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SEVENTH FRAMEWORK PROGRAMME

APRICOT (and other Relevant Technological Developments in Europe)

Peter Wilkinson
U. Manchester

RadioNet

EC Framework7 "RadioNet" Relevant Joint Research Activities

APRICOT : Q-band camera subsystems + MIC/MMICs
- Manchester, MPIfR, IRA, Yebes, Torun

AMSTAR+ : mm/sub-mm cameras (subsytems, SIS, MMIC)
- IRAM + MPIfR + many partners
- continuation of previous JRA
- new is R&D on W-band FPAs (IRAM telescopes)

UNIBOARD: high speed digital (FPGA) backends for many purposes
- ASTRON + many partners

Each now funded by EC at ~€1.2M for 3-year programme

Adding to national-level funding

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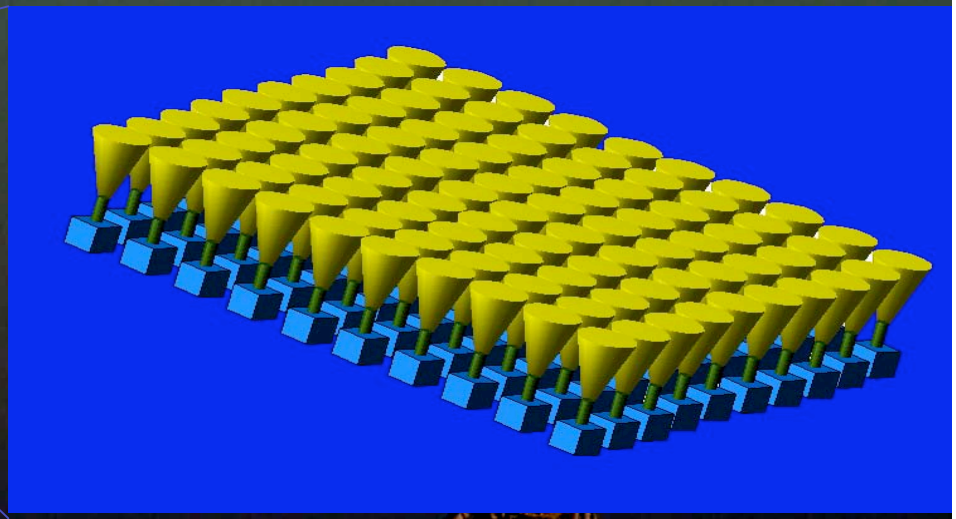
APRICOT aims

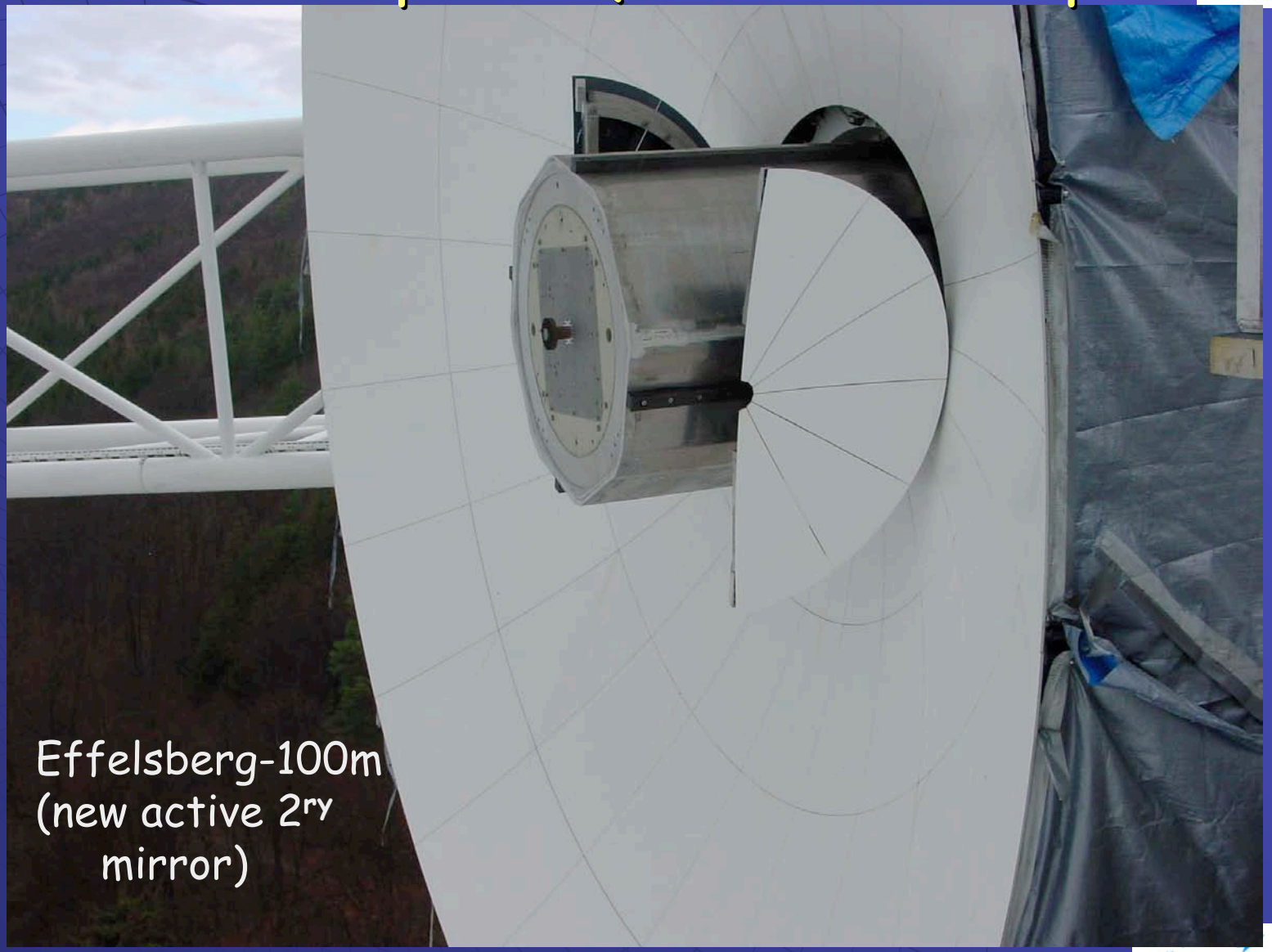


1) Design studies & sub-system prototyping for future large-format Q-band FPA cameras on large telescopes

2) Secure the availability of state-of-the-art MIC + MMIC devices from within Europe.

VERY STRONG OVERLAP WITH KISS & NRAO FPA AIMS

Some European Q-band telescopes



Effelsberg-100m
(new active 2ry
mirror)

Basic APRICOT Specs

- Operating range: 33-50 GHz
  - spectrally rich + many continuum applications
  - follow up with EVLA (& ALMA Band 1 in time?) and VLBI
- All Stokes parameters + spectroscopy
  - Continuum band split into 1-2 GHz sub-bands for atmospheric & spectral discrimination.
  - Broad-band IF output selected from anywhere within the overall band, sent to high-speed digital FT Spectrometers (resolution 0.1 km/sec = 15 kHz: UNIBOARD)

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Some relevant FPA experience

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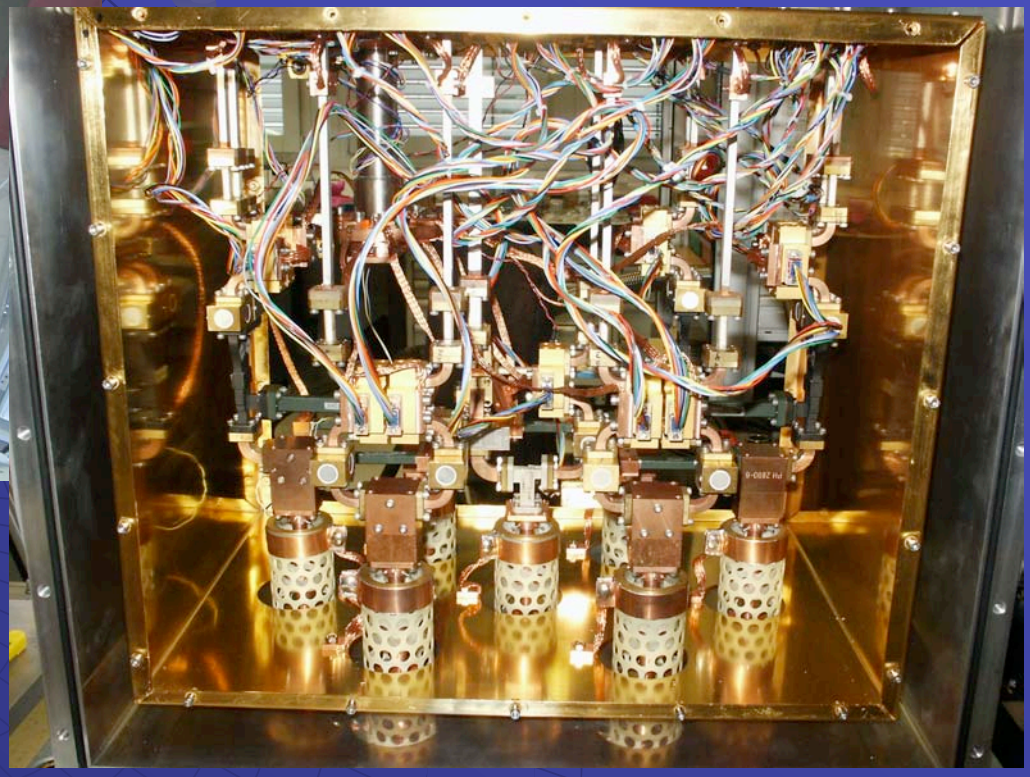
EMBA: MPIfR 32 GHz

