Low Noise Receivers

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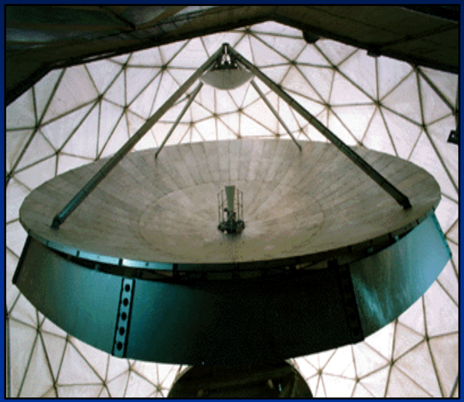
The site: Yebes - Guadalajara

INSTRUMENTS (Operation and maintenance)



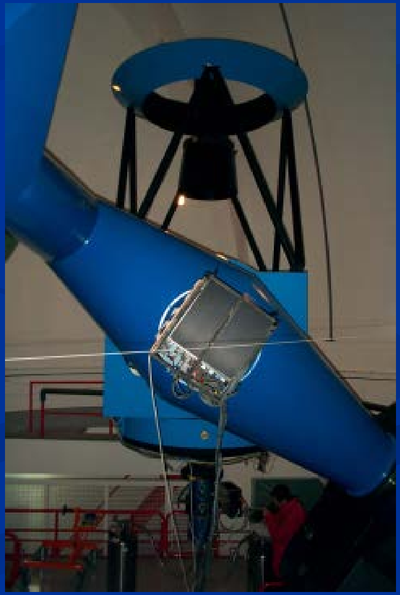
14 meter radiotelescope

40 meter radiotelescope

Gravimetry Building

Demostration radiotelescope

GNSS



Optical telescopes

Yebes staff

- Almost 50 People
  - 15 engineers
  - 12 technical
  - 5 operators
  - 8 support
  - 10 students

The 40 meter radio telescope

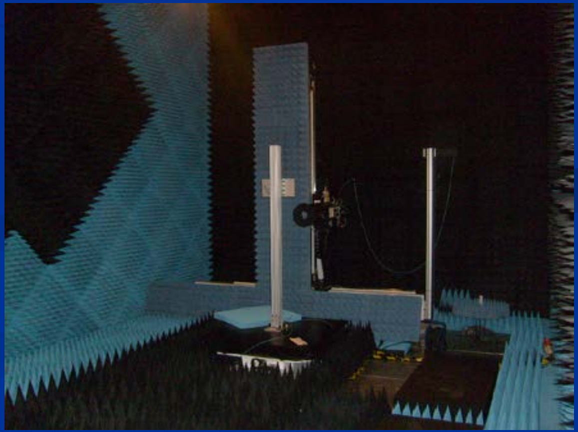
First light in 2006
VLBI astronomy and geodesy & single dish observations
e-VLBI capability
Frequency range: 2-120 GHz

Laboratories & workshops

- More than 500 square meters for laboratories and a mechanical workshop.
- RF instrumentation covering the frequency range up to 140 GHz.
- Laser milling/cutting and wire bonding capability.

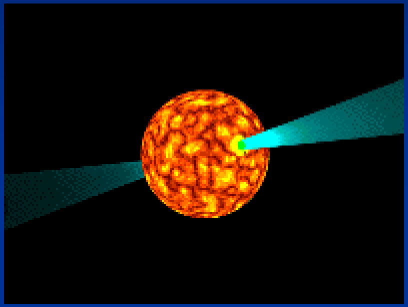


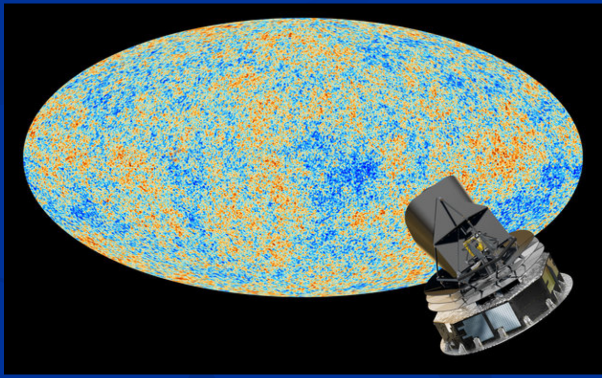




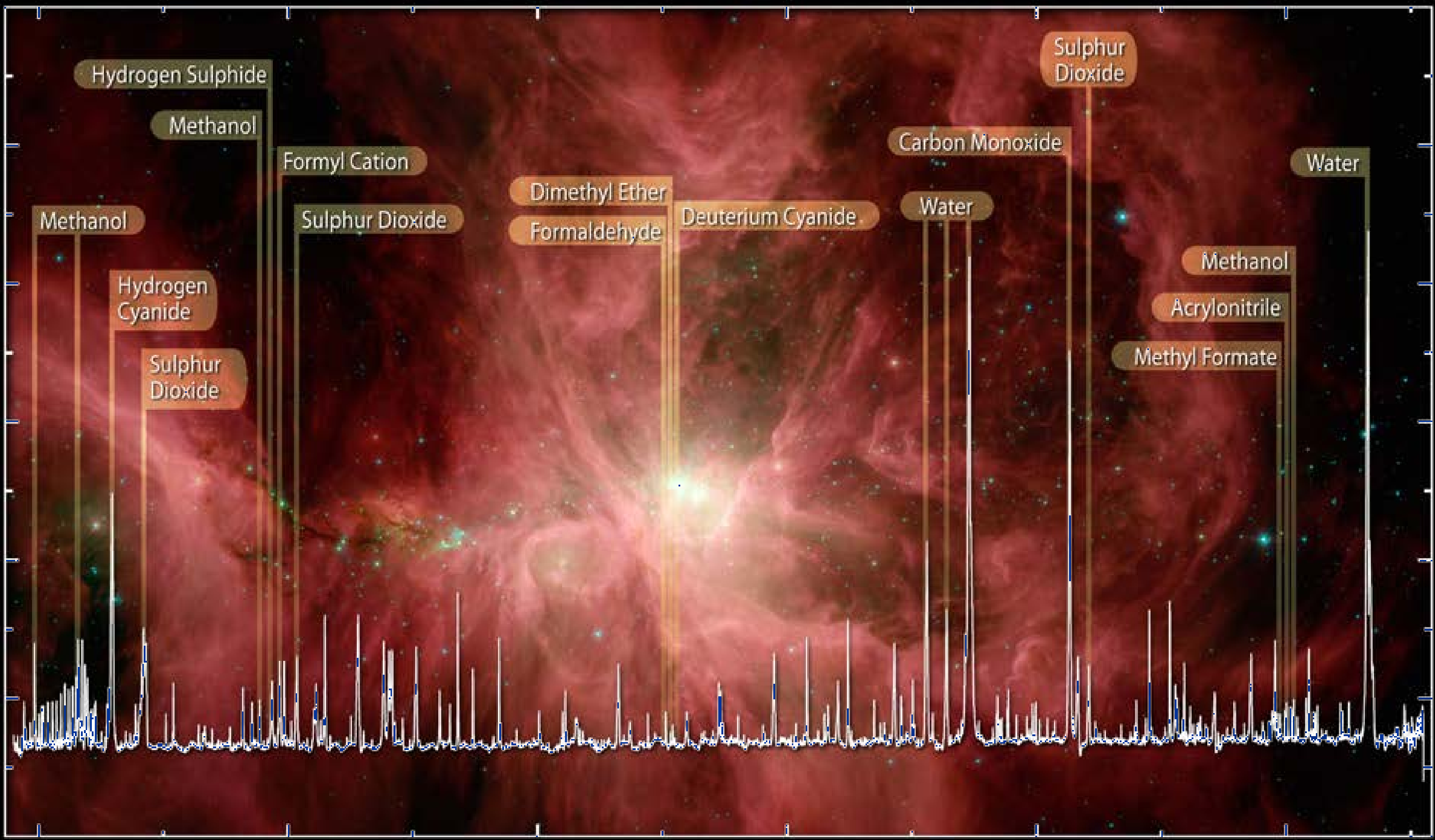
Some radio astronomy applications

- Microwave background radiation
- Pulsars
- Cold H gas
- Molecules (rotational transitions)
- Center of our galaxy
- Regions of star formation
- Interstellar chemistry
- Extreme resolution with interferometry (VLBI)





Molecules in Orion (HIFI-Herschel)



HISTORY of cryogenic receivers

- Cryogenic Receivers are used for:
  - Space communications (DSN, Rosetta, Mars Express, Venus Express, BepiColombo…)
  - Radio Astronomy
  - Fundamental Physics (Qbits…)

- 60s: Maser, Parametric (18 K @ 8.45 GHz in 1964, JPL)
- 70s: GaAs FET amplifiers (13 K @ 1.3 GHz in 1979, NRAO)
- 80s: GaAs HEMTs (5.5 K ! @ 8.5 GHz in 1988, GE-NRAO)
- 90s: InP HEMTs (4.6 K @ 8.5 GHz in 1999, ETH-CAY)
(3.0 K @ 8.5 GHz in 2002, TRW-CAY)
(2.0 K ! @ 4-8 GHz in 2002, TRW-CAY)
- 00s: Metamorphic HEMTs? MMICs ?

➔ EUROPE should develop its own competitive technology

- Higher frequencies: SIS, HEBs

Heterodyne receivers and Bolometers

- **Heterodyne Receivers → Coherent**
  - Phase information is preserved – used in single-dish telescopes and interferometers
  - Spectral information is preserved: very high spectral resolution
  - Used from the cm to the sub-mm region of the spectrum (few GHz to ~THz)
  - Operate at ~4K or ~15 K depending on technology
- **Bolometers → Incoherent**
  - Absorbed photon increases temperature, changes resistance
  - Phase information is lost – used on single-dish antennas
  - Large bandwidths and high sensitivities
  - Total power detection: spectral information is lost
  - Used for the mm and sub-mm region of the spectrum (~100 GHz to ~THz)
  - Operate at ~0.3 K

QUANTUM LIMITS

- Coherent receiver:

  Consequence of *Heisenberg uncertainty principle*

$$\boxed{T_{\rm rx}(\text{minimum}) = \frac{h\nu}{k}}$$

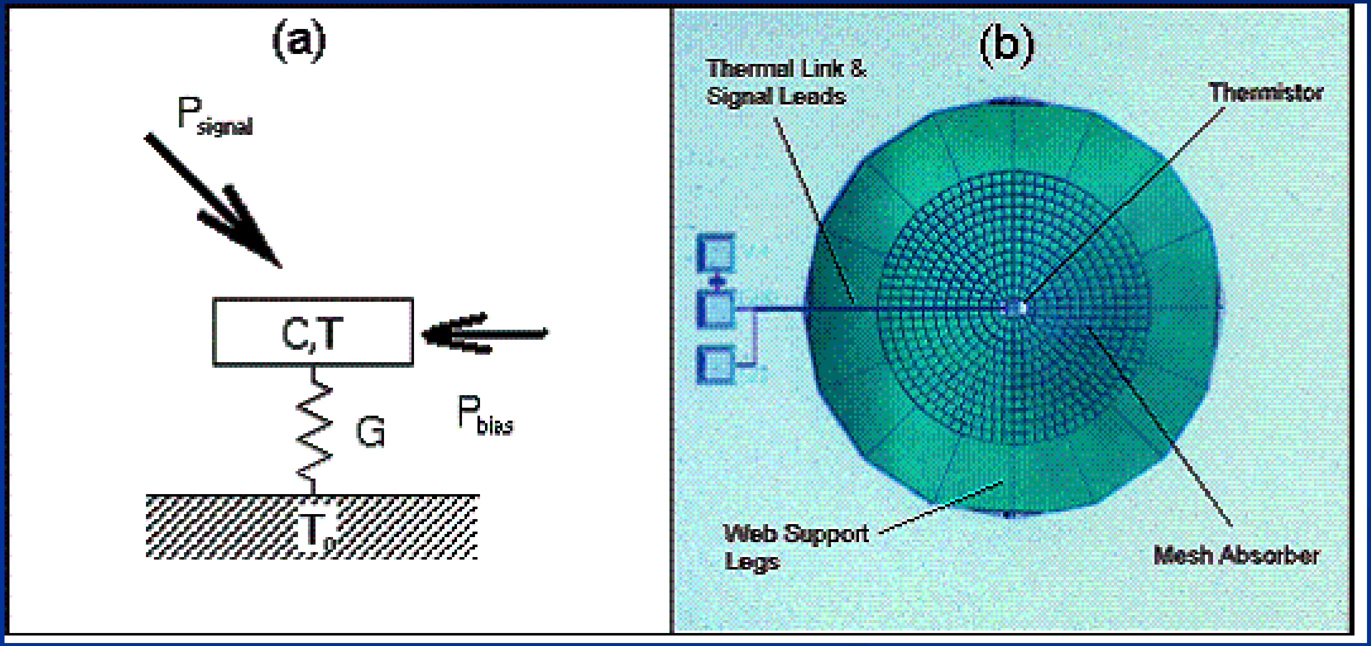
(~5 K (ν/100 GHz)

- Incoherent receiver:

