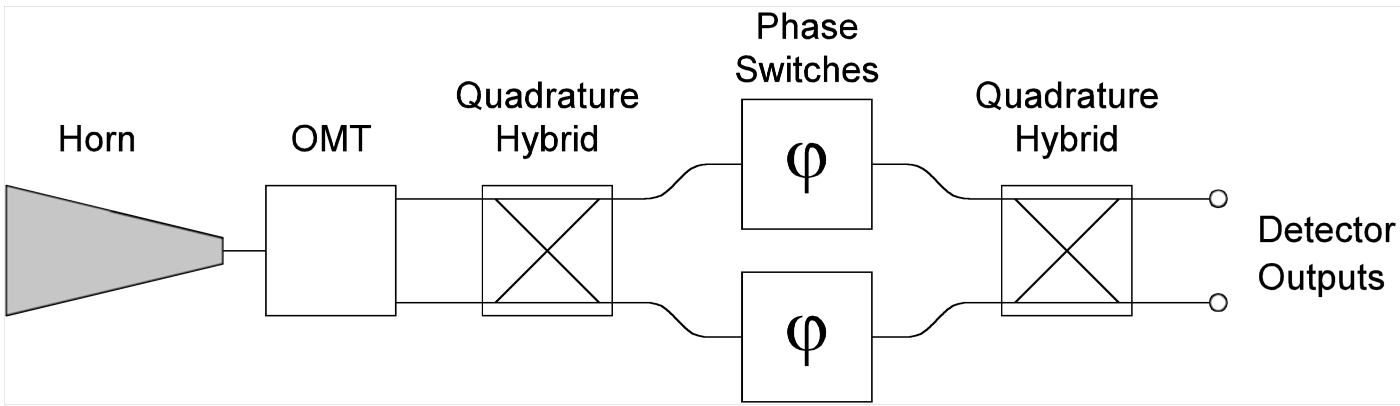
Technology for Ultra-Sensitive Cosmology Instruments

- CMB B-mode science requirements.
- Instruments Design
- Telescope
- **Feed arrays**
- **Phase modulation**
- **Detectors and readout**
- **Data acquisition**

Why Phase Modulate?

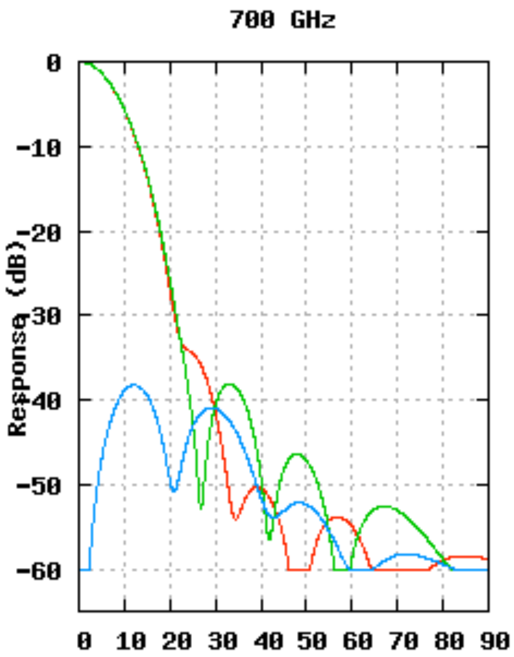
- Reduce 1/f noise
- Measure Stokes parameters without moving correlation receiver components

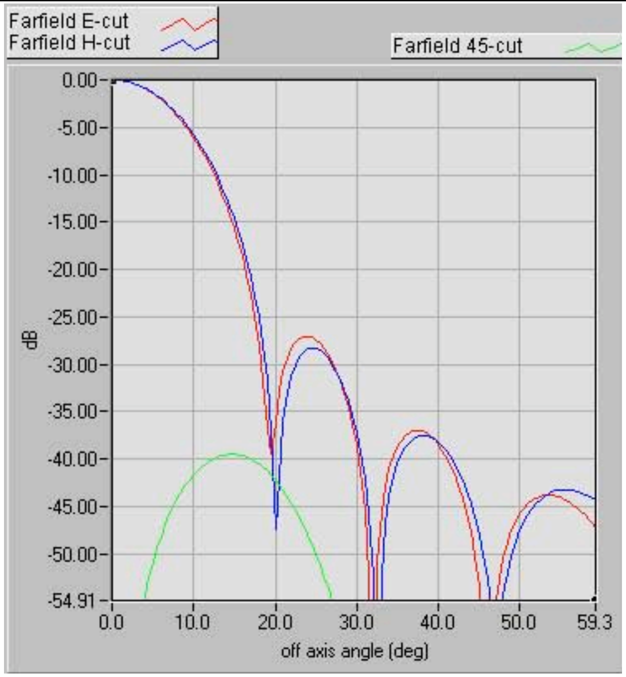


$$D1 = I - Q\cos\psi - U\sin\psi$$
$$D2 = I + Q\cos\psi + U\sin\psi$$

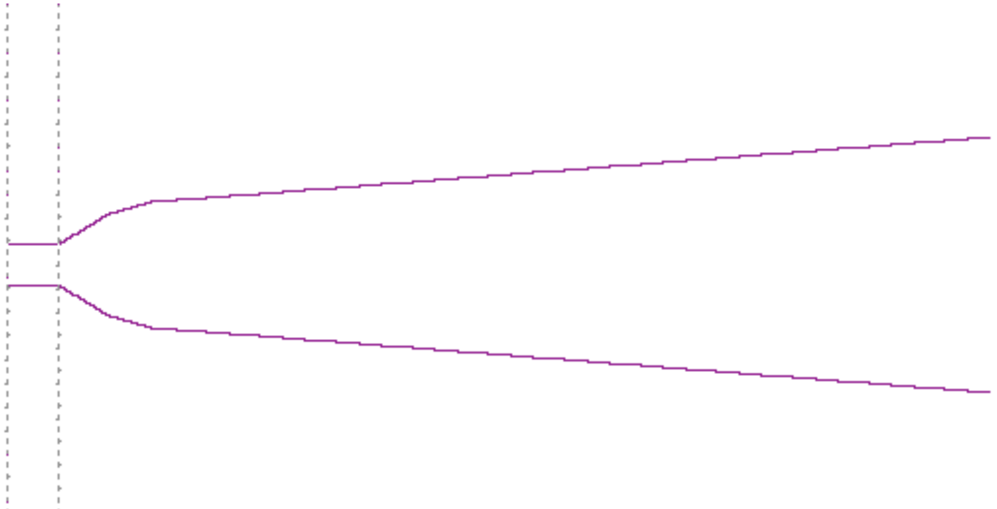
Multi-flare (smooth-walled)

