Multi-octave Balanced Low Noise Amplifier for Radio Astronomy Cryogenic Receivers

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YEBES RECENT PROJECTS

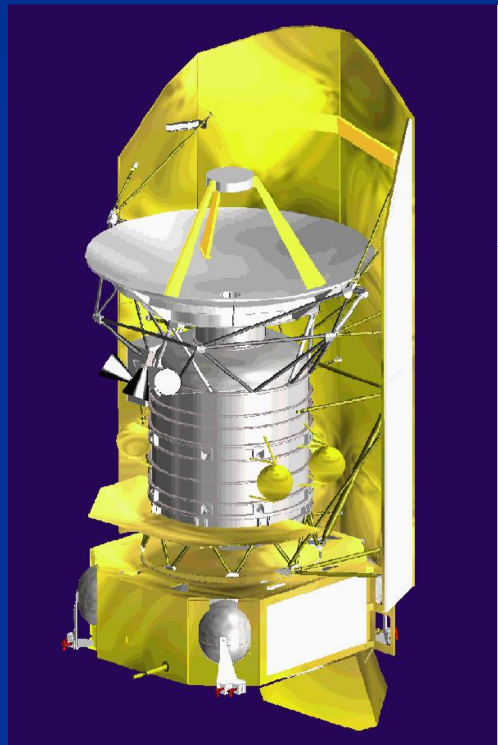
- HERSCHEL (HIFI) → (2-4 GHz & 4-8 GHz, low power dissipation)
- IRAM → (1.2-1.8 GHz PB & 3.2-4.7 GHz PV upgraded to 4-8 GHz & 4-12 GHz)
- RT 40 m CAY → (bands from 2.2 GHz to 26 GHz)
- ALMA → (4-8 and 4-12 GHz)
- (ESOC)
  - X-Band → (8.1-9.0 GHz, same as VLBI)
  - Ka-Band → (25.5- 34 GHz)
- EUROPEAN PROJECTS
  - FP6: AMSTAR (IFs for IRAM & SRON 4-12 GHz)
  - FF7: AMSTAR+ (IF integrated with mixer), APRICOT (33-50 GHz multibeam receiver)
- Over 1000 cryogenic amplifiers delivered to different projects.

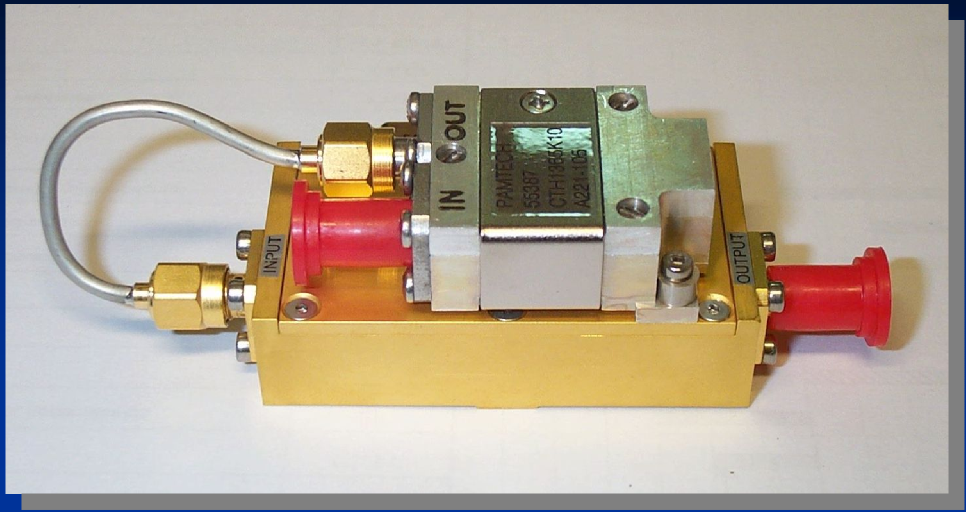
Wide Band Amplifiers

- Wide instantaneous bandwidth high performance amplifiers for mmW IF amps development started ~10 years ago.
- 4-12 GHz is standard IF now in mmW receivers
- Problems:
  - Source of InP devices (NGST, HRL, ETH…)
  - High Input Reflection: cryogenic isolator needed (Pamtech)

HERSCHEL (HIFI)

To be launched April 16 2009 (delayed by 2 w)

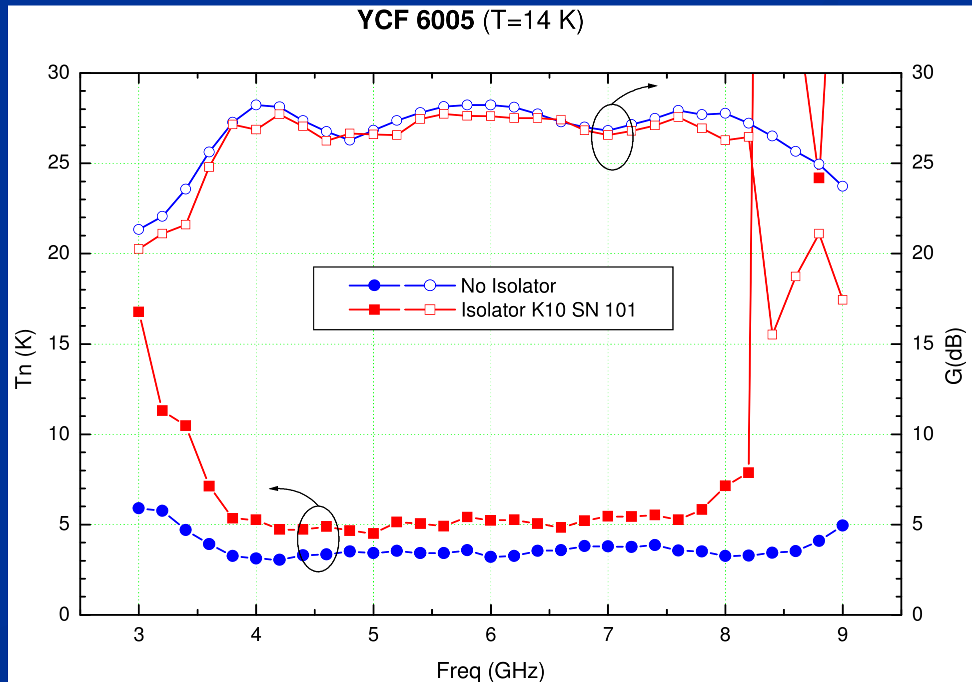




Isolator contribution

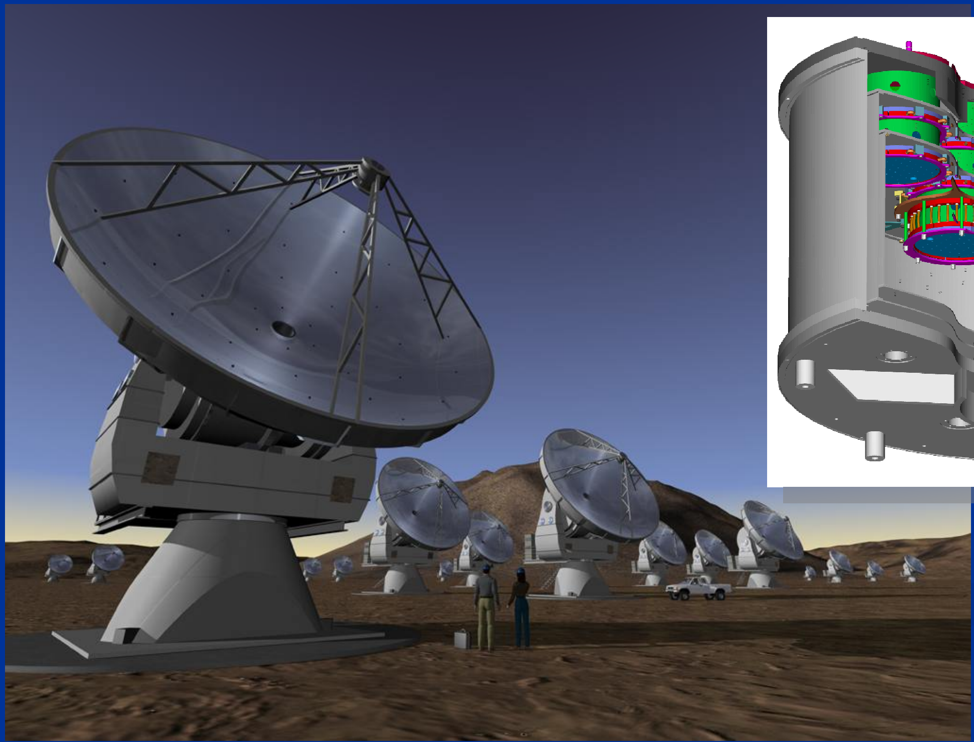
$$\Delta T_c = \left(\frac{1}{G_{iso}} - 1 \right) \cdot \left(T_{amb} + T_{amp} \right)$$