- 7-beam horn array with different properties

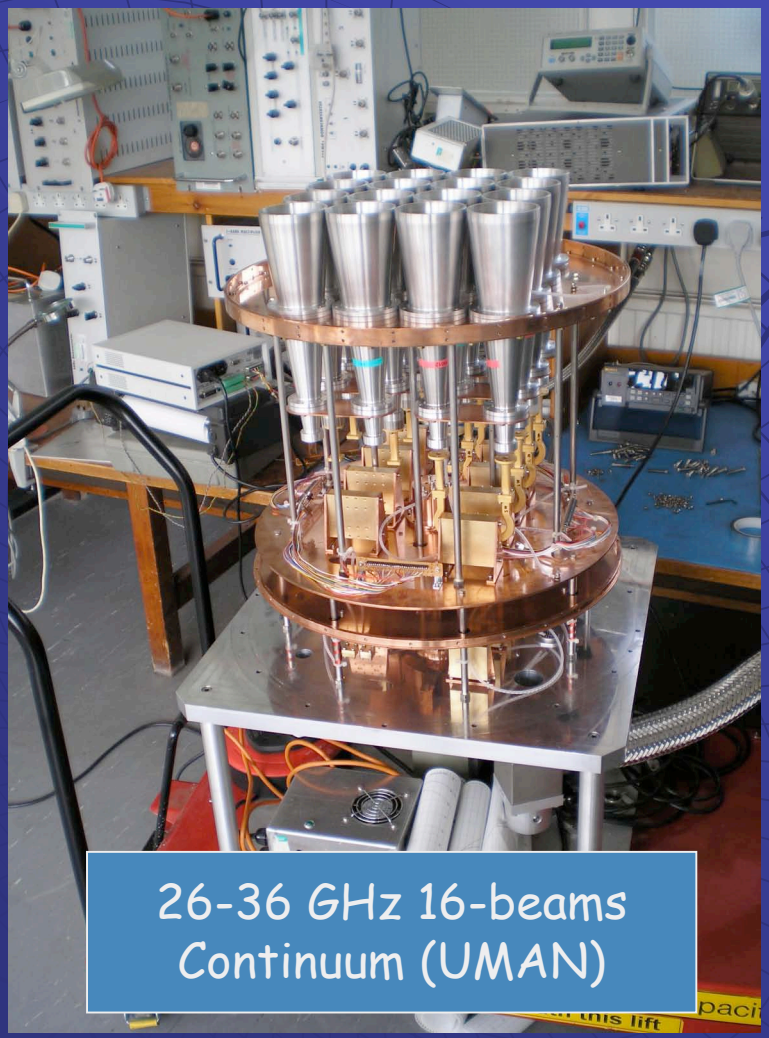
- Dewar interior



IRA 18-26 GHz

- 7 feed, hexagonal configuration with central feed
- 14 x 2 GHz IF outputs right and left polarization;
- Feeds and LNAs cooled at 20 K;
- Mechanical de-rotator to track the parallactic angle

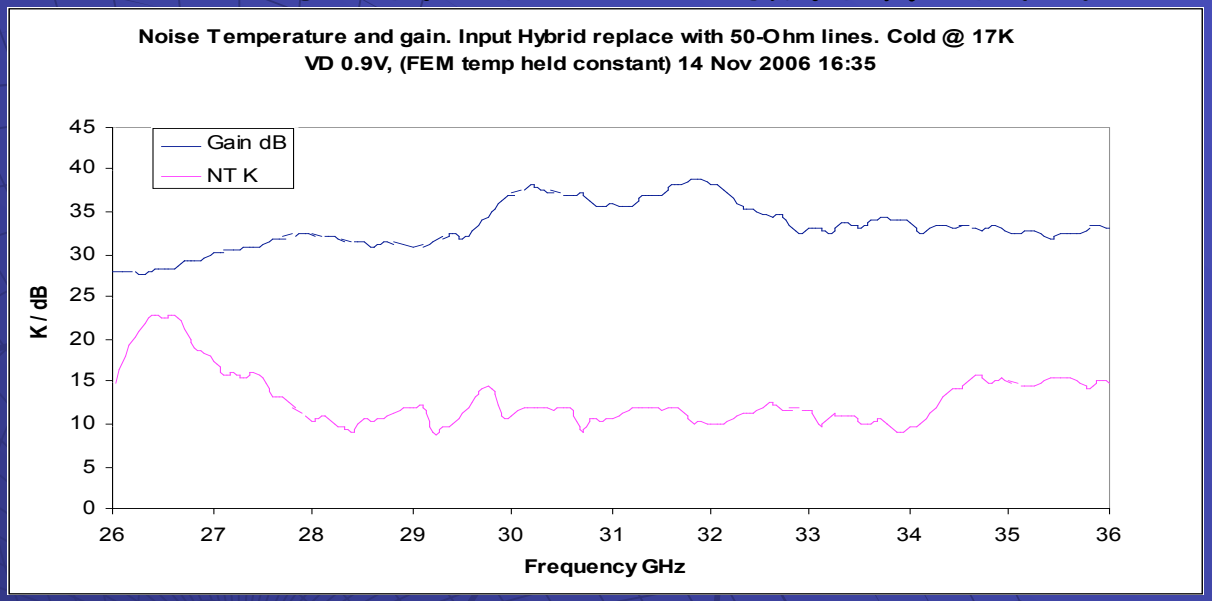
OCRA U. MAN 30 GHz



26-36 GHz 16-beams Continuum (UMAN)

- Single polarisation continuum 26-36 GHz
- Direct detection
- All-MMIC receiver based on WMAP/Planck-LFI design
- NGST InP MMICs designed by D. Kettle
- Self-supporting 480mm vacuum window

T_{LNA} ~ 14K (min 9K), Gain ~ 34dB over 30% bandwidth



T_{FEM} >20K
(losses in hybrids and input circuit)

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EXPERIENCE.....

- NGST MMIC procurement process and performance: very good (ITAR not so!)
- Dewar: many devices, cables, wires, connectors → big, complicated
- MMIC chip to "mass production" of LNAs → extraordinarily long
- Noise marker and LO distribution: simple in principle but_complicated
- LNA power supply: complicated, huge amount of thin wires
- Weight: great
- Maintenance: problematic

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Hence the need for major changes in approach…

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WP1 Receiver Architecture

MPIfR; IRA, UMAN, CAY, TCfA

Architectures for highly integrated multi-pixel receivers

- Modular design with well-defined interfaces
- Design for mechanical and cryogenic stability
- Optimise layout for maintenance/fault-fixing
- Design of monitor, control and calibration systems
- Integration of direct detection and heterodyne systems
- LO generation and distribution
- Design, packaging and integration of RF, IF, LO systems
- Establish capability to batch-produce RF, IF modules

Deliverables are mainly design study reports

WP2: passive components

IRA; MPIfR, UMAN

- Highly integrated chain with OMT, hybrids, transmission sections etc
- Low-loss, low size/weight, low cost, ease of manufacture
  - Standard waveguide technology too expensive
  - Needs technology shift
    → Planar technology, microstrip transmission lines and filters etc

Deliverables - design study reports
- few pixels hardware comparing performance of conventional and innovative approaches (with WP1 and WP3)

WP3: MIC/MMIC development

UMAN; IRA; MPIfR; CAY

- To develop and secure European supply of world-standard MMIC devices for astronomy
- To seek improved noise performance: closer to the quantum limit,
- To explore/achieve increased levels of integration & multi-function capability within a MMIC circuit.