  No limit (photon dominated)

$$\boxed{\text{NEP}_{\rm ph} = 2\varepsilon k\, T_{\rm BG} \sqrt{\Delta\nu}}$$

Example: bolometer

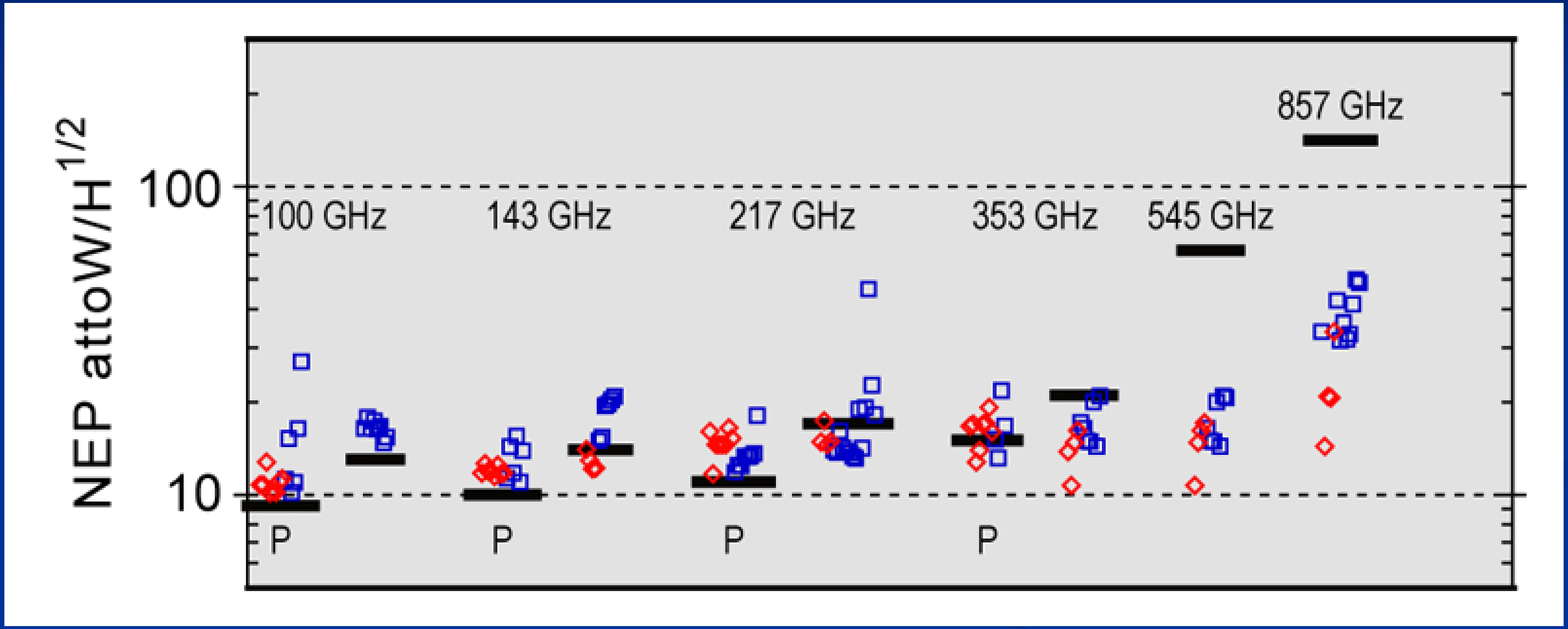


(a) P_{signal} is the power from the source. P_{bias} is the power load from the bias readout electronics. T_0 is the bath temperature. C and T are the bolometer's heat capacity and temperature, respectively.

(b) Example of a single “spider-web” bolometer. The Ge thermistor is located at the center of the web.

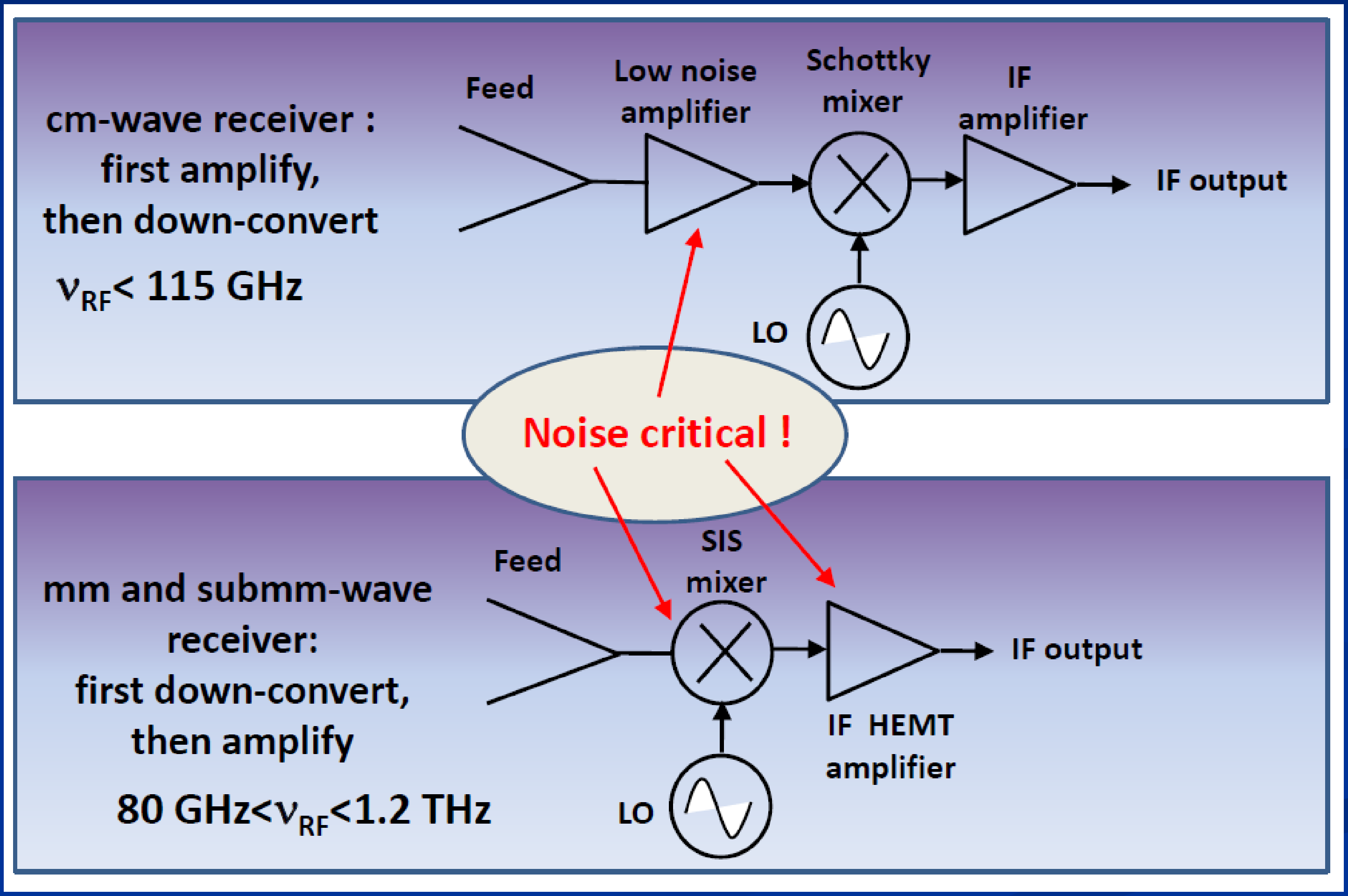
Bolometer sensitivity (Plank mission)

Tamb=0.1 K



Measured dark noise equivalent power (NEP) including 6.5 nV / sqrt(Hz) amplifier noise at nominal bias. The thick solid line segments indicate the photon background limit from a 35 K telescope and astrophysical sources in each band for a 30% bandwidth and 30% in band optical efficiency. (from Holmes et al. (2008))