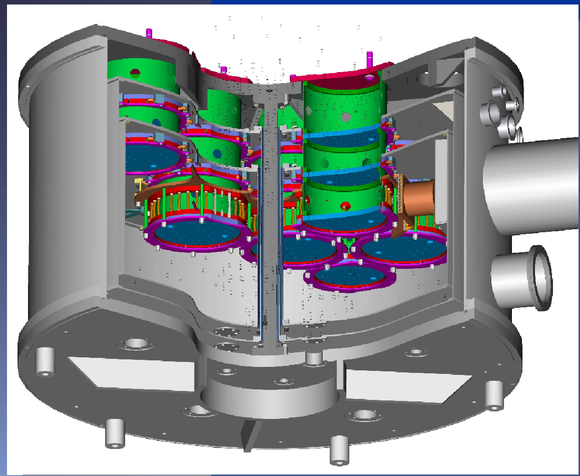
- Isolators measured @ 14 K (PAMTECH gives data @ 77 K)
- Good agreement between measurement and estimation of isolator noise
- Mean contribution 1.1 – 1.4 K



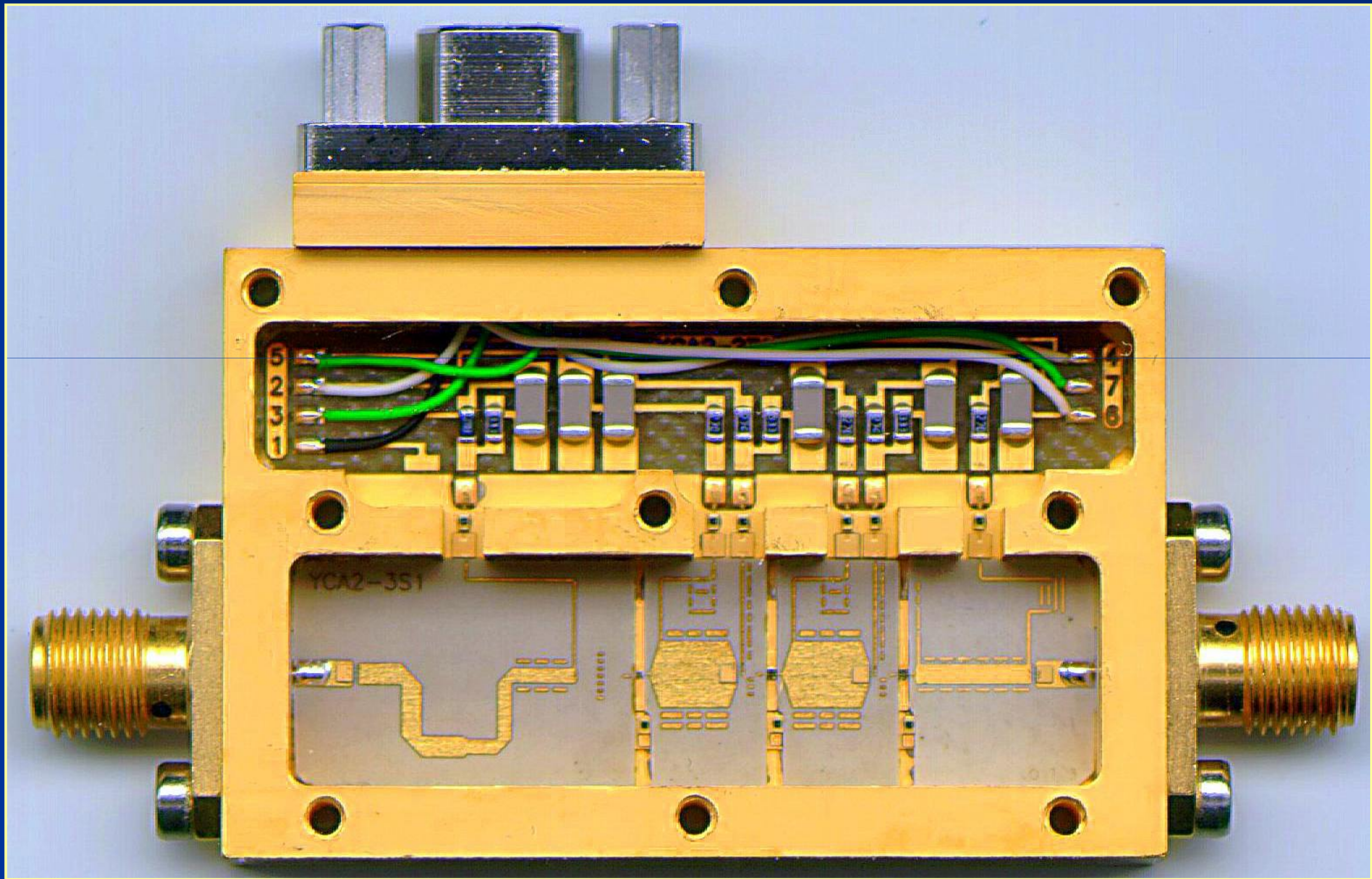
ALMA

- Array of 50×12 m antennas in Atacama, Chile with up to 10 km baseline
- Covers all atmospheric windows up to 1 THz
- **CAY contribution**: Cryogenic IF amplifiers for all European channels (IRAM, Band 7 and NOVA, Band 9)