MIC/MMIC producers

- Fraunhofer Institute (IAF) Freiburg
  - 100 & 50 nm GaAs mHEMT technology
  - Multi-function MMICs
  - Experimental 35nm processes
  - Now interested in low-noise at cryo temps

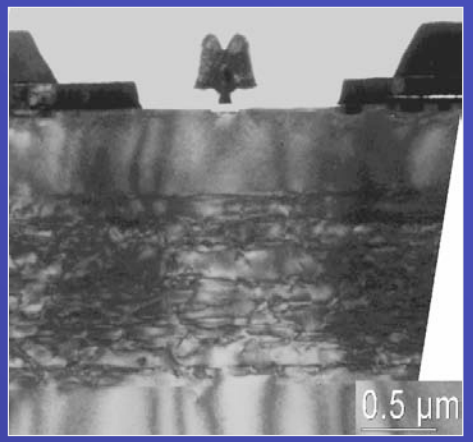
Link with MPIfR & Yebes with AMSTAR+

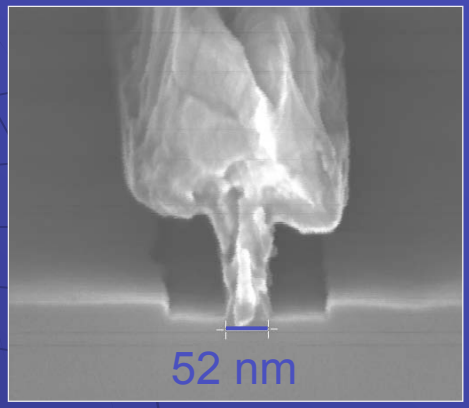
- U. Manchester
  - 100nm InP HEMT technology
  - innovation in materials and architecture for low-noise
  - rapid response to new design inputs

- OMMIC company
  - 70nm GaAs mHEMT technology

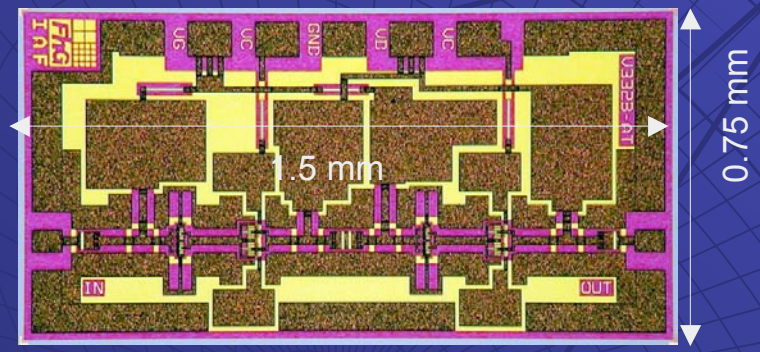
IAF: 50 nm Metamorphic HEMT Technology

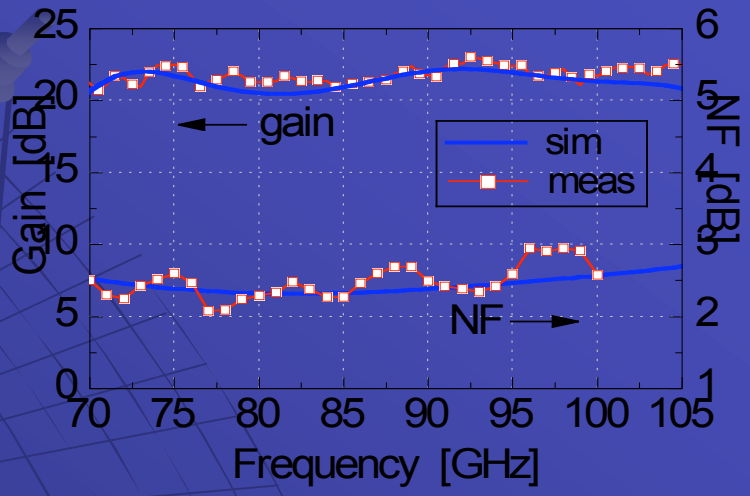
- $In_{0.52}Al_{0.48}As/In_{0.80}Ga_{0.20}As/In_{0.53}Ga_{0.47}As$ composite channel HEMTs
- E-beam defined T-gates
- wet etched mesa
- four layer resist (PMMA)
- $g_{m,\,max}$ = 1800 mS/mm
- R_c / R_s = < 0.1 Ω·mm / < 0.2 Ω·mm
- f_T / f_{max} = 400 GHz / 420 GHz





IAF: Two-Stage W-Band MHEMT Low-Noise Amplifier





- Gate width: 2 x 30 μm
- Gate length: 50 nm
- Coplanar waveguide technology

- Gain: 23 dB @ 94 GHz
- Noise figure: 2.4 dB @ 94 GHz
- Power dissipation: 36 mW

IAF Single-Chip W-Band FMCW Radar Module

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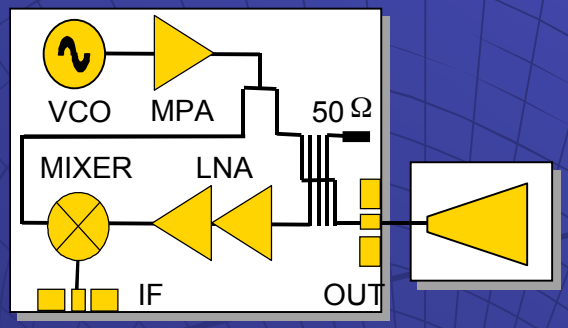
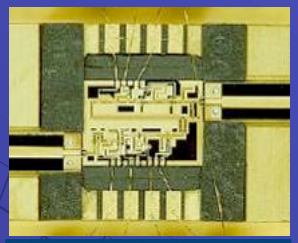
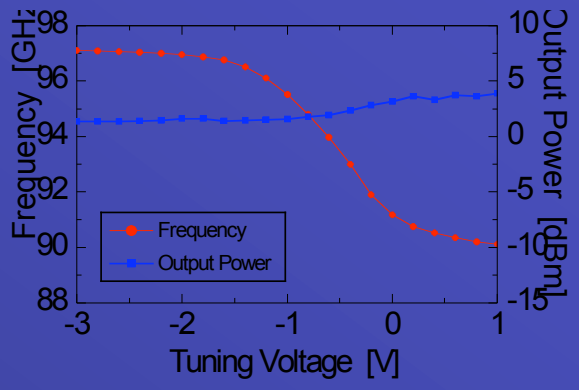
Monolithic Integrated FMCW Radar Chip



Waveguide Antenna





Building blocks

- Varactor tuned oscillator with buffer amplifier
- Single-stage cascode MPA
- Two-stage cascode LNA
- Single-ended resistive mixer

- Chip-size: 2 x 3 mm^2
- Tuning bandwidth: > 6 GHz
- Output power: 2 dBm
- Package-size: 34 x 24 x 10 mm^3

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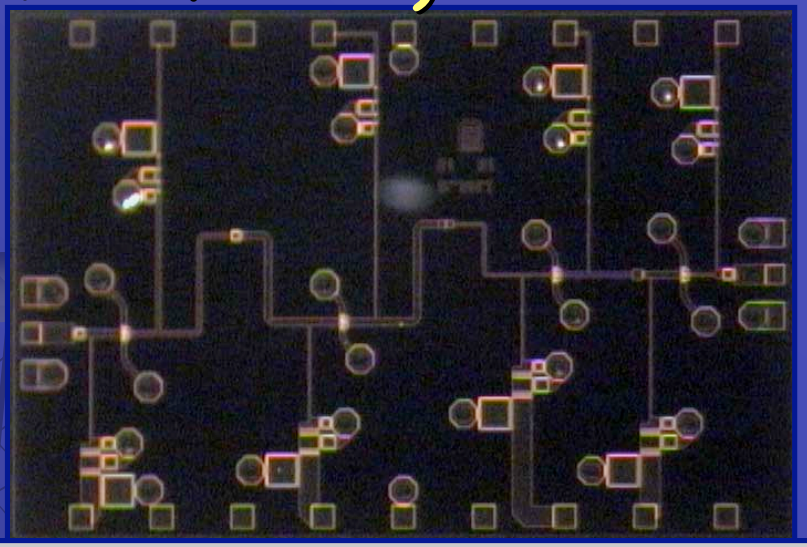
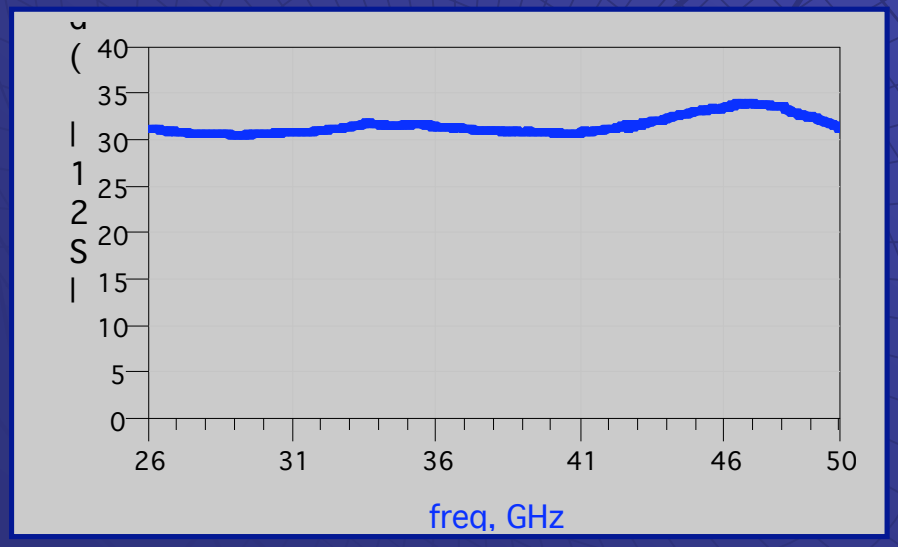
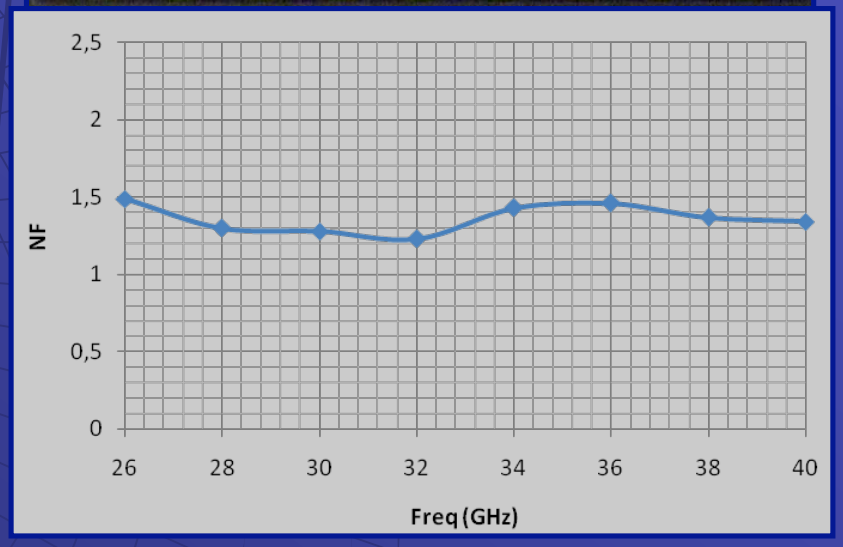
Q-band LNA (U. Rome TV)