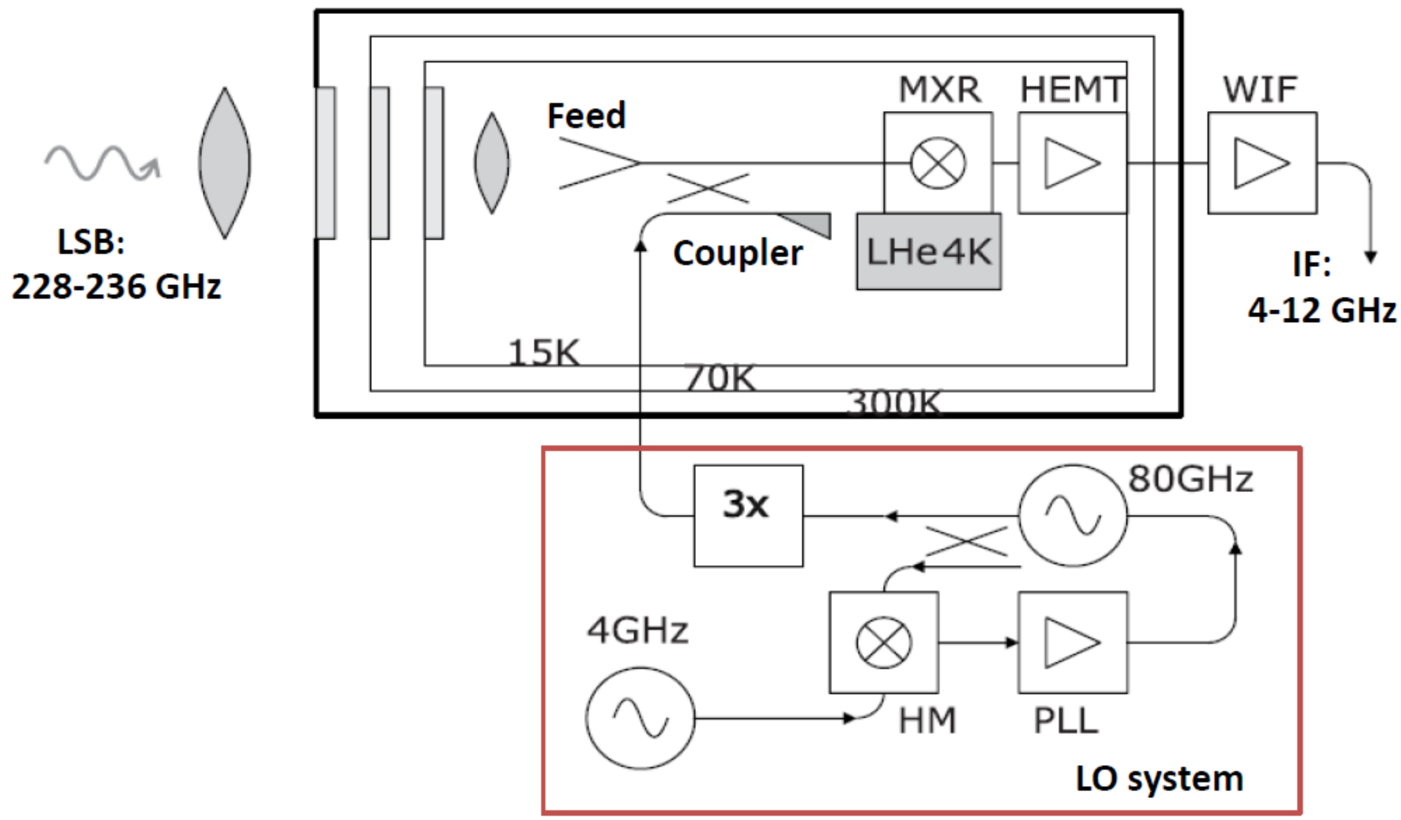
Heterodyne receivers



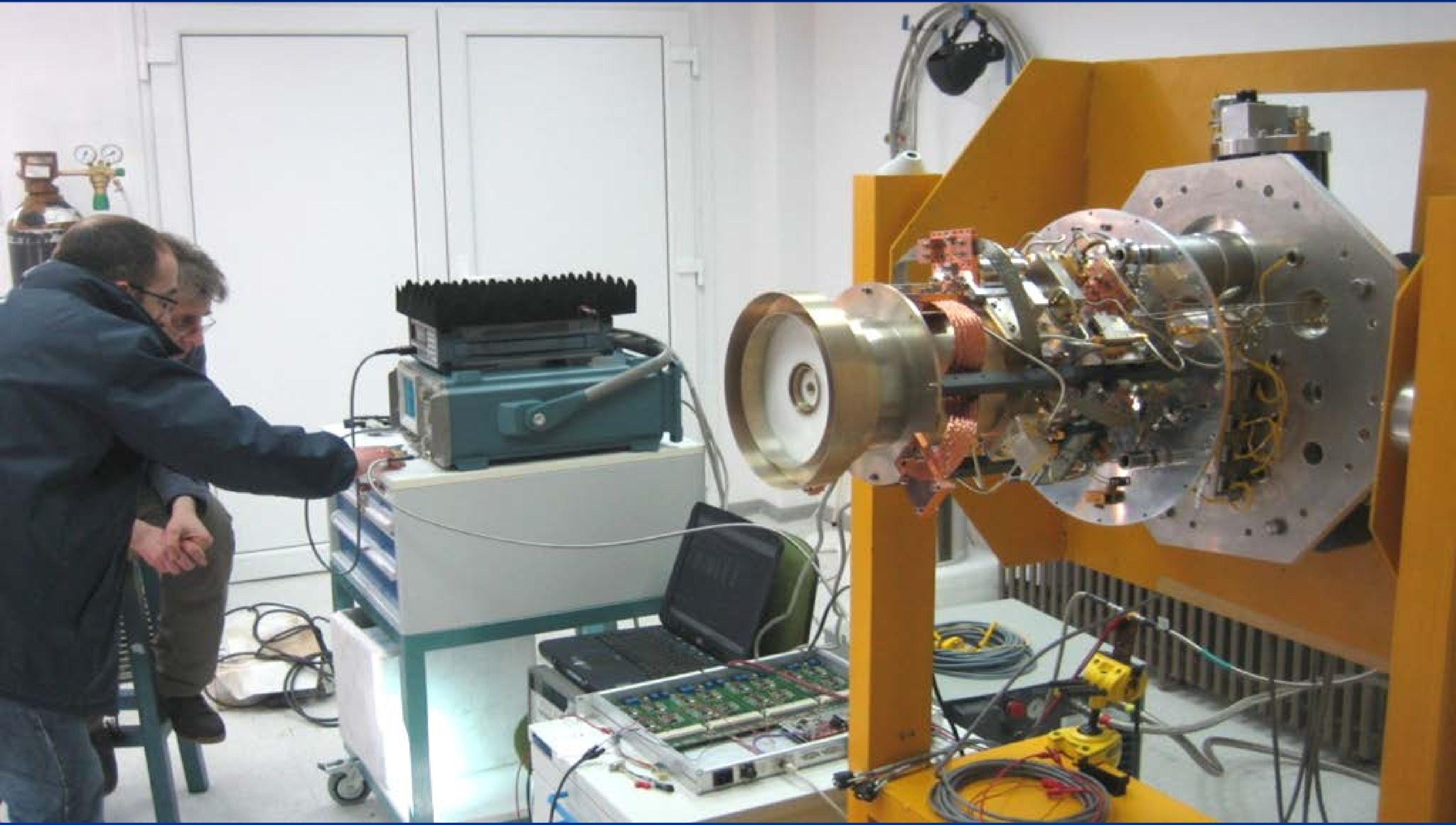
Example: mmW receiver

SIS mixer require cooling at ≈ 4 K; HEMT amplifier can operate at 15 K

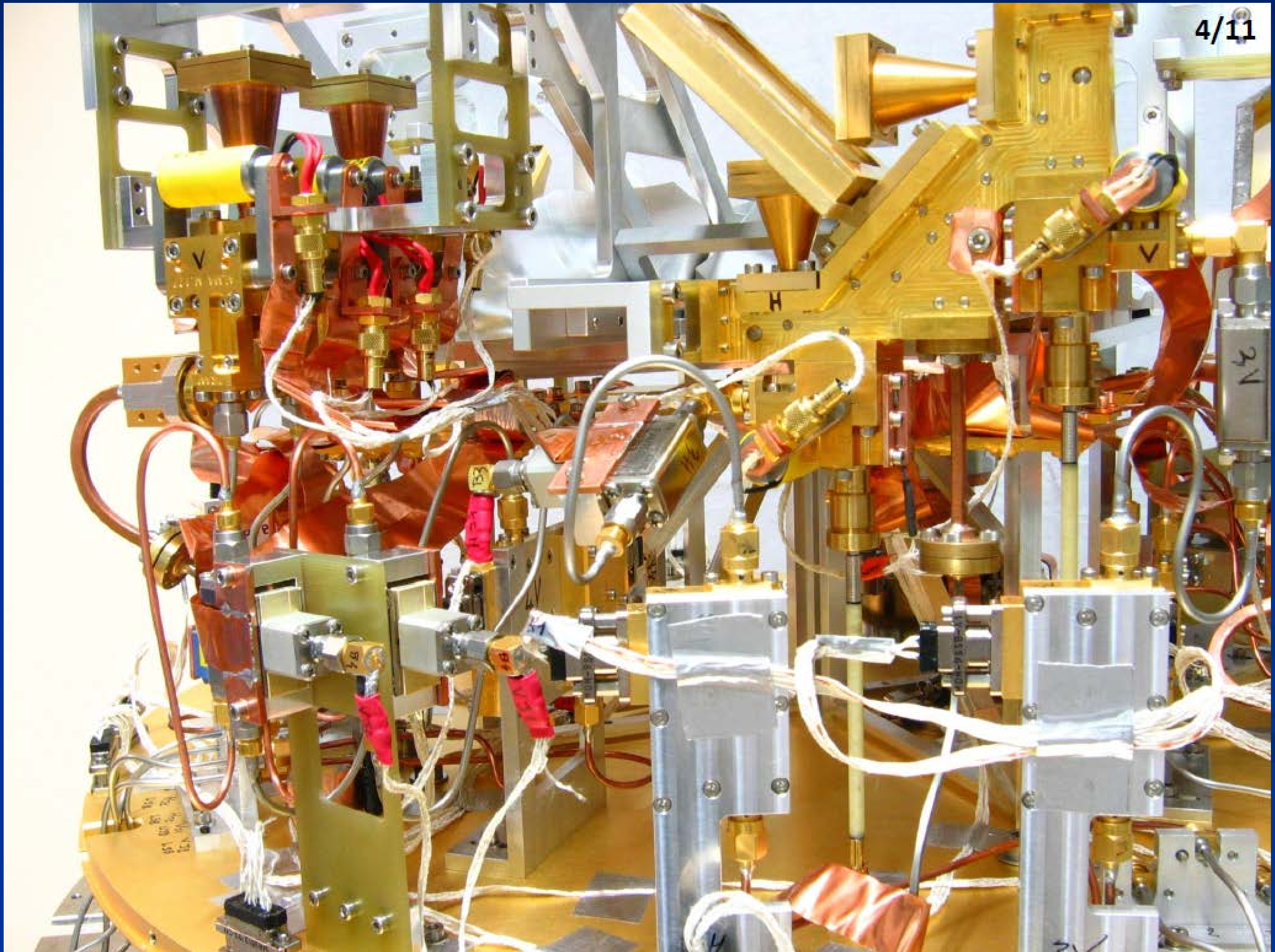
The active devices are located inside a cryostat