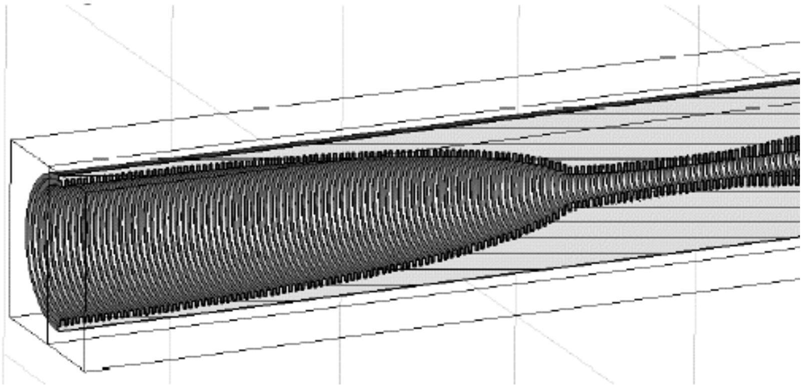
Three flare-steps horn



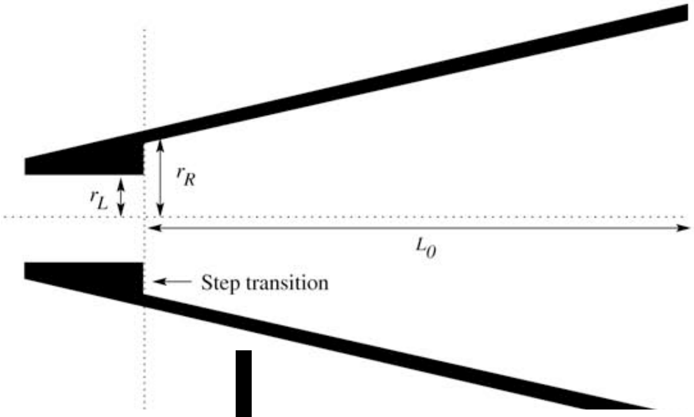


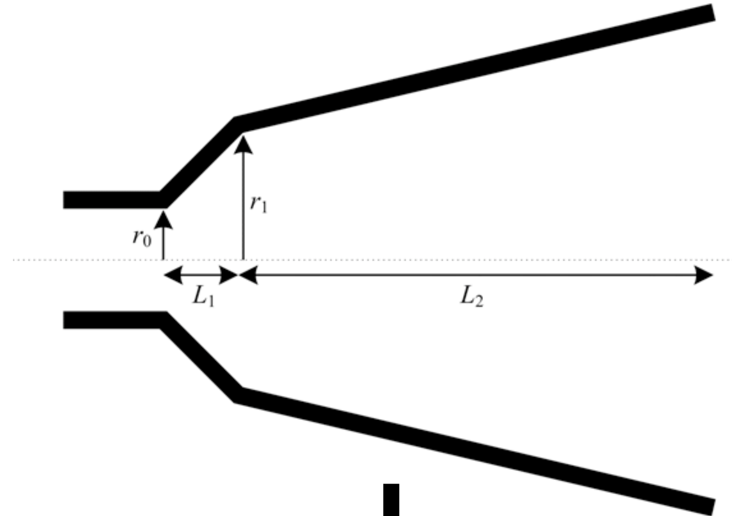
Profiled Corrugate horn

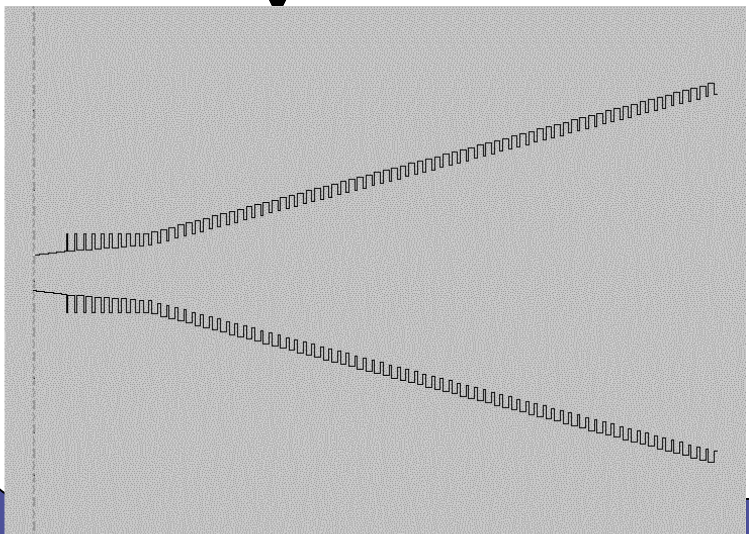


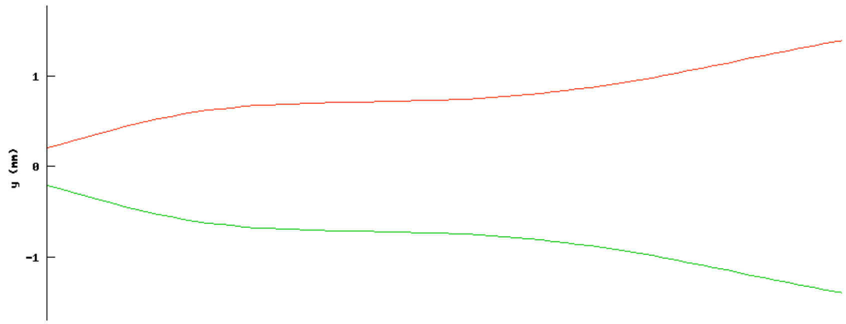


Generalize to a wideband horn





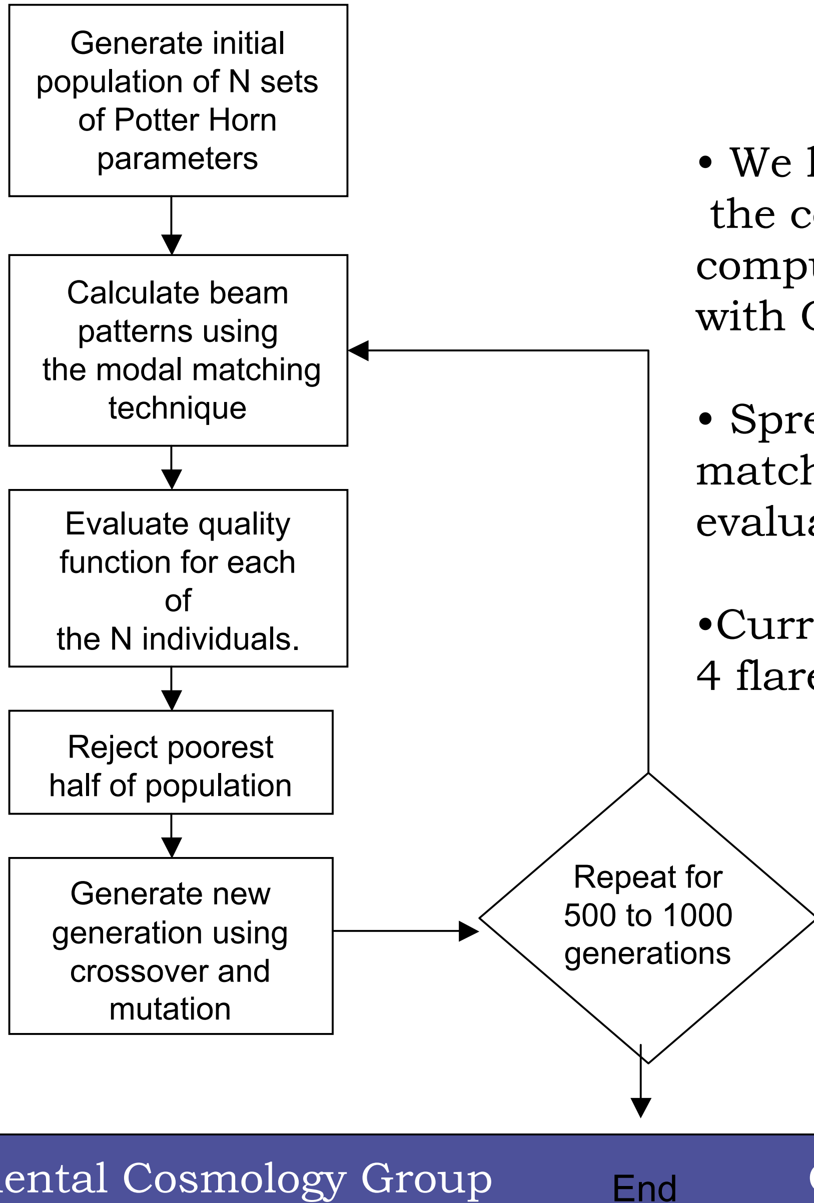




Hornsynth Software Package

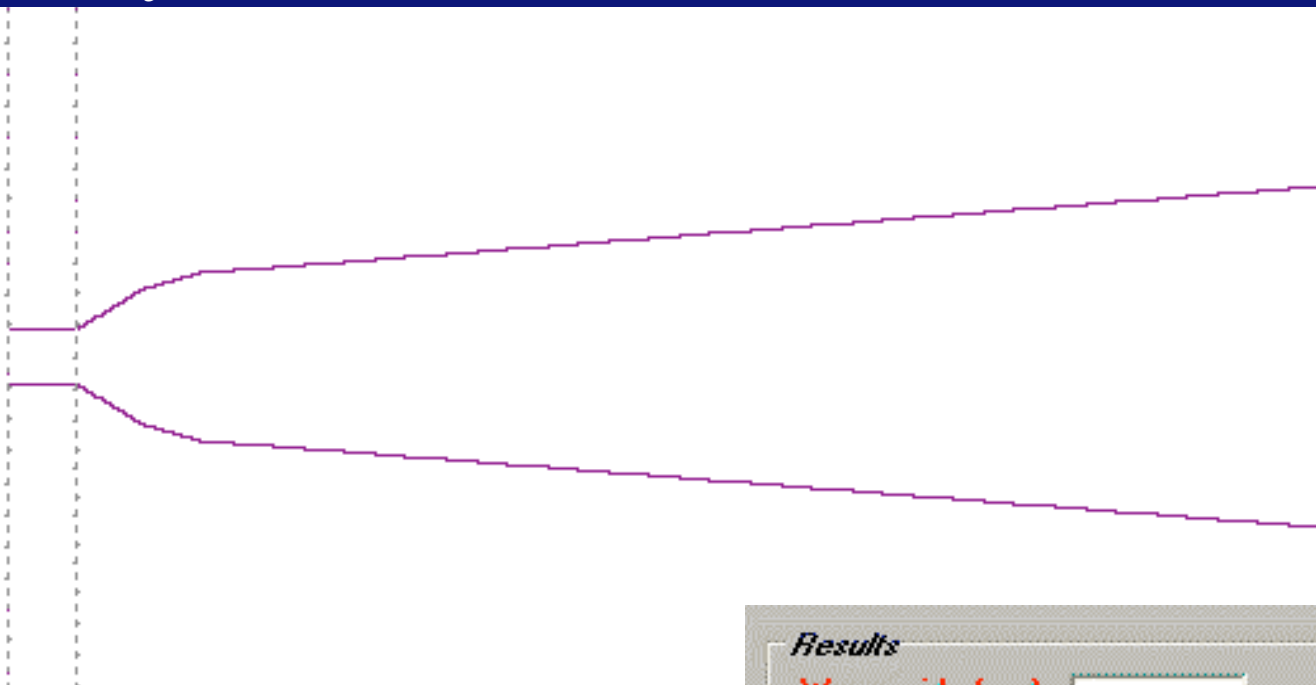
- Written by P. Kittara , A. Jiralucksanawong (Mahidol University, Thailand) in collaboration with Ghassan Yassin (Oxford Physics)
- It consists of two software packages: (1) modal matching software (2) Optimization software
- The minimization package is a Genetic Algorithm routine and a Simplex routine
- The software searches for the global minima according to a “fitness” criteria. In our case it is the circularity and cross-polarization level.

Design using a Genetic Algorithm (GA)

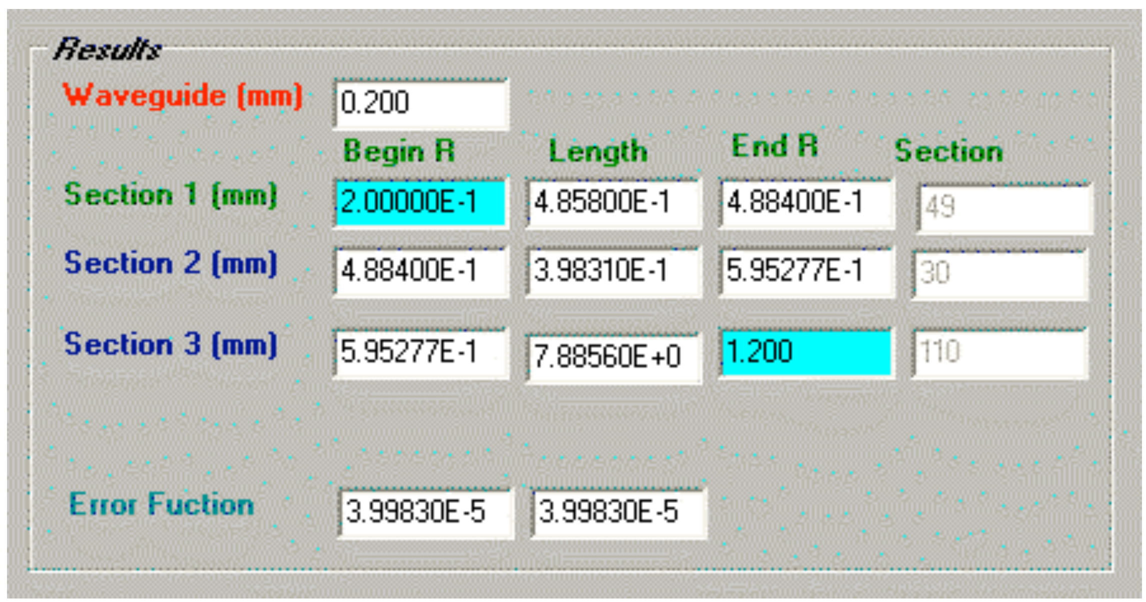


- We have successfully parallelized the code to run over the UK GRID computing system, in collaboration with Oxford eScience.
- Spread processor intensive modal matching and quality function evaluation over multiple processors.
- Currently optimizing designs with 4 flare angles.