Full Q Band LNA
Gain > 30 dB, NF < 1.5 dB
Metamorphic 70 nm
OMMIC (not commercial)

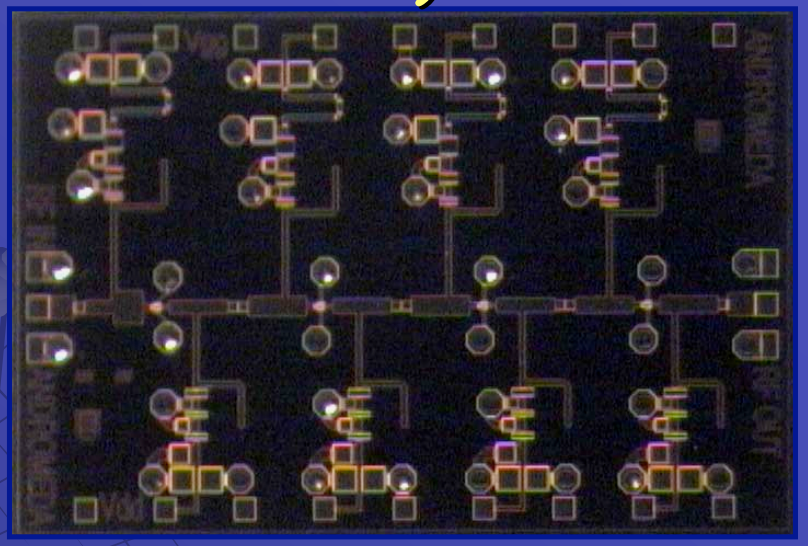


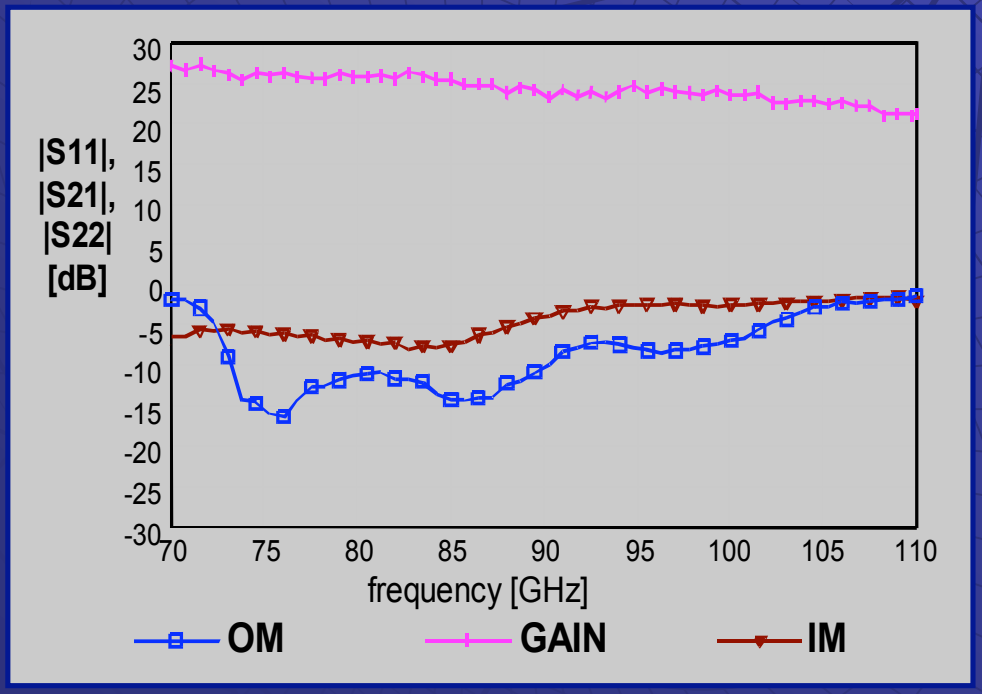


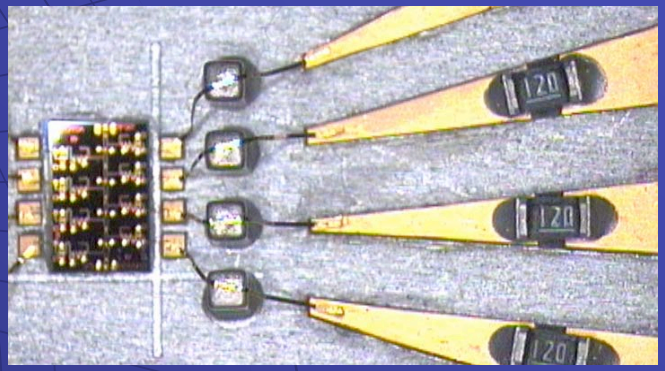


W-band LNA (U. Rome TV)

W Band LNA
Gain > 20 dB, NF < 3 dB
Metamorphic 70 nm Process by
OMMIC (not commercial)