Example: S-X-Ka band receiver

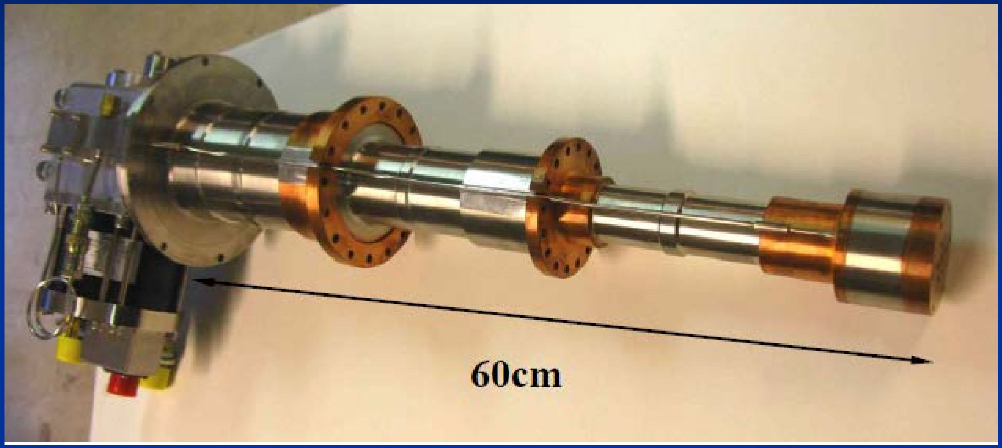


Example: detail of IRAM mmW receiver



Example: cryostat with radiation shield

Example: cryocooler & compressor



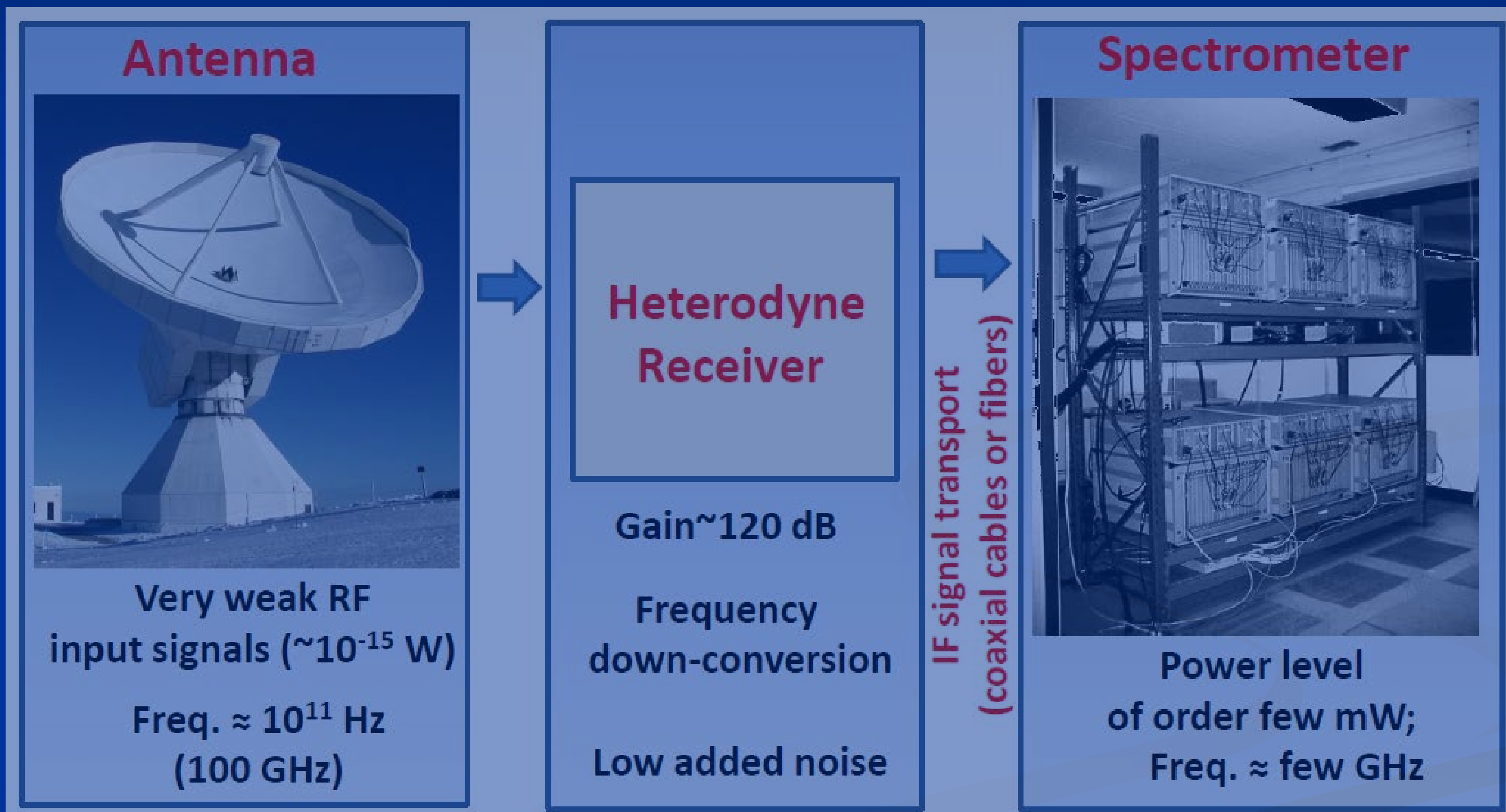
Sumitomo closed cycle system

Air cooled Compressor

3 stages cold head

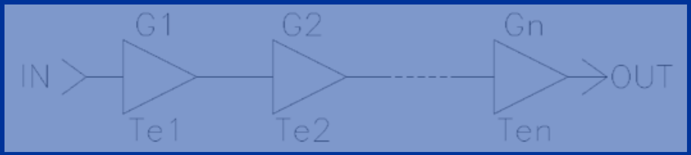
33W@77K, 2W@15K, 1W@4.2K

Example: Signal Chain

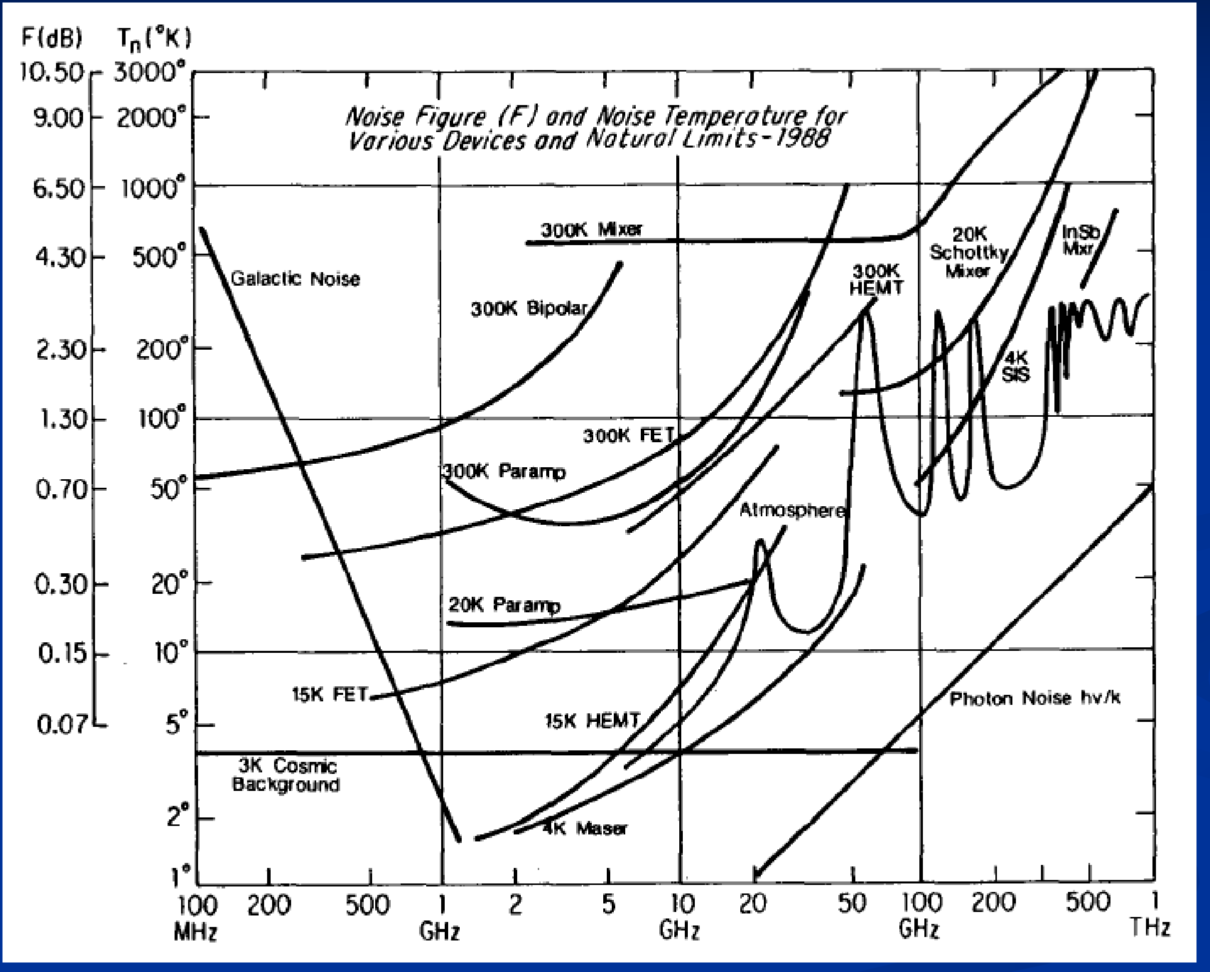


Why are amplifiers so important for Radio Astronomy?

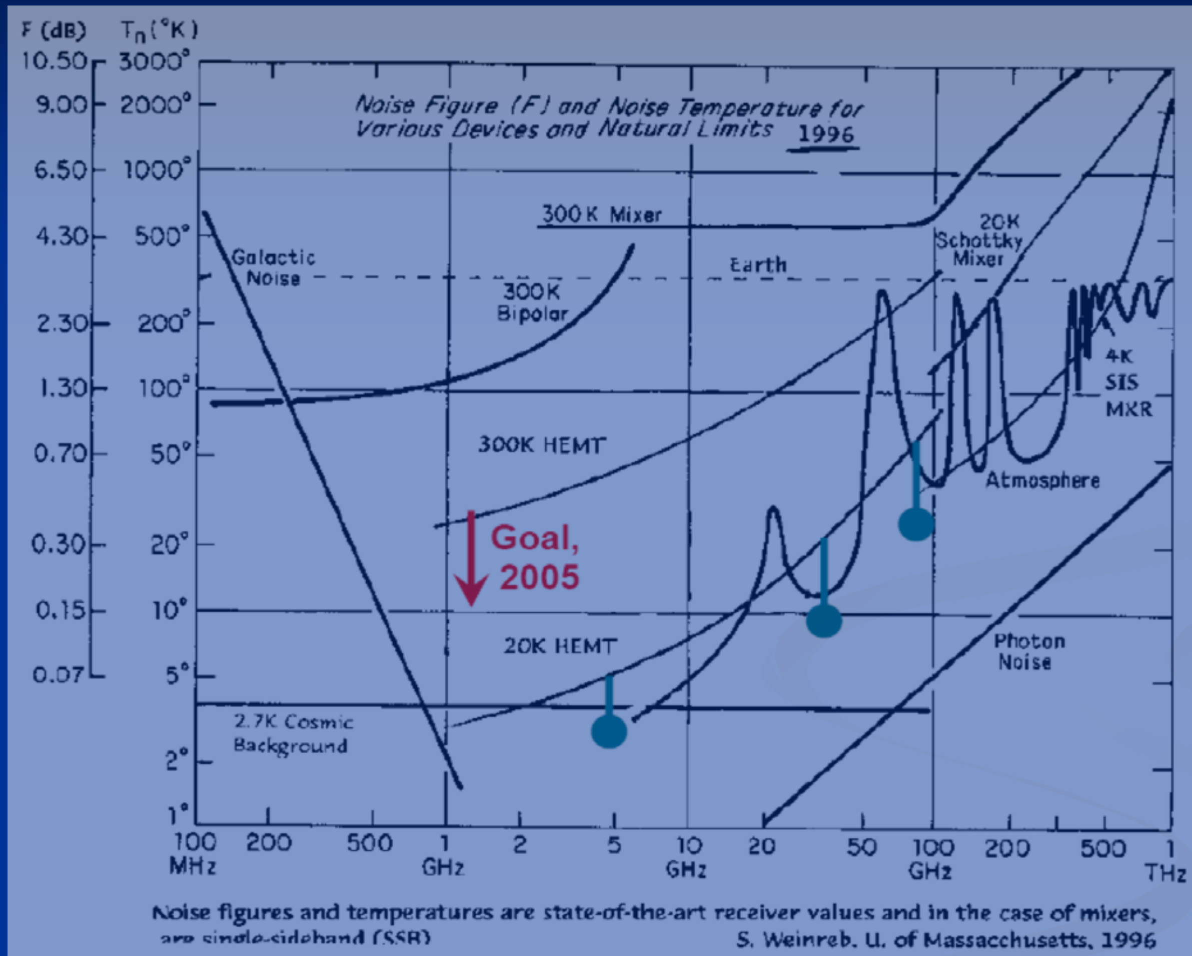
- Signal level
  - Pout (analog meter) = 0.01 mW
  - Pin (sky, 20K, BW:1MHz) = K T B = 2.7 E-16 W
  - G = 36 E9 G(dB) = 10 log (G) = 106 dB !!!!!!!!!
- Noise
  - Noise Temperature of n Cascaded Amplifiers:



$$T_e = T_{e1} + \frac{T_{e2}}{G_1} + \cdots\cdots \frac{T_{en}}{G_1 G_2 \cdots\cdots G_{n-1}}$$

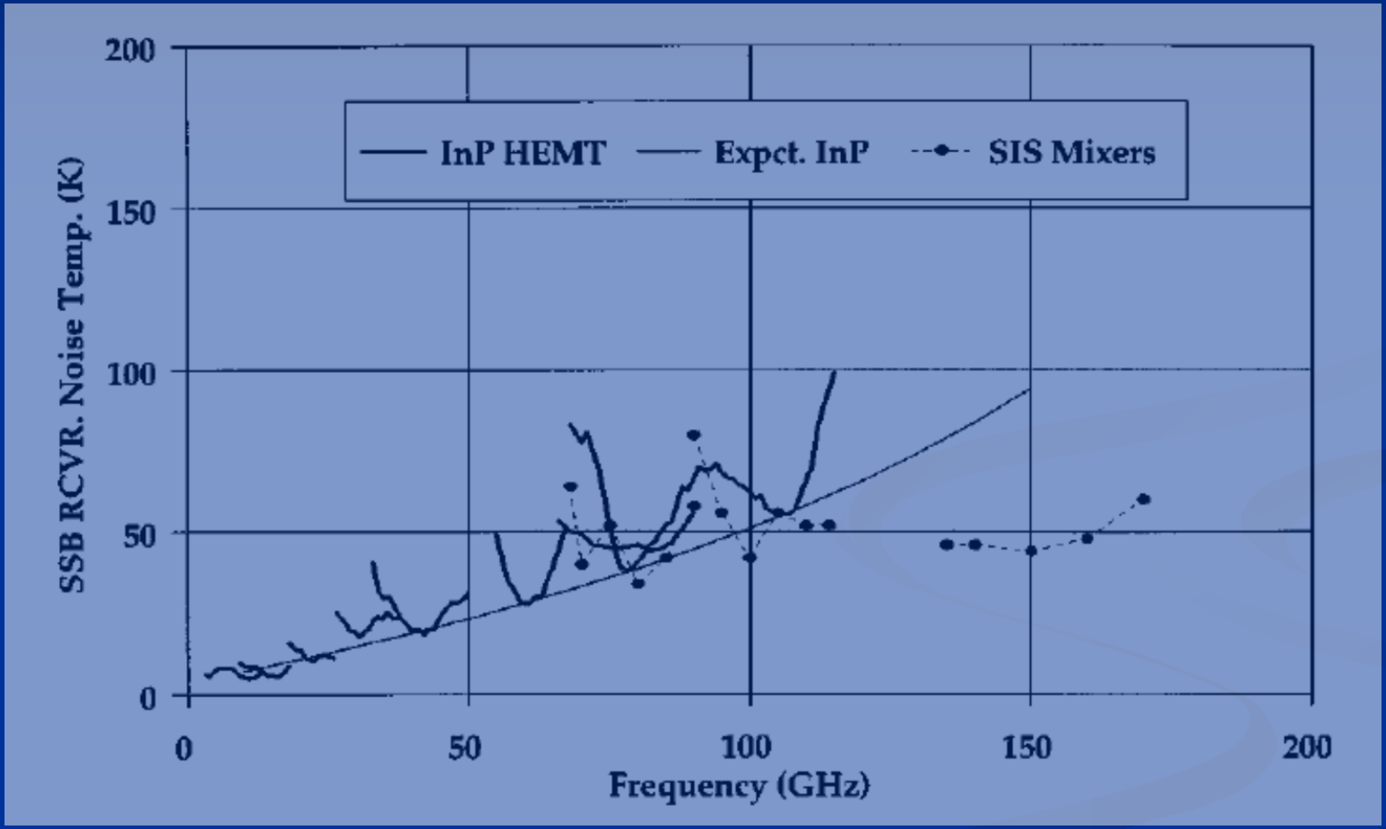


S . Weinreb, M. **W.** Pospieszalski, and R, Norrod, **1988** IEEE **MTT-S** Digest



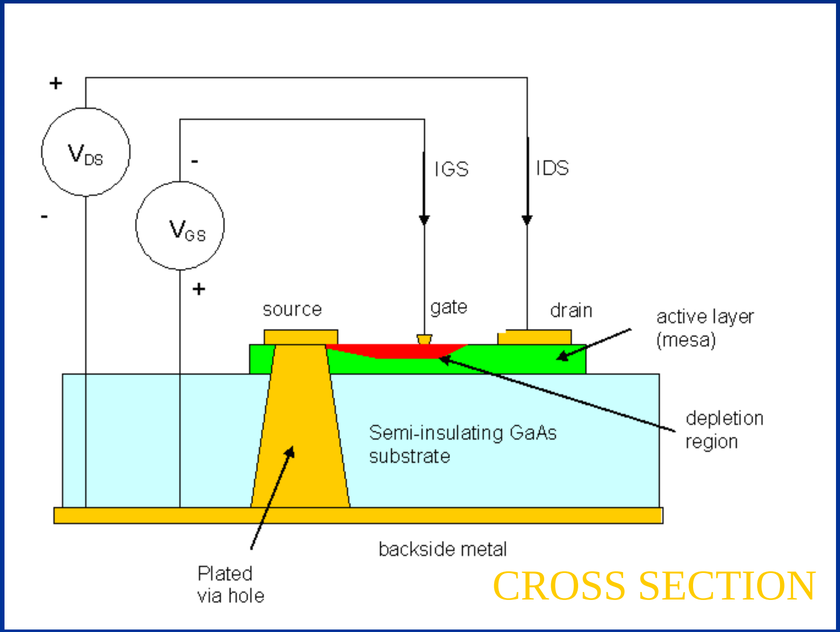
Noise Figure (F) and Noise Temperature for Various Devices and Natural Limits 1996
F (dB)
Tn (°K)
300 K Mixer
Galactic Noise
300K Bipolar
Earth
20K Schottky Mixer
4K SIS MXR
300K HEMT
Atmosphere
Goal, 2005
20K HEMT
Photon Noise
2.7K Cosmic Background
100 MHz
1 GHz
10 GHz
100 GHz
1 THz
Noise figures and temperatures are state-of-the-art receiver values and in the case of mixers, are single-sideband (SSB)
S. Weinreb, U. of Massacchusetts, 1996

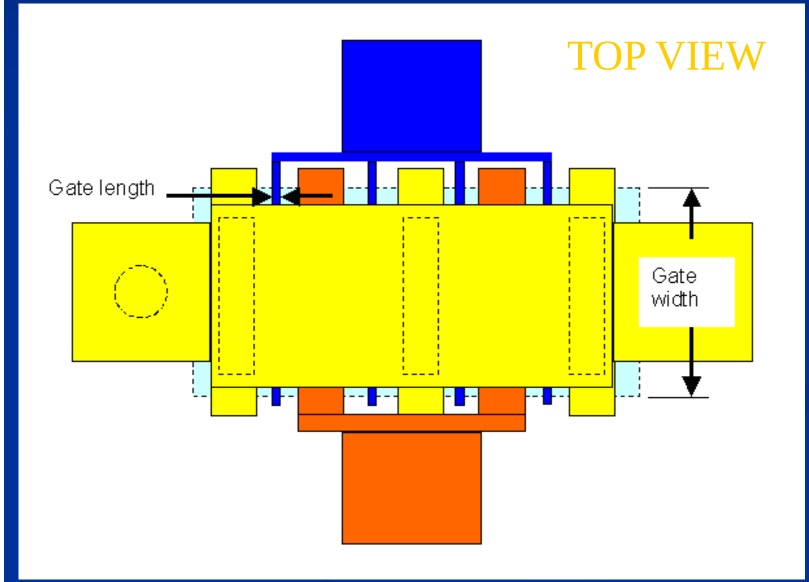
Noise Temperature of Cryogenic InP and SIS