Three angles horn design



Hornsynth
output



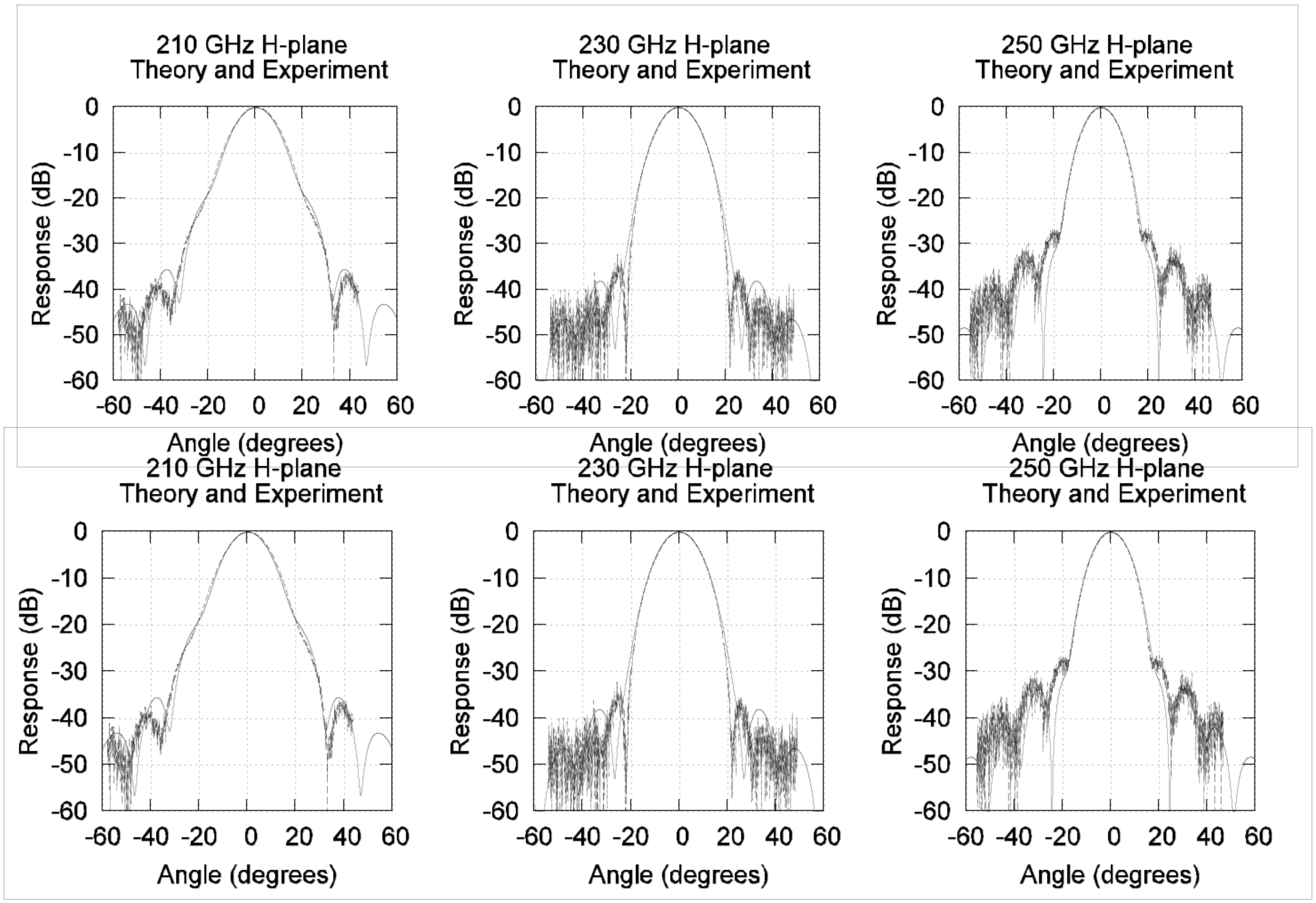
Results

Waveguide (mm)	0.200			
	Begin R	Length	End R	Section
Section 1 (mm)	2.00000E-1	4.85800E-1	4.88400E-1	49
Section 2 (mm)	4.88400E-1	3.98310E-1	5.95277E-1	30
Section 3 (mm)	5.95277E-1	7.88560E+0	1.200	110
Error Fuction	3.99830E-5	3.99830E-5		

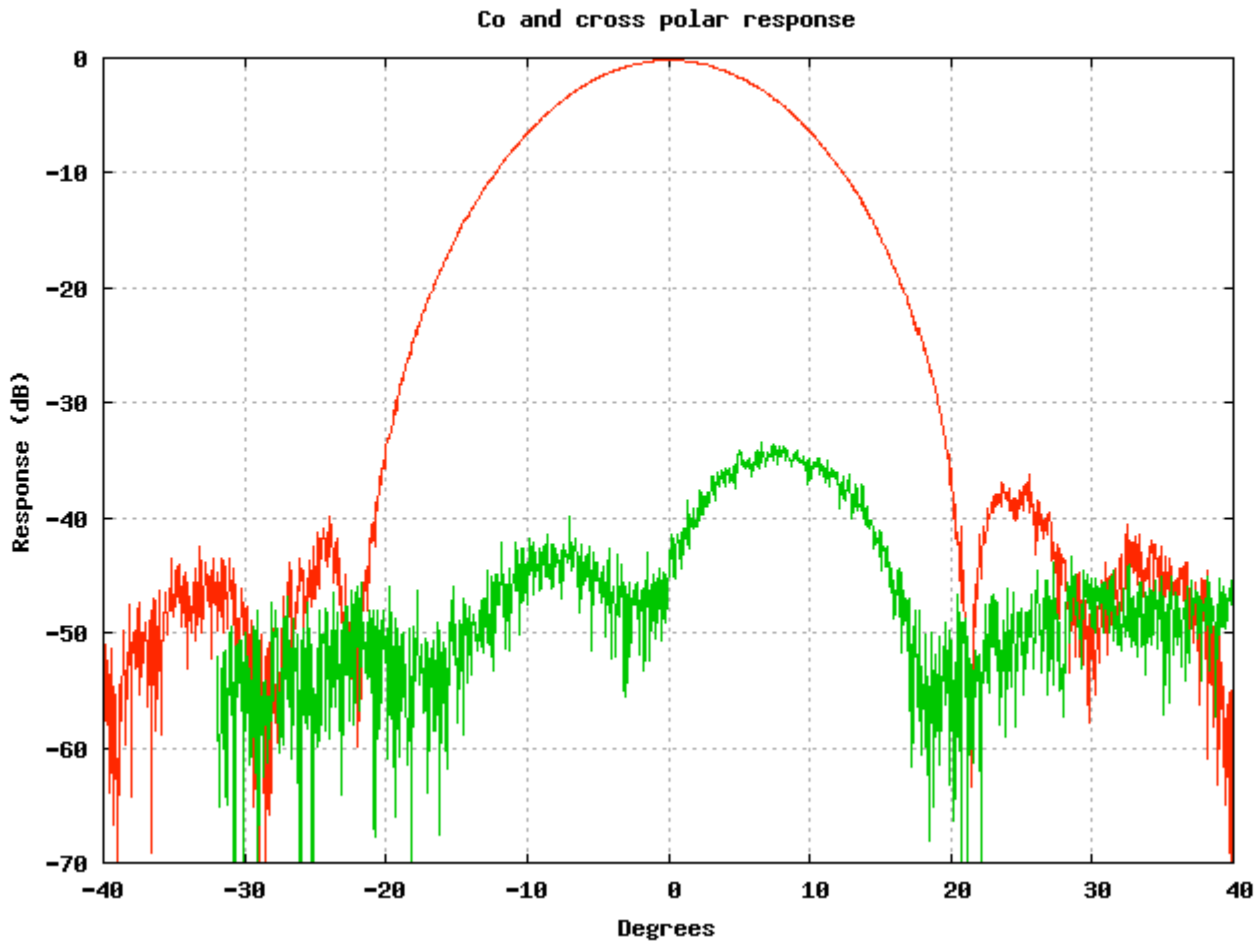
Horn dimensions at 230 GHz

Initial waveguide radius,	1.24 (mm)
Length of the 1st conical section,	1.479
Radius of the 1st conical section,	1.486
Length of the 2nd conical section,	1.212
Radius of the 2st conical section,	1.812
Length of the 3nd conical section,	2.4
Aperture	3.652