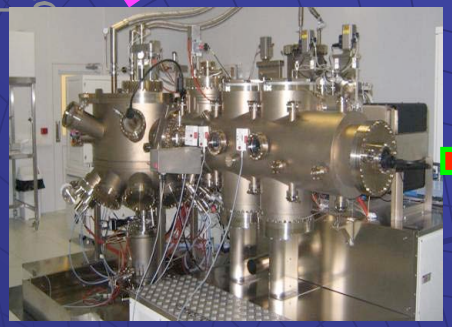


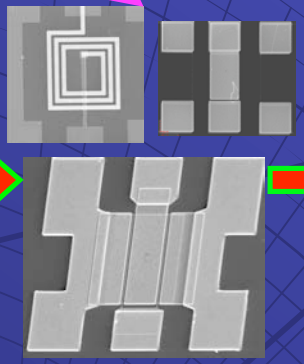


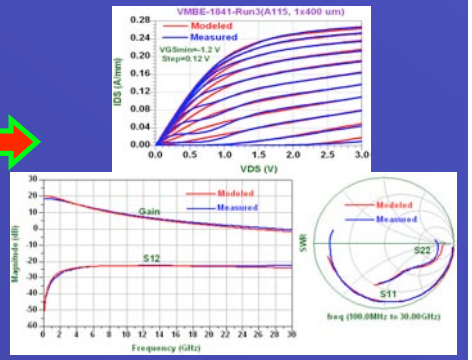


UMAN: InP WORKFLOW

PHYSICAL DEVICE MODELLING





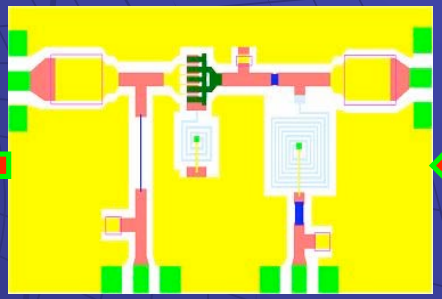


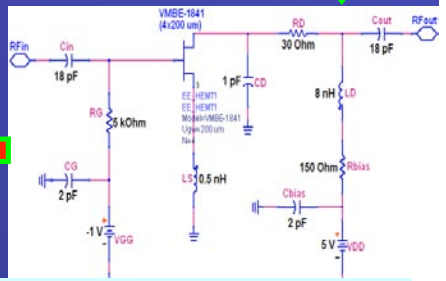
Materials Growth

Active/Passive Device Fabrication

DC+RF Measurements

Linear/Nonlinear Device Modeling





LNA Circuit Measurements

ADC/ LNA Circuits Fabrication

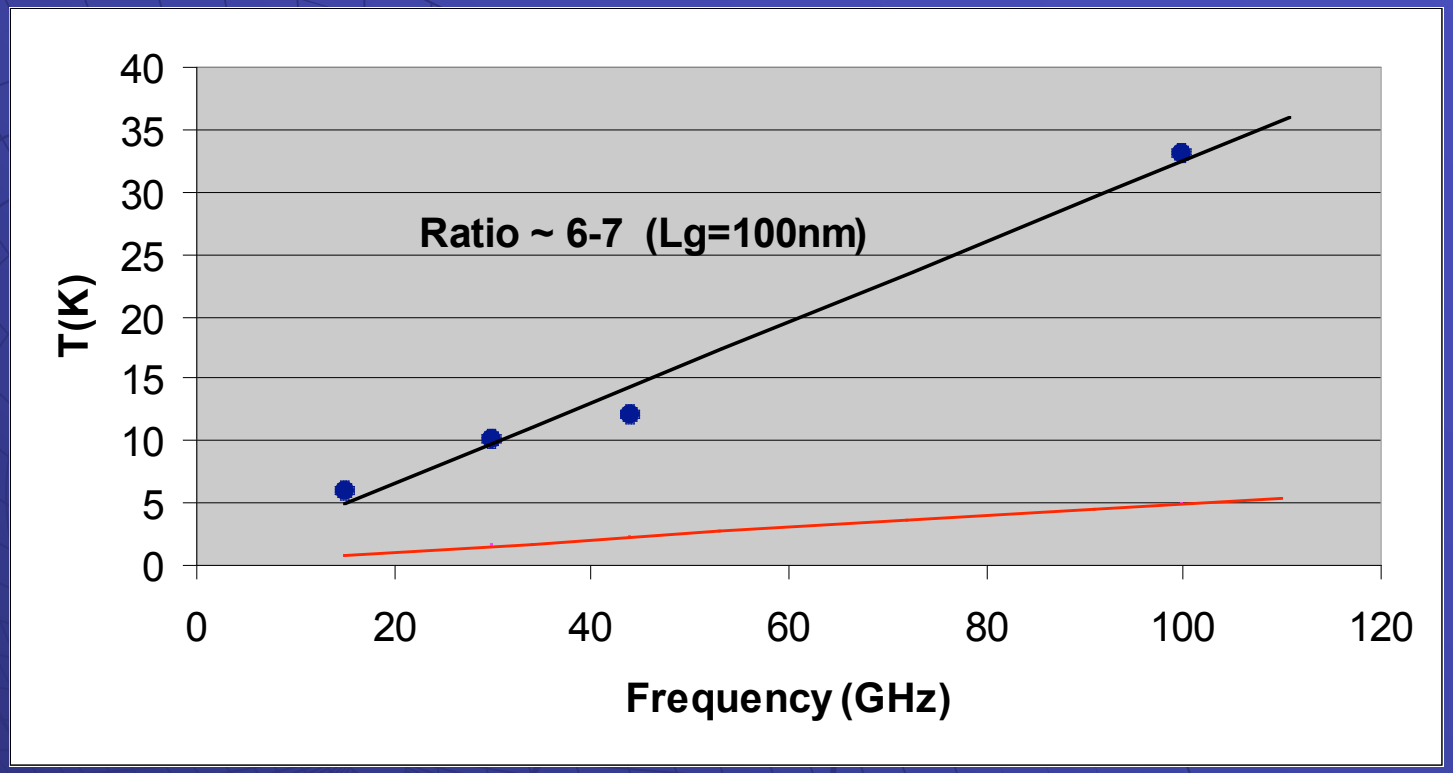
Mask Generation

ADC/ LNA Circuit Design

23-24 March 2009

Caltech KISS MMIC Array Workshop

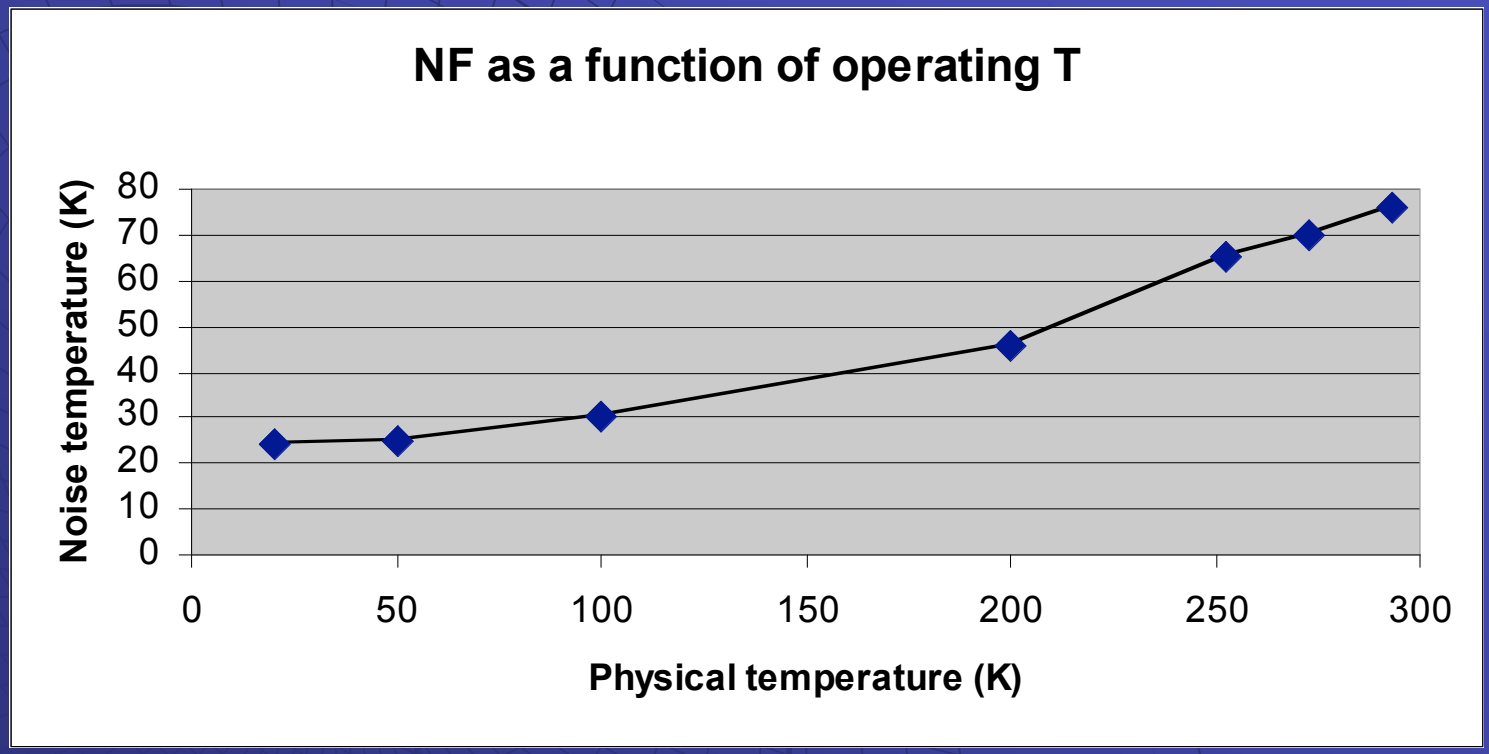
Noise limits-0.1 μm gate length InP MMIC



Measured MMIC noise temperature vs theoretical quantum limit (Lg=100nm) at Tphys~15-20K. Red line is quantum limit.

(T Gaier et al "AMPLIFIER TECHNOLOGY FOR ASTROPHYSICS")

..and observed Noise Figure as a function of operating temperature.



