Ultra Low Power, Ultra Low Noise Amplifiers and MMICs for Heterodyne Arrays

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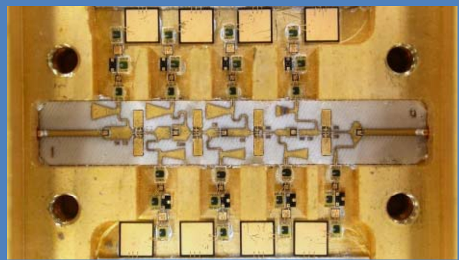
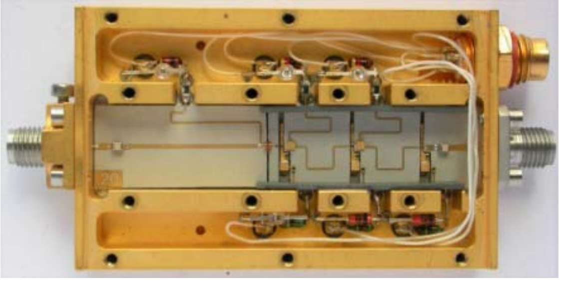
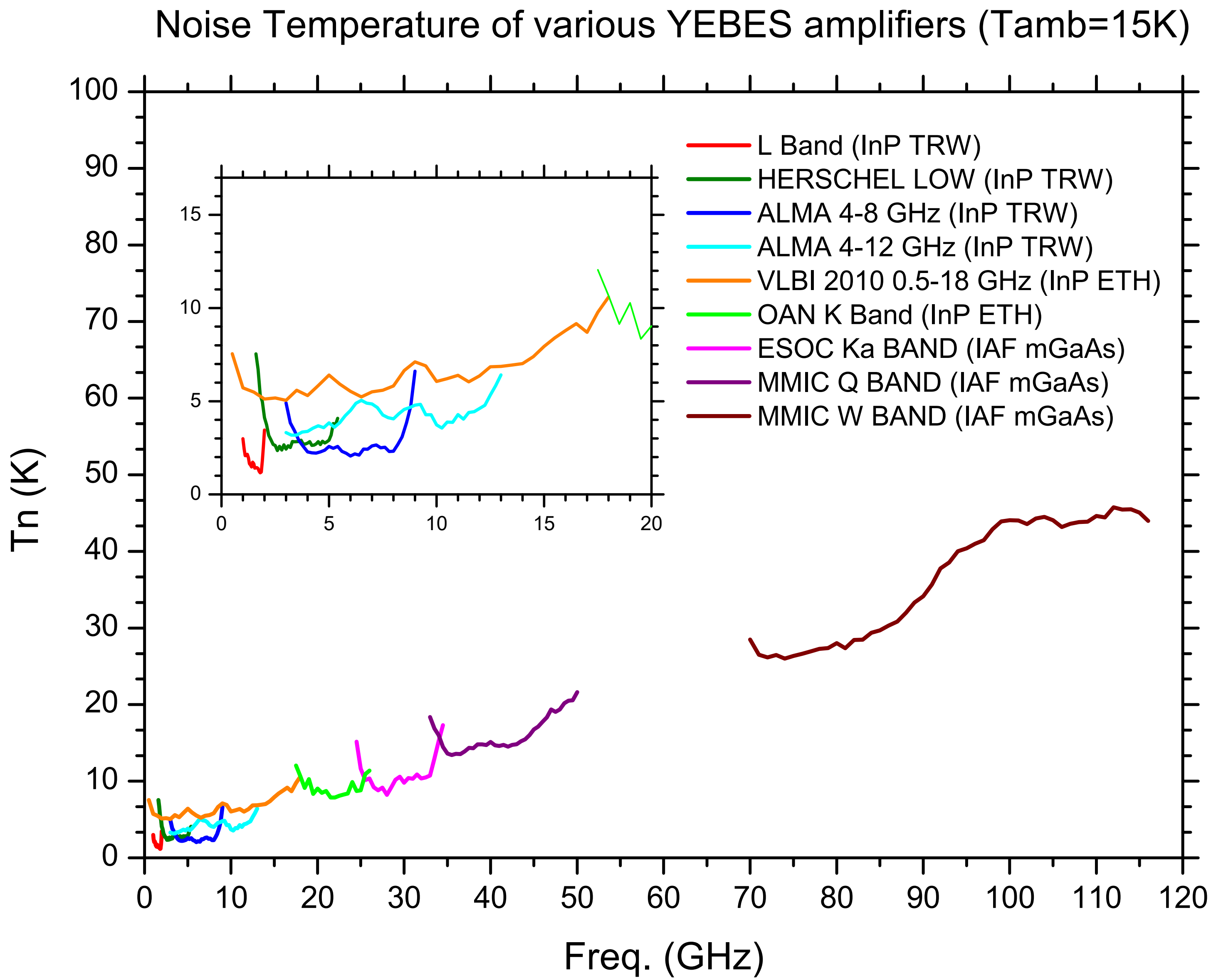


YEBES Background

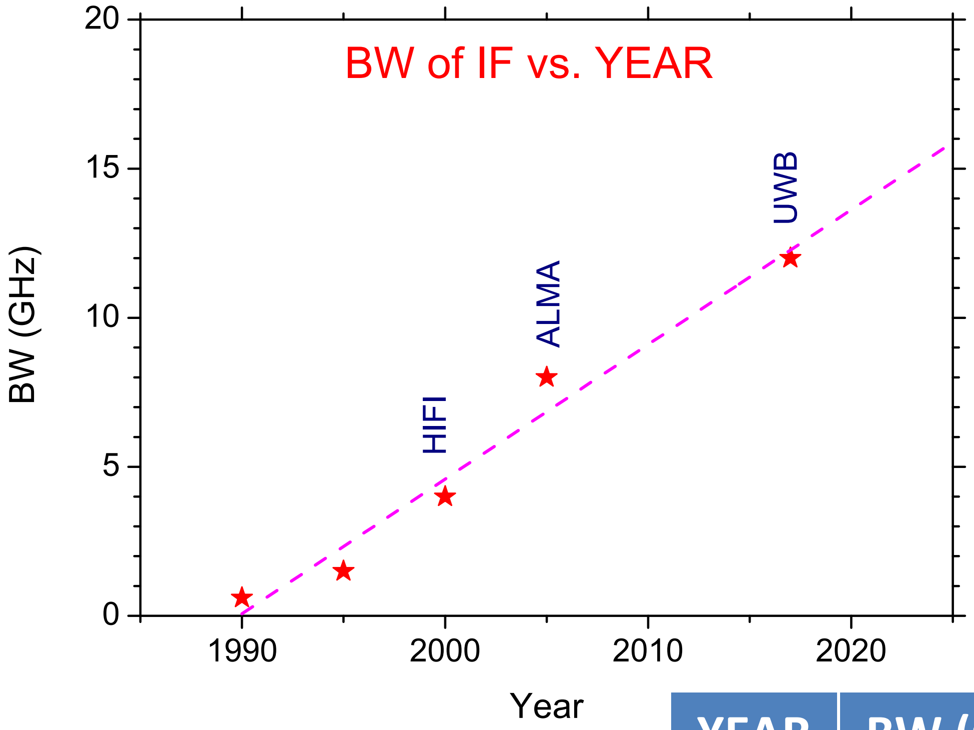
- RT 40 & 13 m YEBES → (bands from 2.2 GHz to 110 GHz)
- IRAM → (1.2-1.8 GHz PB & 3.2-4.7 GHz PV upgraded to 4-8 GHz & 4-12 GHz)
- HERSCHEL (HIFI) → (2-4 GHz & 4-8 GHz, low power dissipation)
- ALMA
  - IF LNAs of Bands 7 (&5) and 9 → (4-8 GHz & 4-12 GHz, low power dissipation)
  - Q band prototypes for Band 1→ (35-52 GHz)
- ESOC (ESA)
  - X-Band → (8.1-9.0 GHz)
  - Ka-Band → (25.5- 32.4 GHz)
- EUROPEAN PROJECTS
  - FP6: AMSTAR (IFs for IRAM & SRON-NOVA 4-12 GHz)
  - FP7: AMSTAR+, AETHER (IF integrated with mixer), APRICOT (33-50 GHz multibeam receiver)
- NANOCOSMOS → (33-50 GHz and 72-115 GHz)
- Over 1000 cryogenic amplifiers delivered to different projects



Yebes LNAs Noise

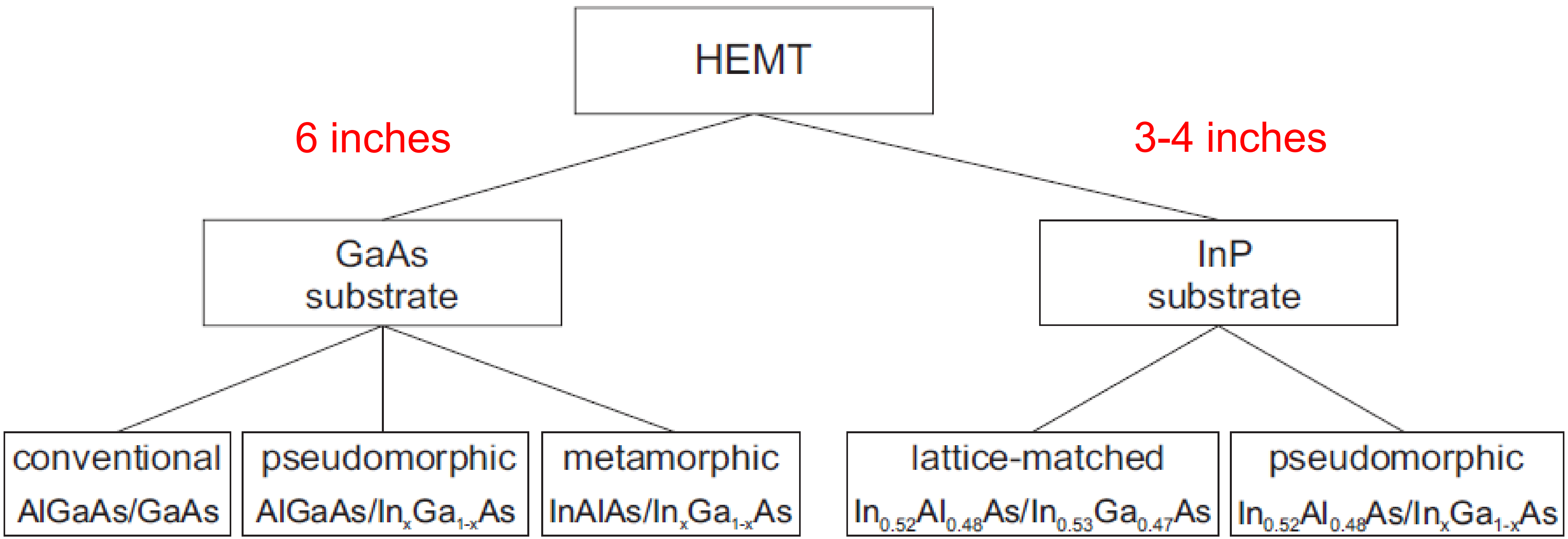


Evolution of IF Bandwidth

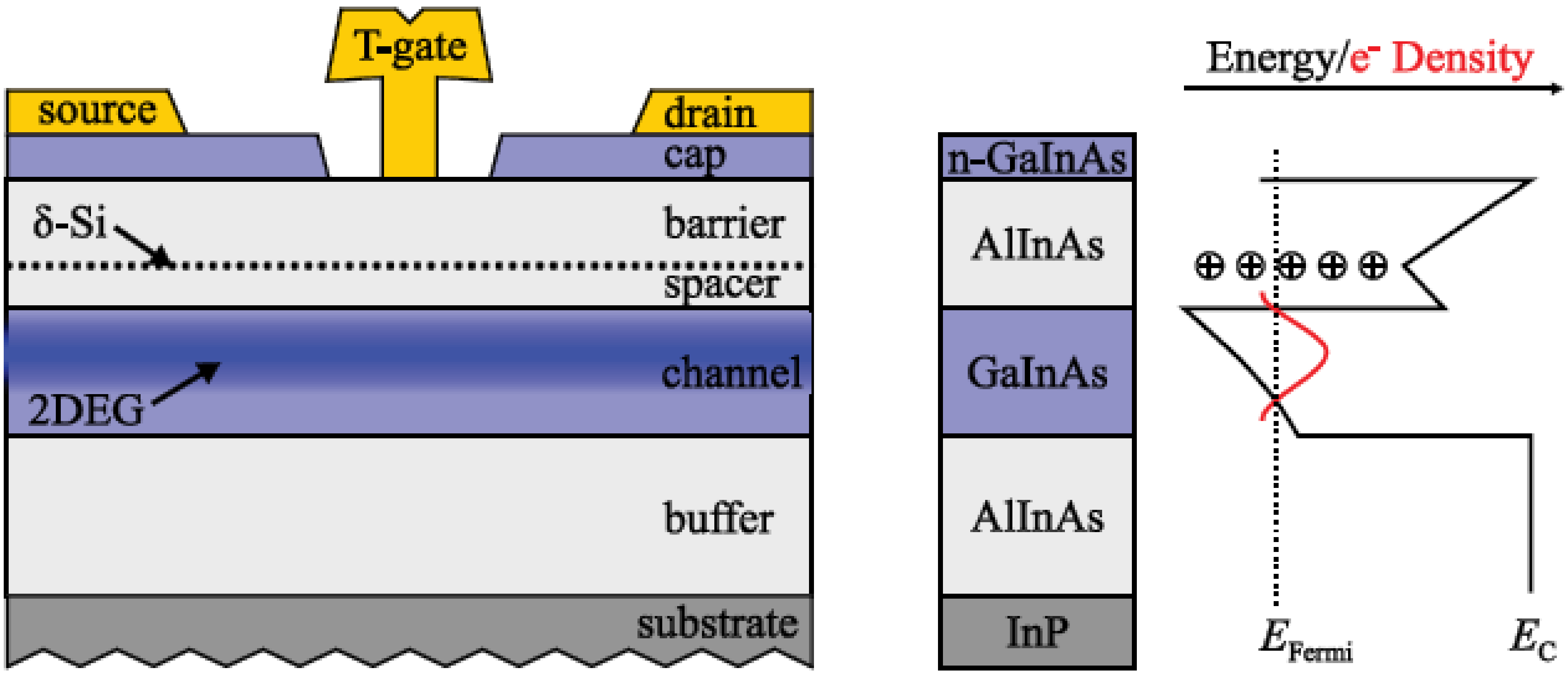


YEAR	BW (GHz)	Tn (K)	P (mW)	
1990	0.6	3	67	L Band (GaAs)
1995	1.5	5	28	C Band (GaAs)
2000	4	5	5	HIFI 4-8 GHz (InP)
2005	8	6	9	ALMA 4-12 GHz (InP)
2017	12	7	36	UWB 2-14 GHz (InP)

HEMT types (low noise)



HEMT structure



Active Devices (HEMTs)