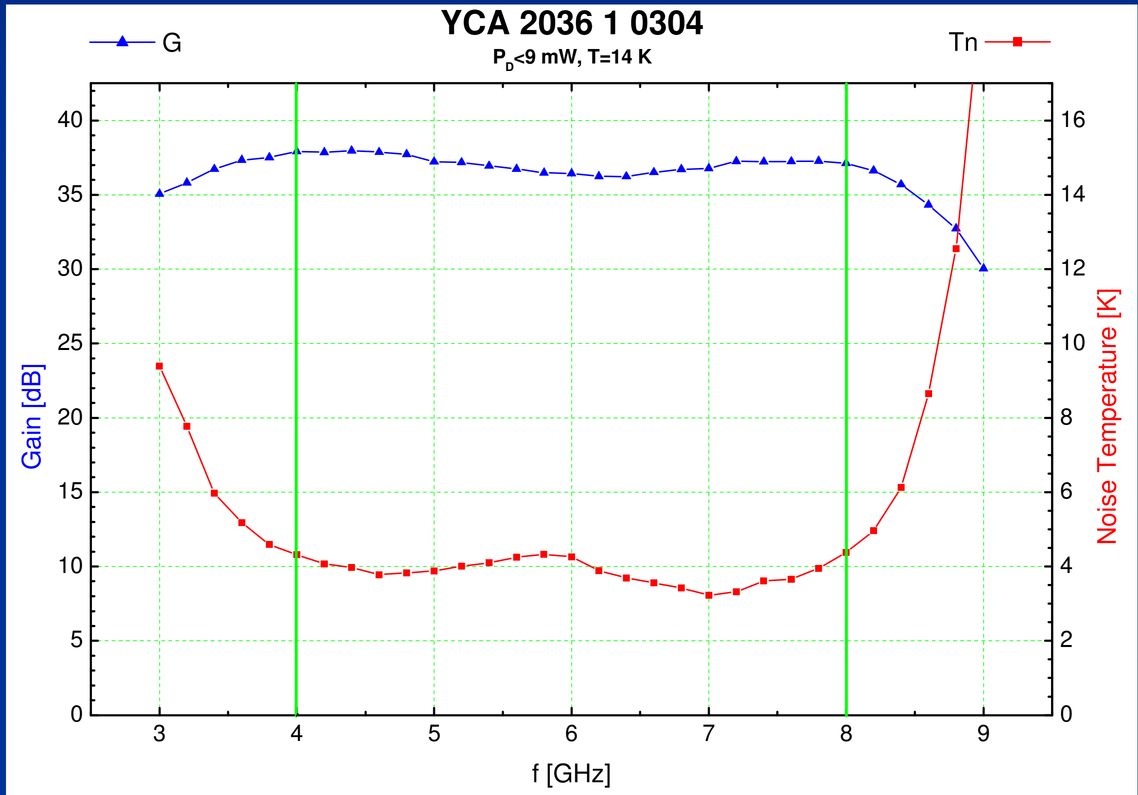




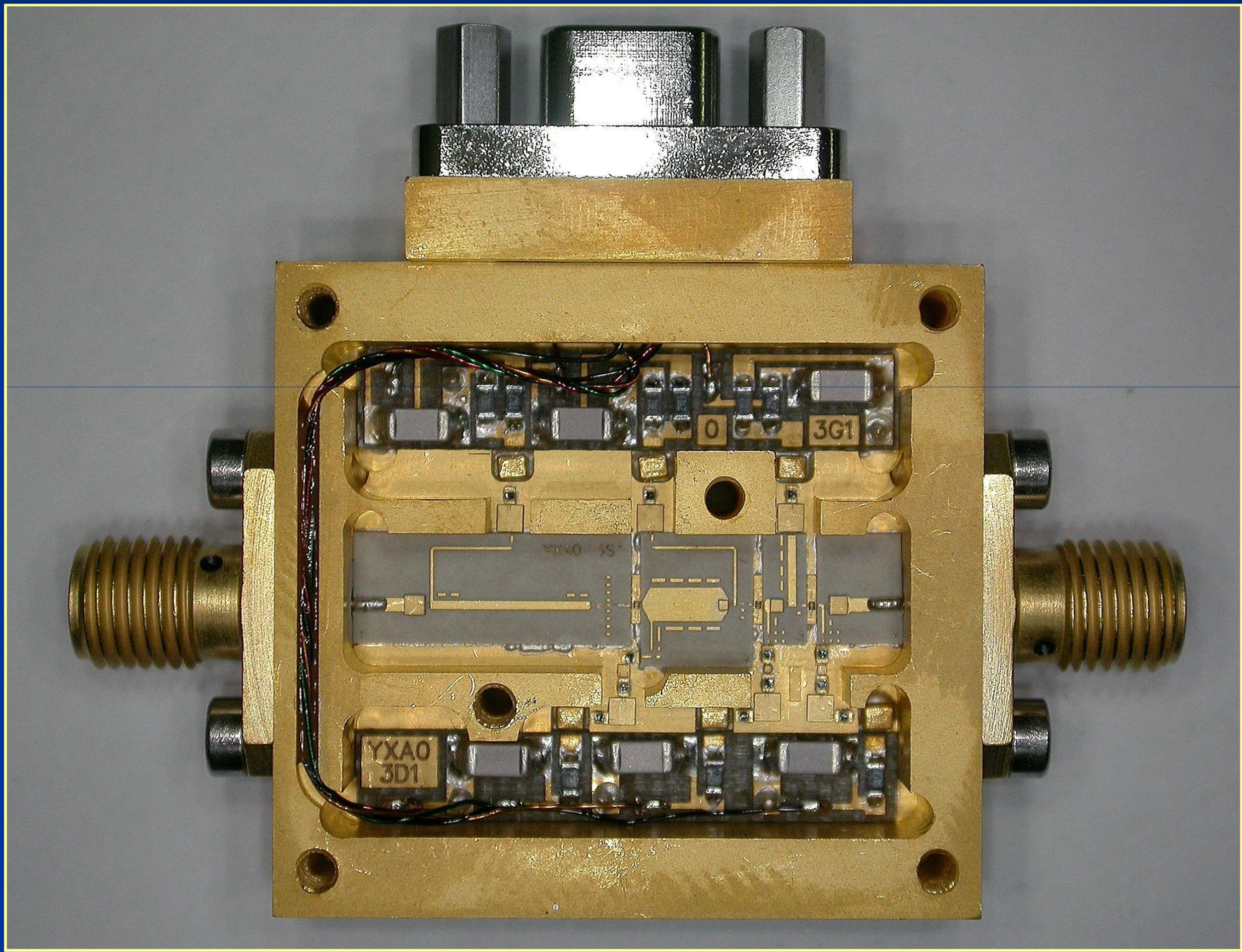
4-8 GHz ALMA amplifiers (Band 7)



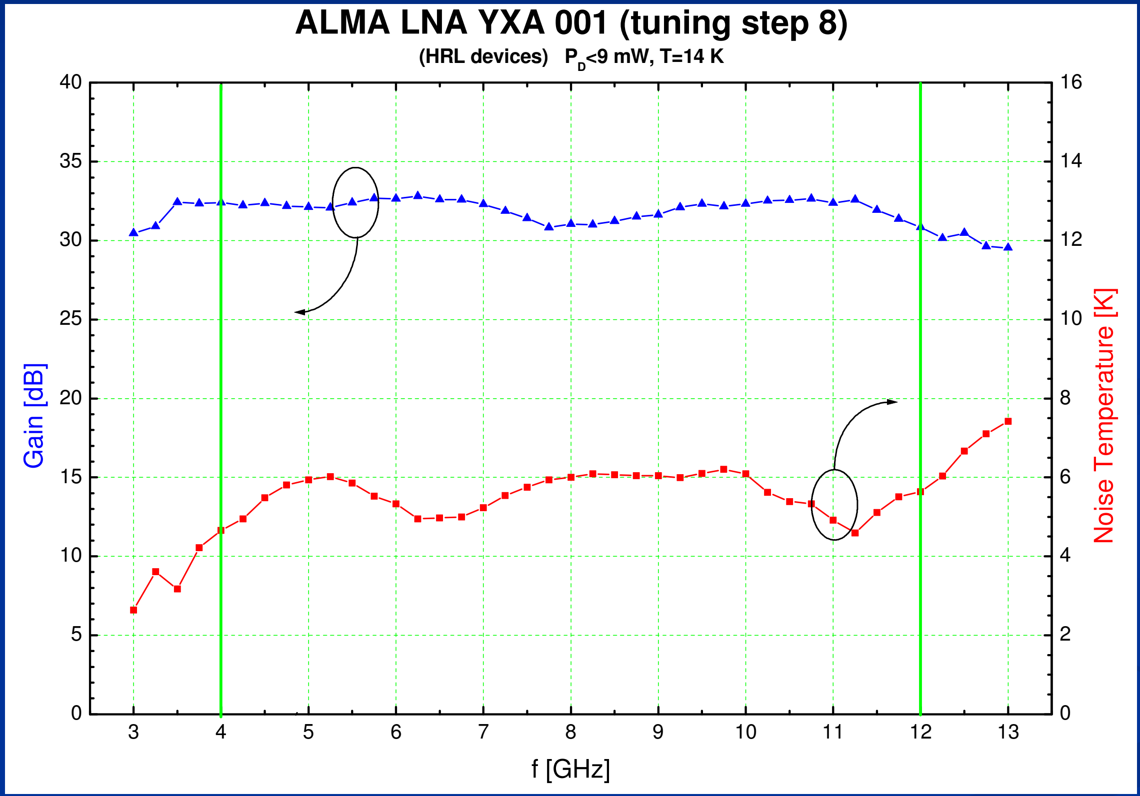
4-8 GHz ALMA amplifiers (Band 7)