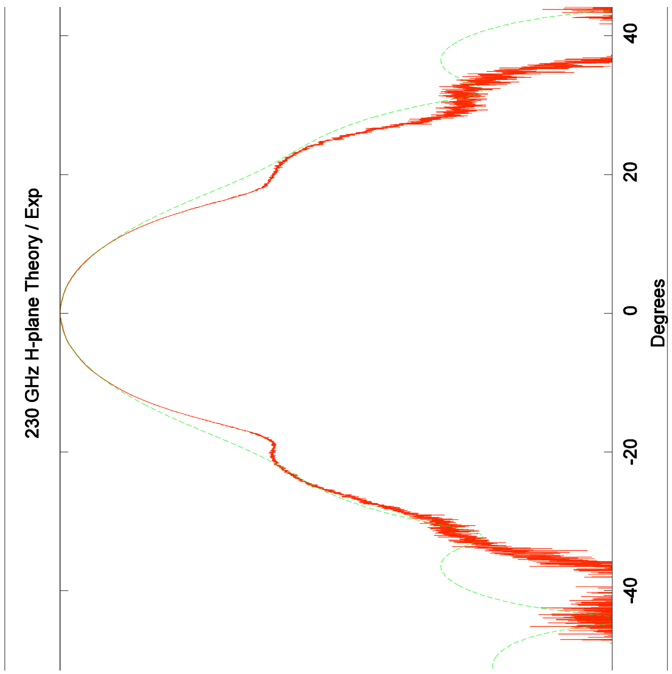
Radiation pattern of electroformed horn

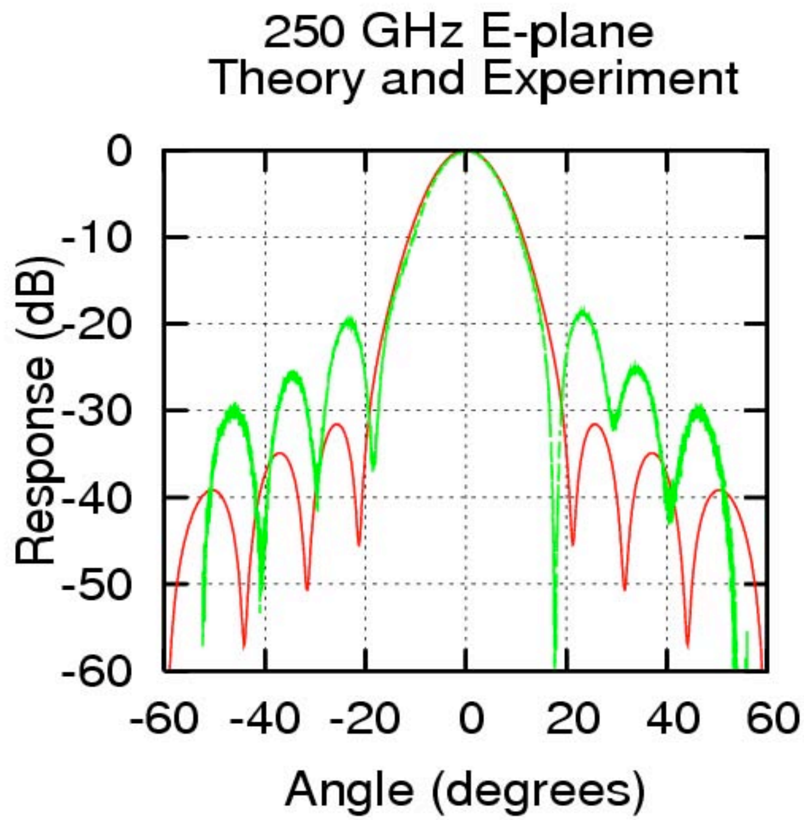


Cross Polarization Measurement

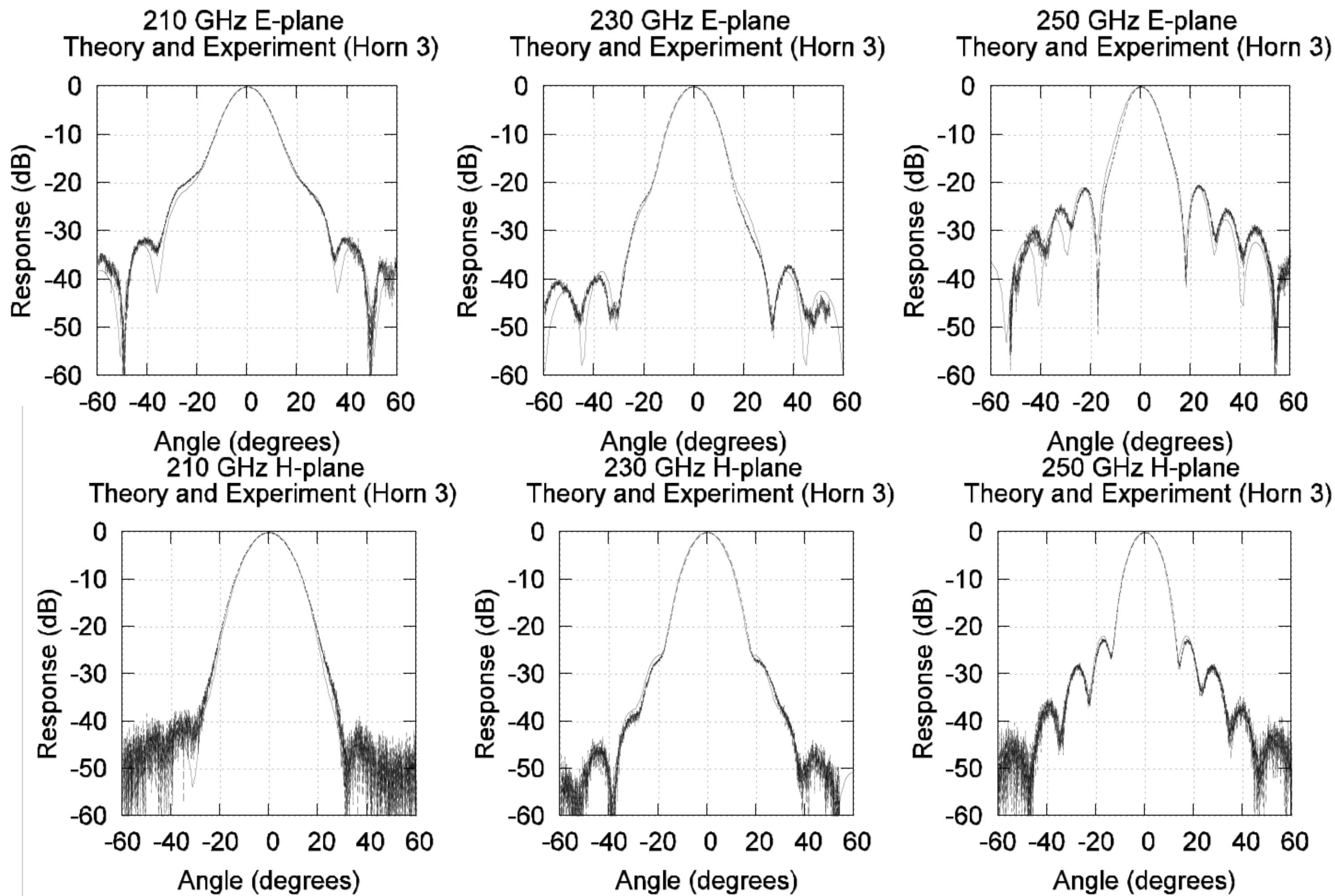


Drilling Technology



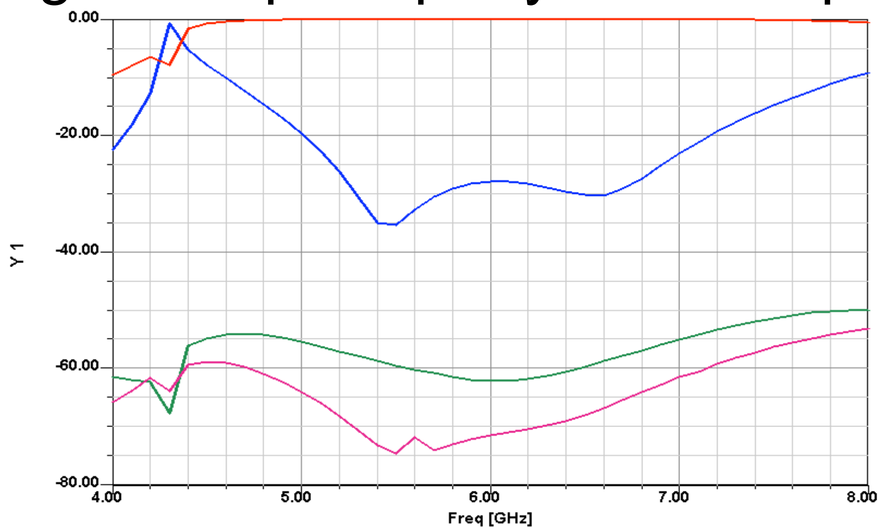


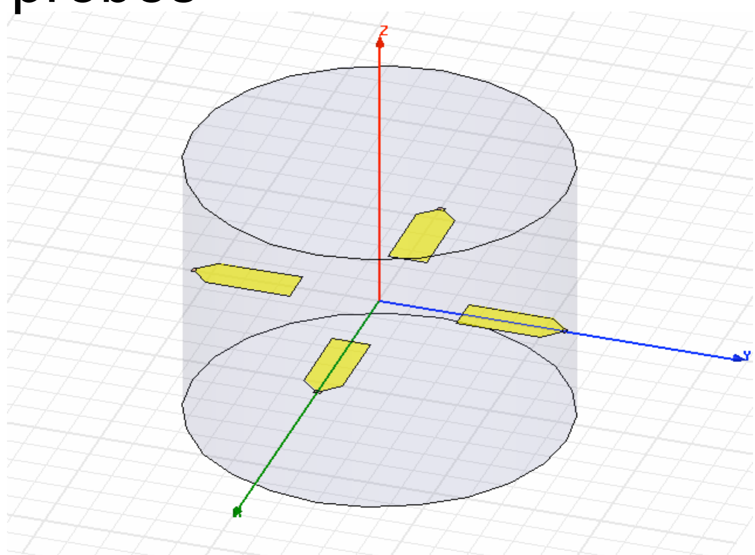
Radiation pattern of drilled horns



Four probe OMT

- Combine orthomode transducer and waveguide to transmission line coupling in single on-chip structure
- 4 rectangular probes in circular waveguide
- Probes sit in front of waveguide backshort
- Each pair of probes only respond to one polarization mode
- Signal is split equally between pair of probes

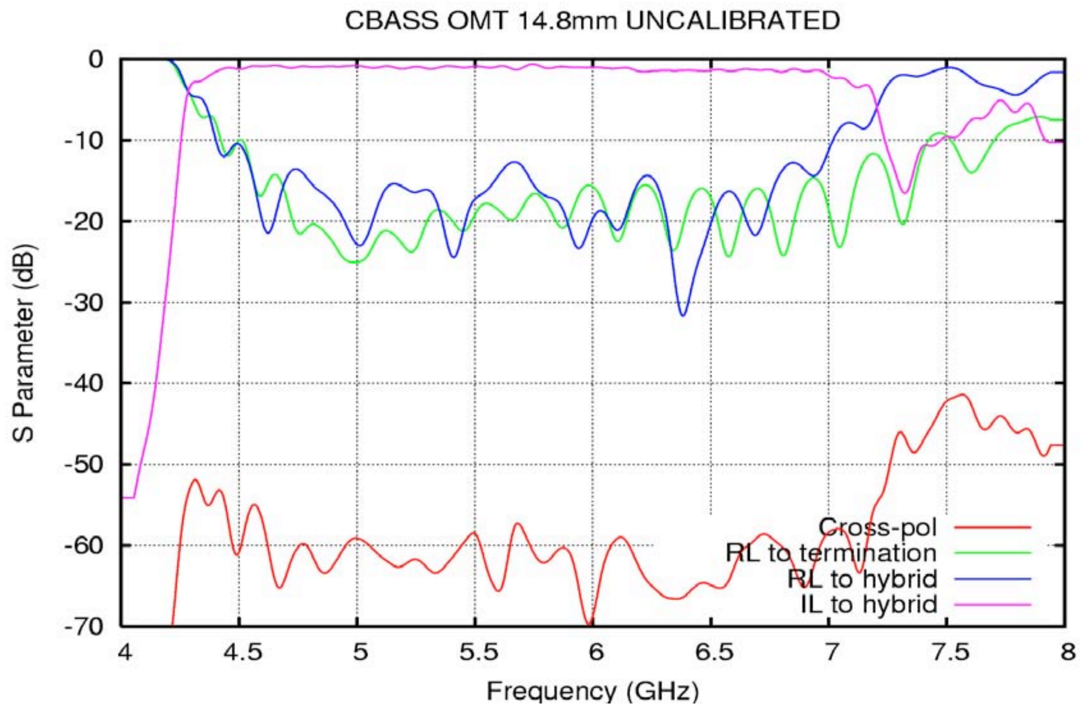


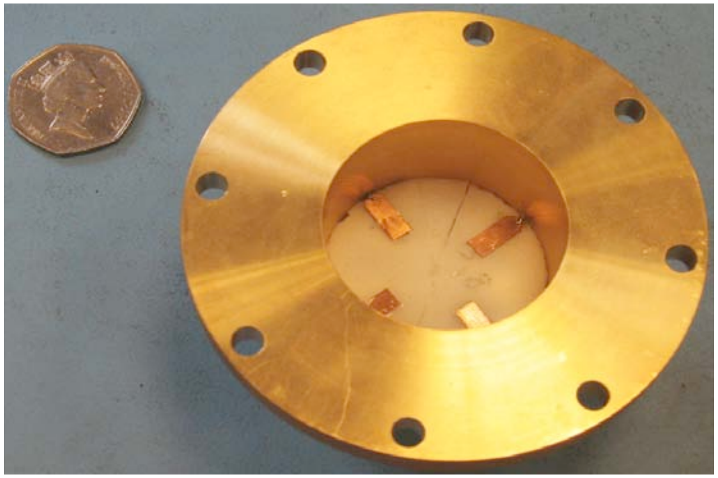


- Recombine signals in 180^{O} hybrid, or send to separate detectors
- Hybrid improves cross-polar rejection - usually by > 20 dB
- Design is optimised in HFSS to give best return loss and cross-polar performance over desired band