Webber, J.C.; Pospieszalski, M.W., IEEE MTT march 2002

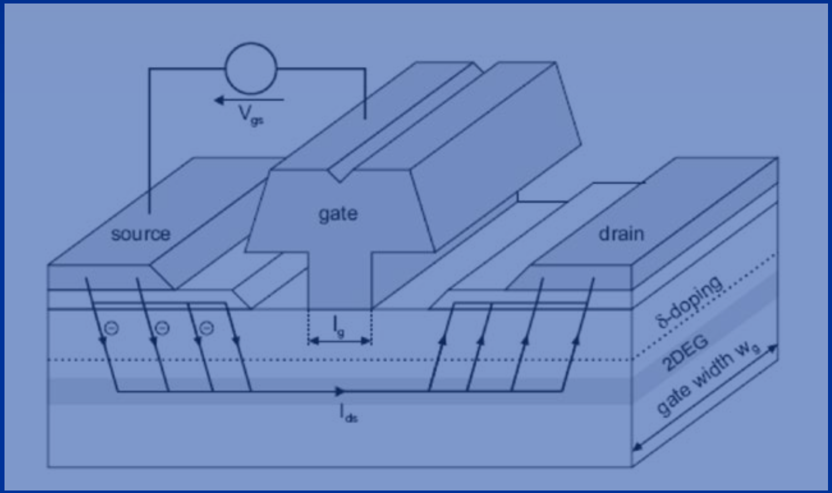
ANATOMY of Field Effect Transistor (FET)





High Electron Mobility Transistors (HEMTs) used in modern cryogenic amplifiers are built on heterostructures of Indium Phosphide (InP)

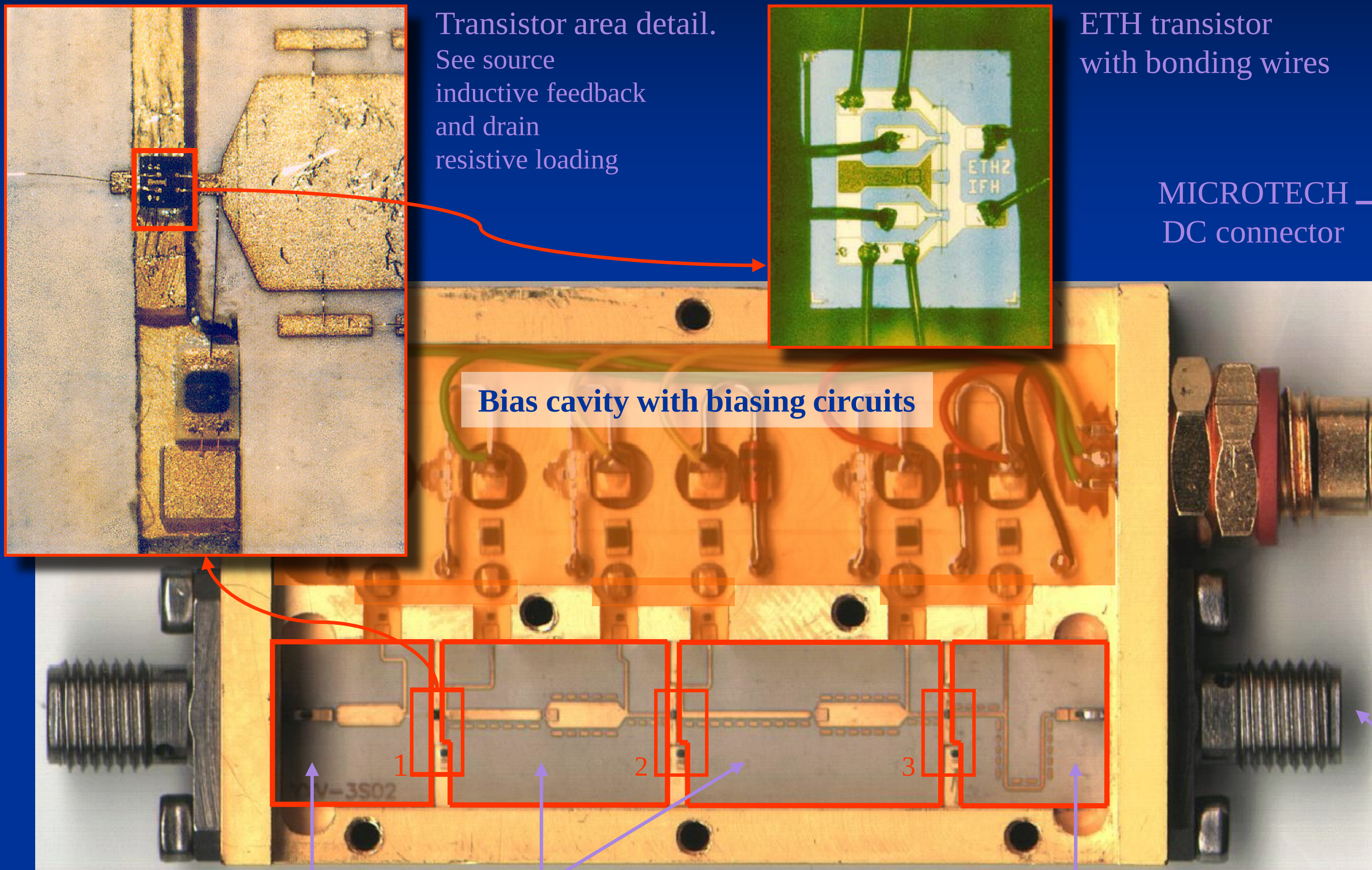
Typical structure of InP HEMTs



Cross section of a generic HEMT. Vgs controls, the number of electrons underneath the gate (lg) and the current Ids in the two-dimensional electron gas (2DEG)

Cap layer	10 nm	InGaAs	$5.0 \cdot 10^{18}$ cm^{-3}
Schottky barrier	15/15/19 nm	InAlAs	n.i.d.
δ-doping			$4.4/4.4/4.5 \cdot 10^{12}$ cm^{-2}
Spacer	10/10/6 nm	InAlAs	
Channel	50/10/15 nm	$In_xGa_{1-x}As$	n.i.d.
Pre-Channel	0/40/0 nm	InGaAs	n.i.d.
Buffer	350 nm	InAlAs	n.i.d.
S.I. Substrate	350-625 µm	InP	Fe doped

Example of vertical structure of a Lattice Matched InP HEMT.

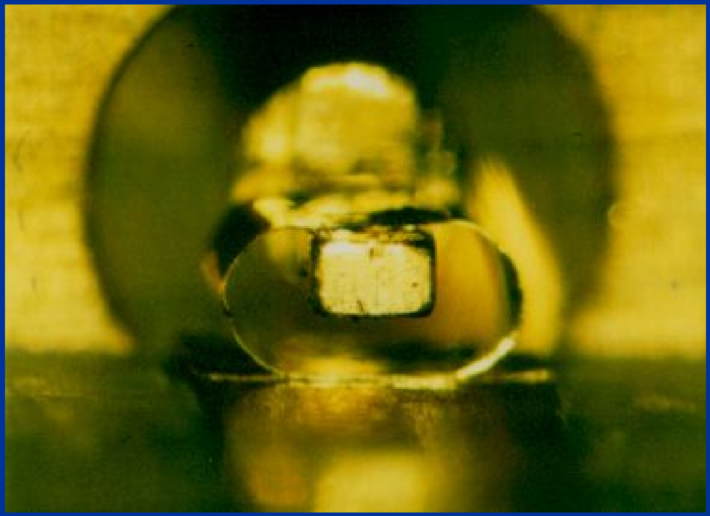

Transistor area detail.
See source
inductive feedback
and drain
resistive loading
ETH transistor
with bonding wires
MICROTECH
DC connector
Bias cavity with biasing circuits
1
2
3
Input matching circuit
Interstage matching circuits
Output matching circuit
SMA connector

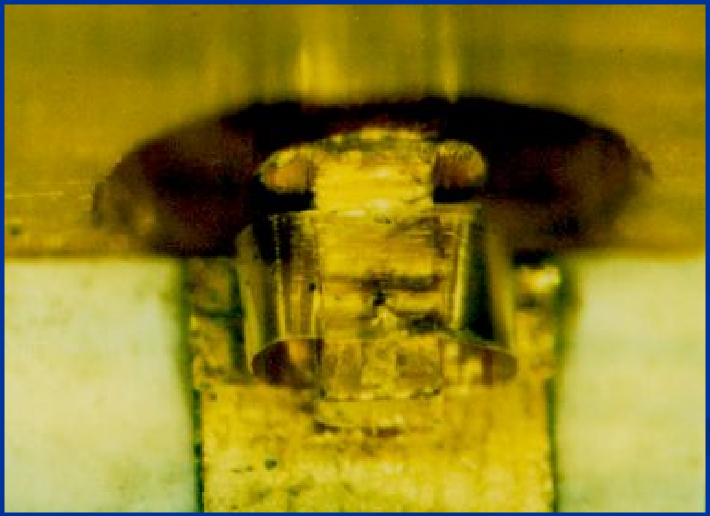
Particularities of Cryogenic Amplifiers

- Extreme range of temperatures (≈400 K)
- Mechanical stress due to differential expansion coefficients
  - Substrates
  - Connectors
  - Epoxy
- Some passive components do not work
  - Resistors
  - Capacitors
- Some semiconductors do not work (carrier freezing)
  - HEMTs may need illumination
  - LEDs
  - Zenner

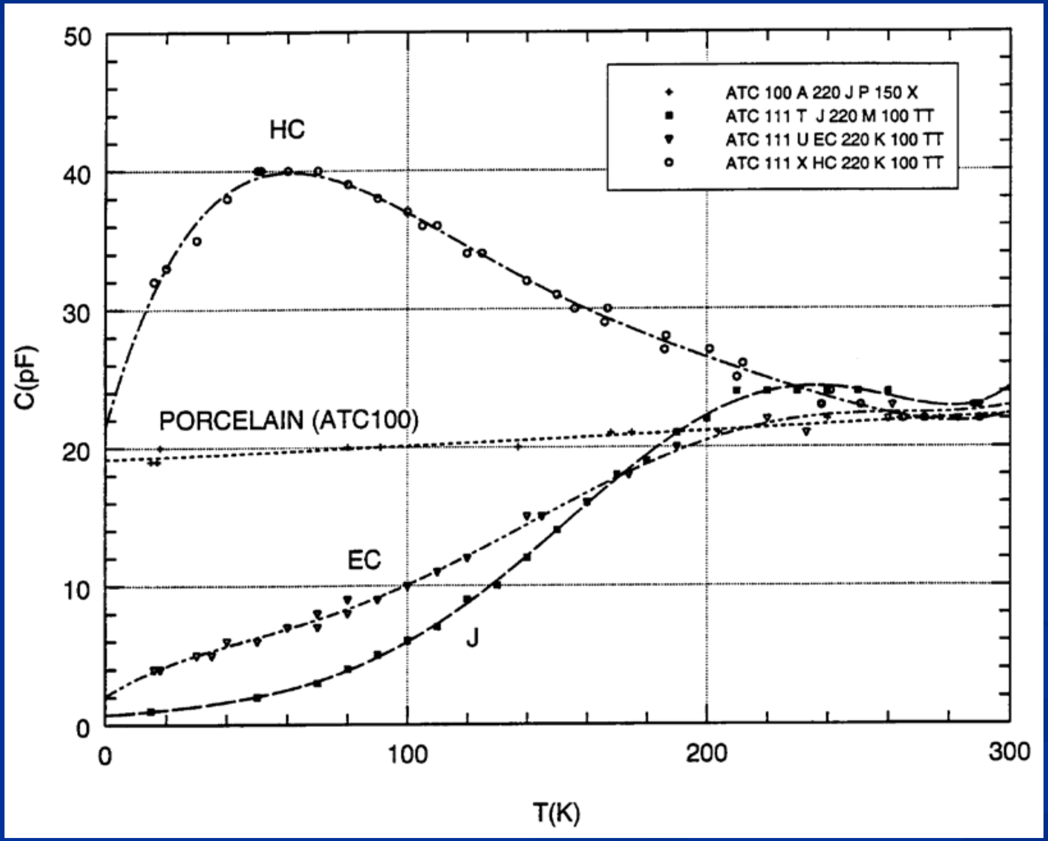
Stress Relief Contacts

- An example: ‘O’ ribbon connection in the SMA tab contact:
  - Allows mobility in three axis
  - Excellent electrical properties compared with traditional SMA connections