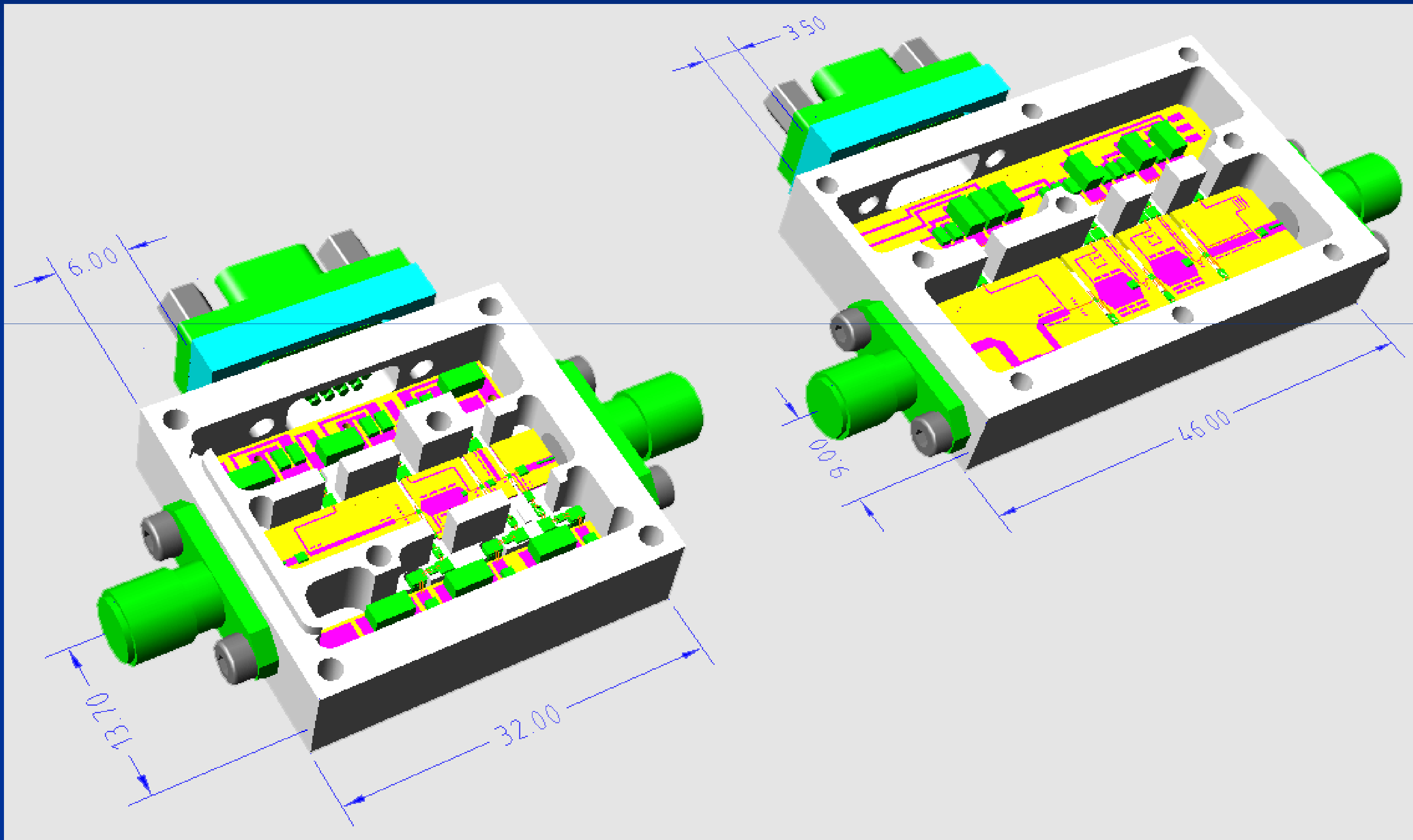
4-12 GHz ALMA amplifiers (Band 9)



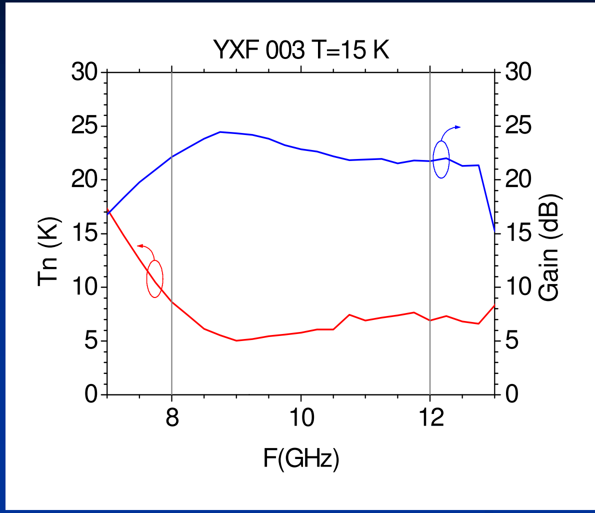
4-12 GHz ALMA amplifiers (Band 9)