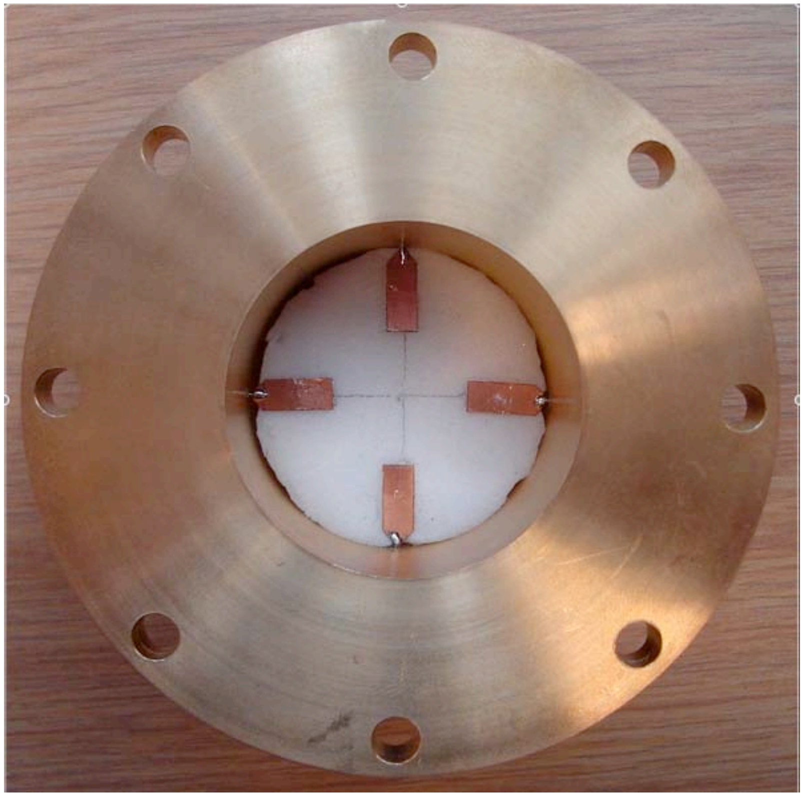
Four probe OMTs in action

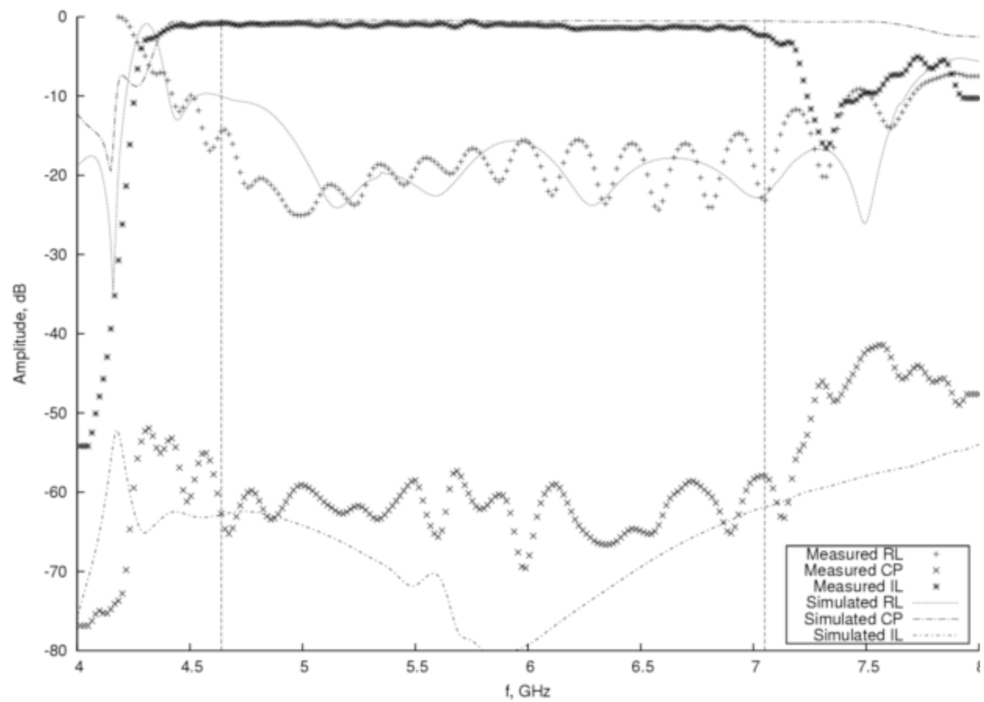
- 4 probe OMTs have been developed for C-BASS, a 5 GHz polarimeter, and the 150 and 225 GHz channels of Clover
- Now working on OMT for 350 GHz CEB





CBASS OMT at 5 GHz





Grimes *et al Electron Lett.*, 43, 1146, 2007

Oxford Physics

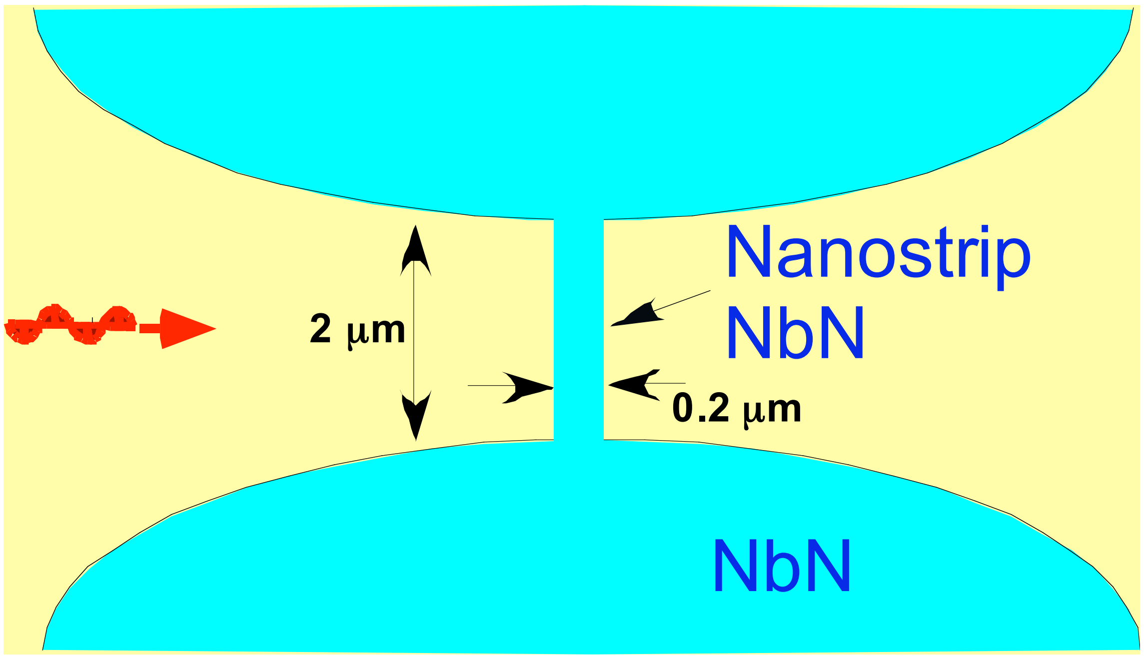
Existing Methods of Modulation at Millimetre wavelengths

- Mechanical rotation: difficult and expensive to realise and mass produce in cryogenic environment and expensive
- Faraday Rotor Ferrite Rods: difficult to mass-produce and lossy.
- Rotating Wave-plate: Obstructs the array can suffer from anisotropy.

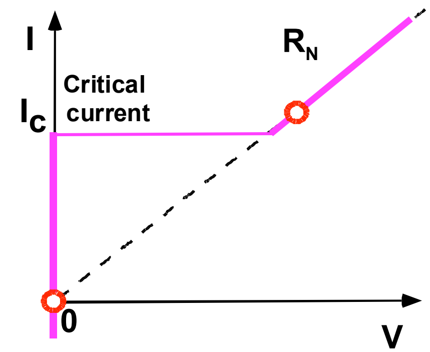
Planar Phase Modulation

- Collaboration between Oxford and Chalmers
- References:
  - Yassin,G., Kuzmin, L. S., Grimes, P., Tarasov, M., Otto, E. and Mauskopf, P. D. (2007) "An Integrated Superconducting Phase Switch for Cosmology Instruments" *Physica C: Applied Superconductivity and Application,* vol. 466 (issue 2) pp. 115-123
  - Kuzmin,L.S., Tarasov, M., Otto, E., Yassin, G., Grimes, P. K., and Mauskopf, P. D.(2007): "Superconductive sub-Terahertz nanoswitch," JETP Letters, vol. 86 no. 4 pp. 275-277.