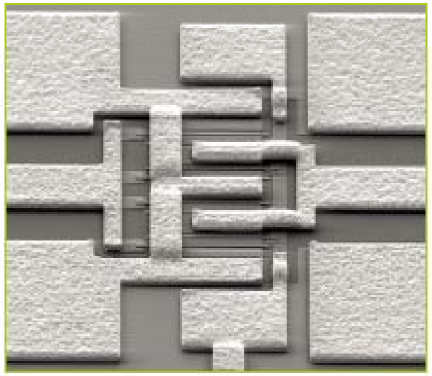
- **CRITICAL: only a few foundries have successfully produced competitive devices for cryogenic amplifiers:**
  - JPL (TRW, NG): InP 35-100 nm
  - ETH (now Diramics): InP (InAs), 100 nm
  - HRL : InP, 50-100 nm, used in ALMA, discontinued
  - Chalmers: InP, for LNF
  - IAF: mGaAs, 35-100 nm
  - OMMIC: mGaAs, 70 nm (industrial)

Problems of HEMTs

- Very high Ft, Fmax (>100 GHz). IF amplifiers very prone to oscillate at cryogenic temperature.
- Cryogenic noise performance of different batches not repeatable. Not always related with ambient temperature data (CRYO3).
- Evolution towards smaller Lg (< 35 nm). For IF amplifiers Lg<100 nm is not an advantage.
- Gain Fluctuations (worse for smaller devices).
- Reasons for batch success not totally understood.
- Experimental devices are expensive.
- Good devices for IF amplifiers are "OLD FASHION"

Example: IAF

IAF mHEMT Processes



Fraunhofer IAF

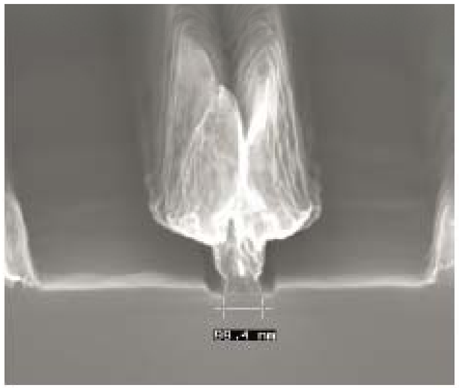
mHEMT

- metamorphic High Electron Mobility Transistor

Comparison with InP-HEMTs :

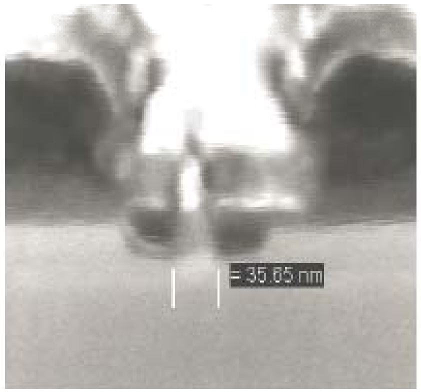
- different substrates
- identical active layer structure

L_G = 100 nm established

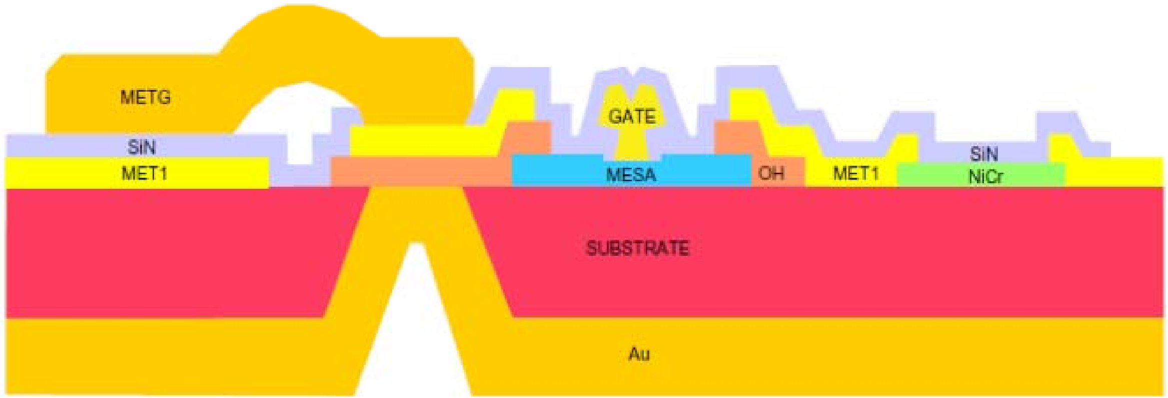


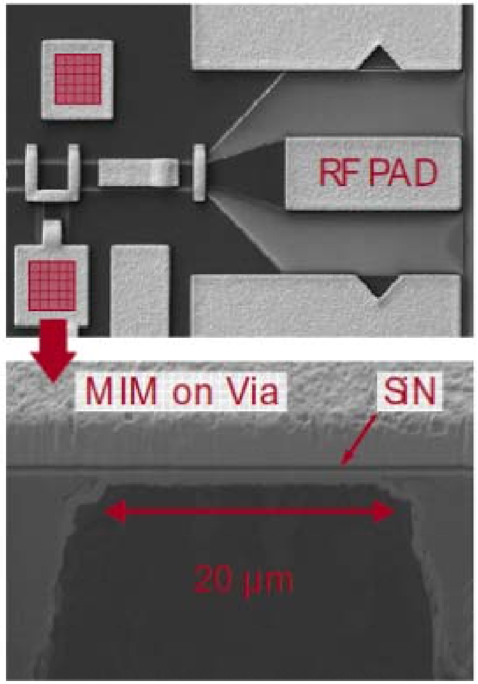
L_G = 50 nm established

L_G = 35 nm final test phase



Example: IAF

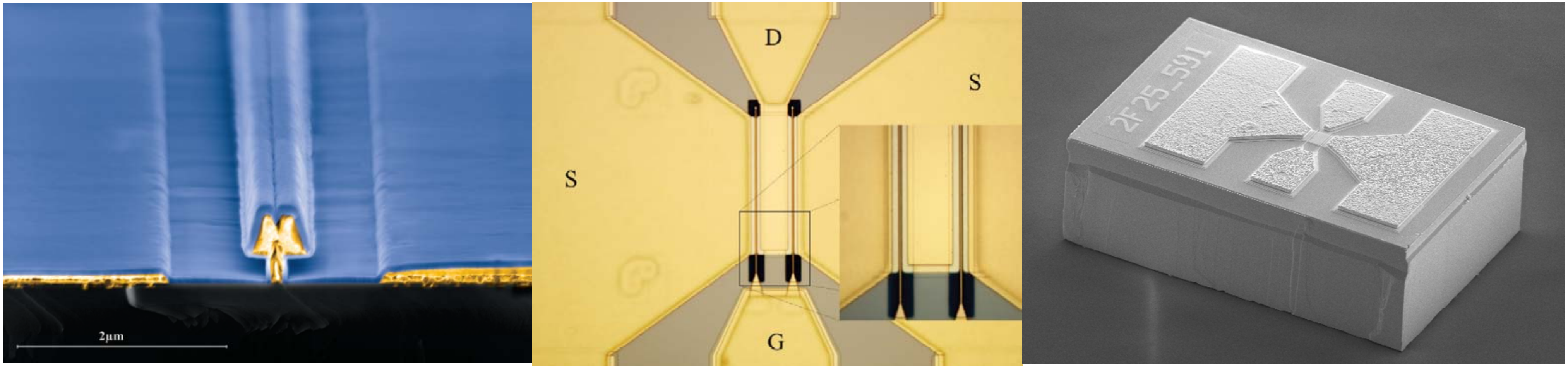


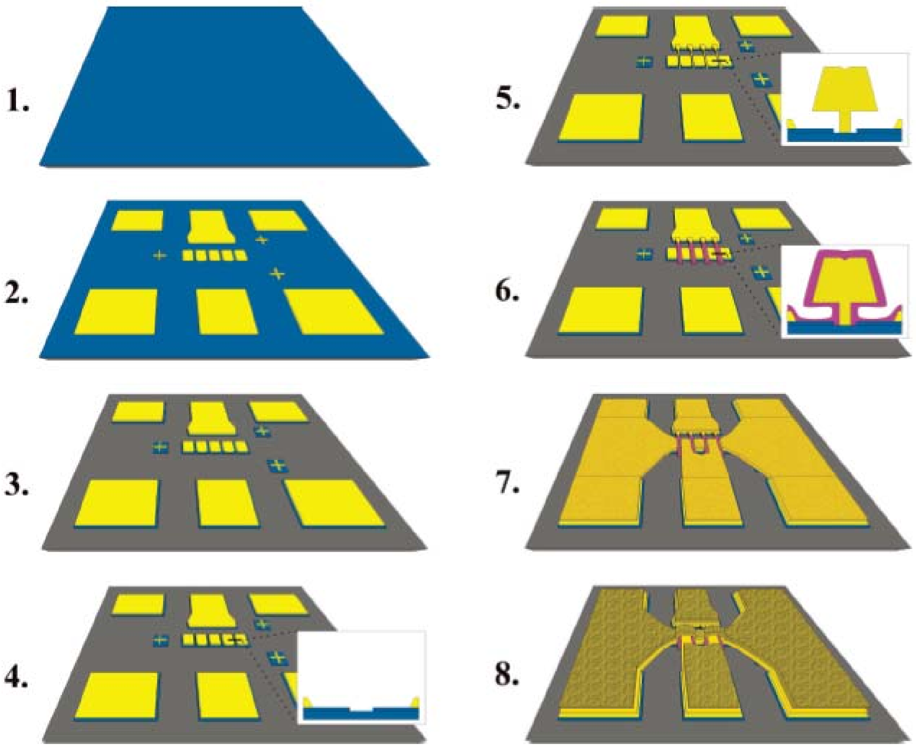


Characteristic features

- 2 Metallization layers
- 2.7 µm Au air bridges
- 225 pF/mm^2 MIM capacities
- 50 Ω/ NiCr resistors
- 250 nm CVD SiN passivation
- Back side process (thinning and via-holes)

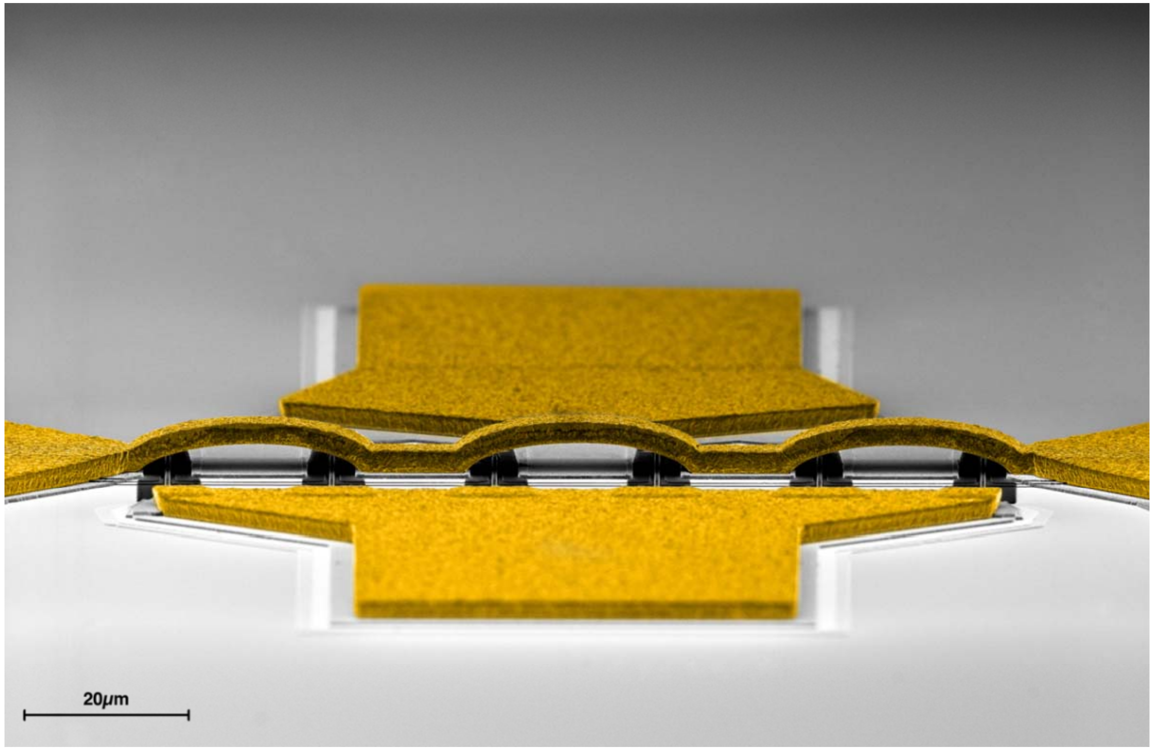
Example: ETH (Diramics)



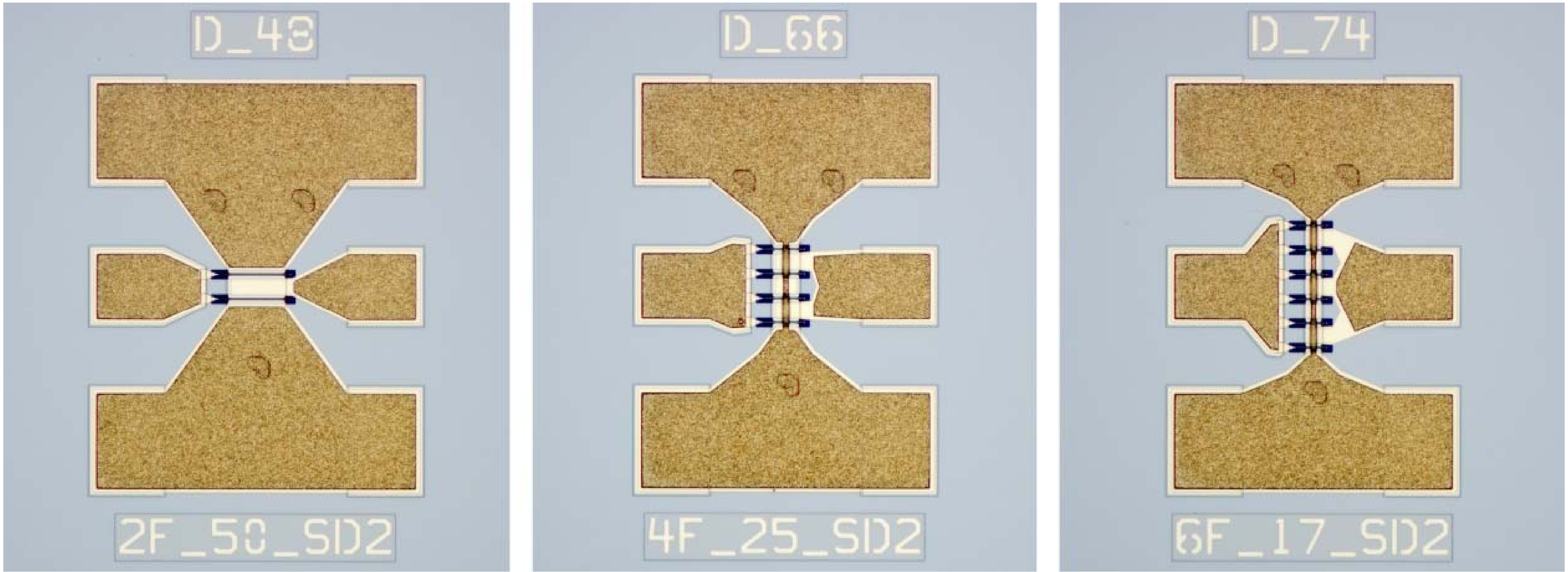


DIRAMICS

1. Grow of epitaxial layers
2. Ohmic contact formation
3. Device isolation
4. Gate recess etching
5. Gate contact definition
6. Passivation
7. Overlay metallization
8. Air bridge / thick metal
9. Wafer thinning & sawing