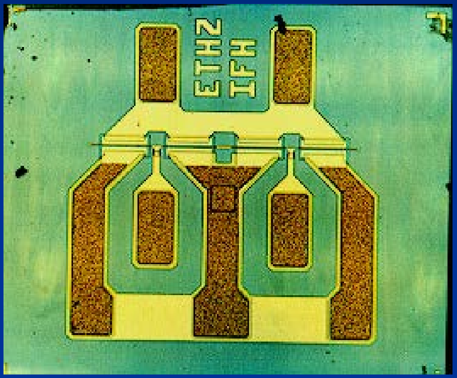




Microwave Capacitors at Cryogenic Temperature

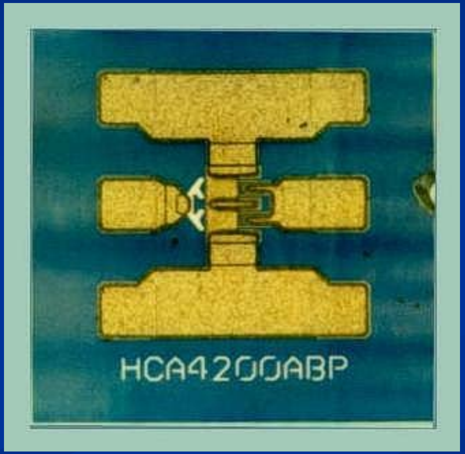


Example of InP HEMTs

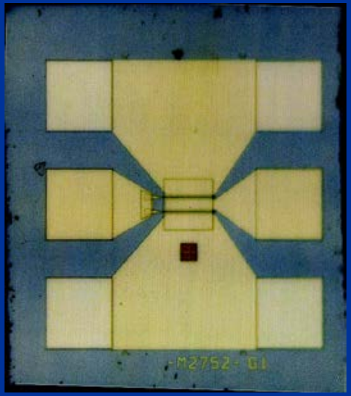


ETH

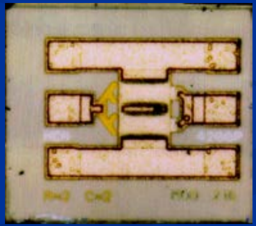
0.3 mm



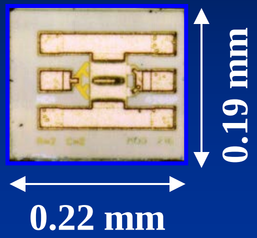
JPL



ETH

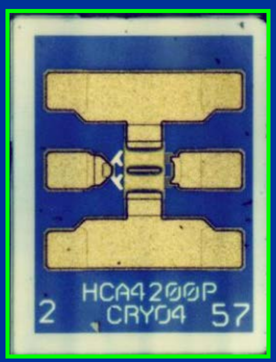


JPL



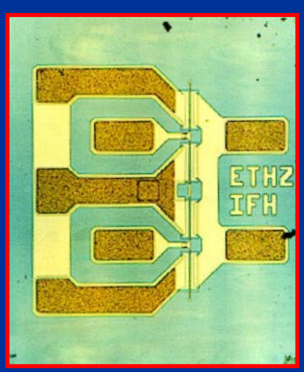
TRW T-42 CRYO3

- 200 × 0.1 µm gate
- Best performance



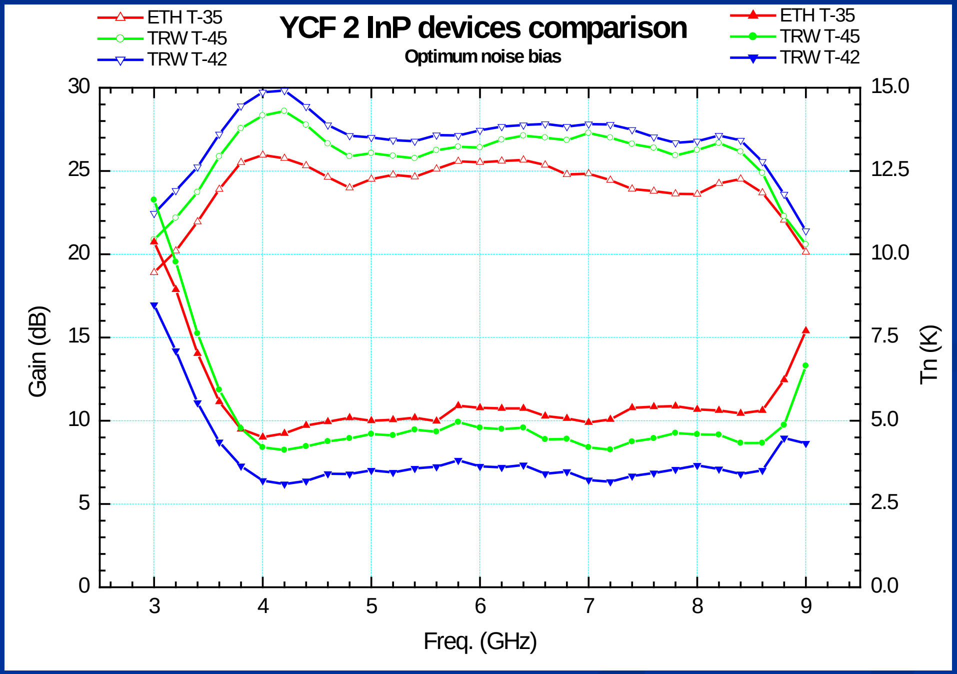
TRW T-45 CRYO4

- 200 × 0.1 µm gate
- Used in DMs
- Space qualifiable, to be used in FMs
- CHOP developed



ETH T-35

- 200 × 0.2 µm gate
- Experimental transistor
- Design by request
- Used in DMs



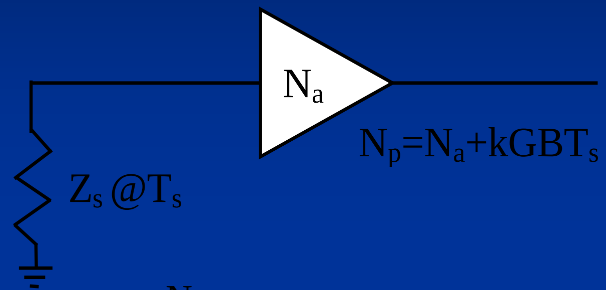
Figures of Merit (Specifications)

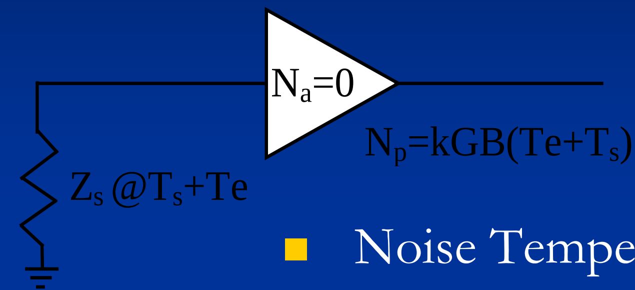
- Band
- Noise
- Gain
- Input/output reflection coefficients
- Gain Fluctuations (short term stability)
- Long term stability
- Stability (oscillations)
- Stability (with bias)
- Linearity
  - 1 dB compression point
  - Intermodulation (IP3)
- Phase/Delay/Phase stability
- Power dissipation
- <u>M</u>ean <u>T</u>ime <u>B</u>etween <u>F</u>ailures (MTBF)
- Weight / size / price / availability

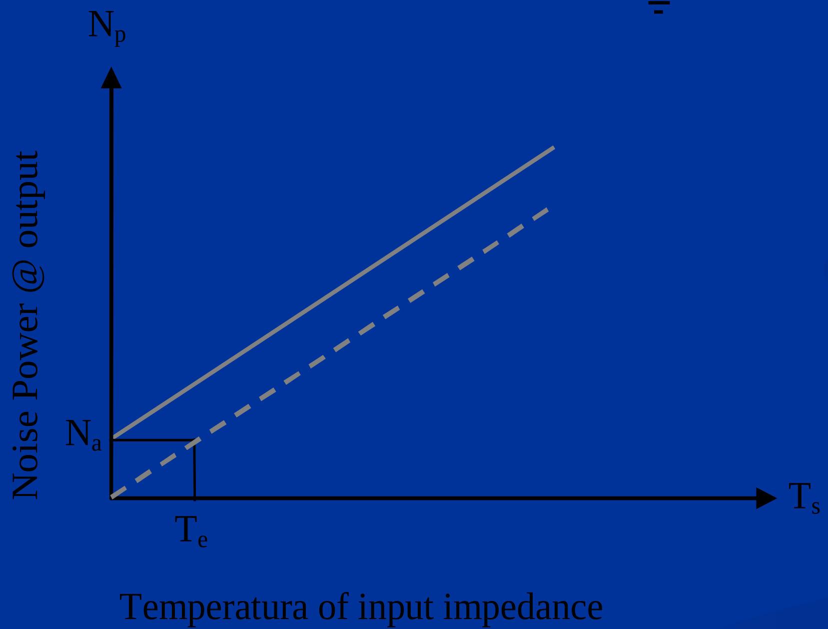
Band /Bandwidth

- Amplifiers are the best option for lowest noise in the 0.1-50 GHz range and competitive with SIS mixers up to 100 GHz
- Instantaneous bandwidth has been increased dramatically:
  - Old masers-parametric amps: BW=10-100 MHz
  - Classical VLBI receivers : BW=0.5 GHz
  - HERSCHEL: 4-8 GHz BW=4 GHz
  - ALMA 4-12 GHz BW=8 GHz
  - SKA?
- Backends are evolving to take advantage of very wide instantaneous bandwidths
- Bandwidths of 1 or 2 octaves are common in today's cryogenic amplifiers

Noise Temperature







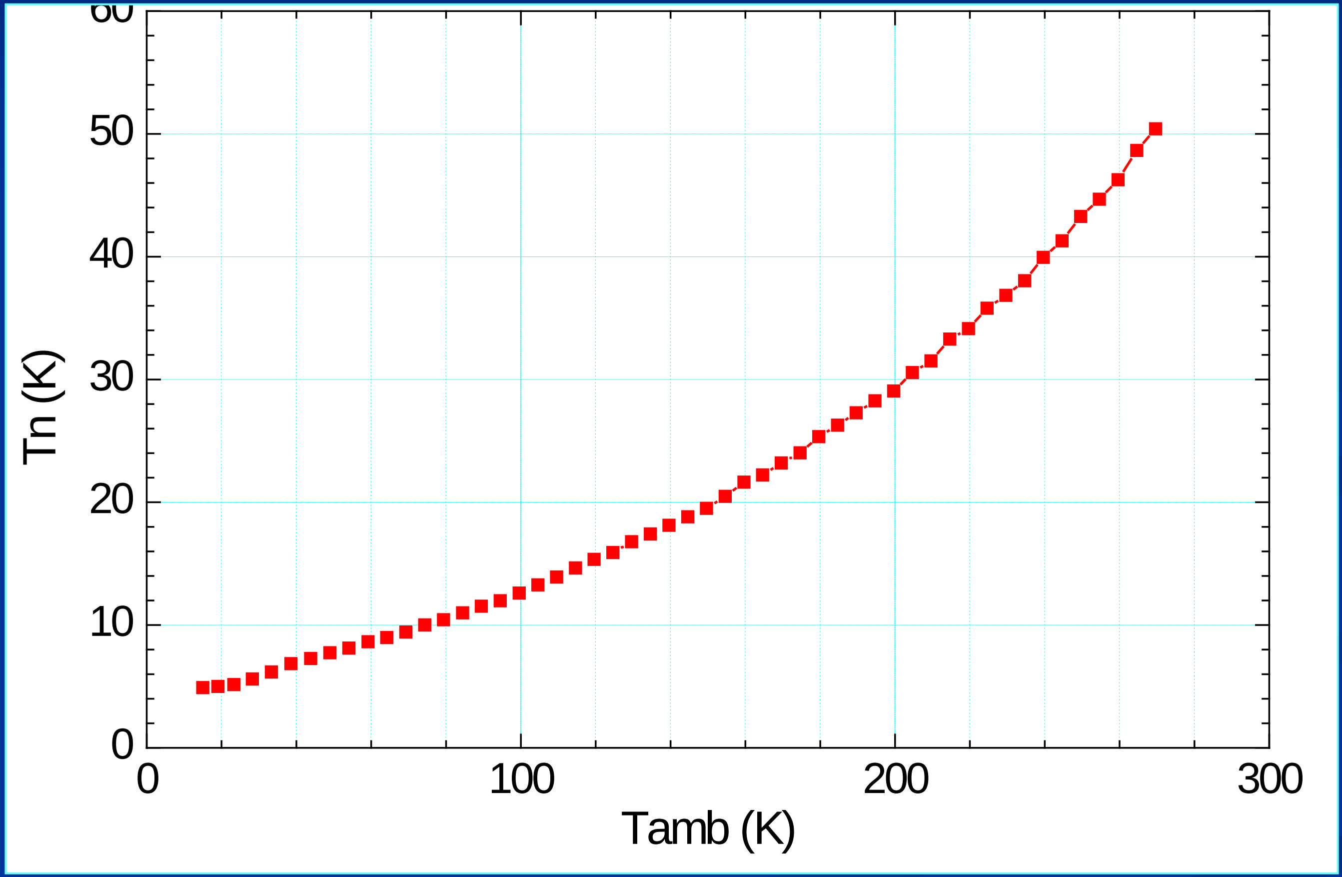
- Noise Temperature is a measurement of the noise generated in the amplifier expressed as an increment in the physical temperature of the input termination
- Noise Temperature of cryogenic amplifiers is very low and difficult to measure with standard instrumentation