NbN Nanostrip Switch



$$Z_0 << R +$$

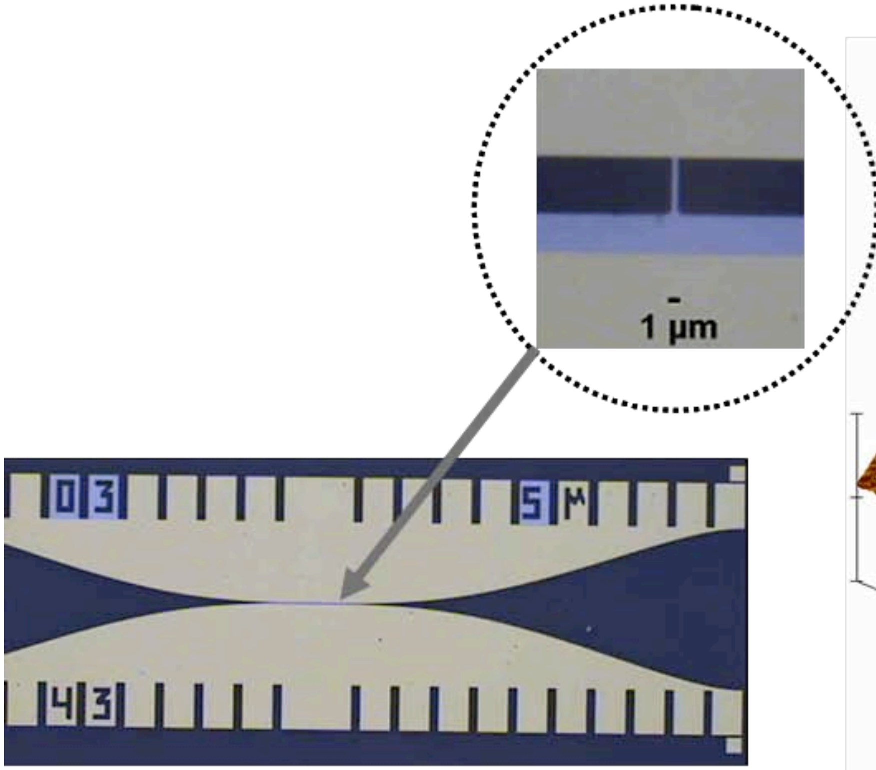


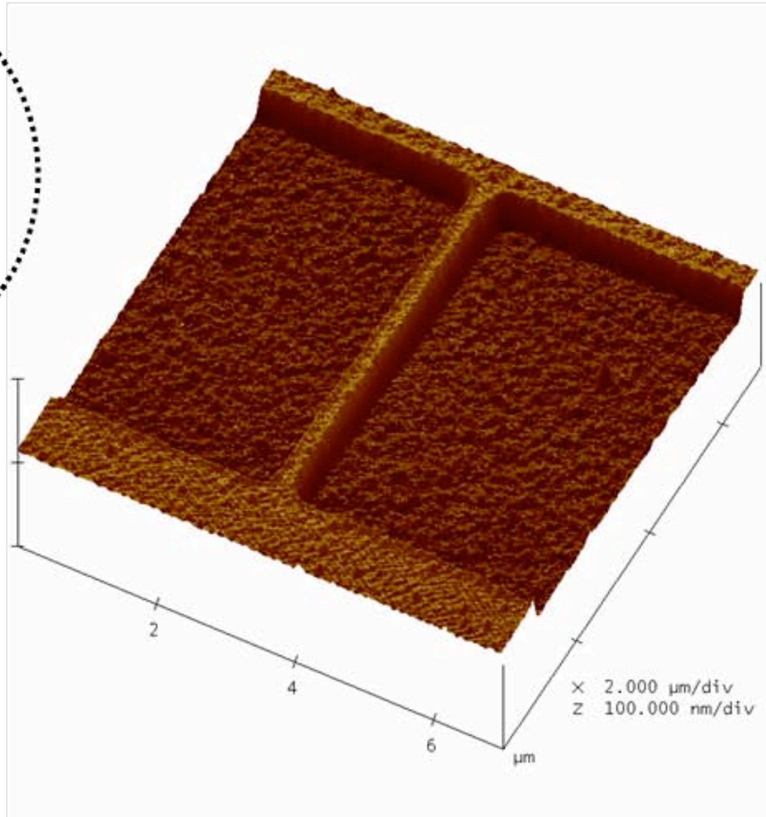
$$\omega L_c + \omega L_g << Z_0 << R$$

$$I_c = j_c * S, \quad L_c = \frac{\hbar}{2eI_c}, \quad R = \rho \frac{l}{S}$$

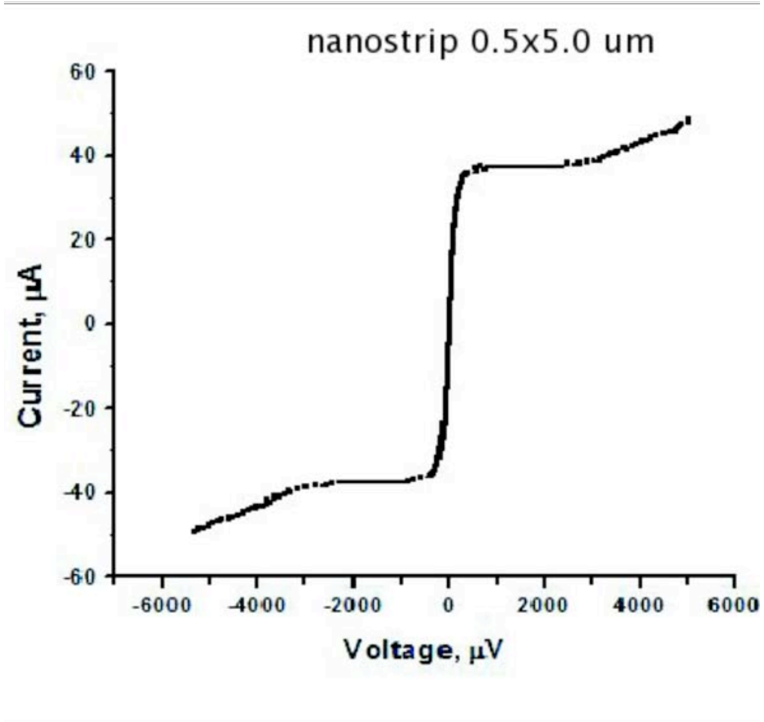
90, 150, 220 GHz

Devices fabricated at Chalmers

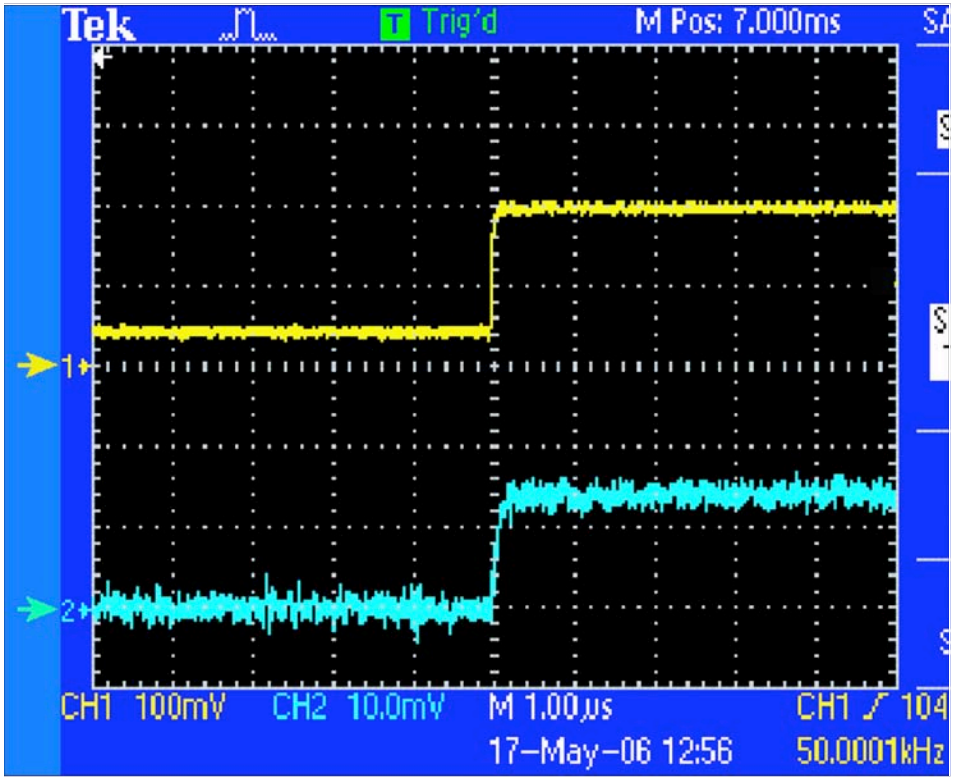




DC Tests

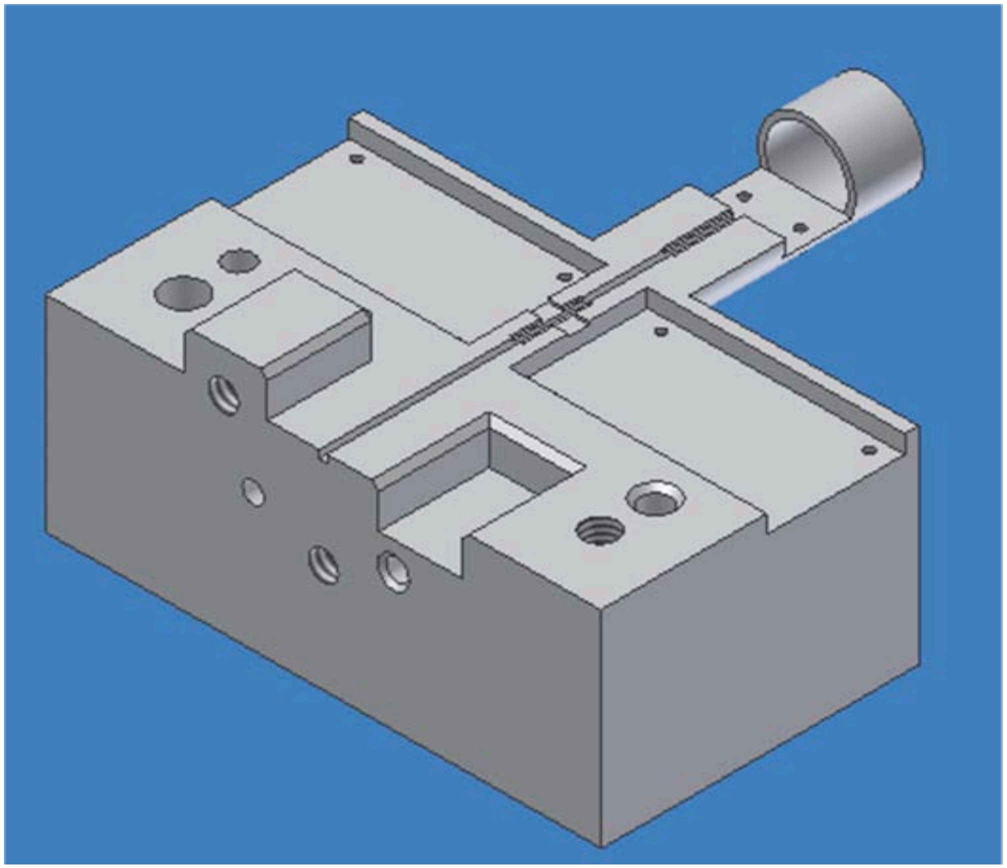


nanostrip 0.5x5.0 um
Current, μA
Voltage, μV
60
40
20
0
-20
-40
-60
-6000
-4000
-2000
0
2000
4000
6000

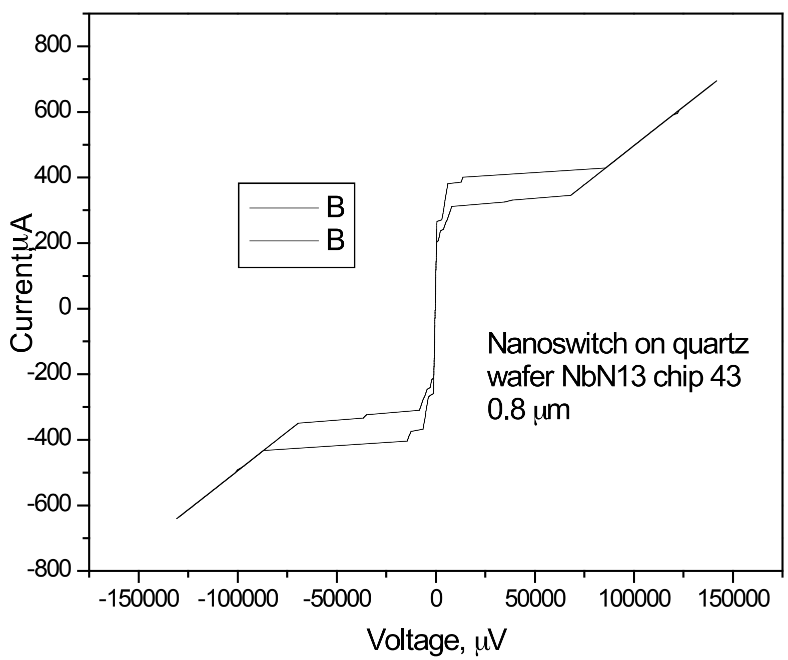


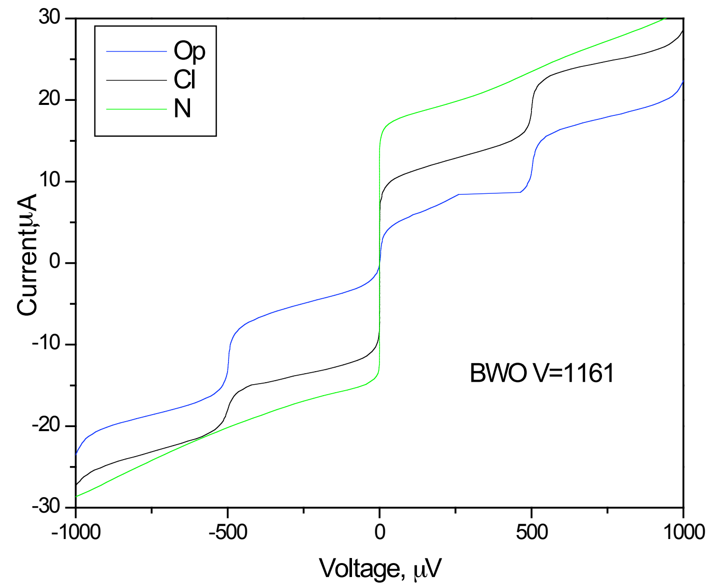
Tek
Trig'd
M Pos: 7.000ms
CH1 100mV
CH2 10.0mV
M 1.00μs
17-May-06 12:56
50.0001kHz