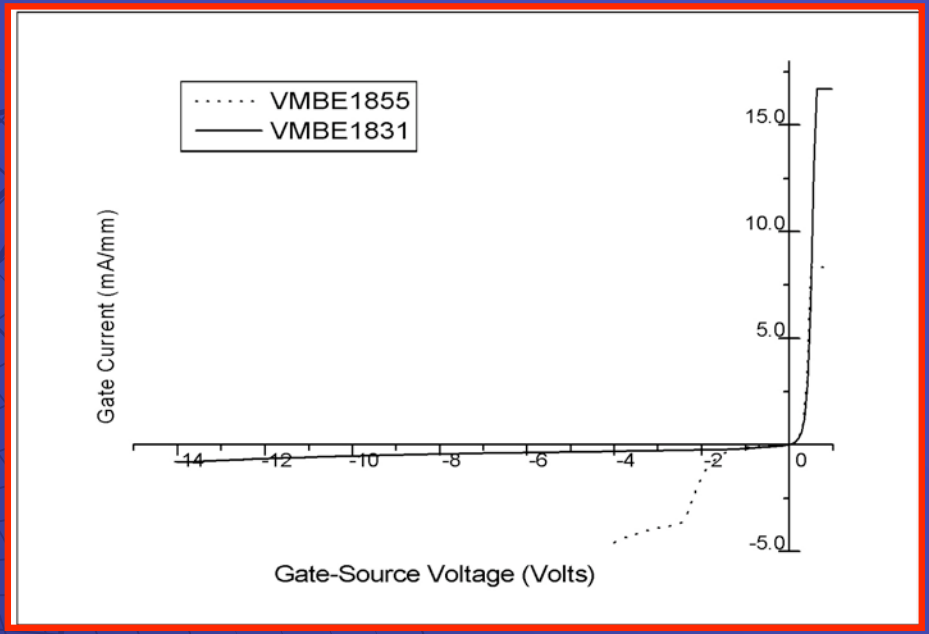
@ 12GHz data, single transistor, 0.5μm gate length

InP LNA: developments

Novel transistor arhitecture

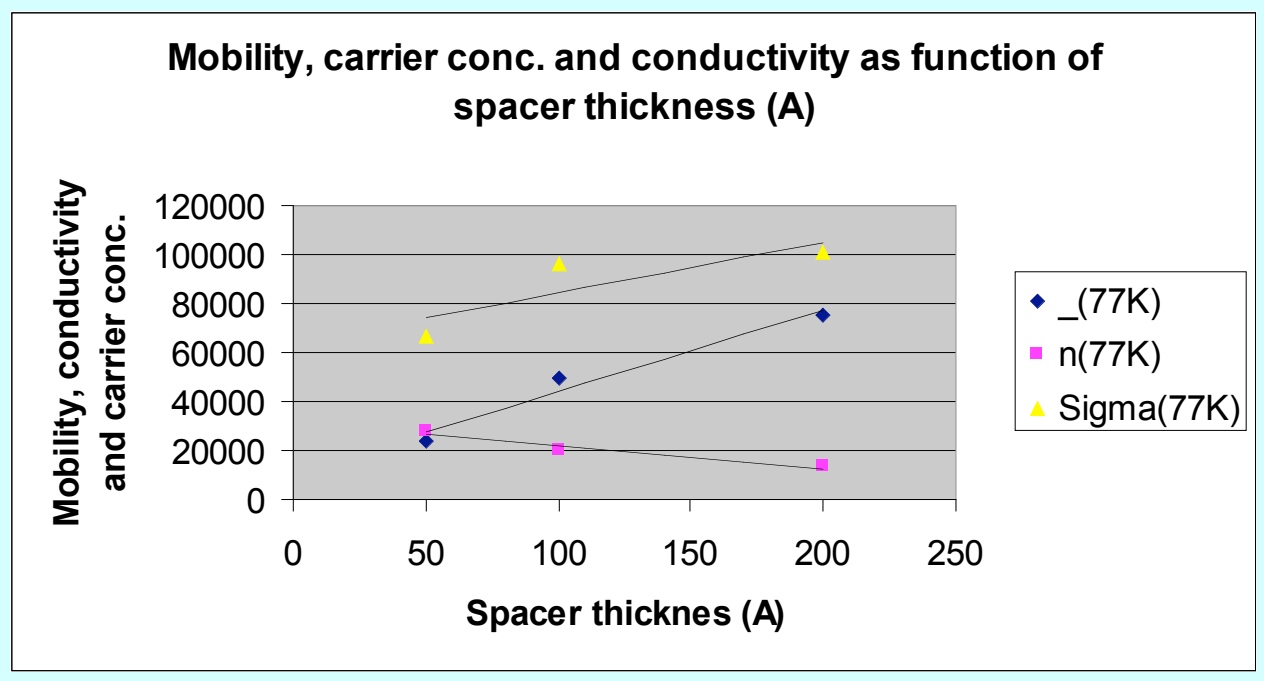
High Breakdown (> 15V). (patent pending)

- receiver robustness
- Low leakage → large transistor topologies for SKA
- Improved performance at small feature sizes?



Comparison of gate-drain diode IV characteristics of conventional and new high breakdown structure

Carrier concentration and mobility



- Produced many InGaAs-InAlAs wafers with varied properties
- Characterized in terms of mobility, carrier concentration as function of temperature (down to 77K),
- Next step is same tests at ~4K

InP SUMMARY

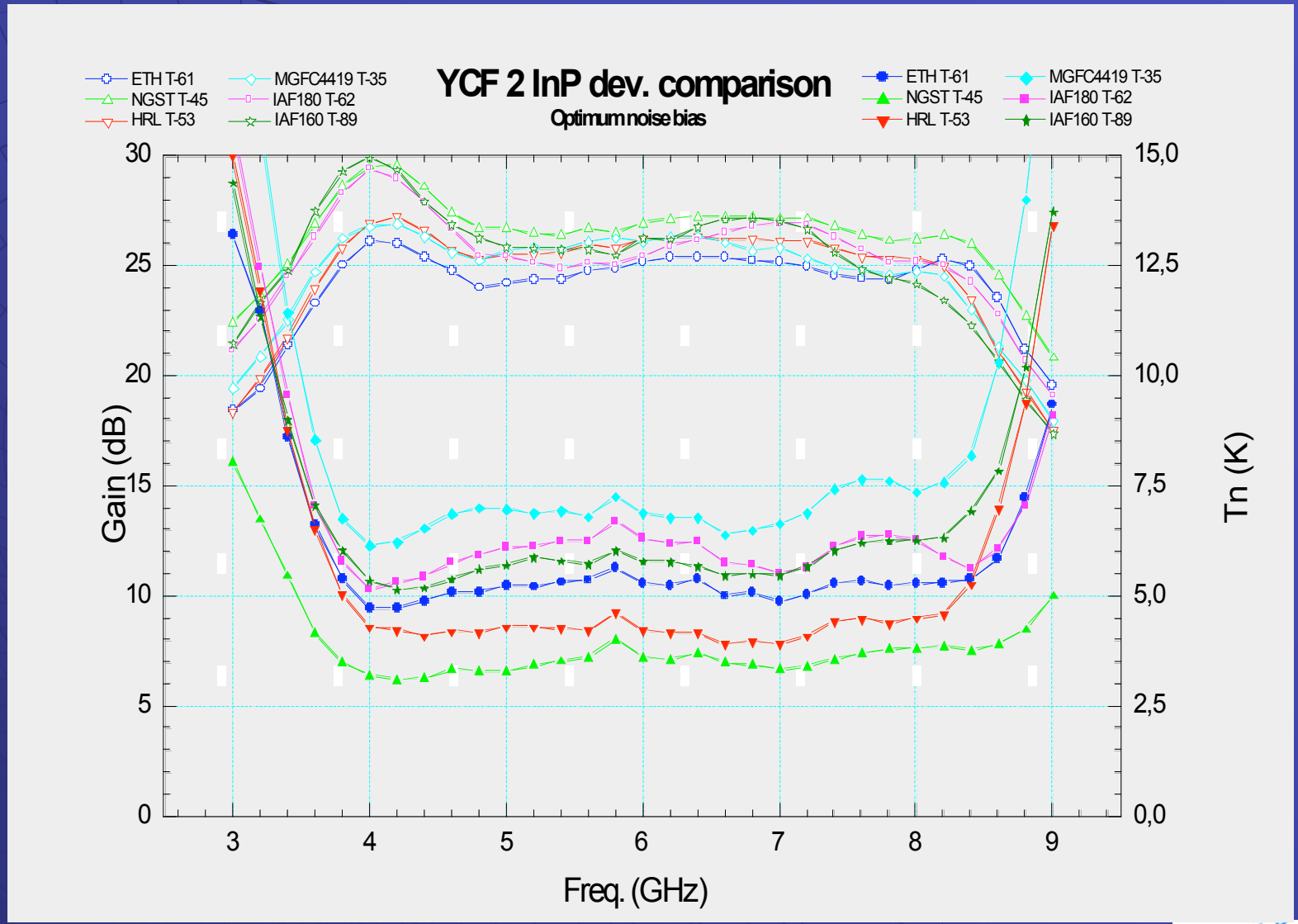
Reaching closer to the quantum limit for noise may be achieved with this material system by manipulation of scaling and band gap engineering of the $In_xGa_{(1-x)}As$-$In_yAl_{(1-y)}As$ system guided by physical modelling