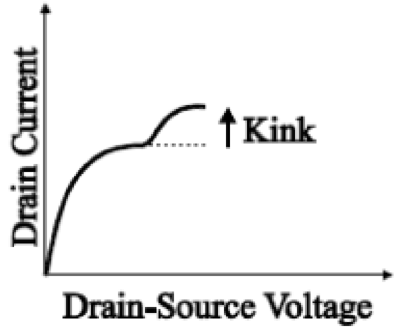
20µm



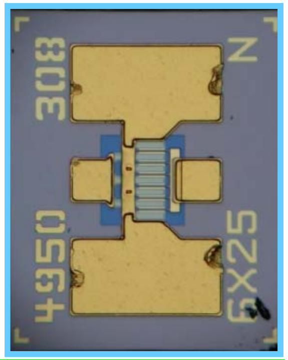
D_48
2F_50_SD2
D_66
4F_25_SD2
D_74
6F_17_SD2

Some Key Parameters

- High mobility
- High transconductance <u>at low drain current</u>
- Low parasitic resistances (Ohmic & Gate)
- Low gate leakage
- Controlled “kink” effect
- High Ft (Lg < 100 nm)
- Risk of high frequency oscillations for unknown reasons (Layout?)
- Of course; <u>***LOW NOISE***</u>

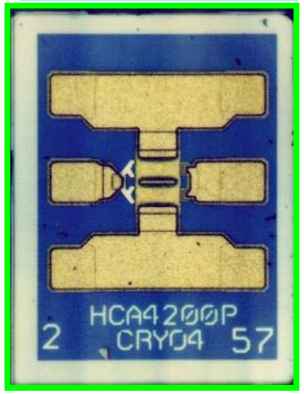


Results of some HEMTs



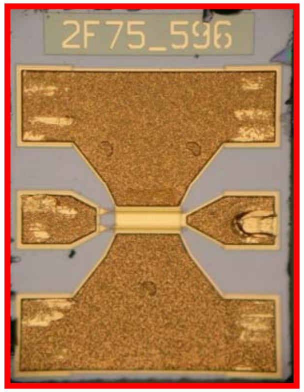
HRL T-78

- 150×0.1 µm gate
- ALMA production



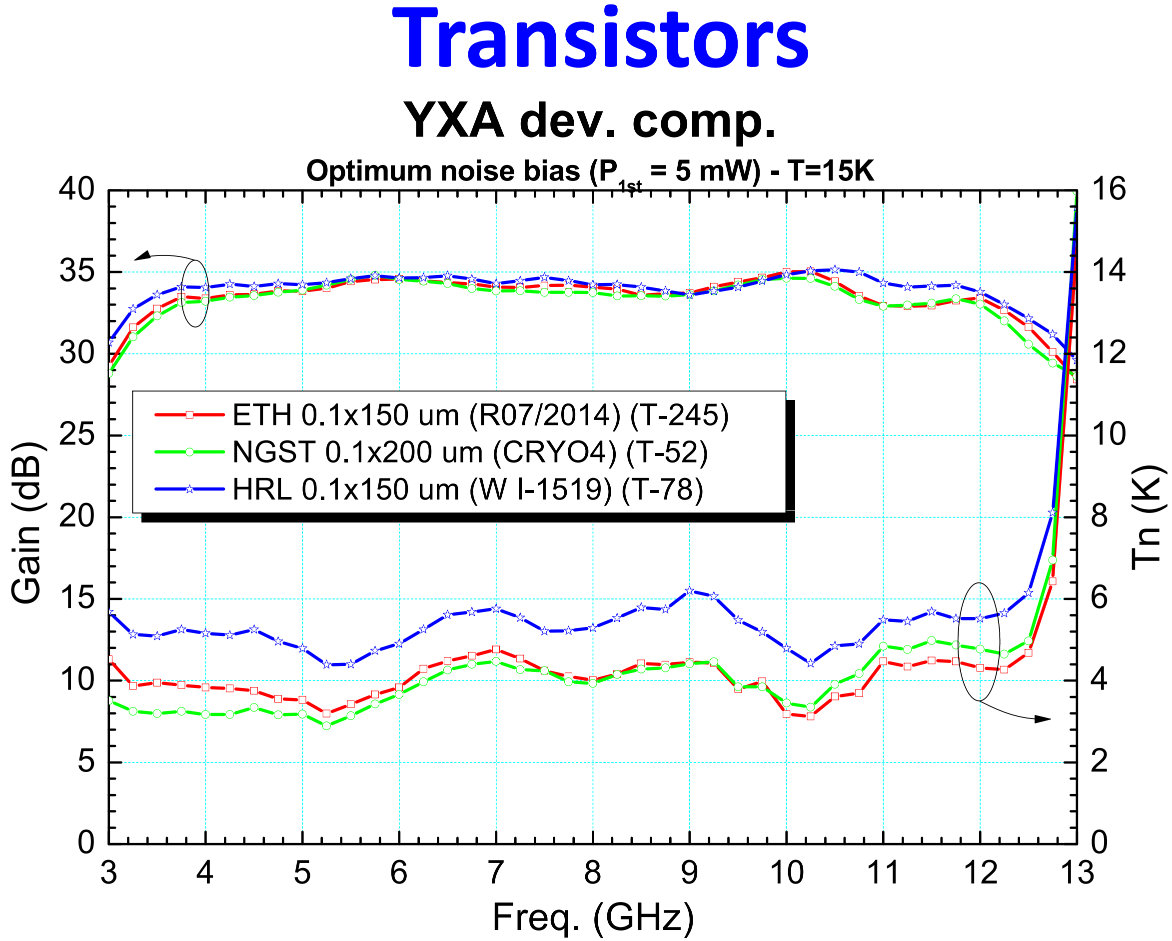
TRW T-52 CRYO4

- 200×0.1 µm gate
- Used in HIFI DMs
- Not space qualified



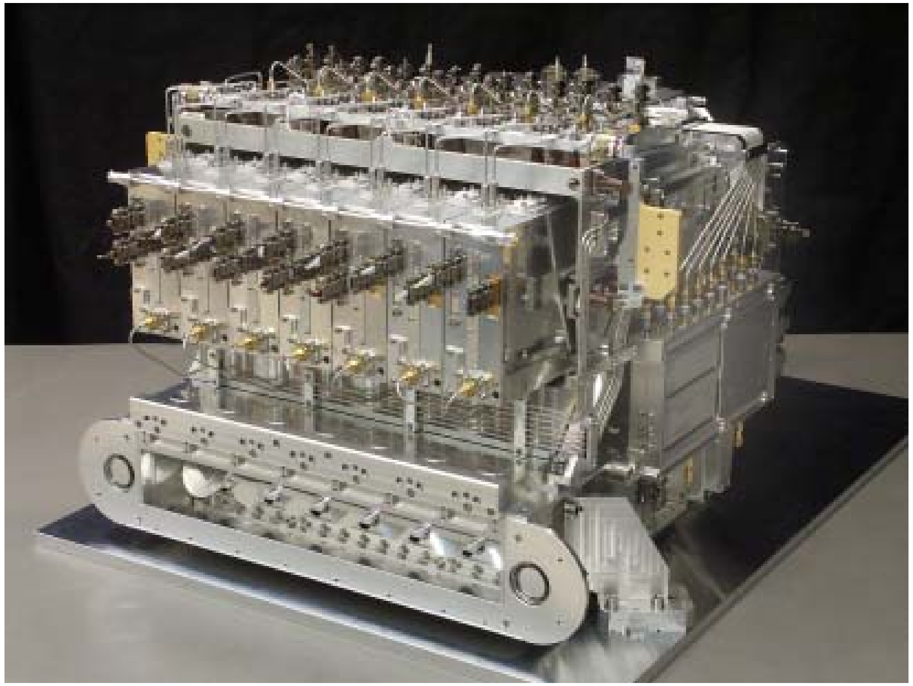
ETH T-245

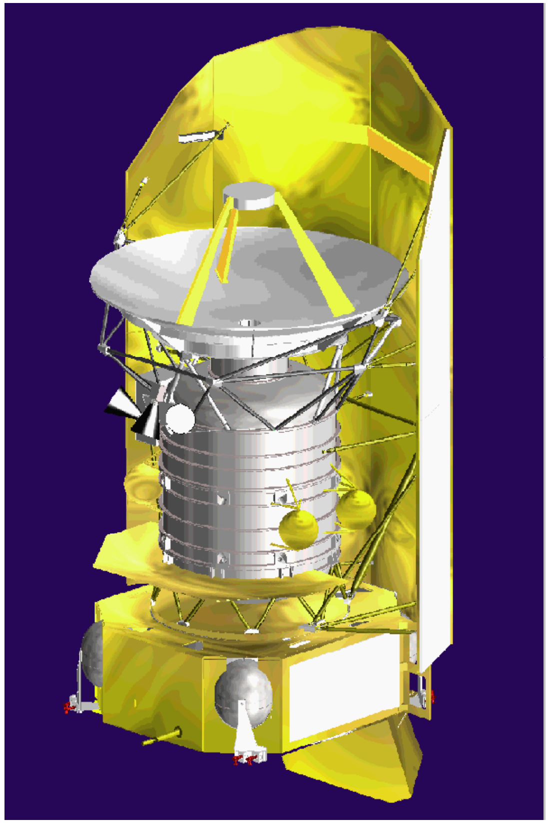
- 150×0.1 µm gate
- Very good noise



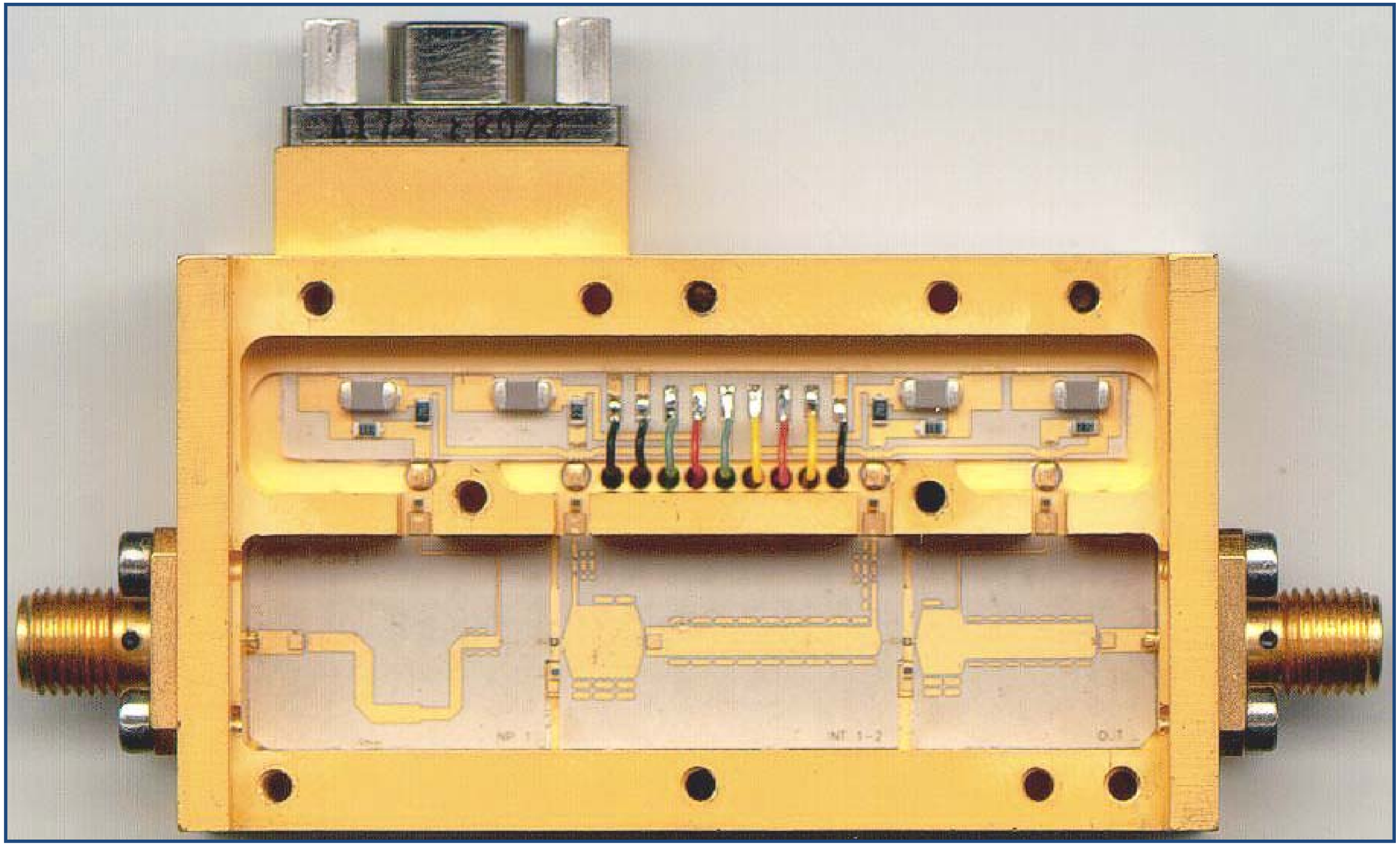
HERSCHEL (HIFI)