Commercial Microwave Noise Figure Meter

Noise Temperature

- Noise temperature improves by a factor of 10-20 by cooling from ambient to cryogenic temperature (15 K).
- Noise temperature obtainable in cryogenic amplifiers cooled to 15 K is typically 0.5 K per GHz (at the max frequency). It can be 0.25 K per GHz with excellent (rare) devices.
- Examples:
  - 4-8 GHz: 4 K
  - 8-12 GHz: 6 K
  - 18-26 GHz: 13 K

Example: Noise vs. ambient temperature

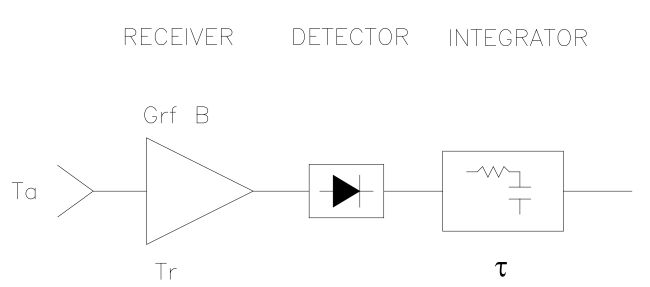


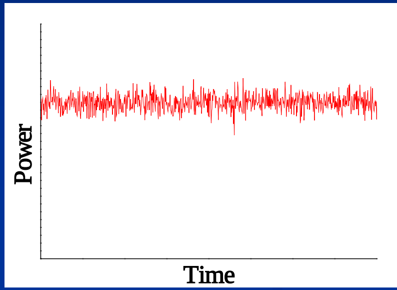
Noise and Gain Fluctuation: Radiometer Sensitivity

- Radiometer

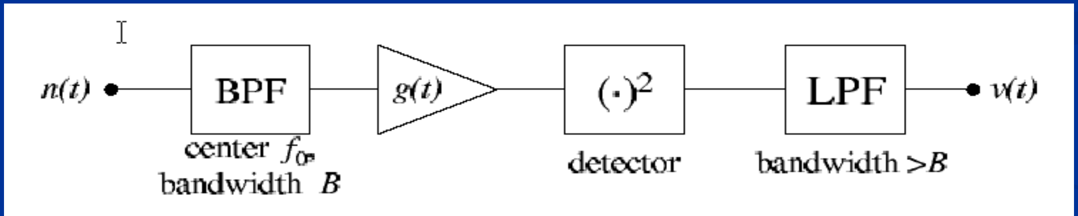
$$P_{out} = K \cdot G_{rf} \cdot B \cdot (T_a + T_r)$$

$$\frac{\Delta P_{out}}{P_{out}} = \frac{k}{\sqrt{B\tau}} + \frac{\Delta G_{rf}}{G_{rf}}$$





- Radiometer model



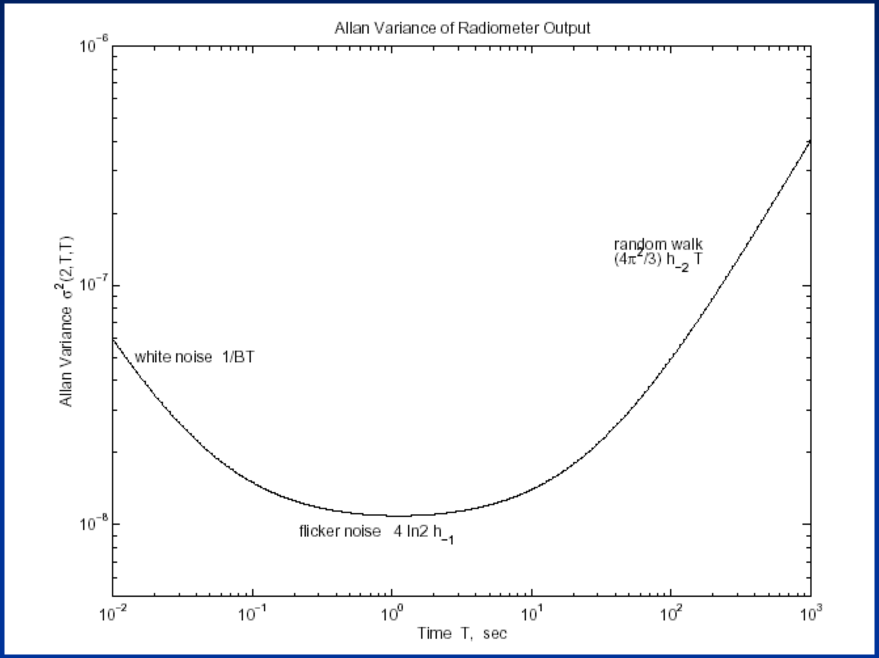
- Radiometer sensitivity

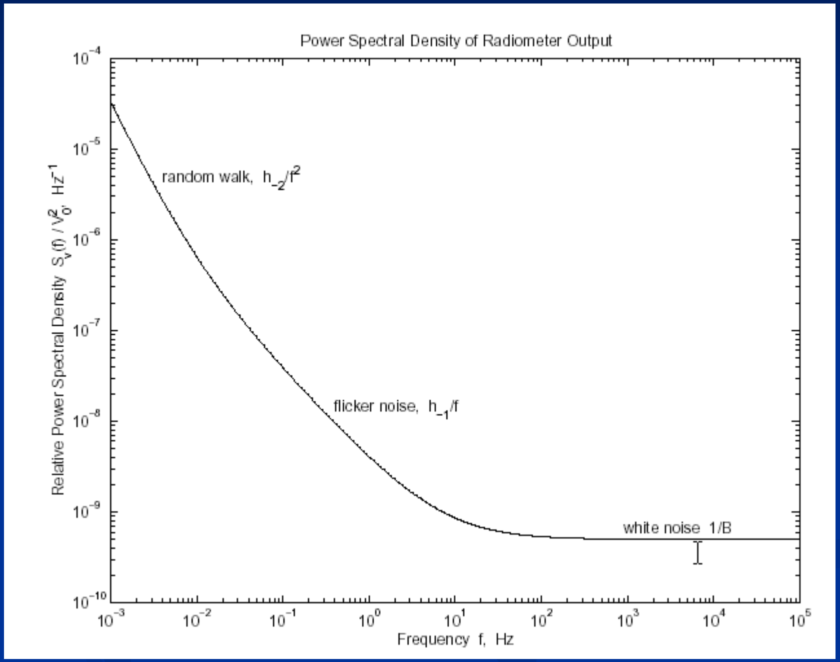
$$\frac{S_v(f)}{V_0^2} = \delta(f) + \frac{1}{B} + \frac{2 \cdot S_g(f)}{G_0}, \quad |f| << B$$

Allan Variance

- Engineers prefer SNGF
  - Individual interferences (1 Hz, 50 Hz) are easily detected
- Astronomers prefer Allan Variance
  - Easy to use for estimation of σ as function of integration time
- Definition of Allan Variance:

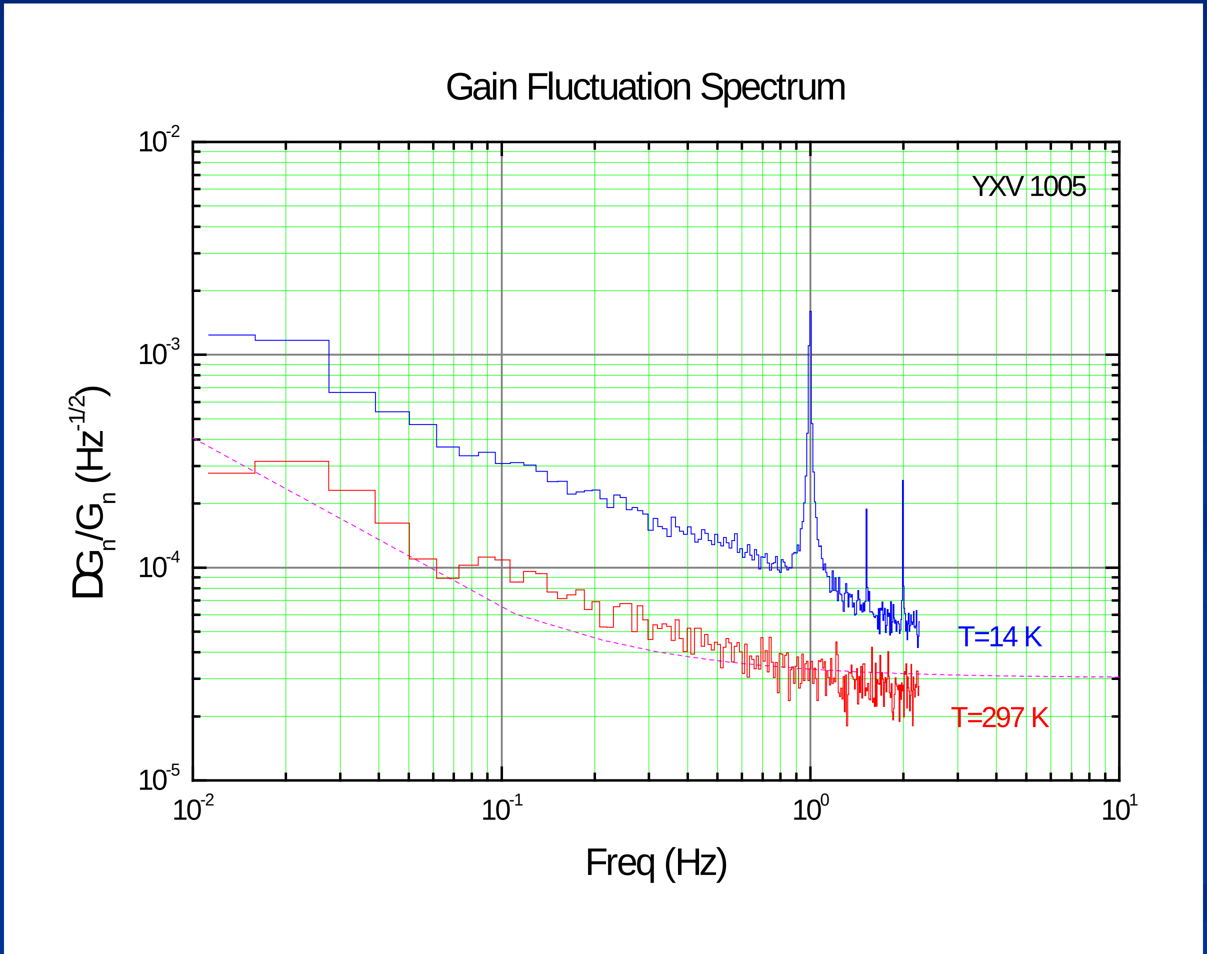
$$\sigma^2(\tau) = \frac{1}{2}\left\langle \left(\overline{G}(t+\tau) - \overline{G}(t) \right)^2 \right\rangle$$





$$\sigma^2(\tau) = \int_{-\infty}^{+\infty} S(\nu) \left| 4 \frac{\sin^4(\pi\tau\nu)}{(\pi\tau\nu)^2} \right|^2 d\nu$$

Gain Fluctuation of a cryogenic 4-8 GHz amplifier



Some common misconceptions on gain stability

- Gain stability is not a problem in modern receivers
  - **WRONG!** Gain stability can be a severe limitation in wide bandwidth observations unless some kind of Dike switching is performed (continuum, cosmic background)
- There is nothing we can do improve gain fluctuations of cryogenic InP amplifiers
  - **WRONG**! Only by playing with the bias point a factor of ~5 can be improved (or degraded), although the measurements are quite tedious
- The improvements in the devices will improve gain fluctuations of cryogenic InP amplifiers
  - **WRONG**! Reductions in the gate length could improve the noise but degrade the gain fluctuations although improvements in material quality could help by reducing the traps