WP4: Device Testing

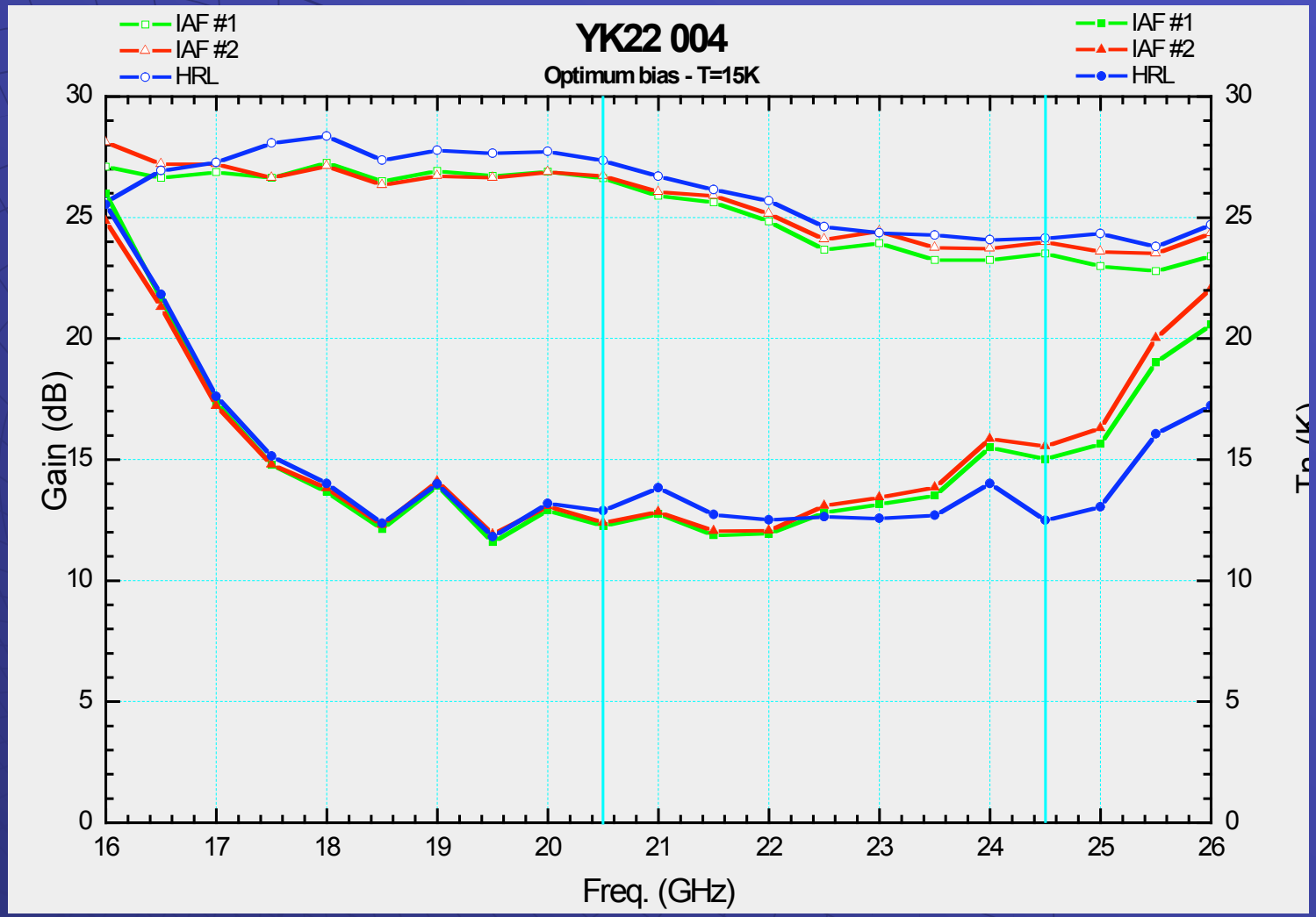
CAY; UMAN; MPIfR, IRA

- Accurate measurement of noise temperature and gain fluctuation of devices at cryo temperatures not easy
- Results from well-respected labs often differ !
- CAY have lots of experience in this arena from LNA work for Herschel (HIFI), ALMA, IRAM, ESOC etc
- Will construct and characterise a "test amplifier" for circulation between partners

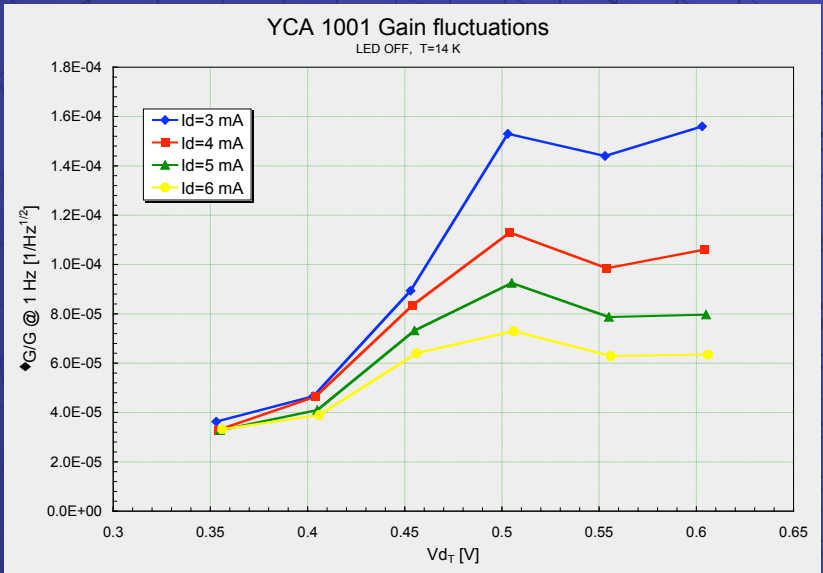
Previous X-band comparisons

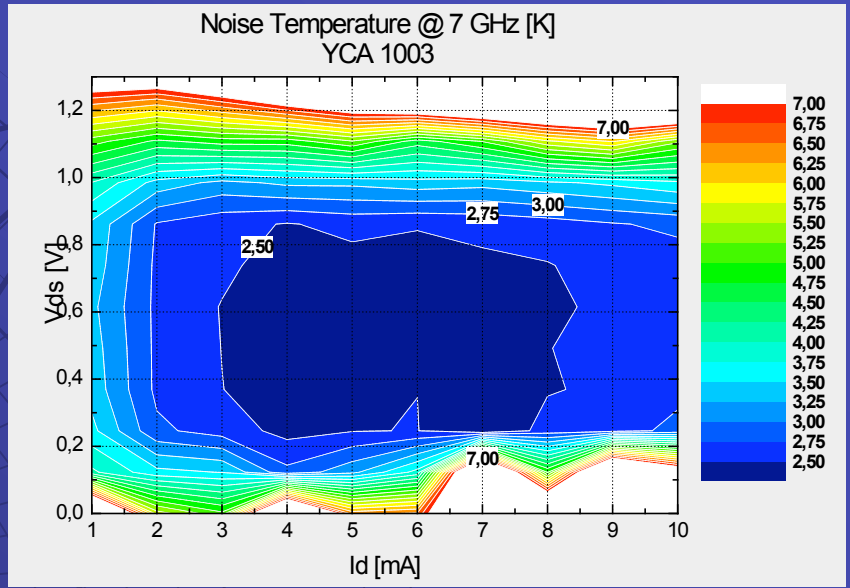


K-band comparisons



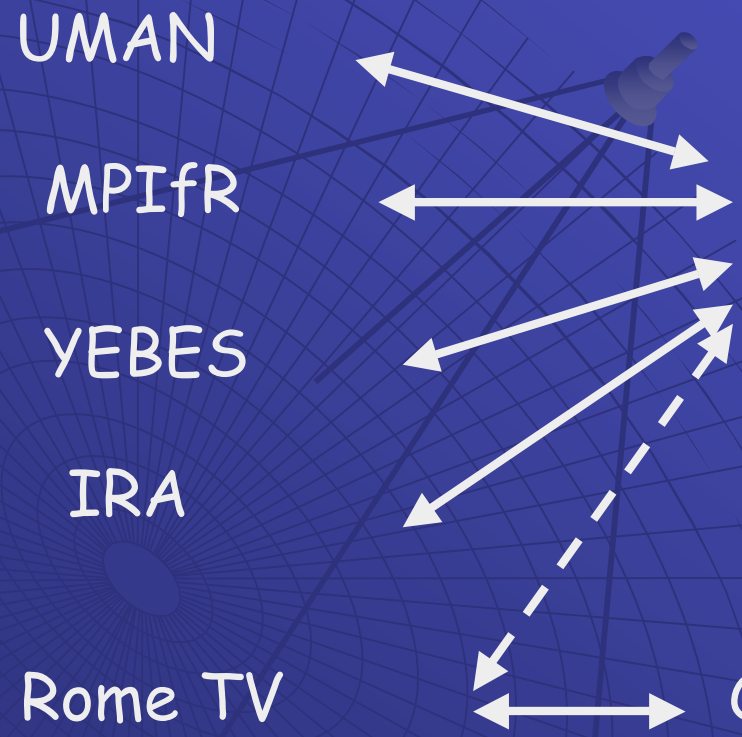
Gain fluctuations of LNAs should be characterized





- Bias dependence of Gain Fluctuations and Noise follow a different law!
  - Noise (and gain) are much more insensitive to bias changes
  - High fluctuation zones could be avoided with no penalty in noise or gain

Summary MIC/MMIC Consortium within APRICOT & AMSTAR+



Jointly coordinated R&D for Q and W-bands

Commercial run

WP5: Data handling

TCfA: UMAN, IRA, MPIfR

- Develop and test algorithms using the full range of multi-pixel and multi-spectral data for the subtraction of atmospheric water vapour without spatial switching, ("on the fly-mapping")

- Develop and test figures-of-merit to support queue-scheduling of the receiver in both continuum and spectroscopic modes (LESSONS FROM GBT!)