Launched May 14 2009



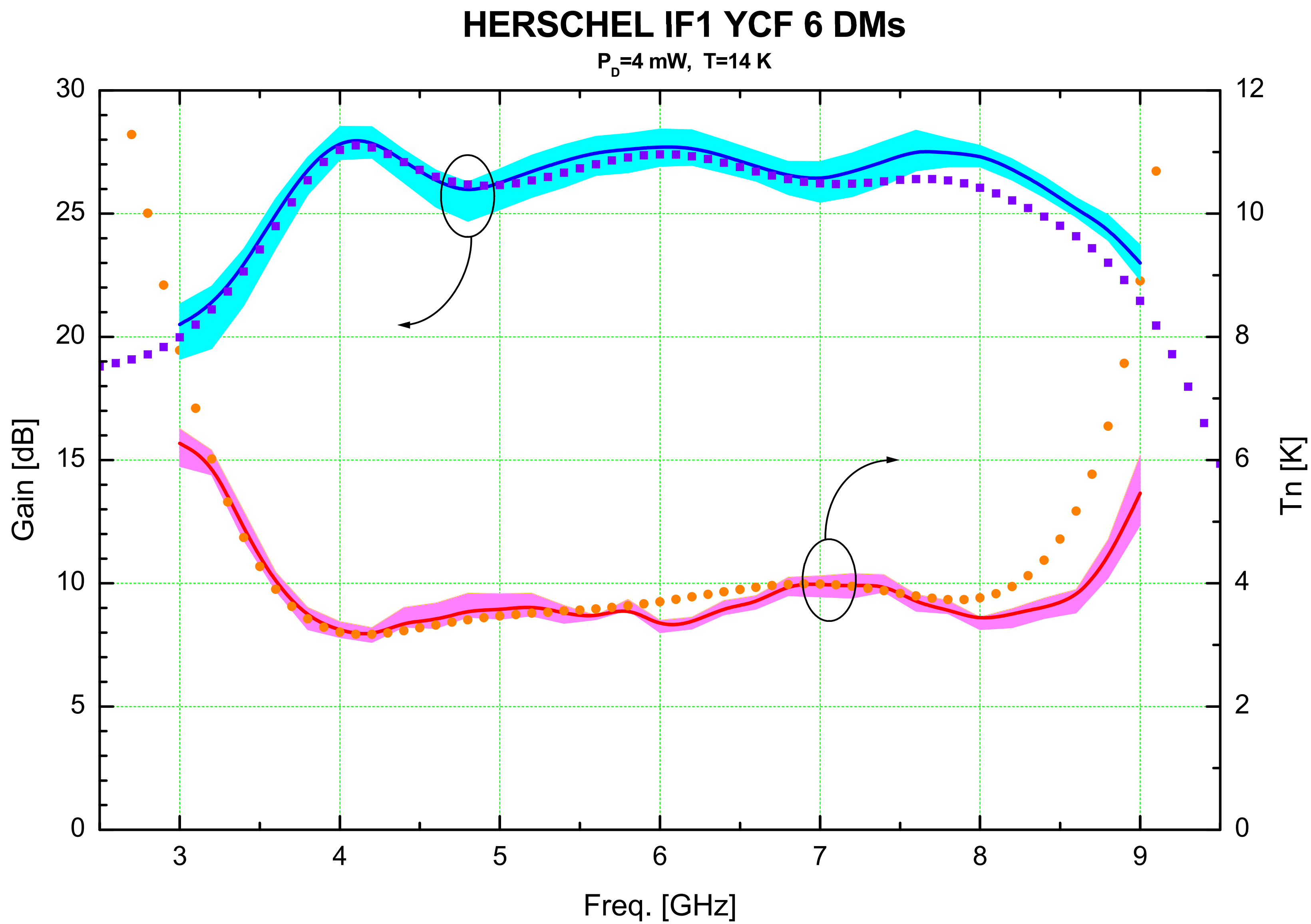


HIFI YCF 6004 (4-8 GHz)

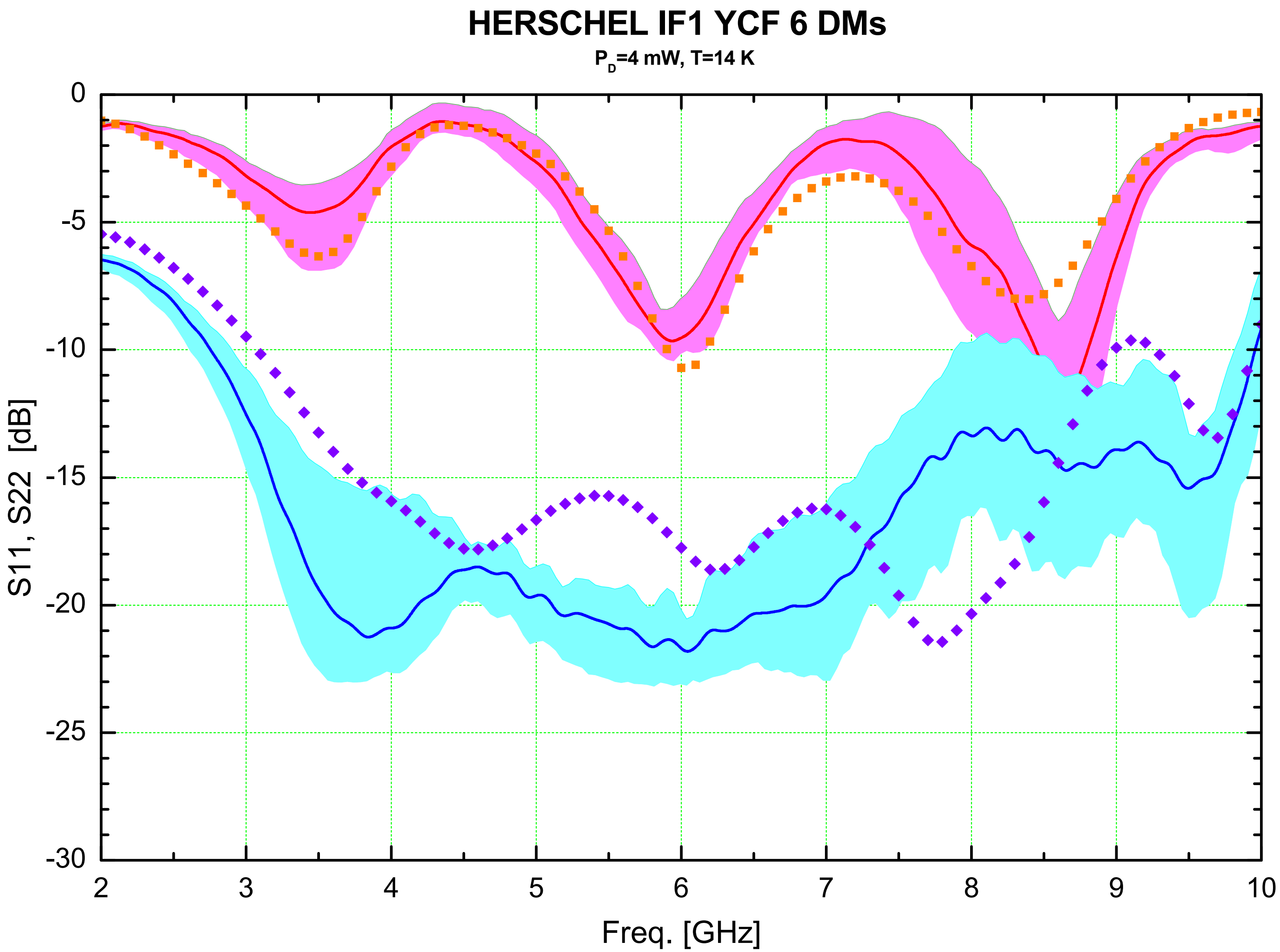


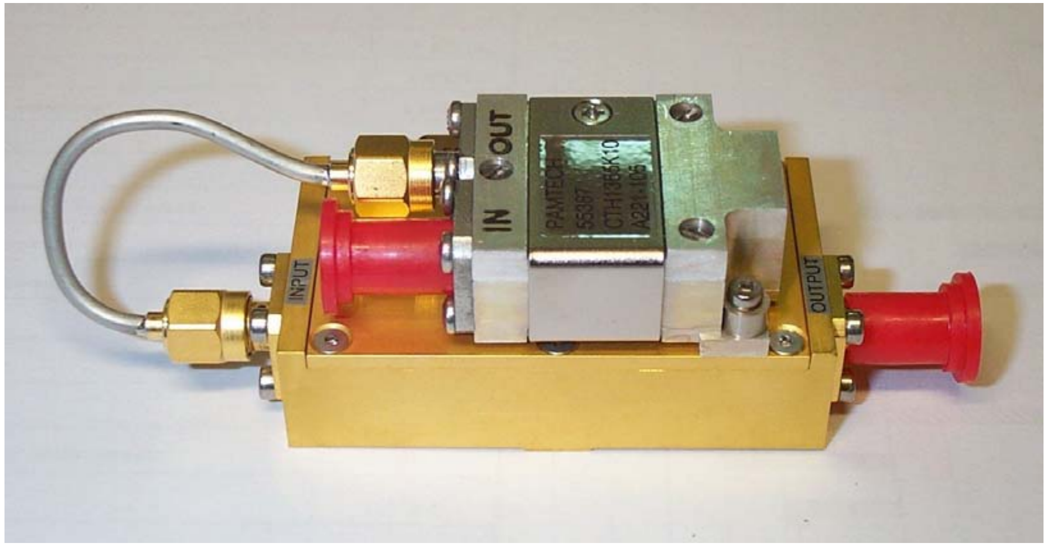
m=65 g   58 x 32 x 15 mm

HIFI YCF 6000 (Noise and Gain)



HIFI YCF 6000 (I/O Reflection)

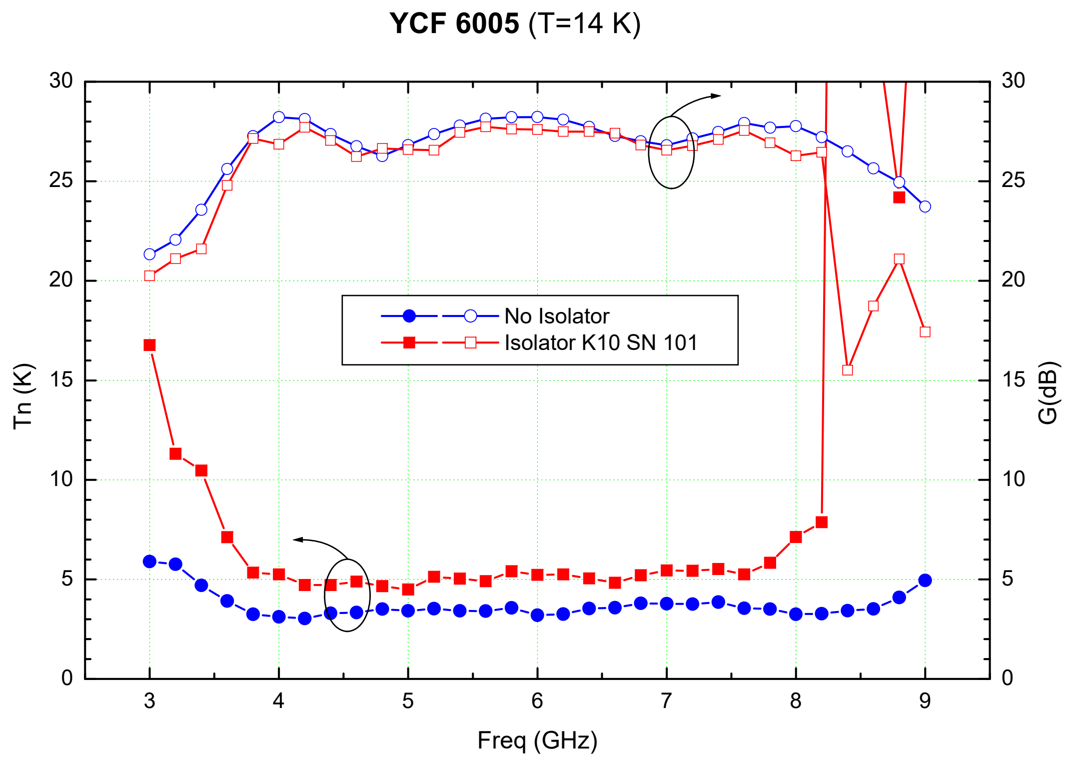




Isolator contribution

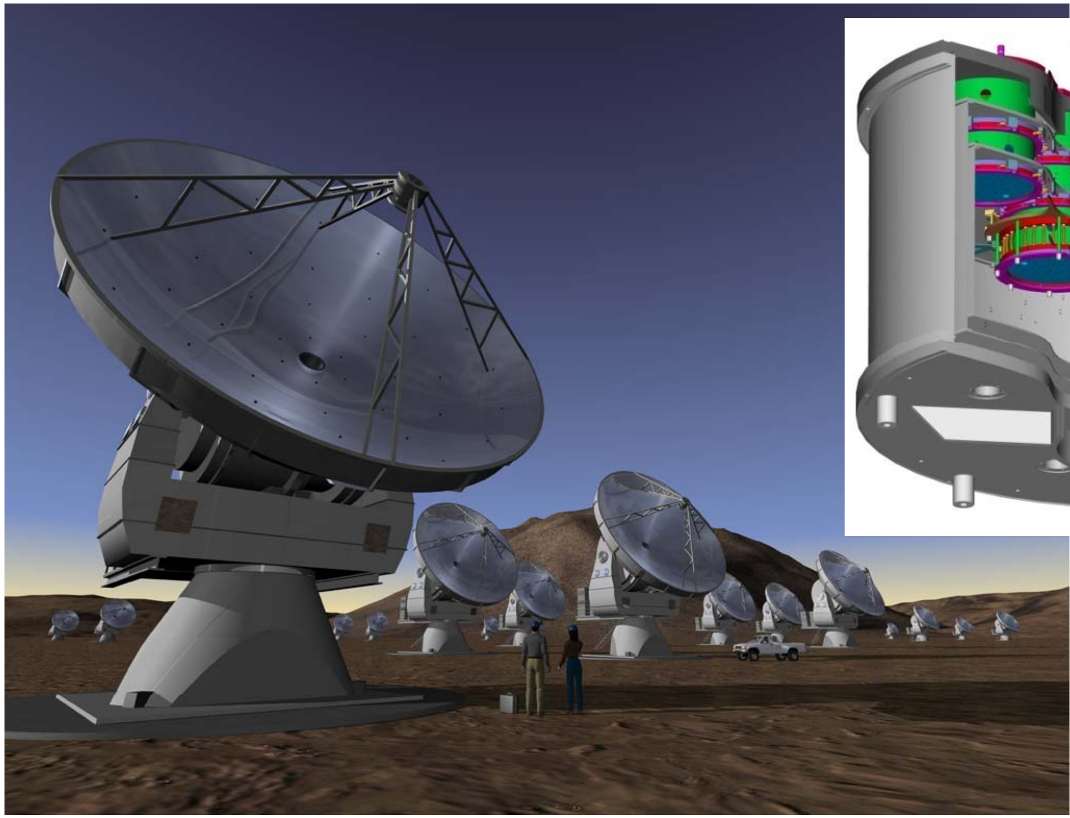
$$\Delta T_c = \left(\frac{1}{G_{iso}} - 1 \right) \cdot \left(T_{amb} + T_{amp} \right)$$

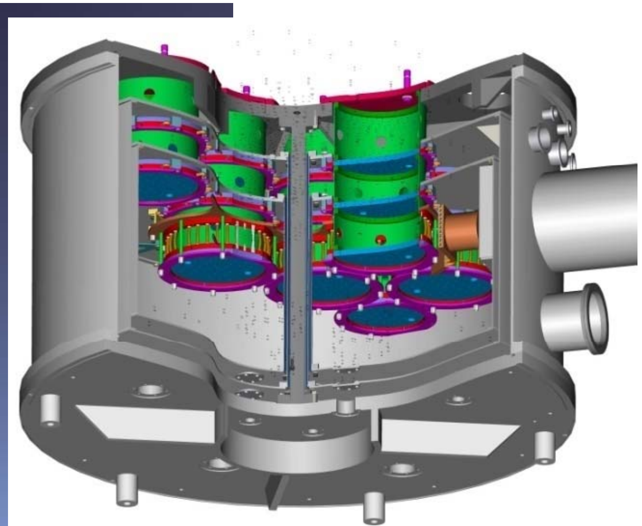
- Isolators measured @ 14 K (PAMTECH gives data @ 77 K)
- Good agreement between measurement and estimation of isolator noise
- Mean contribution 1.1 – 1.4 K