Detector Block for Phase switch RF tests

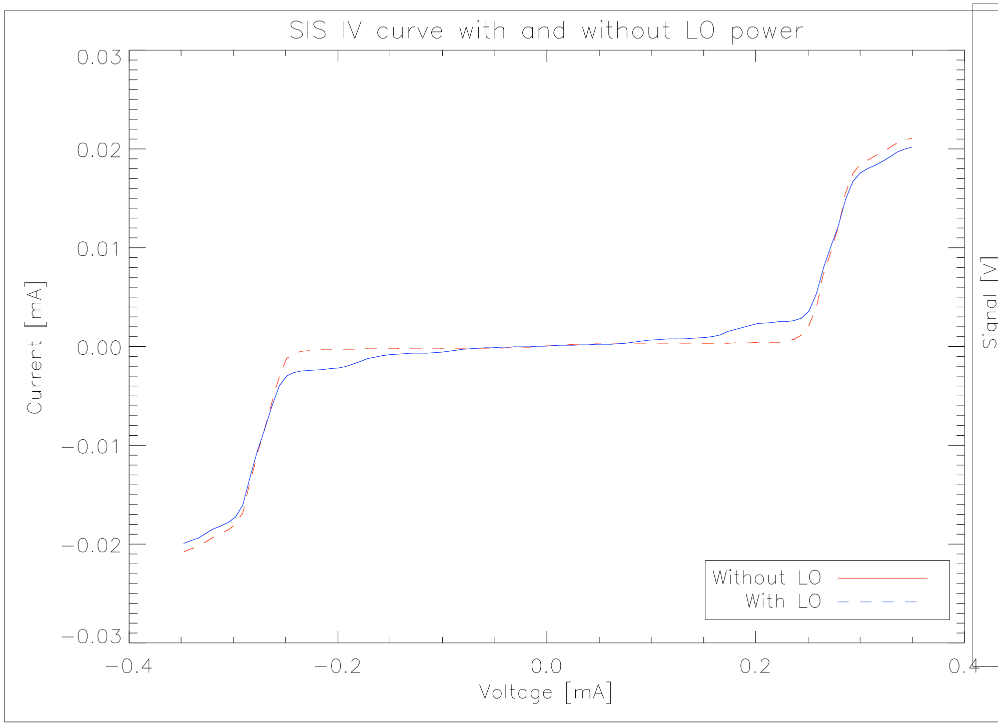


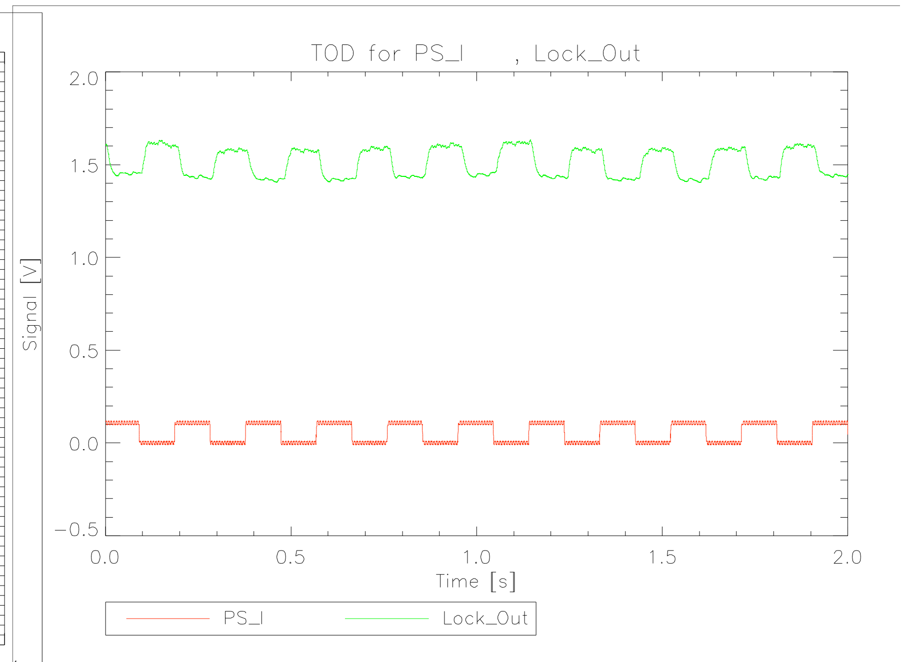
RF Results see Kuzmin et al





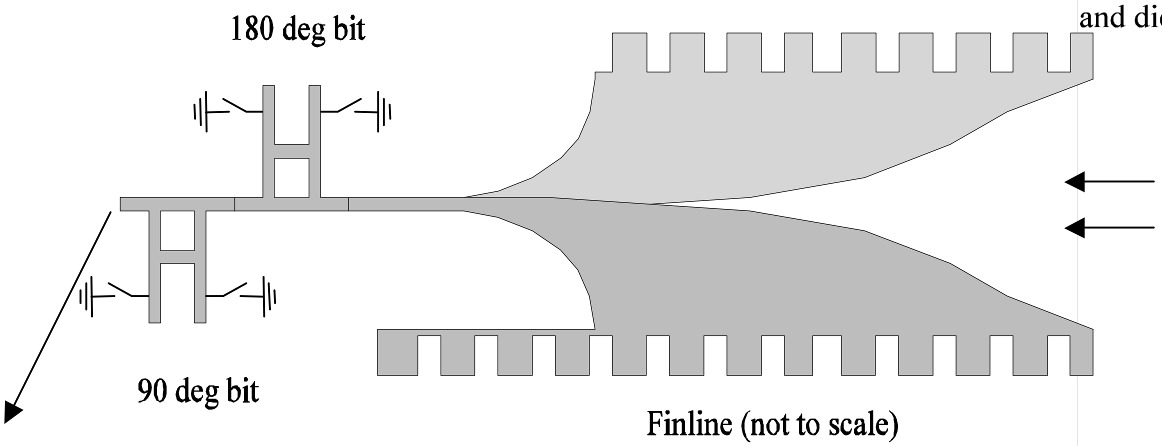
Preliminary Results at oxford

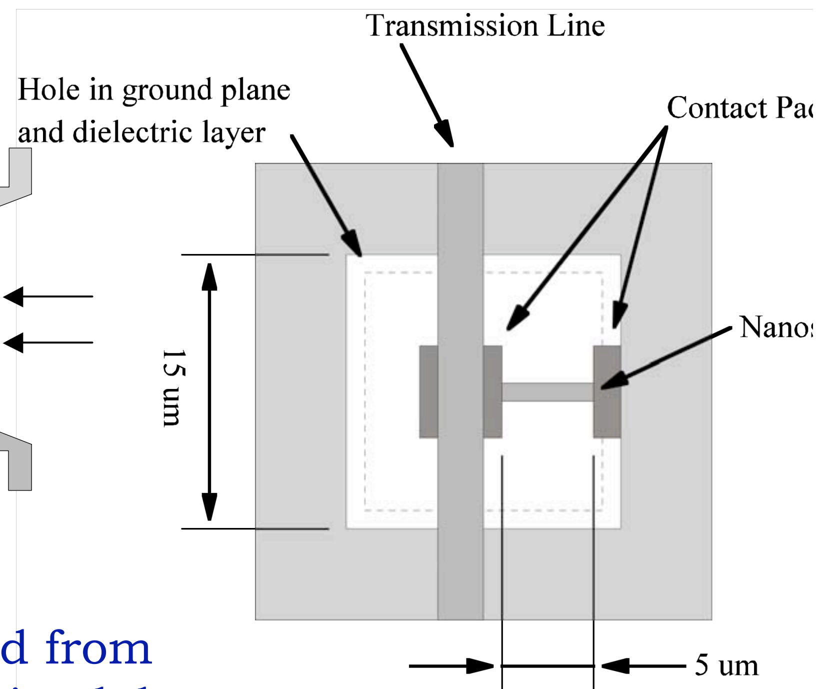




Phase Modulation work at Oxford…Cont

- Stage Three: Integrate nanostrip in microstrip: Designed





Nonostrip in microstrip

Potential detectors Used in CMB instruments

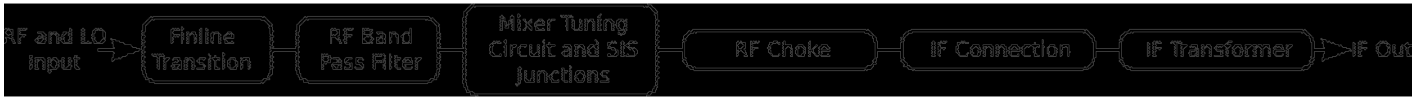
- SIS
  - Very high dynamic range and saturation power
  - Very fast response
  - Cheap readout
  - Easy to integrate with planar circuits
  - Can be used as a direct detector and a Mixer
  - Problem:
    - Suppression of pair tunnelling
    - Shot noise

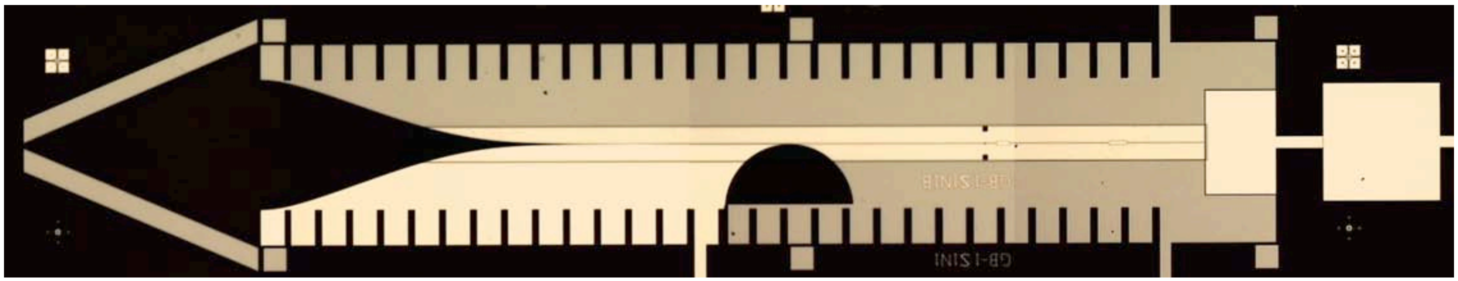
The Project

220-**G**Hz **U**ltra-**B**road**B**and **IN**terferometer for **S**-Z – GUBBINS

- Single baseline interferometer at 190-260 GHz
- 0.5m baseline, 0.4m primary mirrors (11’ primary beam)
- 2x SIS mixers, designed for ultra-wide IF bandwidth
- Single closed cycle cryostat
- Single LO with phase switching in LO optical path
- Very wideband IF system:
  - Wideband, low noise IF amplifiers (initially 3-13 GHz, with upgrades intended)
  - 2-20 GHz analogue sideband separating complex correlator with 16 spectral channels