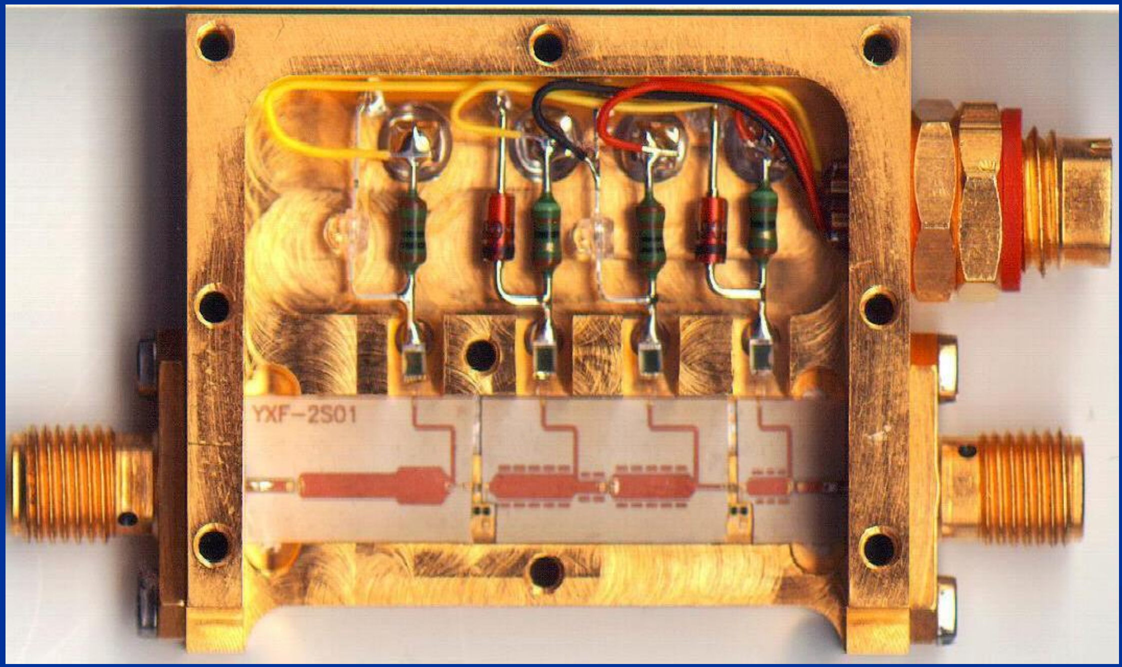


4-8 GHz/ 4-12 GHz amplifiers



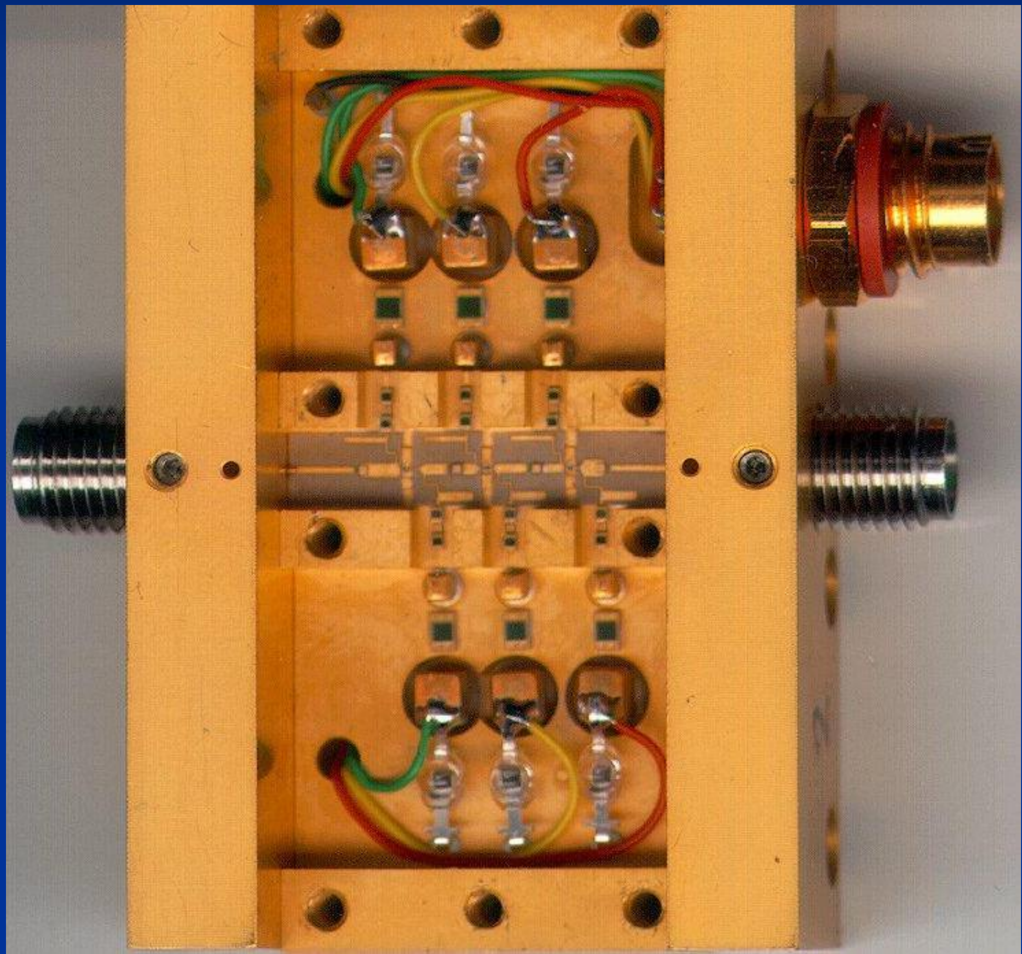
X Band (8-12 GHz)

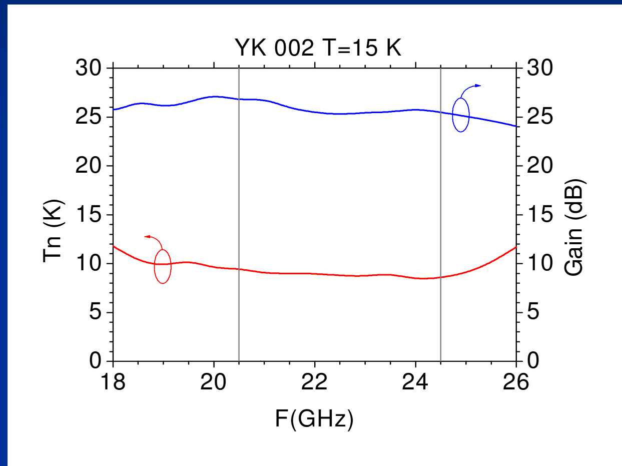




CHARACTERISTICS	
Working Band	8 – 12 GHz
Working Temperature	15 K
Dimensions	39 x 32 x 10.5 mm
Transistors	InP HEMT 0.1 x 160 μm (TRW)
PERFORMANCE	
Noise Temperature / Factor	6.5 K / 0.093 dB
Gain (variation)	22.9 dB (± 1.4 dB)
Output Reflection	>12.5 dB

K-Band (18-26 GHz) VLBI





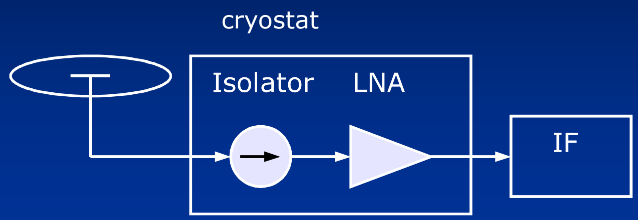
CHARACTERISTICS	
Working Band	20.5 – 24.5 GHz
Working Temperature	15 K
Dimensions	32 x 48 x 13 mm
Transistors	InP HEMT 0.1 x 160 μm (TRW)
PERFORMANCE	
Noise Temperature / Factor	8.9 K / 0.13 dB
Gain (variation)	26.1 dB (± 1 dB)
Input / Output Reflection	>7 dB / >8.5 dB

ESOC (ESA)

- Deep Space Network
- Needed for missions like: Venus express, Mars express, Rosetta, Herschel, Plank
  - X-Band → (8.1-9.0 GHz)
  - Ka-Band → (25.5- 34 GHz)
- Specs on (X band):
  - Max. input without damage: 0 dBm
  - Output 1 dB compression: +5 dBm
  - Output IP3: +15 dBm

Towards wider band receivers

Present cryogenic VLBI front-end



Future VLBI 2010 Much wider band

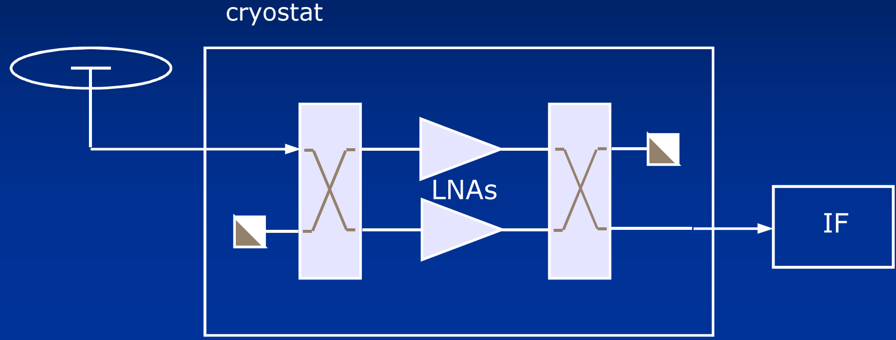
Wide band Cryogenic Isolators

Needed to reduce input reflection of wide band low noise amplifier, but they..