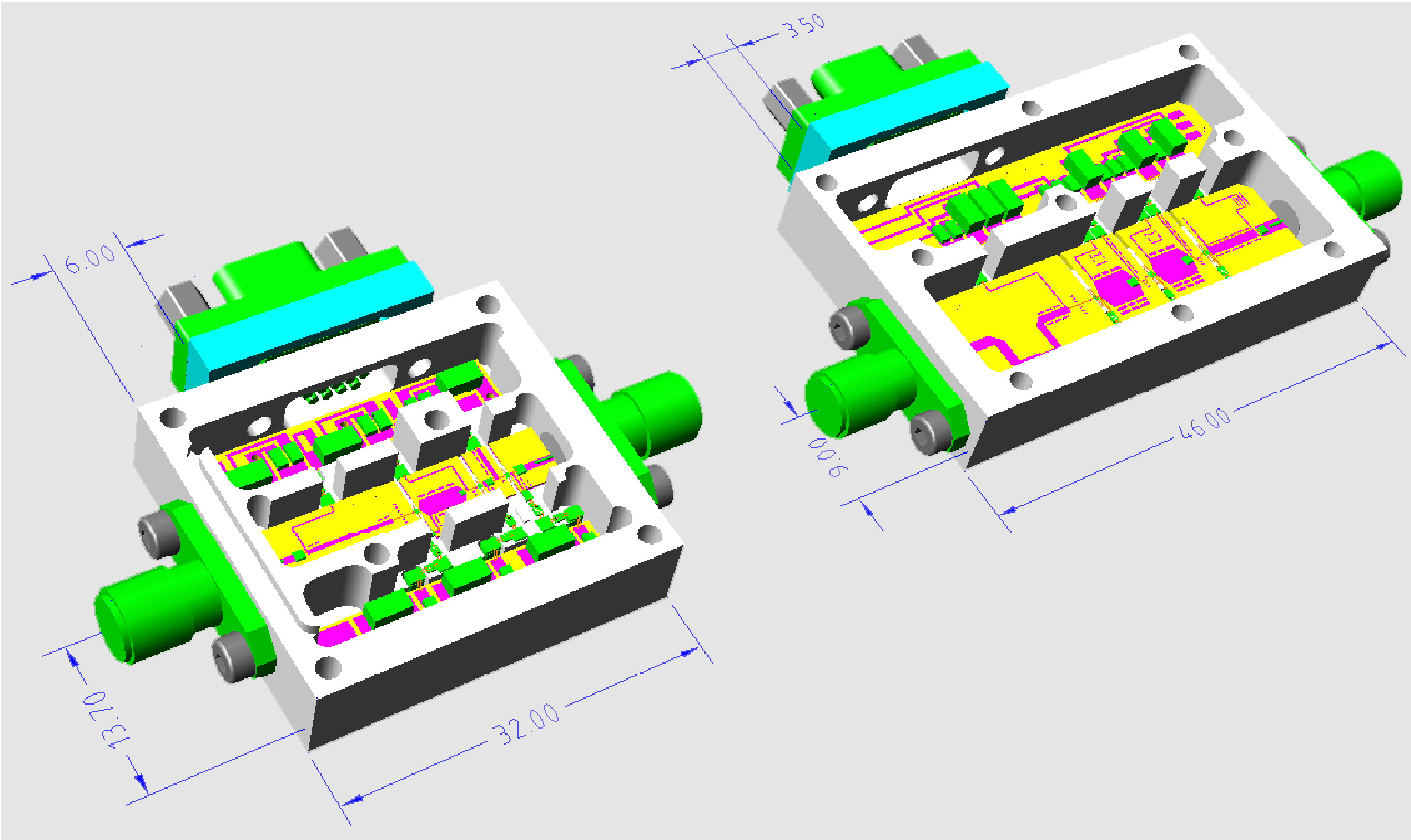
ALMA

- B7 (IRAM) 4-8 GHz 2SB
- B9 (SRON) 4-12 GHz DSB

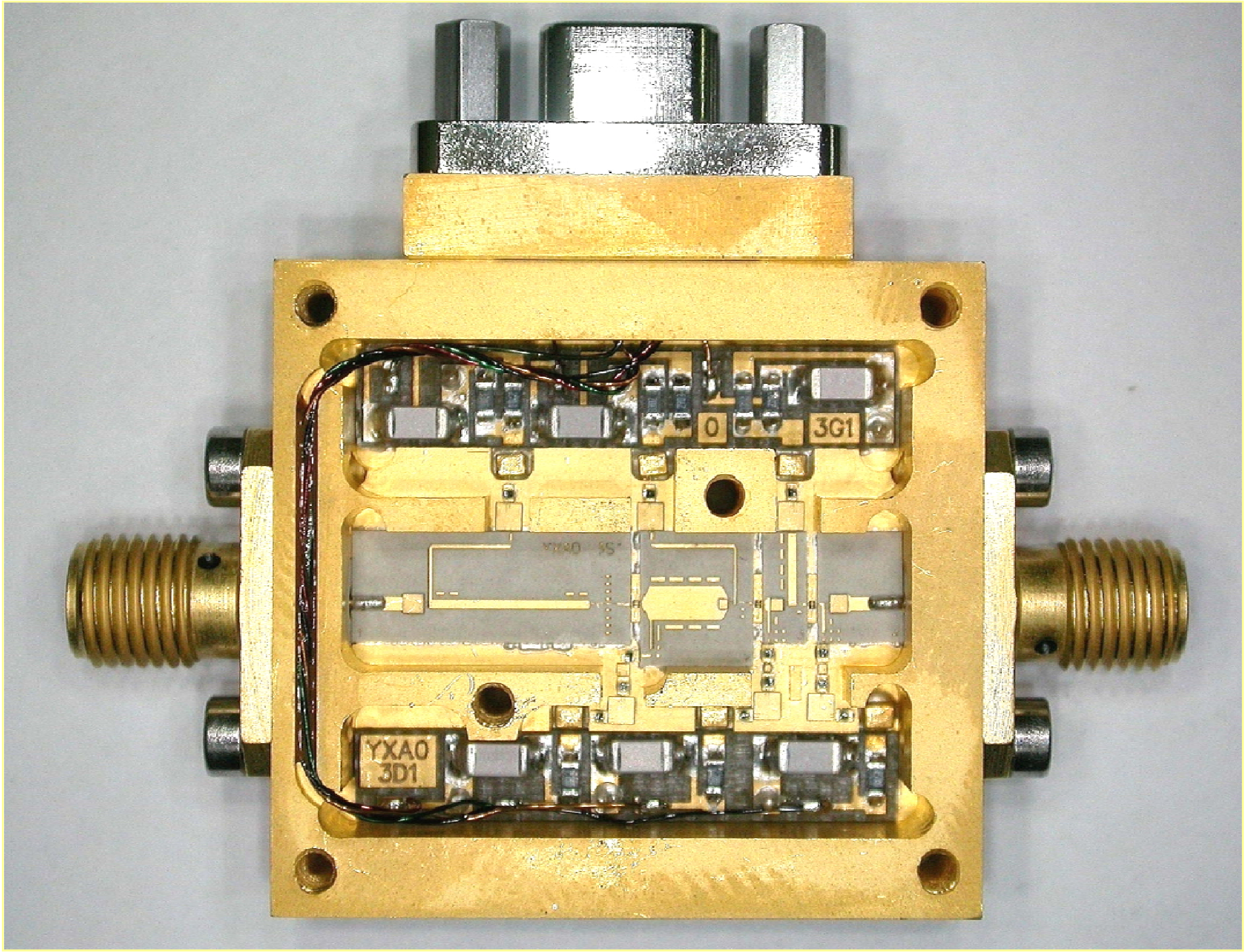




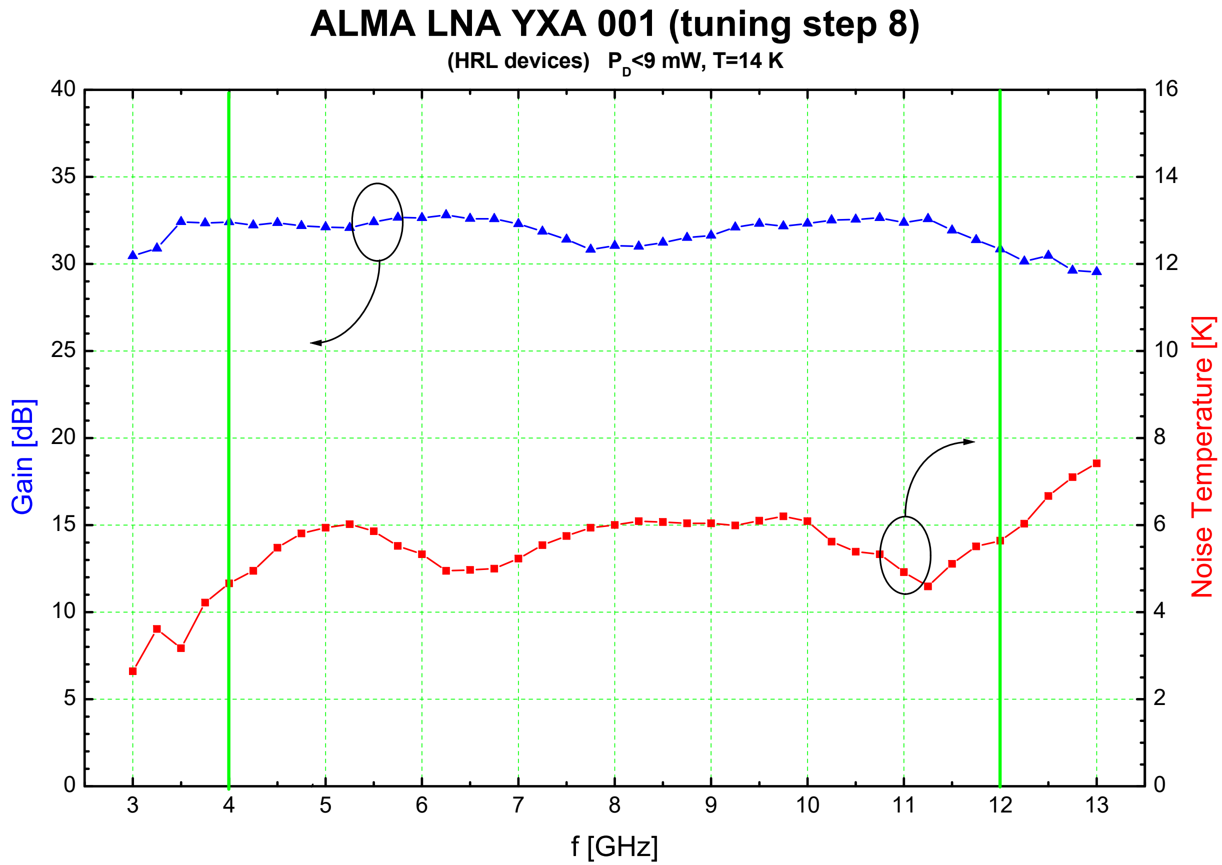
4-8 GHz/4-12 GHz amplifiers



4-12 GHz ALMA amplifiers (Band 9)



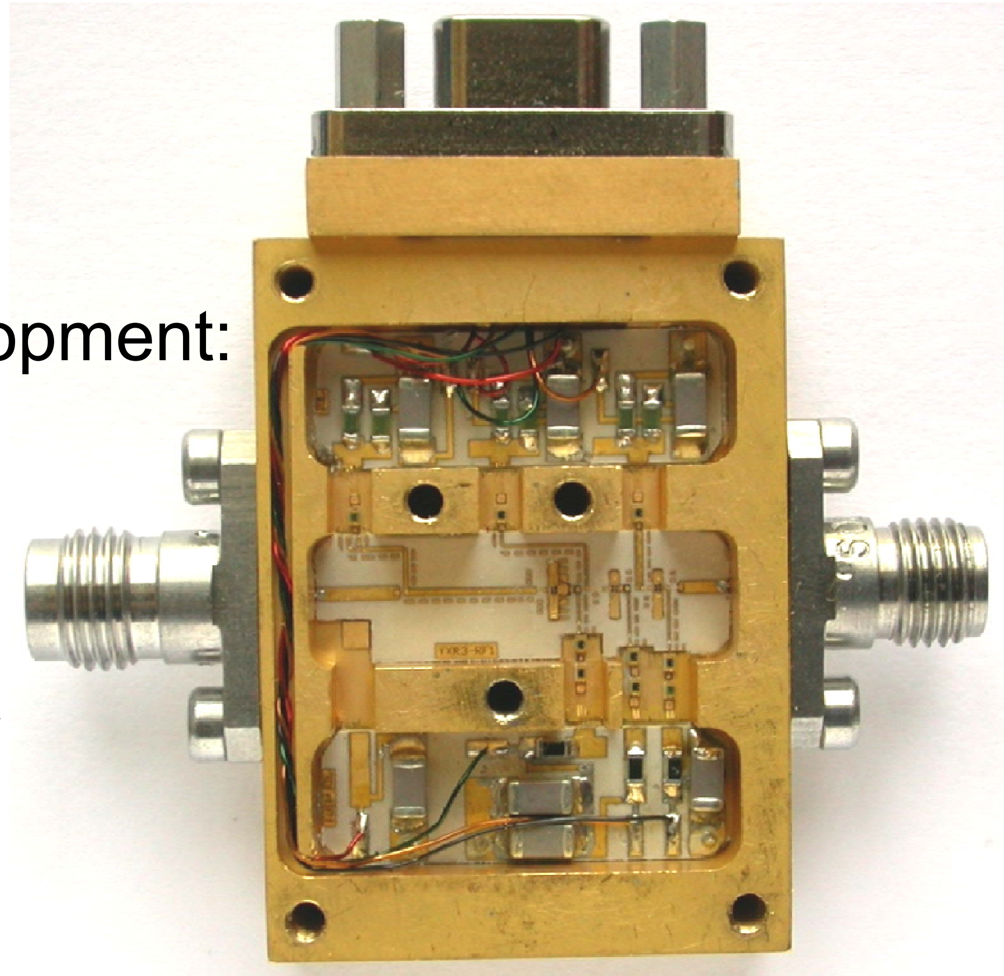
4-12 GHz ALMA amplifiers (Band 9)



AETHER (4-12 GHz, no ISOLATOR) Hybrid Version

RADIONET AETHER Development:

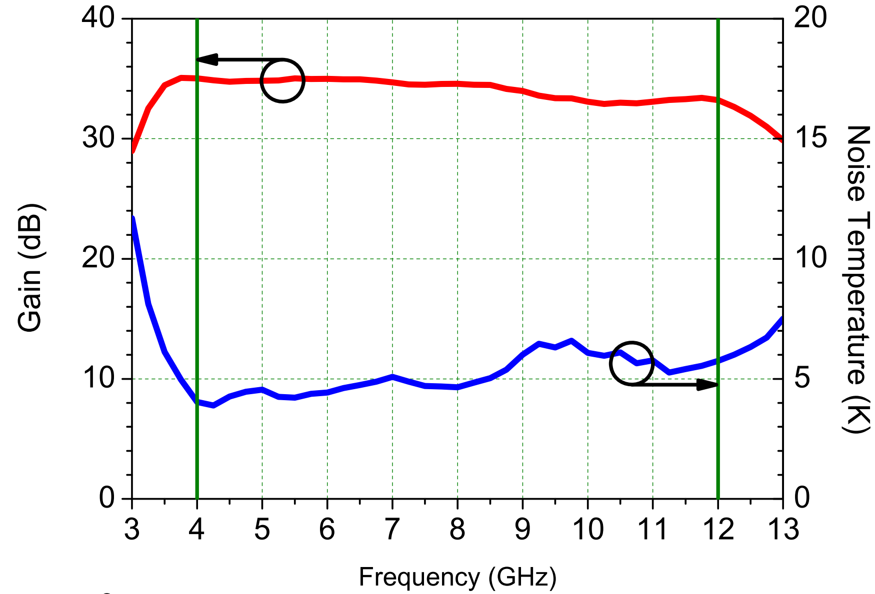
- Evolution of ALMA design
- To be connected directly to mixer
- Bias T included
- Goal: IRL (<-10 dB)
- Still 50 ohm interface SMA connector
- Dimensions: 23.4 x 19.5 x 8.2 mm^3