Ultra-wideband SIS mixer





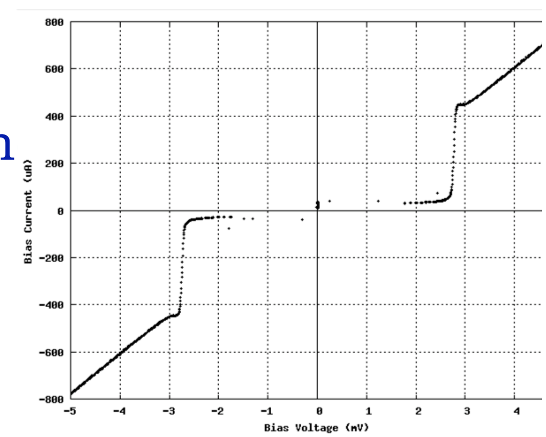
IF bandwidth 2-15 then extend to 20 GHz

Band pass filter to isolate the high IF frequen

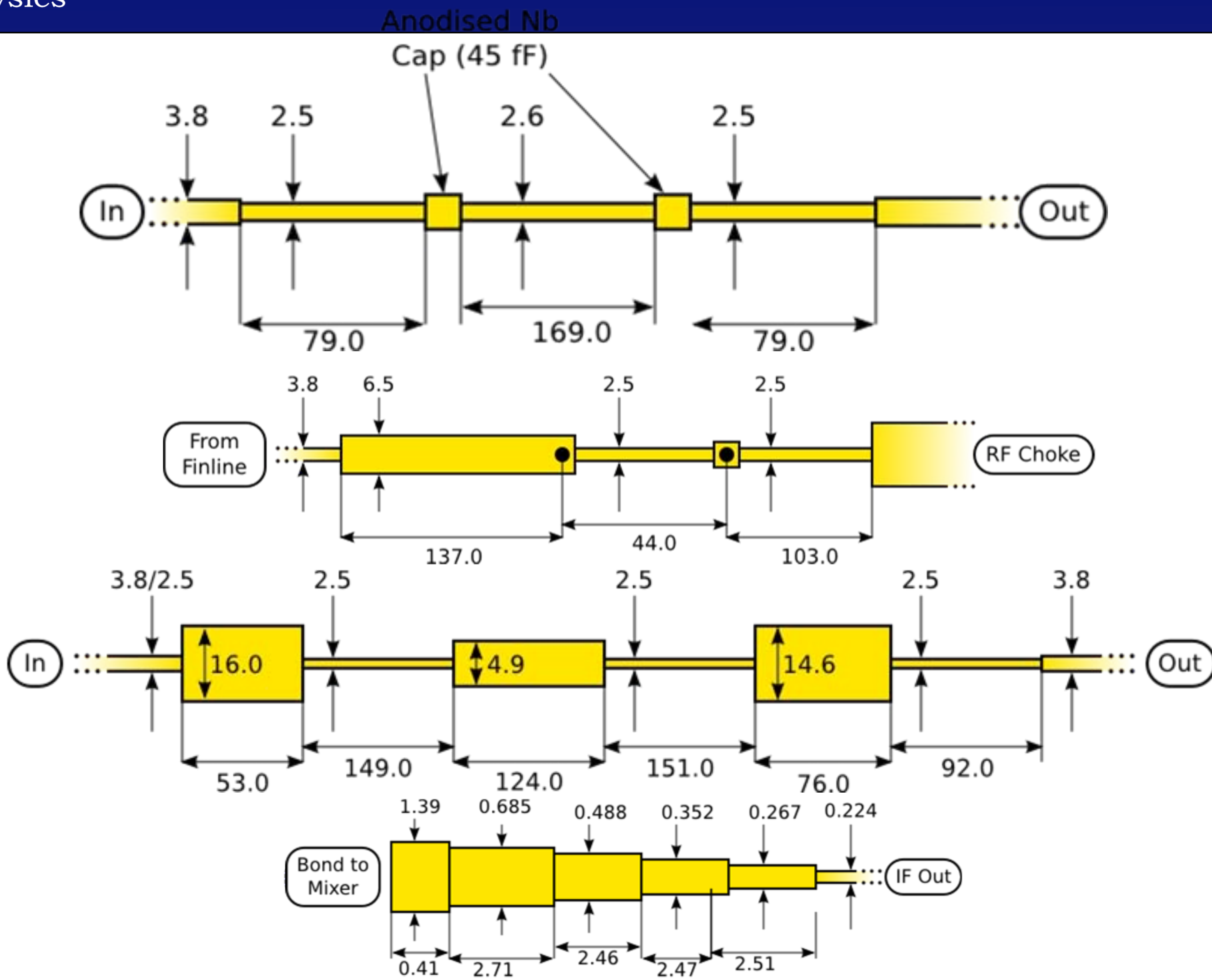
Complex mixer tuning circuits

RF transformer

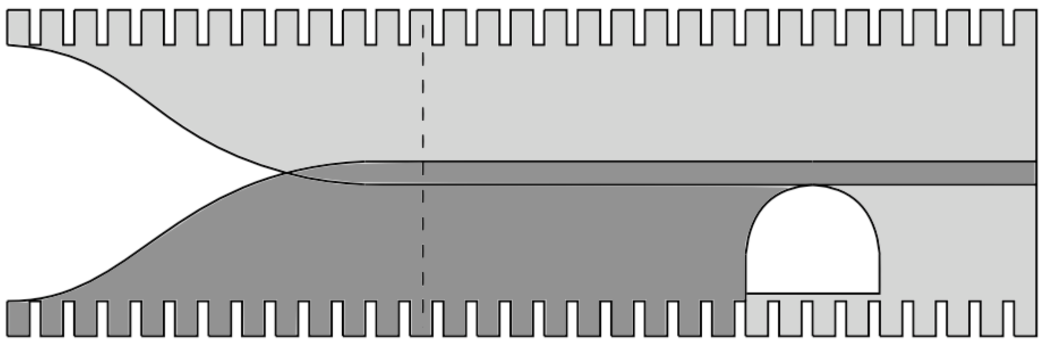
Grimes *et al*, STT, Groningen

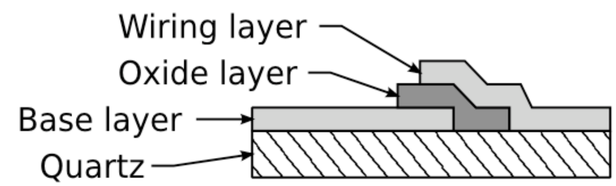


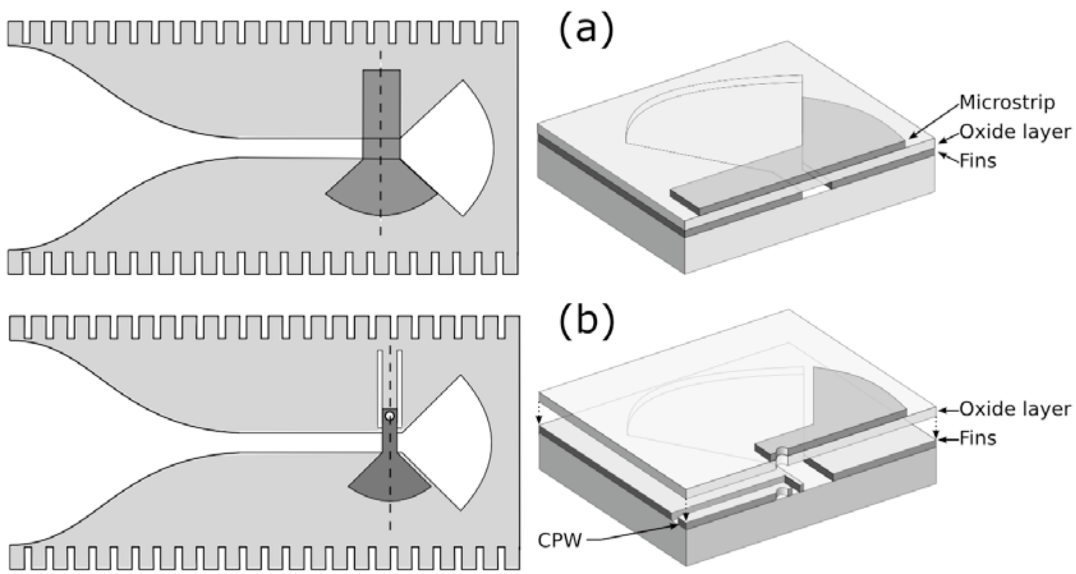
Mixer circuits



New Finline Transition

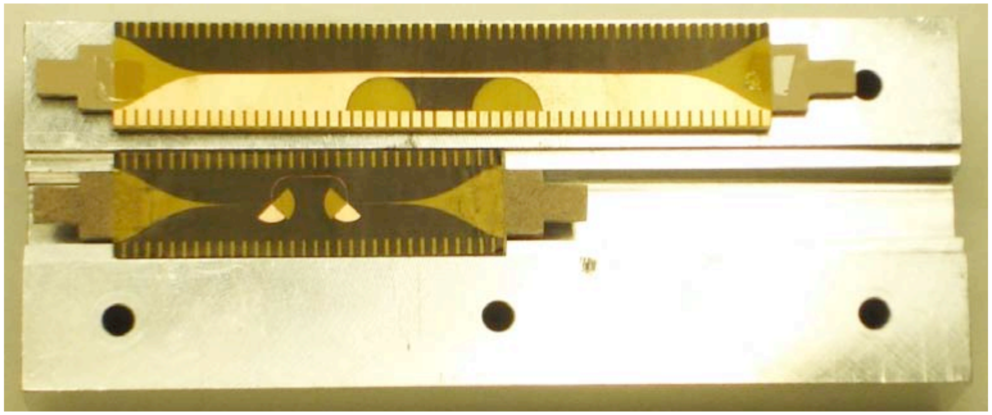


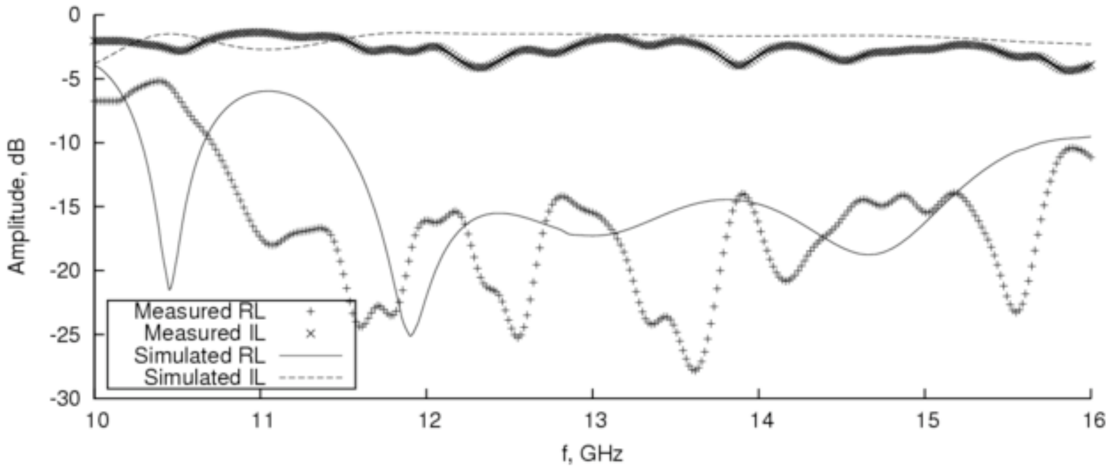




Yassin, *et al, Electron lett.* (in press)

Scale model measurements





Funding

- STFC rolling grant (to work on SIS mixers, CEB, planar phase modulation, CLOVER/CBI, correlators)
- Follow-on fund: Application deadline October, 7th- Development of horn arrays.
- PRD application: Application deadline, May- Correlator and on-chip LNA integration