- are hard to procure
- have high insertion loss
- show poor unit to unit repeatability

Proposal: Balanced amplifier

4-12GHz prototyp
e

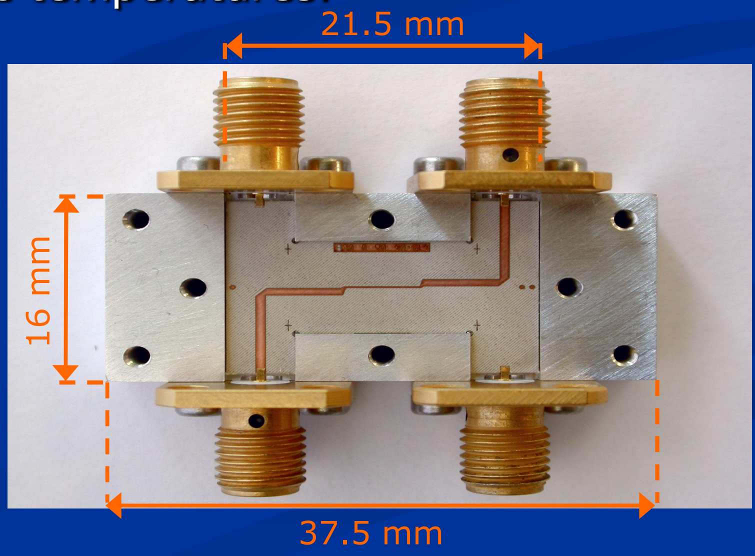


90º cryogenic hybrid

No commercially available for cryogenic temperatures.

CAY prototype:

- Very compact, reliable and low thermal mass device.
- Able to survive extreme thermal cycling.
- Coupling and reflection: little temperature dependence.

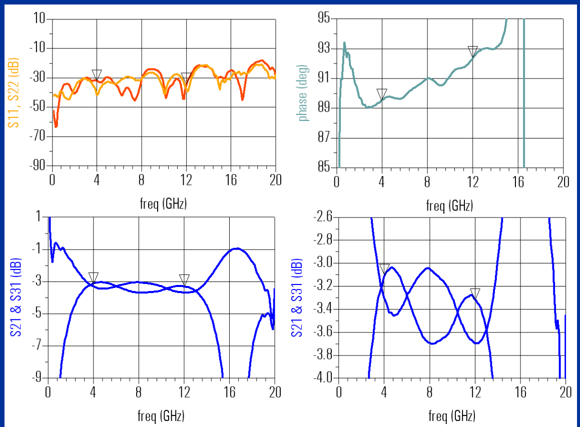


CAY hybrid

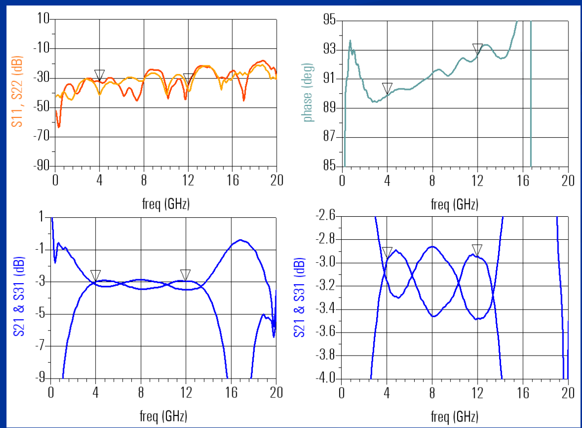
Comparison with best commercial unit

T_{amb}=20 Kelvin	***Yebes*** *(3 units built and tested)*	*Pasternack* *(Best commercial unit tested)*
Return loss	**<-22 dB**	<-19 dB
Amplitud unbalance	**±0.3 dB**	±0.9 dB
Phase unbalance	**±2º**	±3º
Connector	**Sliding pin** (to survive thermal cycling)	Standard SMA

Ambient temperature (290 K)

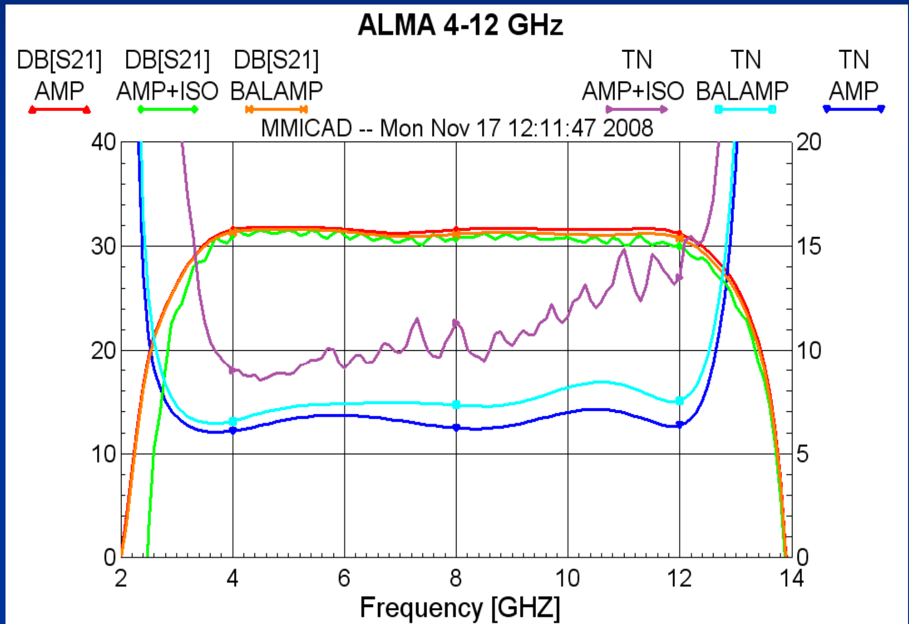


Cryogenic temperature (20 K)



Almost no degradation in performance when cooled !!

Advantages of balanced amplifier



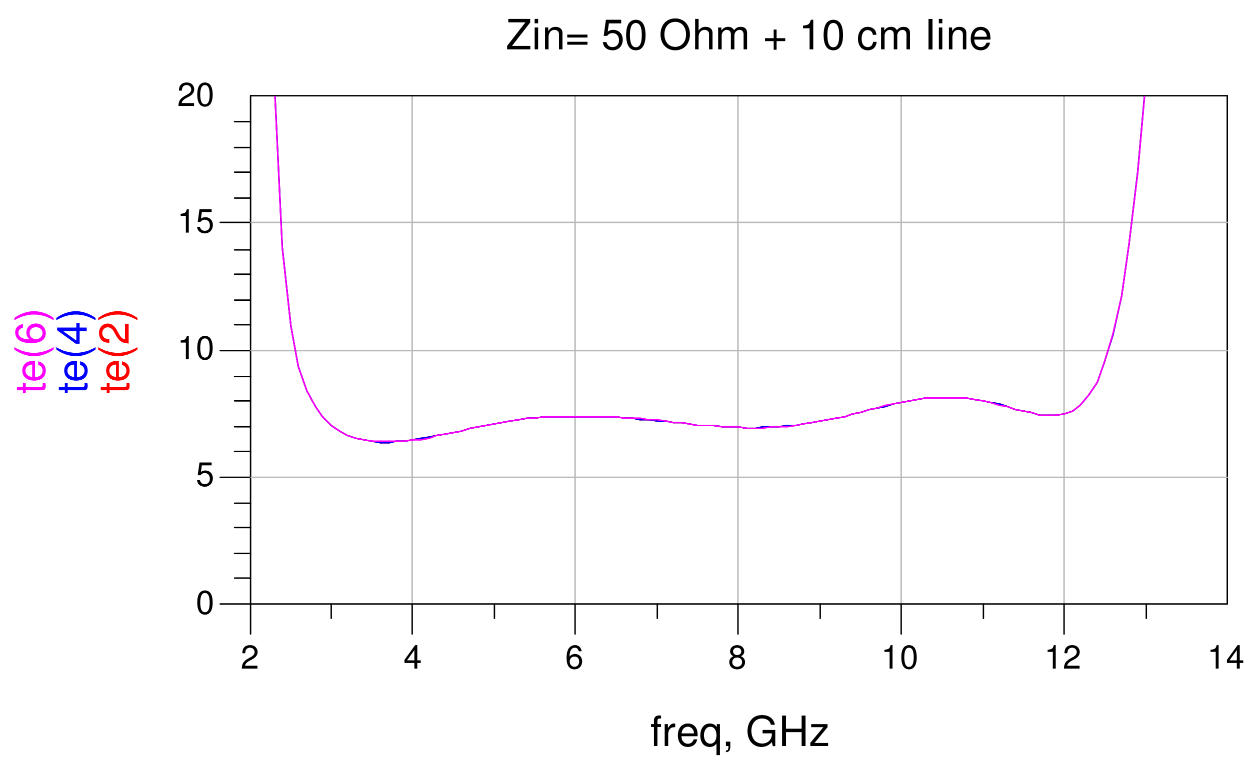
4-12GHz Prototype.
Results could be extrapolated to wider band.