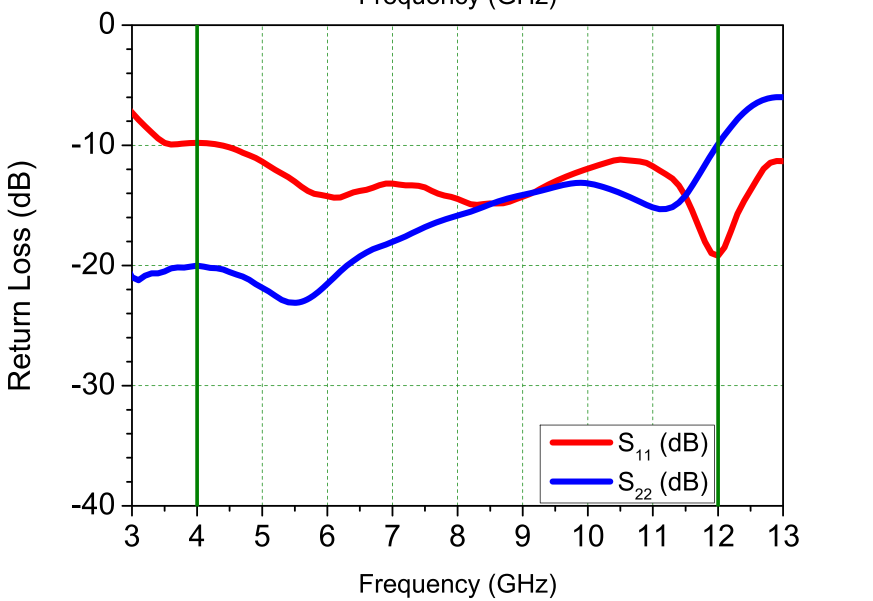


AETHER (4-12 GHz, no ISOLATOR) Hybrid Version

Test prototype measured results
(with ETH+2 HRL InP HEMTs)
Some noise penalty (≈1K)

15 K meas	YXR 3002 (low refl.)	NOEMA YXA 1225 ref.	Spec.
T_{avg} (K)	**5.1**	**4.0**	--
G_{avg} (dB)	34.1	34.0	>30
ΔG (dB)	2.4	2.1	--
S11 max (dB)	-9.8	-3.5	<-10
S22 max (dB)	-9.9	-10.7	<-10
P (mW)	11.4	10.2	--





AETHER (4-12 GHz, no ISOLATOR) MMIC Version

SELECTION OF DESIGN:

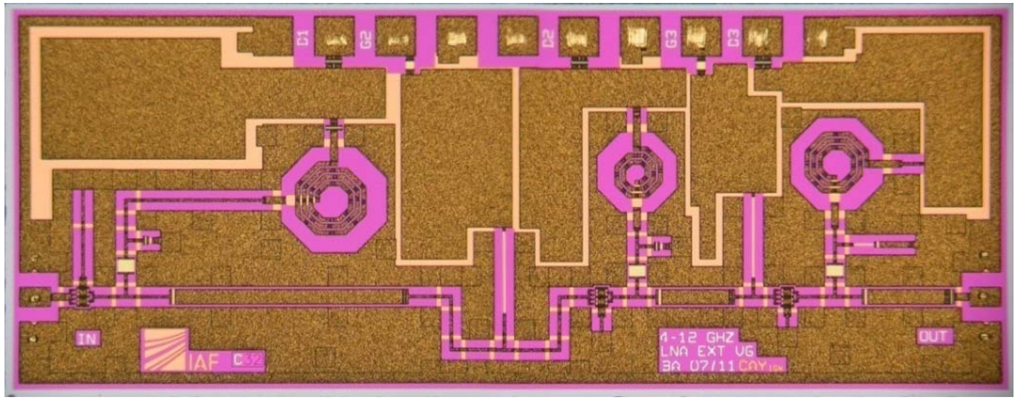
- **Compromise** between noise and IRL (8 different designs tested!)
- IAF Run with good noise results, but **not prone to oscillations**

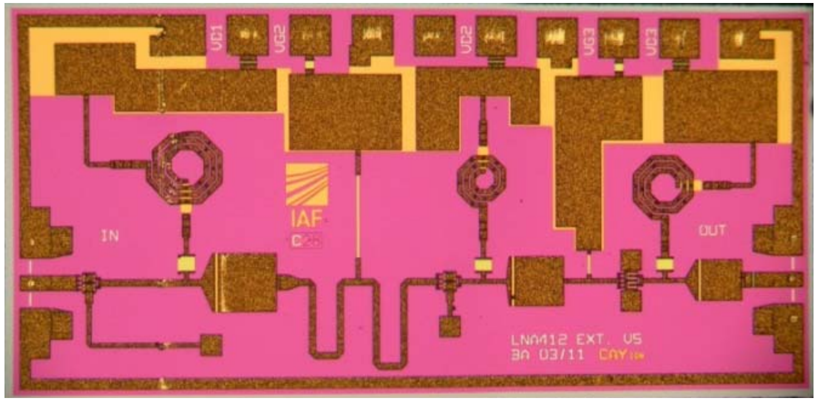
Run 740 – Design E6

- 100 nm technology
- External input matching network
- Coplanar layout, 2.5×1 mm
- Noise around 5.8 K
- Pros: Excellent stability
- Cons: bad IRL and noise around 4-5 GHz

Run 738 – Design E5

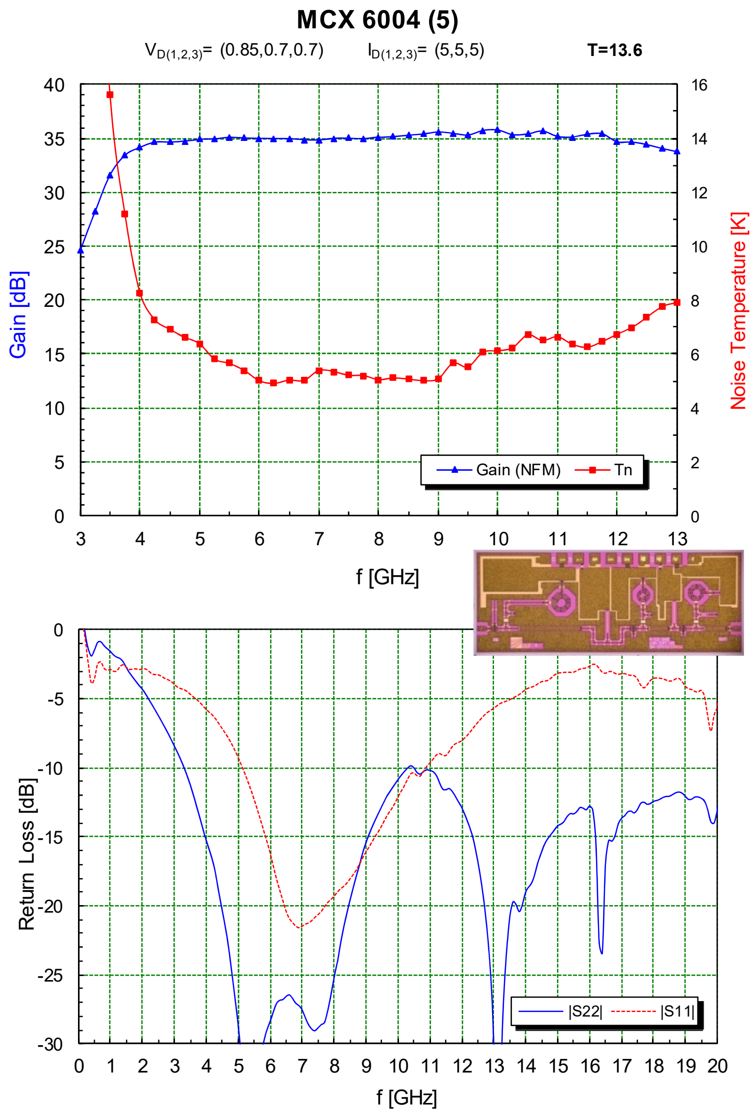
- 100 nm technology
- External input matching network
- Microstrip layout, 2×1 mm
- Noise around 6.3 K
- Pros: Excellent stability
- Cons: IRL between 5 – 10 dB above 8 GHz