PHAROS: Phased Arrays for Reflector Observing Systems

- PHAROS is an EC-funded R&D project (FP6)
- 6 partners: ASTRON, INAF, JBCA, Torun, MECSA, UBIR
- Concept:
  - 4-beam phased array, cryogenically-cooled, receiver system covering frequency-range 4-8 GHz with Tsys < 20K
- Realisation:
  - 364-element Vivaldi array cooled to 20K
  - 24 LNAs (3-stage GaAs MMIC)
  - Analogue beam-forming system cooled to 77K
  - Frequency range optimised to 6.0-6.7 GHz
  - To be mounted on 76-m Lovell Telescope

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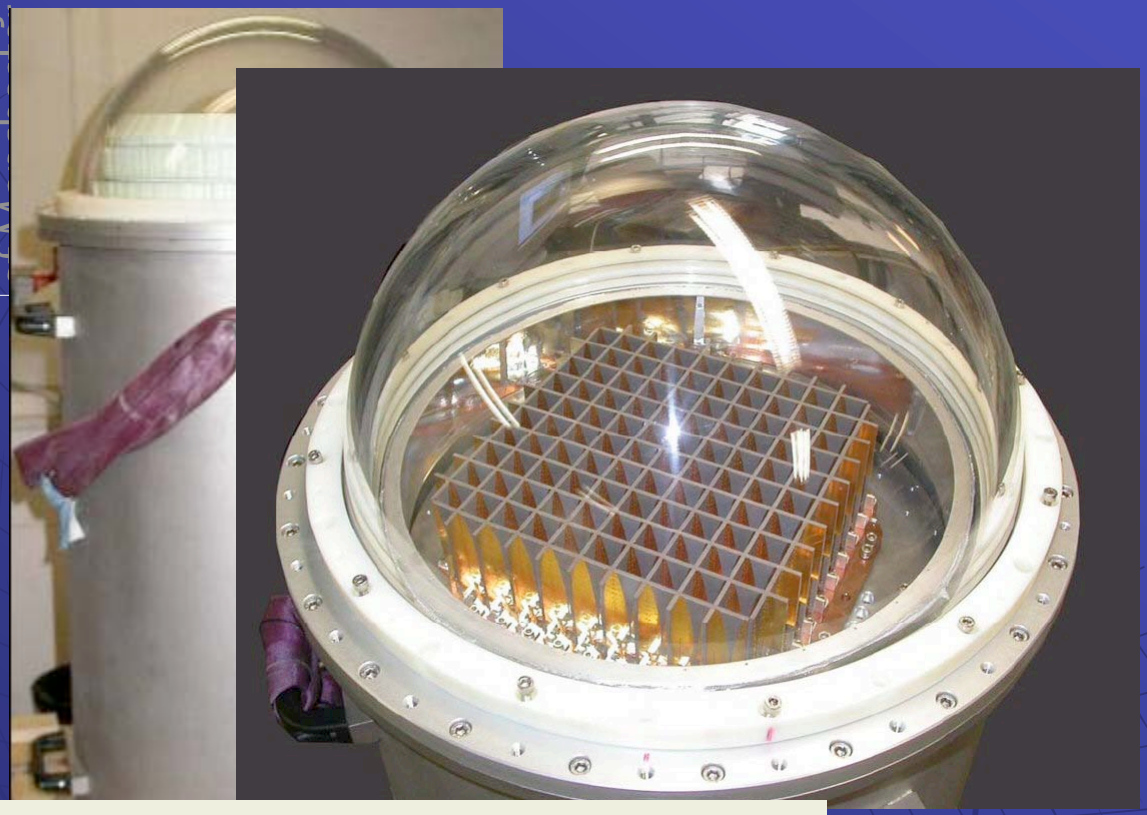
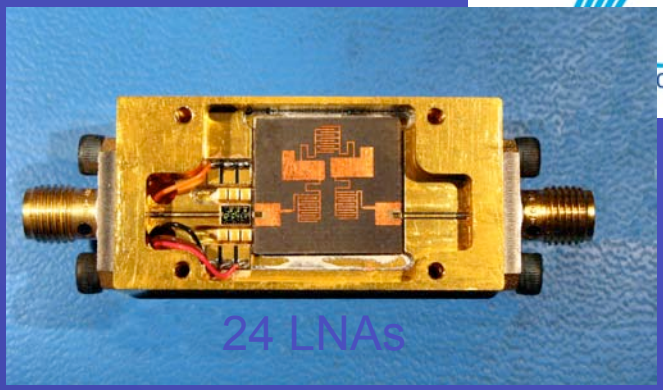
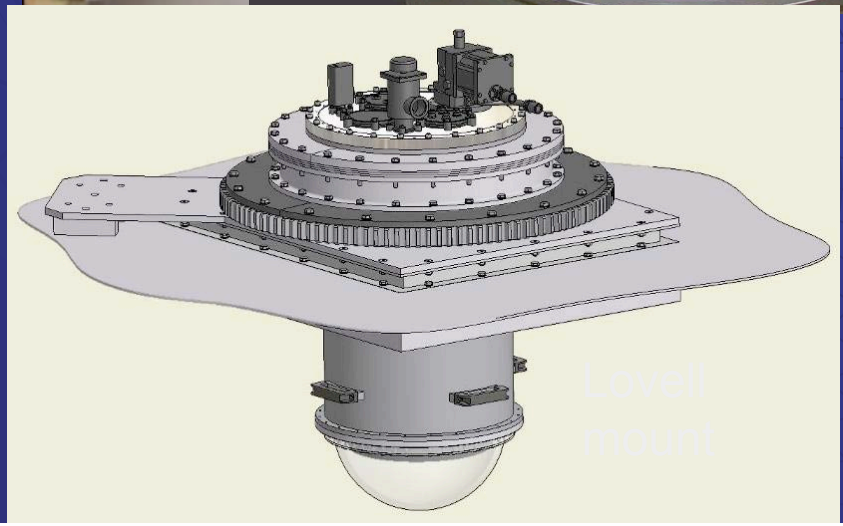




24 LNAs

52 MMIC phase & a,pl conrol



Lovell mount

Status:
Single-beam tests on LT this spring
4-beam system in Autumn

MMIC Array Workshop

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SKA beam-forming Arrays

- Integrated "aperture array" antennas , close packed dual-pol elements
- Potential for multiple beams and all-sky monitoring
- Low frequency 300MHz – 1000 MHz
- Analogue and/or Digital beam-forming

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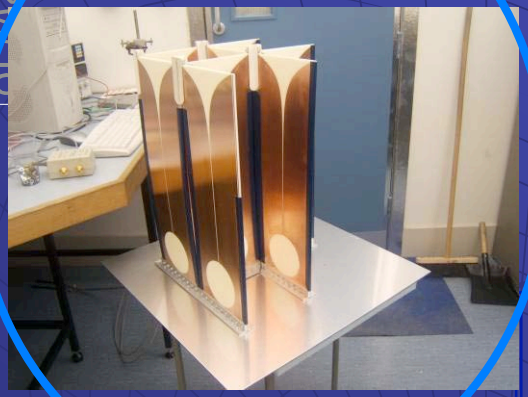
Low sidelobe Array Element Evolution

1st generation	2nd and 3rd generation	4th generation
		
Conventional Vivaldis	•Improved Vivaldis •BECA	• Planar Octagonal Ring Array (ORA)

Polarisation issues

Impedance "spikes"

number of elements required sub-optimal

Phase 1

Phase 3

Jun July Aug Sep Oct

n July Aug Sep Oct Nov Dec

2007 2008

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Looking to future

- SKADS demonstrating planar arrays with integrated LNAs at 1 GHz

- UMAN started thinking about lithographic production of planar arrays with integrated LNAs for mm-wavelengths

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Work together to maximise outputs from closely complementary US & European programmes !

e.g. Missous wants to spend ~1 month in CIT/JPL in 2009/10

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STOP PRESS

First fringes from broad-band fibre-connected e-MERLIN expected next week !

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