Same S_{11} but LESS TN.

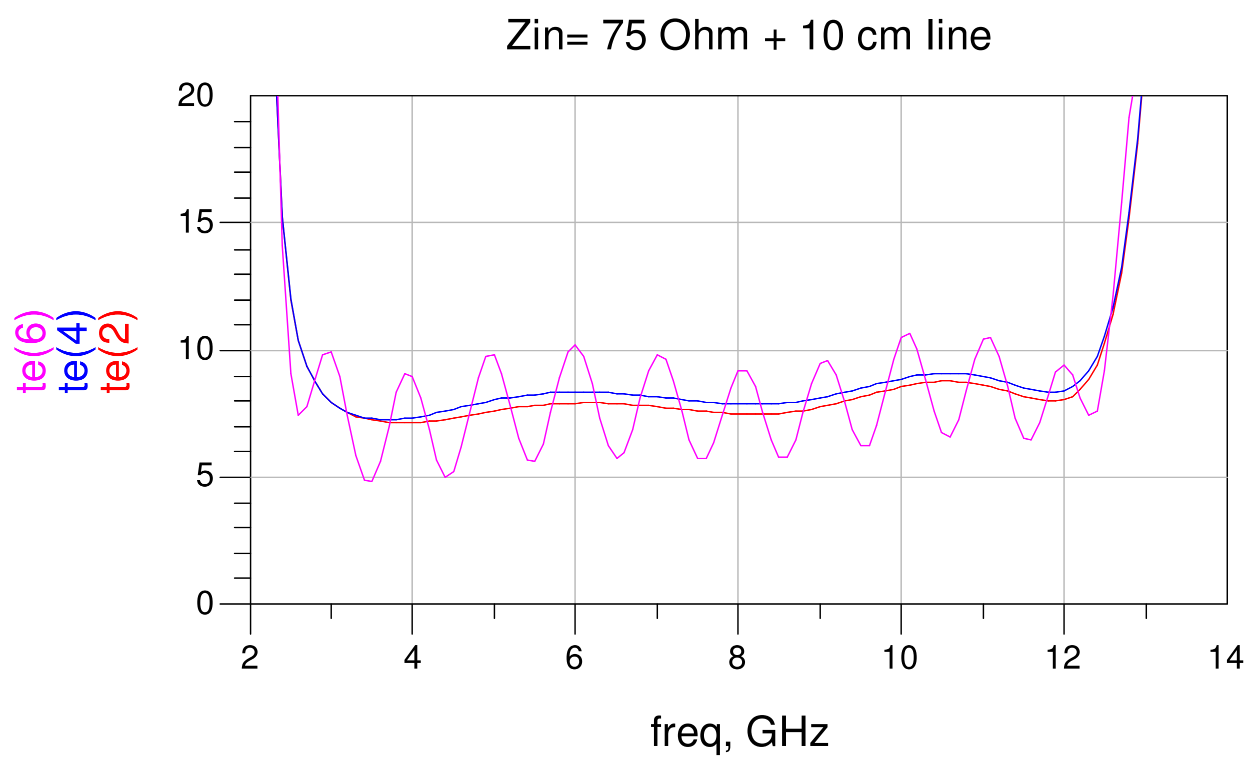
TN no dependent on the phase of input reflection coefficient (as isolator configuration).

Balanced amplifier is less sensitive to input mismatches: Tb (outgoing noise wave) is lower!