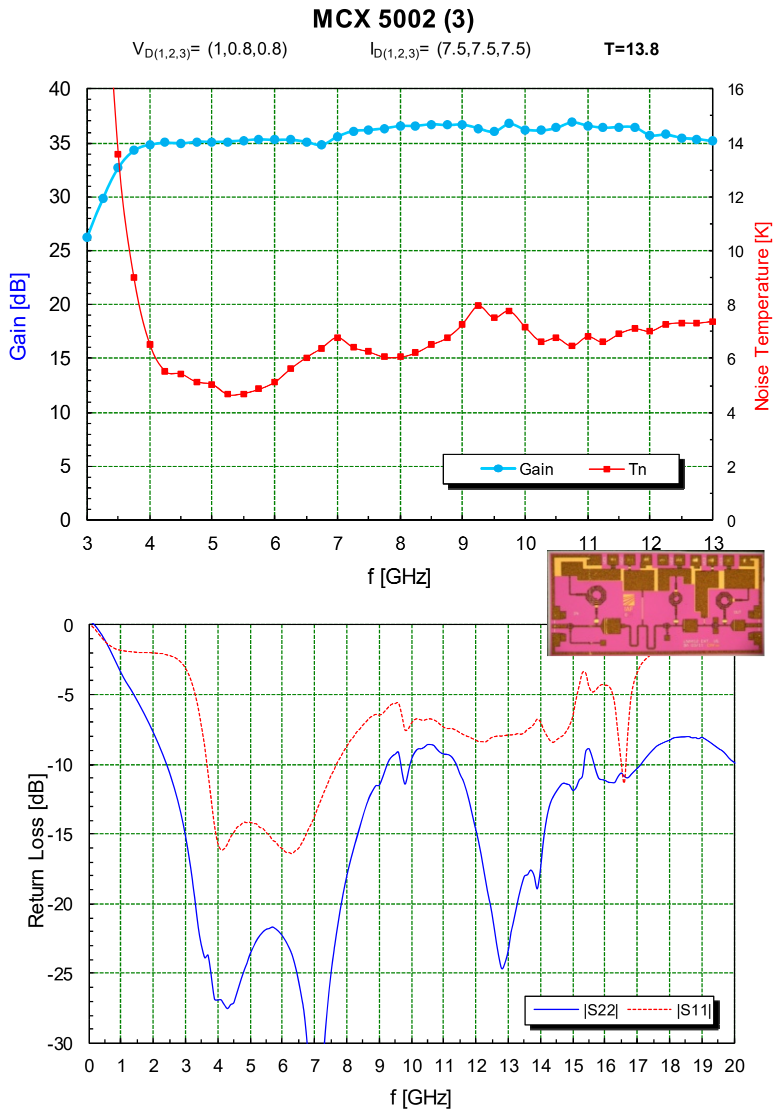


AETHER (4-12 GHz, no ISOLATOR) MMIC Version

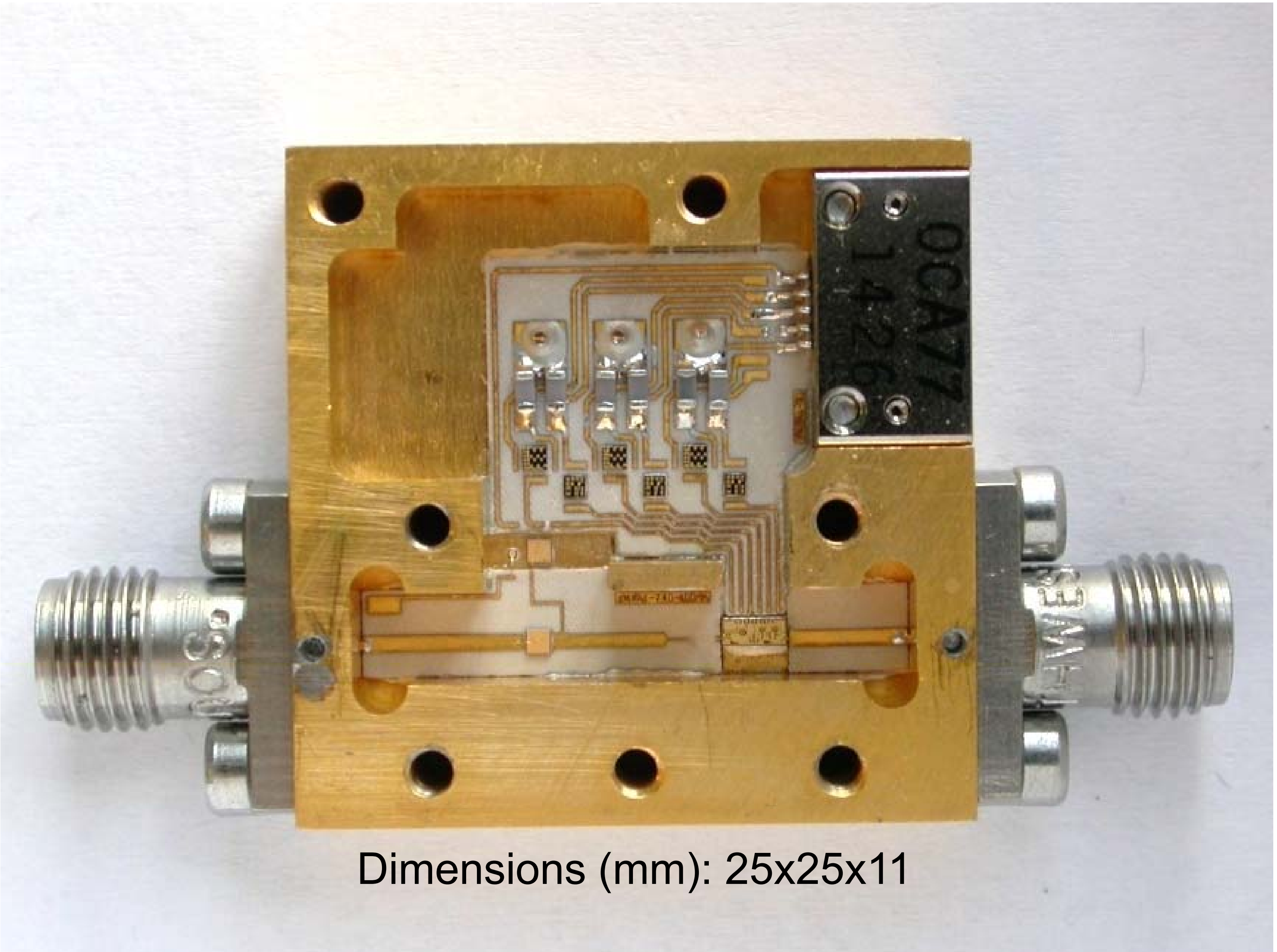
Run 740 – Design E6



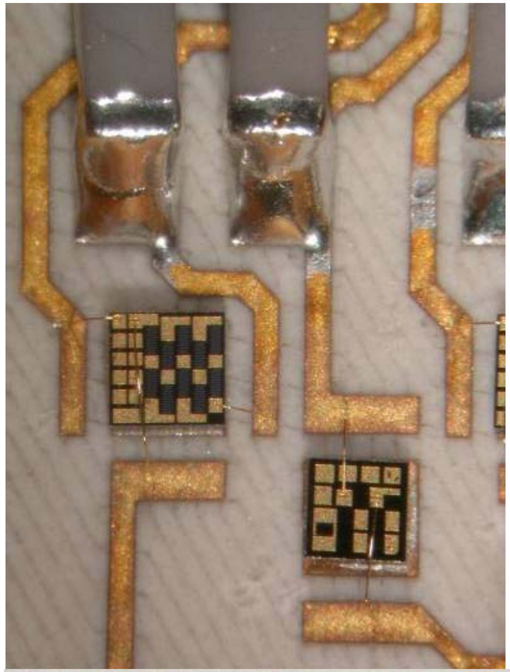
Run 738 – Design E5



AETHER (4-12 GHz, no ISOLATOR)
MMIC Version



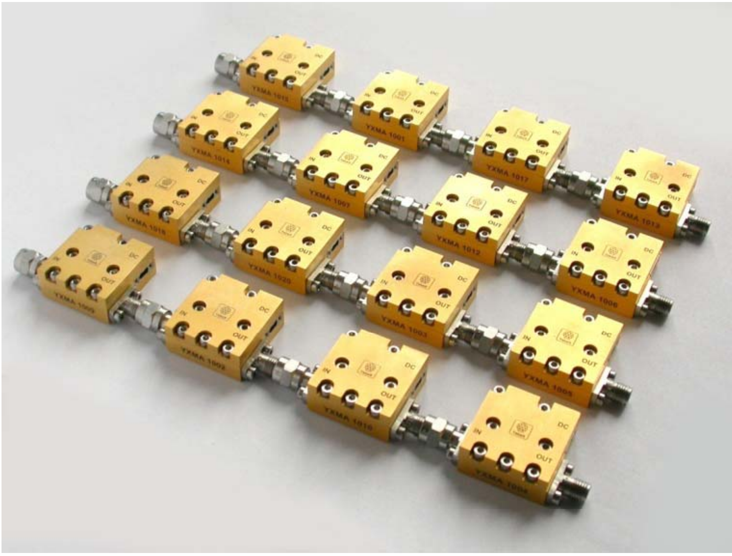
Dimensions (mm): 25x25x11



AETHER (4-12 GHz, no ISOLATOR) MMIC Version

Final design

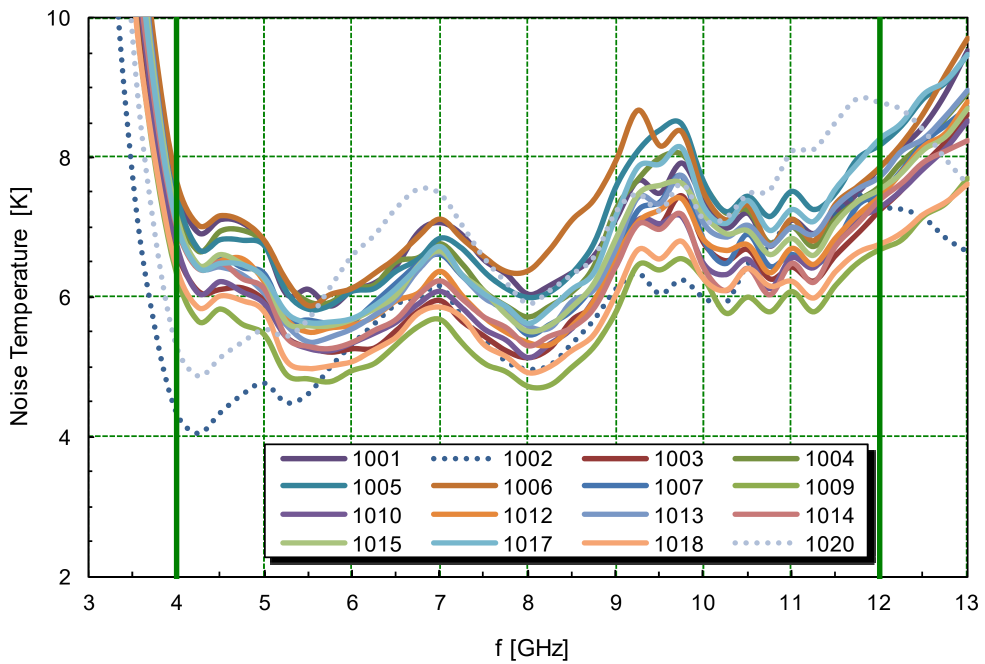
- 4 wire simplified bias has been implemented
  - Bonding wire selectable multi-tap resistors (possible bias ajustment)
  - 5 pin miniature connector on output face

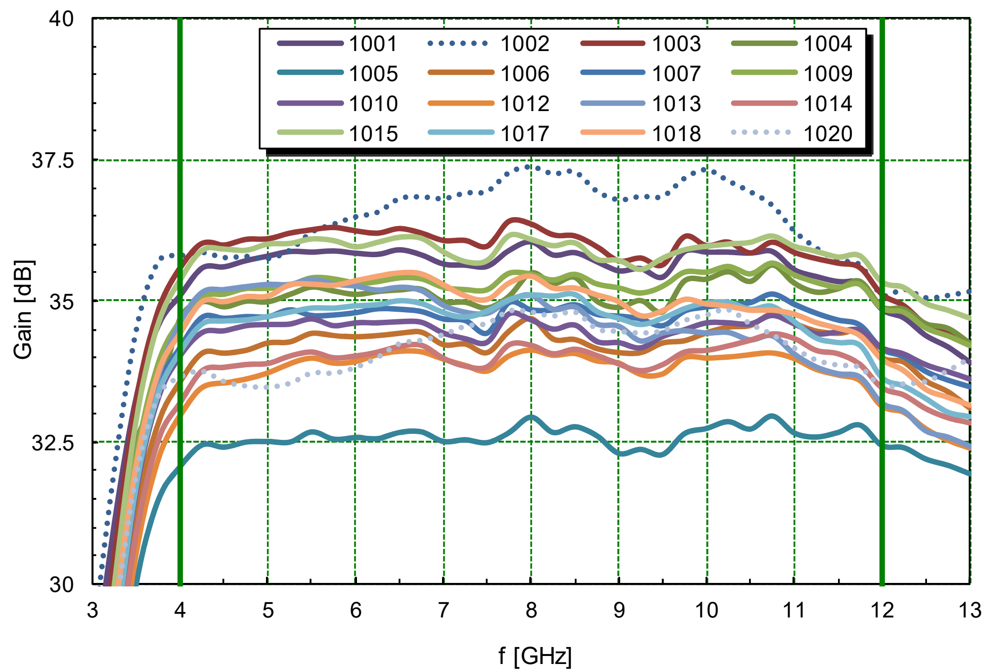


View of the 16 amplifier units delivered
(14 to IRAM and 2 to SRON)

Final configuration.
Dimensions (mm): 25x25x11

AETHER (4-12 GHz, no ISOLATOR) MMIC Version





Noise temperature and gain plot of the units delivered

AETHER (4-12 GHz, no ISOLATOR) MMIC Version

S/N	Dest.	Run/Vers./Chip	Avg. Tn (K)	Avg. Gain/Span (dB)	% BW IRL <-10 dB	% BW ORL <-15 dB	Pdiss (mW)
YXMA 1001	IRAM	R740 / V6 / C-41	6.8	35.6 / 1.0	80	93	12.00
YXMA 1002	SRON	R738 / V5 / C-04	5.7	36.4 / 1.8	48	84	9.10
YXMA 1003	IRAM	R740 / V6 / C-35	6.1	36.1 / 1.1	81	96	16.15
YXMA 1004	IRAM	R740 / V6 / C-30	6.8	35.1 / 1.2	83	61	13.50
YXMA 1005	IRAM	R740 / V6 / C-34	6.9	32.1 / 0.9	80	69	14.45
YXMA 1006	IRAM	R740 / V6 / C-40	7.0	34.2 / 1.1	78	84	12.00
YXMA 1007	IRAM	R740 / V6 / C-38	6.4	34.7 / 0.9	76	78	12.75
YXMA 1009	IRAM	R740 / V6 / C-24	5.6	35.3 / 1.2	79	86	13.50
YXMA 1010	IRAM	R740 / V6 / C-26	6.1	34.5 / 0.8	78	83	13.60
YXMA 1012	IRAM	R740 / V6 / C-11	6.3	33.7 / 1.2	76	74	13.60
YXMA 1013	IRAM	R740 / V6 / C-28	6.5	34.6 / 1.9	76	84	12.00
YXMA 1014	IRAM	R740 / V6 / C-12	6.2	34.0 / 1.2	75	65	16.00
YXMA 1015	IRAM	R740 / V6 / C-20	6.5	35.9 / 0.8	76	80	18.00
YXMA 1017	IRAM	R740 / V6 / C-21	6.7	34.6 / 1.2	78	88	12.00
YXMA 1018	IRAM	R740 / V6 / C-10	5.8	35.0 / 1.3	76	73	18.00
YXMA 1020	SRON	R738 / V5 / C-20	6.8	34.3 / 1.6	46	100	13.60

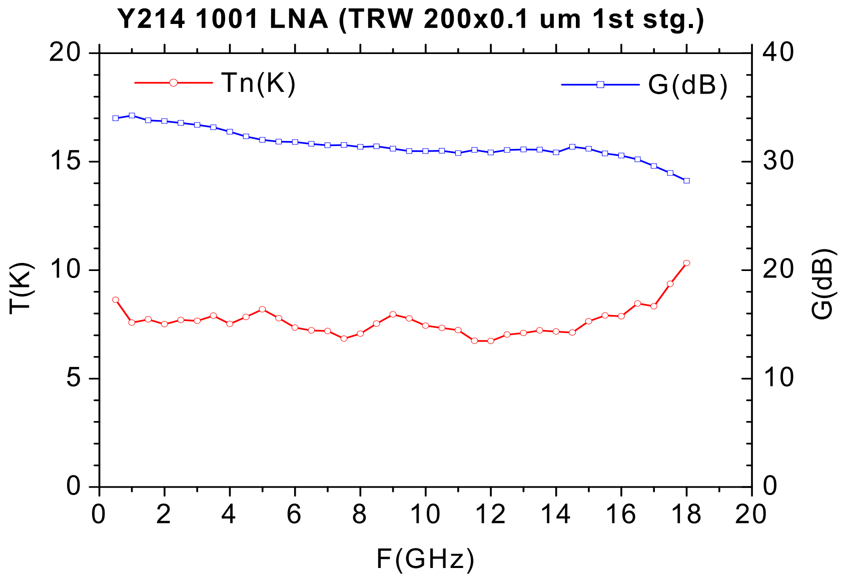
Ultra Wide Band

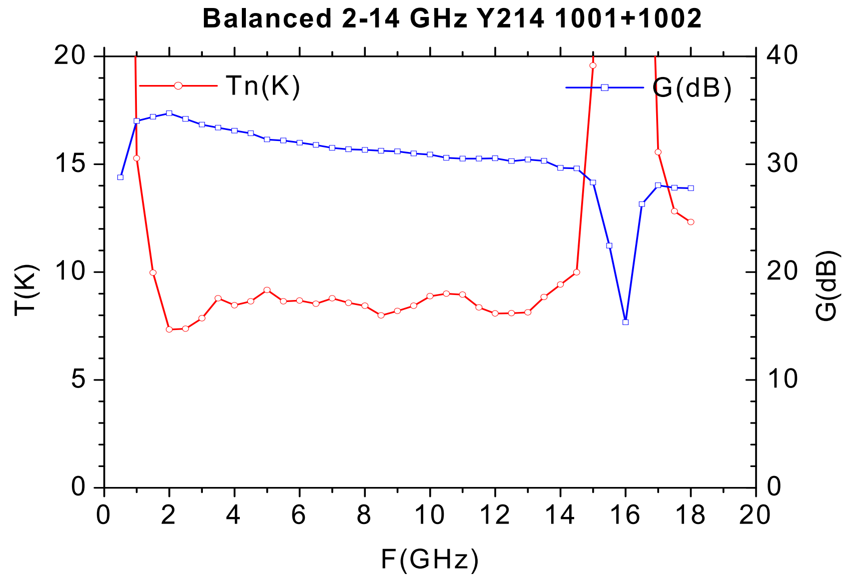
- Hybrid
- Very small
- InP HEMTs
- Usable in 0.5-18 GHz
- Balanced version for 2-14 GHz
- One unit being tested in Oxford:

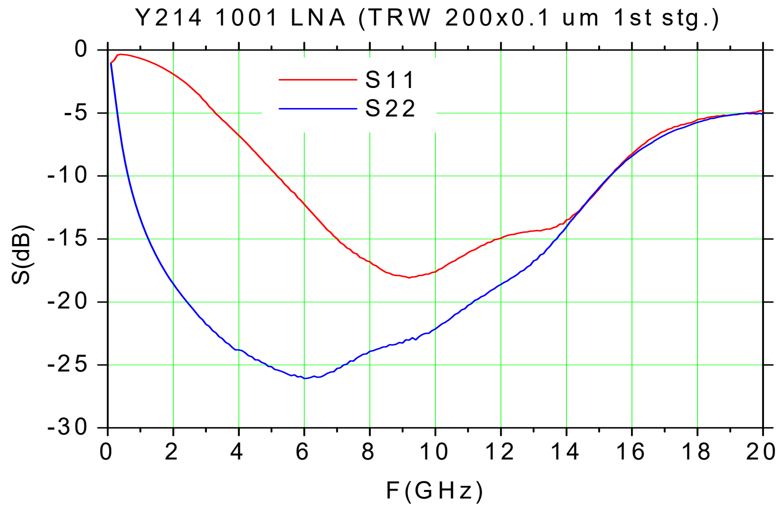
Band	2-14 GHz
Tn	6.1 K (ETH)
Gain	33.9 dB
IRL	-1.5 dB
ORL	-16.9
Power	36 mW

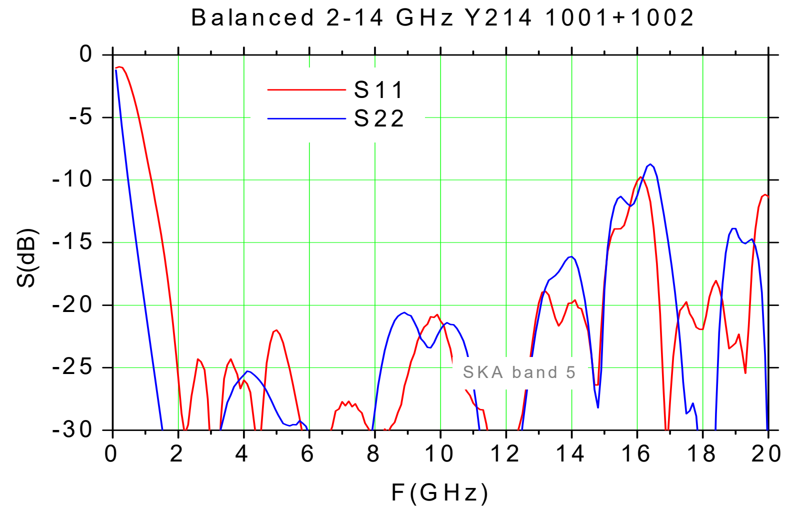
20 x 22 x 9 mm (excl. conn.)

Ultra Wide Band

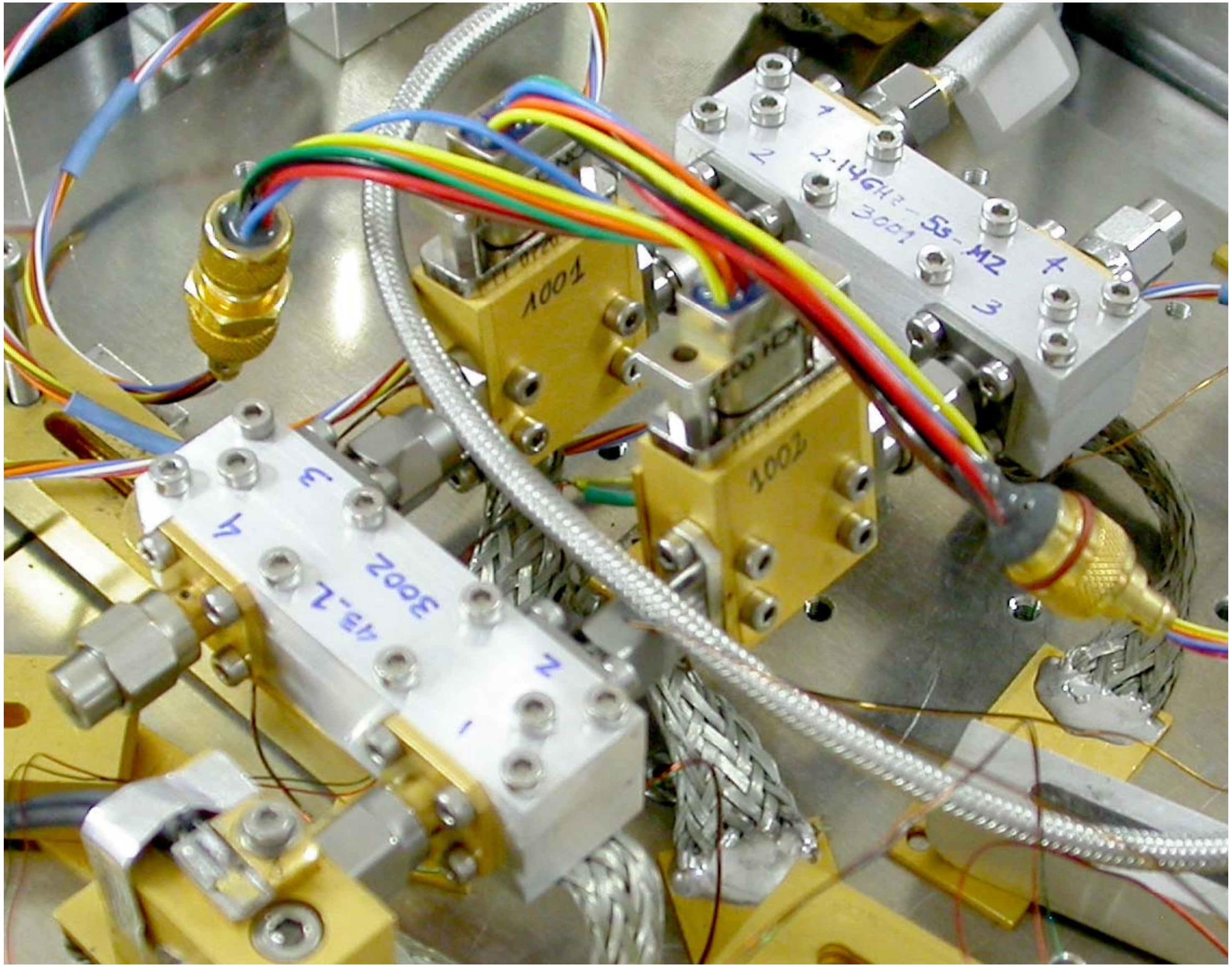








Ultra Wide Band



Low power InP HEMTs

- In 2003 Niklas Wadefalk demonstrated 1 mW Pdis with a factor 1.7 of noise degradation (4-8 GHz 2 stg. amplifier). HIFI was operated at 4 mW

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Cryogenic Wide-Band Ultra-Low-Noise IF Amplifiers Operating at Ultra-Low DC Power

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TABLE II
BIAS POINTS (BPs) AND DATA CORRESPONDING TO FIG. 5

	BP1	BP2	BP3	BP4
V_{d1}, V_{d2} [V]	1.15	0.5	0.3	0.1
I_{d1}, I_{d2} [mA]	5.0	3.0	1.7	0.5
P_{DC} [mW]	11.5	3.0	1.0	0.1
T_{avg} [K]	1.44	1.74	2.44	7.24

SiGe Amplifiers

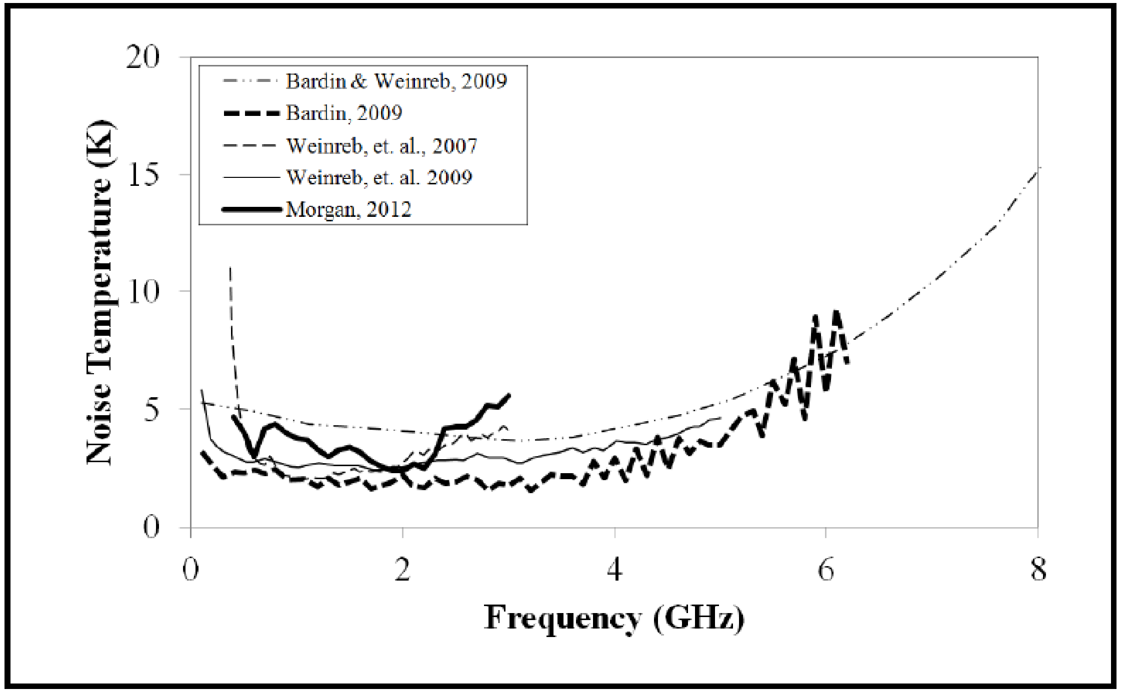
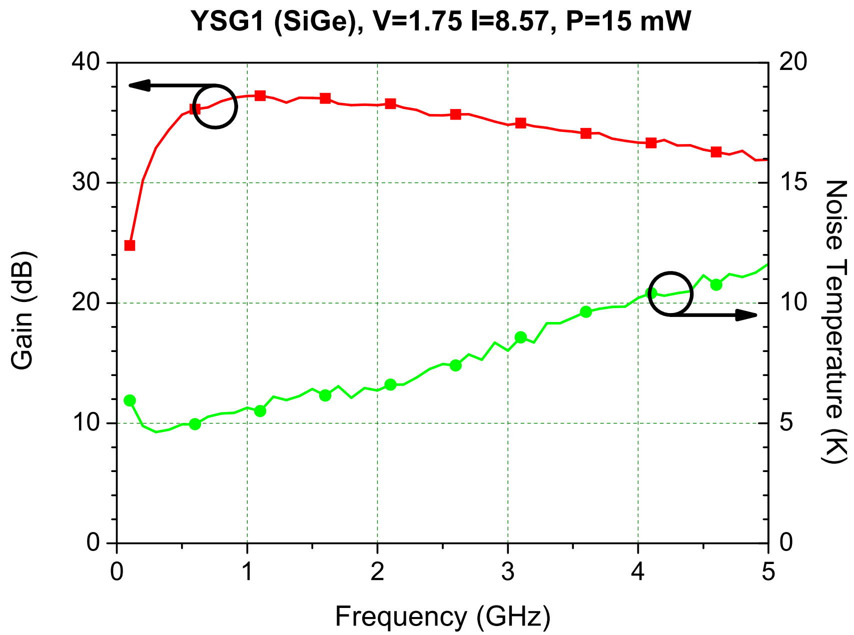
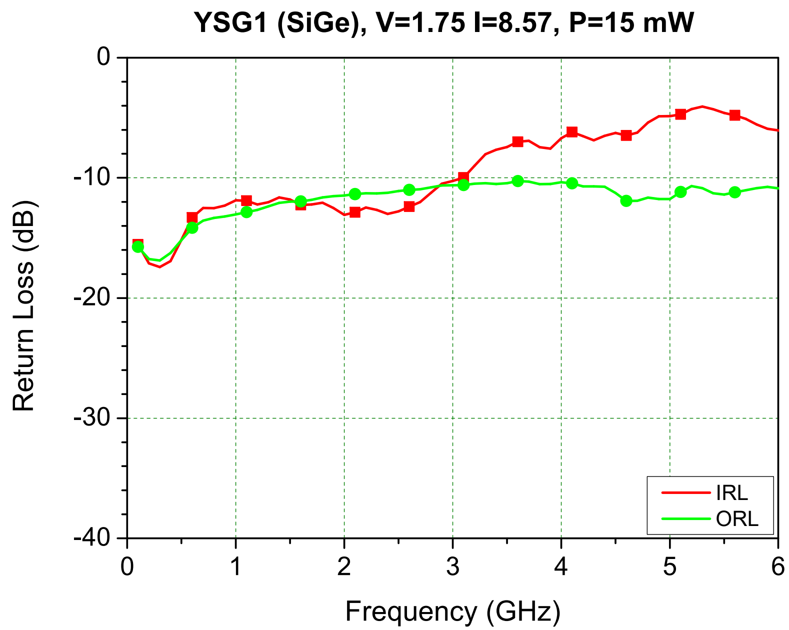


Fig. 3. Summary of the best equivalent noise temperatures reported in recent years for cryogenic SiGe amplifiers.

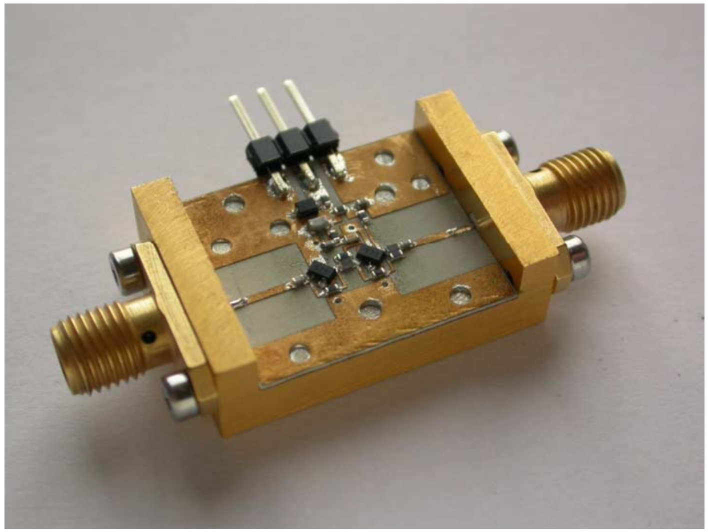
E. W. Bryerton, M. Morgan and M. W. Pospieszalski, "Ultra low noise cryogenic amplifiers for radio astronomy," *2013 IEEE Radio and Wireless Symposium*.

SiGe Amplifiers





- •Yebes test
- •Quick & dirty prototype
- •Super-simple
- •Using commercial BFU725 (NXP)
- •Power: 15 mW



SiGe Amplifiers

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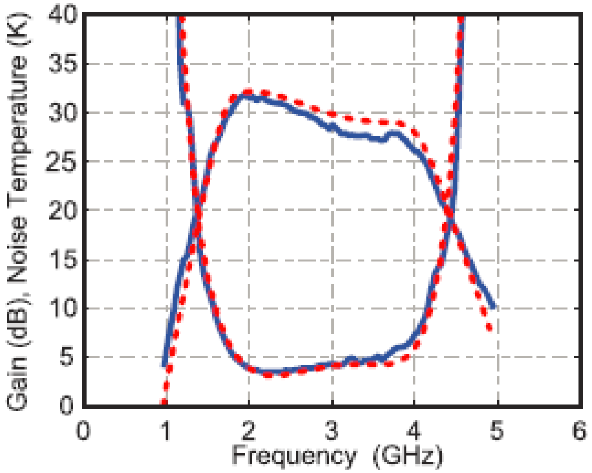
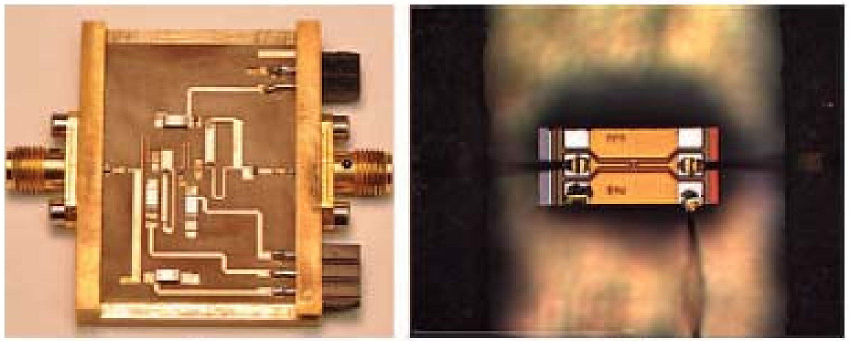
Ultra-Low-Power Cryogenic SiGe Low-Noise Amplifiers: Theory and Demonstration

Shirin Montazeri, *Student Member, IEEE*, Wei-Ting Wong, *Student Member, IEEE*,
Ahmet H. Coskun, *Student Member, IEEE*, and Joseph C. Bardin, *Member, IEEE*

Band= 1.8-3.6 GHz
Pdis= 0.3 mW
IBM BiCMOS8HP



(a)



(a) (b)

CONCLUSIONS

- HEMTs (InP & mGaAs) cryogenic amplifiers are a mature technology for future wide band low power IF amplifiers BUT good 100 nm devices needed (risk!)
- Do not neglect MICs (hybrids)!
- Close cooperation between mixer and amplifiers groups needed (AETHRA?)
- SiGe is a promising technology. Low power seems possible, but some difficulties to achieve very wide bands.

END