amp, isolator + amp, balanced amp



amp, isolator + amp, balanced amp



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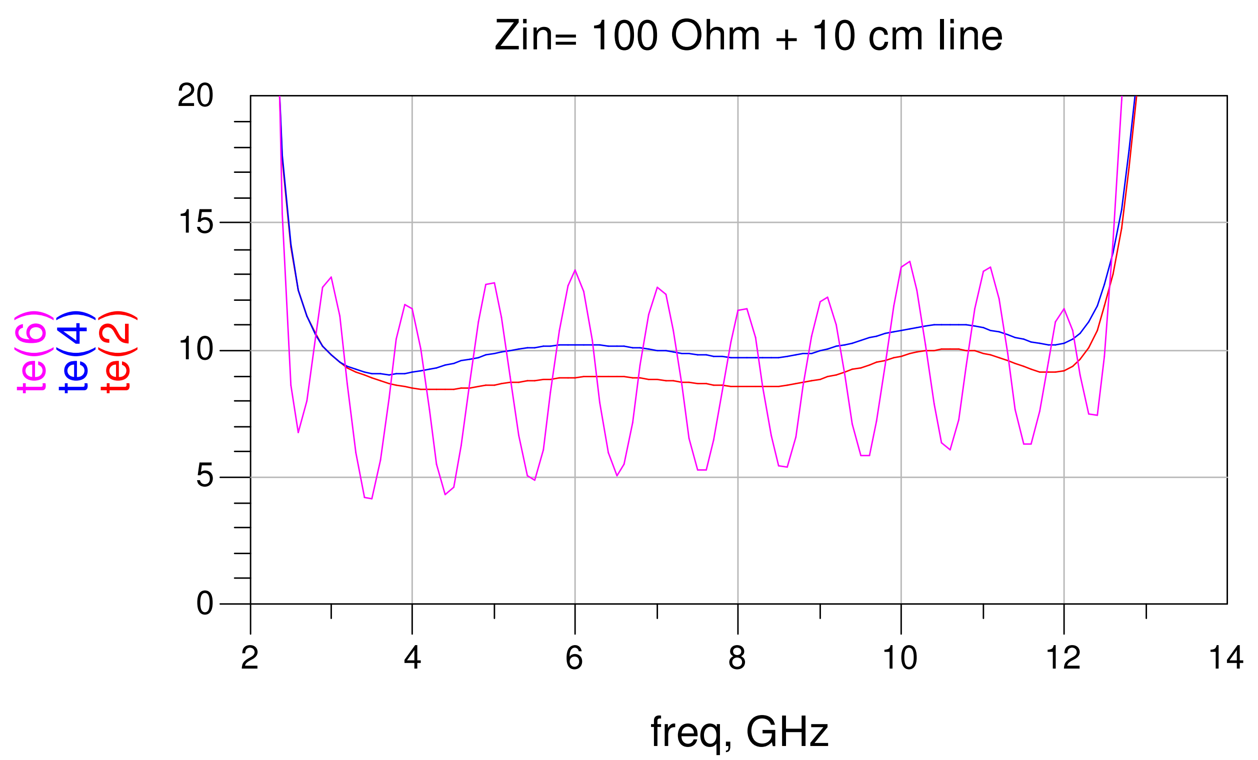
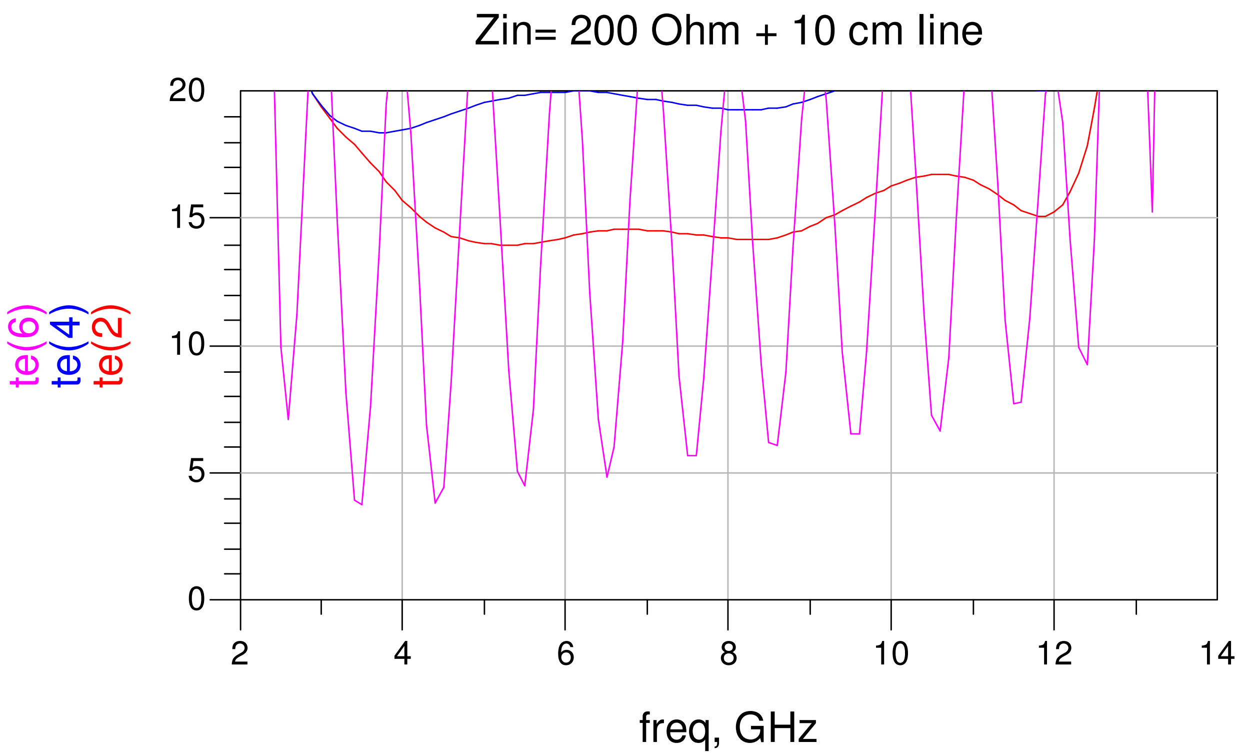
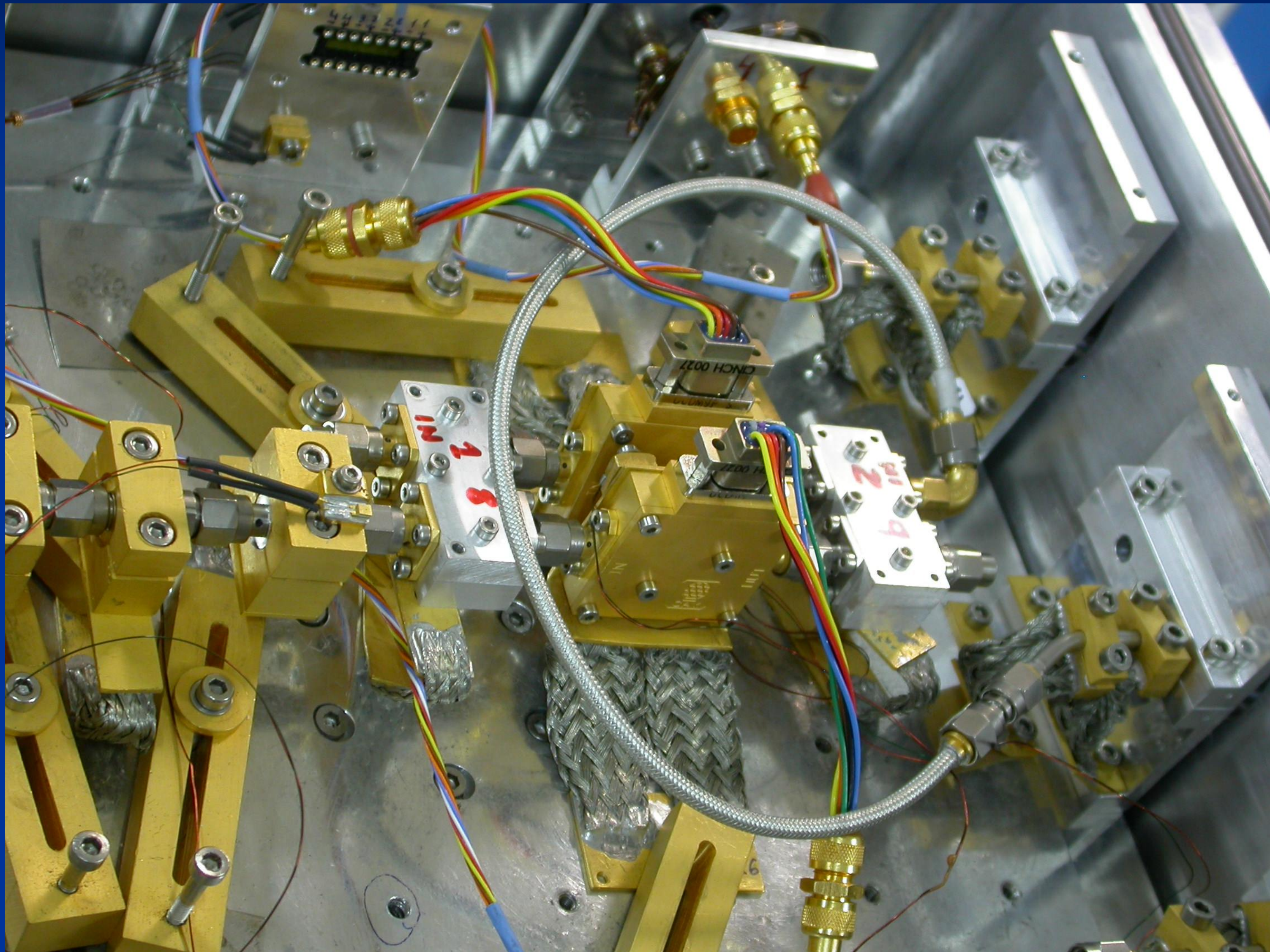


amp, isolator + amp, balanced amp



Test in cryostat:



More details in:

- **IMS 2009:** "Cryogenic hybrid coupler for ultra low noise Radio Astronomy receiver", I. Malo, J. D. Gallego, M.C. Díez, C. Cortés, C. Briso, 2009 International Microwave Symposium, Boston, 7-12 June 2009.

- **ISSTT 2009:** Improved Multi-octave 3 dB IF Hybrid for Radio Astronomy Cryogenic Receivers, I. Malo, J. D. Gallego, M.C. Díez, I. López-Fernández and C. Briso, 20th International Symposium on Space Terahertz Technology, Charlottesville, 20-22 April 2009

Conclusion

- Balanced amplifier vs. input cryogenic isolator:
  - Has lower noise temperature (about 40%).
  - Is less dependant on input mismatch.
- Balanced amplifier could be the best option where:
  - Noise performance is a must.
  - Too wide band to consider a cryogenic isolator practical.
  - Additional complexity and power dissipation is acceptable (not for FPAs)