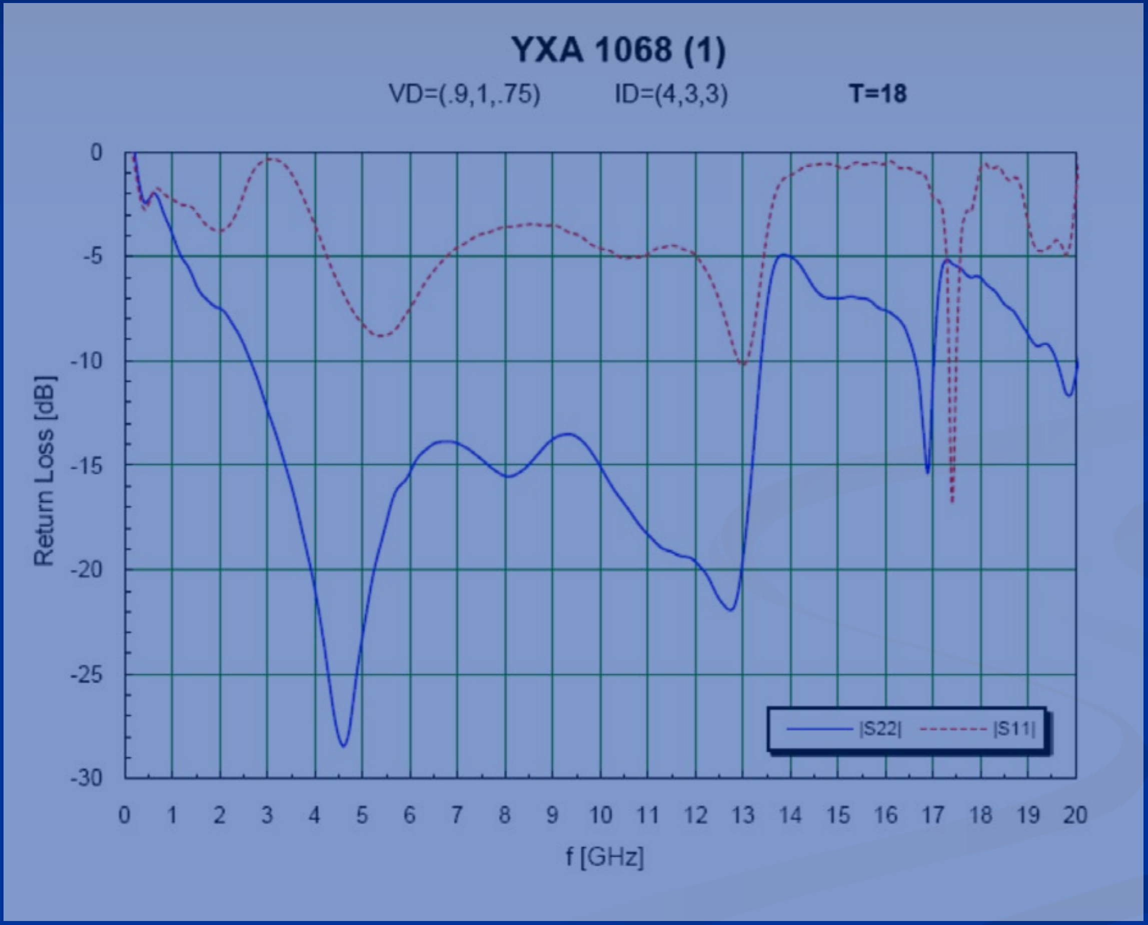
Input/Output reflection coefficient

- Specified in terms of reflection loss:

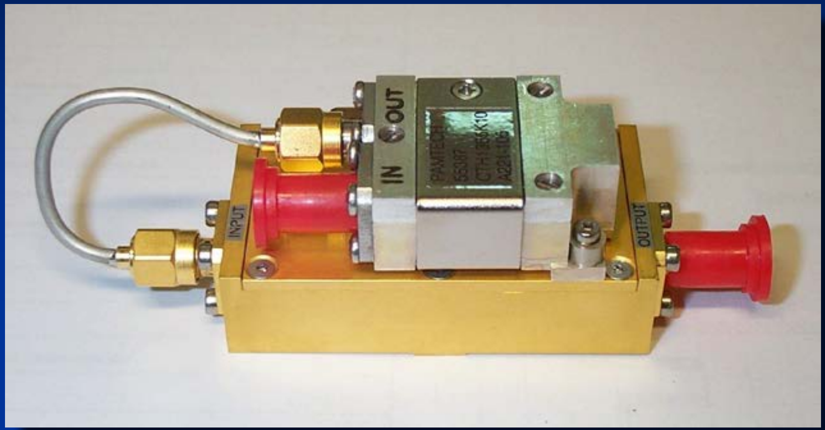
$$IRL_{dB} = -20 \cdot \log_{10}\left(\left|S_{11}\right|\right) \qquad ORL_{dB} = -20 \cdot \log_{10}\left(\left|S_{22}\right|\right)$$

- Low input reflection is difficult to obtain in low noise amplifiers (the impedances for optimum noise and minimum reflection are different)
- Isolators (passive non reciprocal devices) can be used to improve input reflection
- Example: ALMA 4-12 GHz amplifier specification:
  - IRL : 3 dB ($|S_{11}|<0.70$)
  - ORL : 10 dB ($|S_{22}|<0.32$)

Example: Reflection loss in 4-12 GHz amplifier

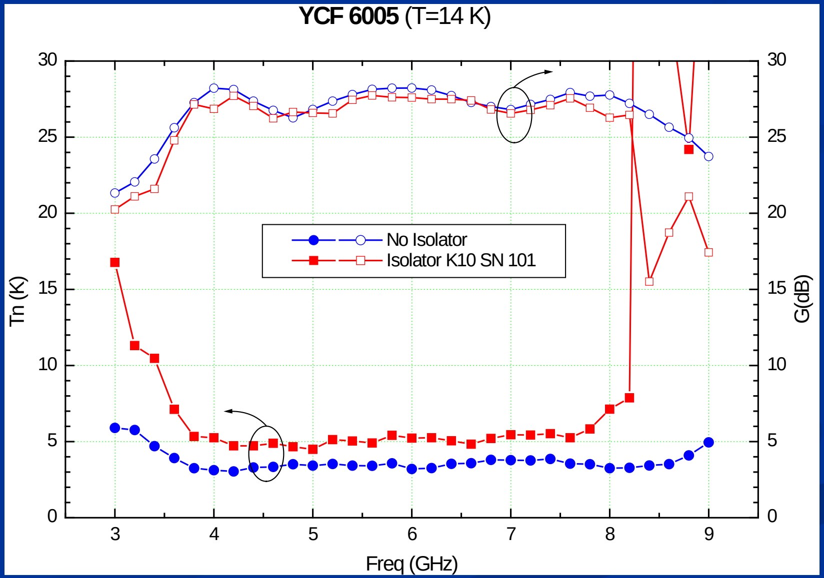


Cryogenic Isolator 4-8 GHz

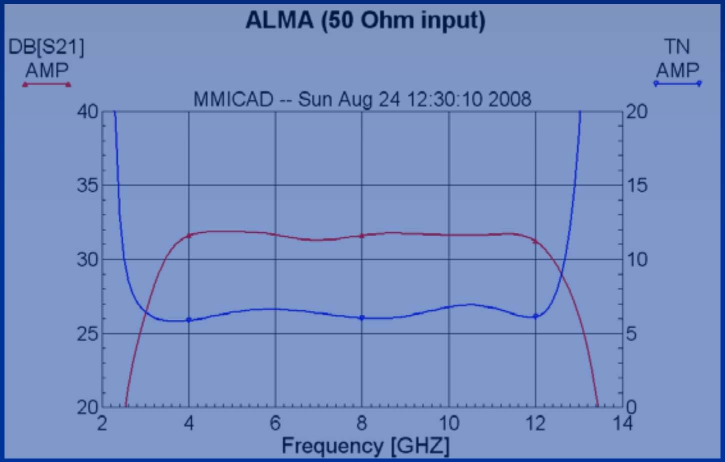


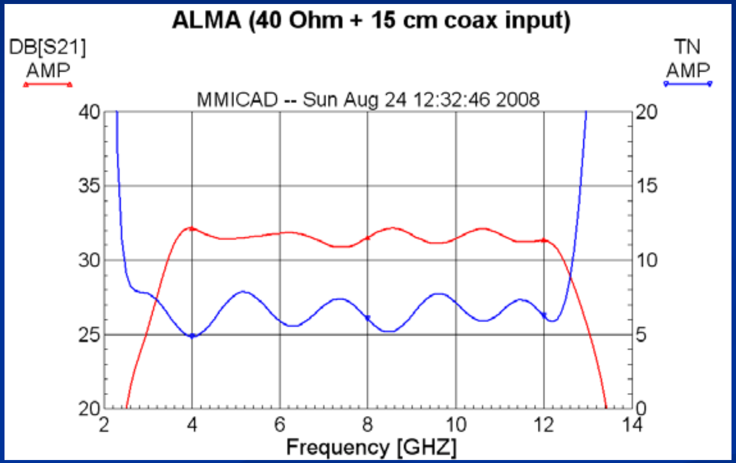
$$\Delta T_c = \left(\frac{1}{G_{iso}} - 1 \right) \cdot \left(T_{amb} + T_{amp} \right)$$

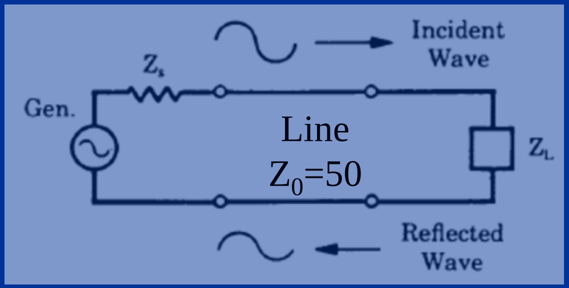
- Herschel Amplifier + Isolator
- Large improvement in input reflection (up to 15-20 dB in IRL)
- Noise degradation: 1.1 – 1.4 K



What is the effect of a high reflection coefficient?







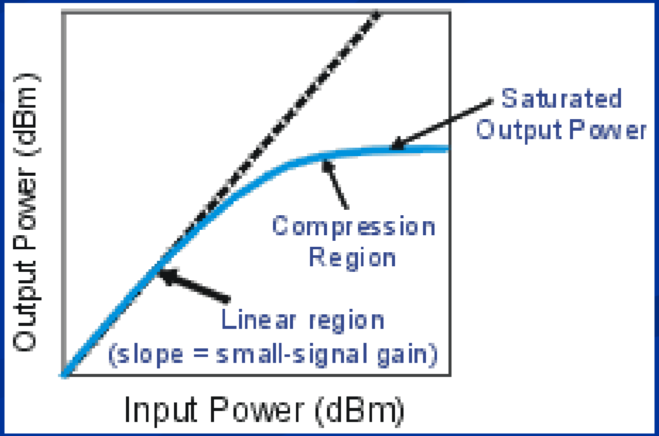
Reflections at both ends of a transmission line cause **ripple** in gain and in noise!

The figure shows the effect of connecting a 40 Ohm input termination thru a length of 15 cm of TEFLON coaxial cable

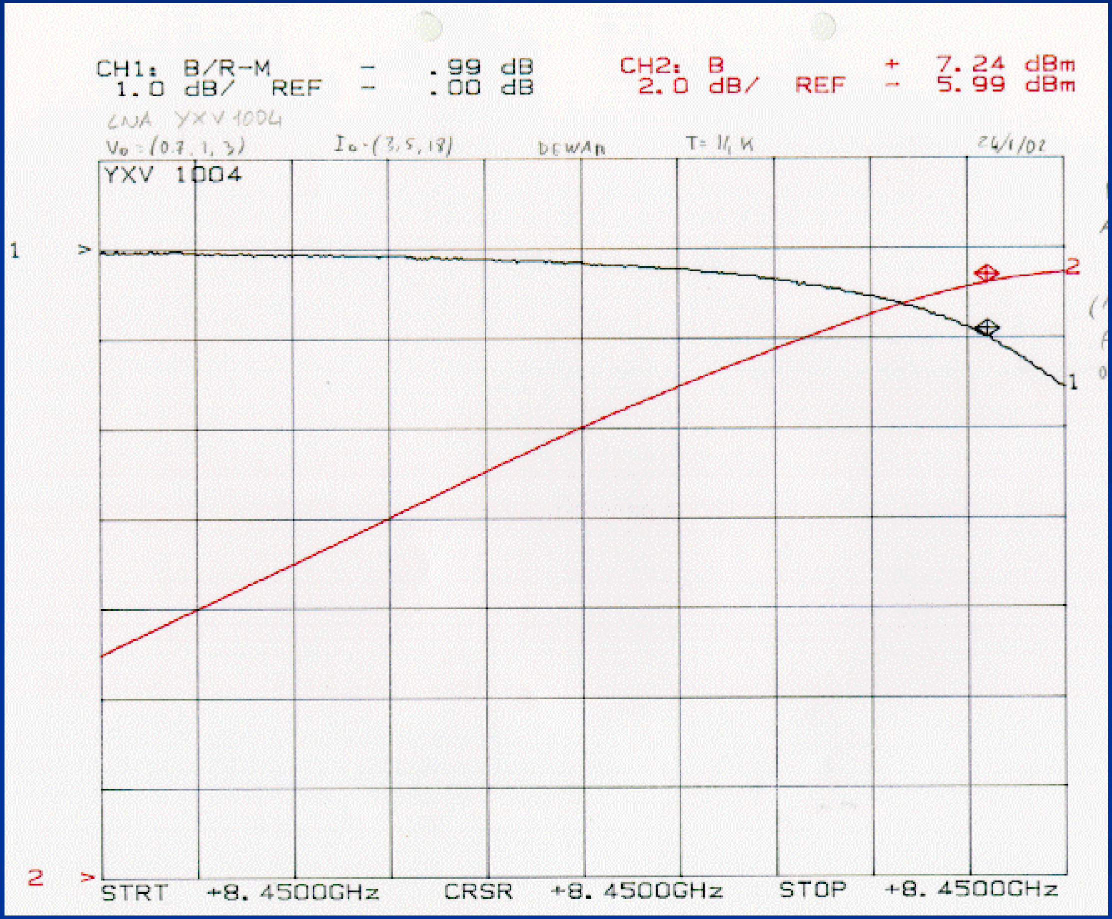
Nonlinearity: 1 dB compression point

- A real amplifier can not deliver unlimited output power
- Gain compression occurs when the input power of an amplifier is increased to a level that reduces the gain of the amplifier and causes a nonlinear increase in output power
- With the level of signal of radio astronomy sources the saturation of input LNAs is unlikely

Saturation of an amplifier could be produced by strong out-of-band signals or self-oscillations



Example: 1 dB compression of X-Band DSN amplifier



Spec: +5 dBm

Meas: +7 dBm

(at output port)

Nonlinearity: Intermodulation (IP3)

- A non-linear system can be described by the Taylor series:

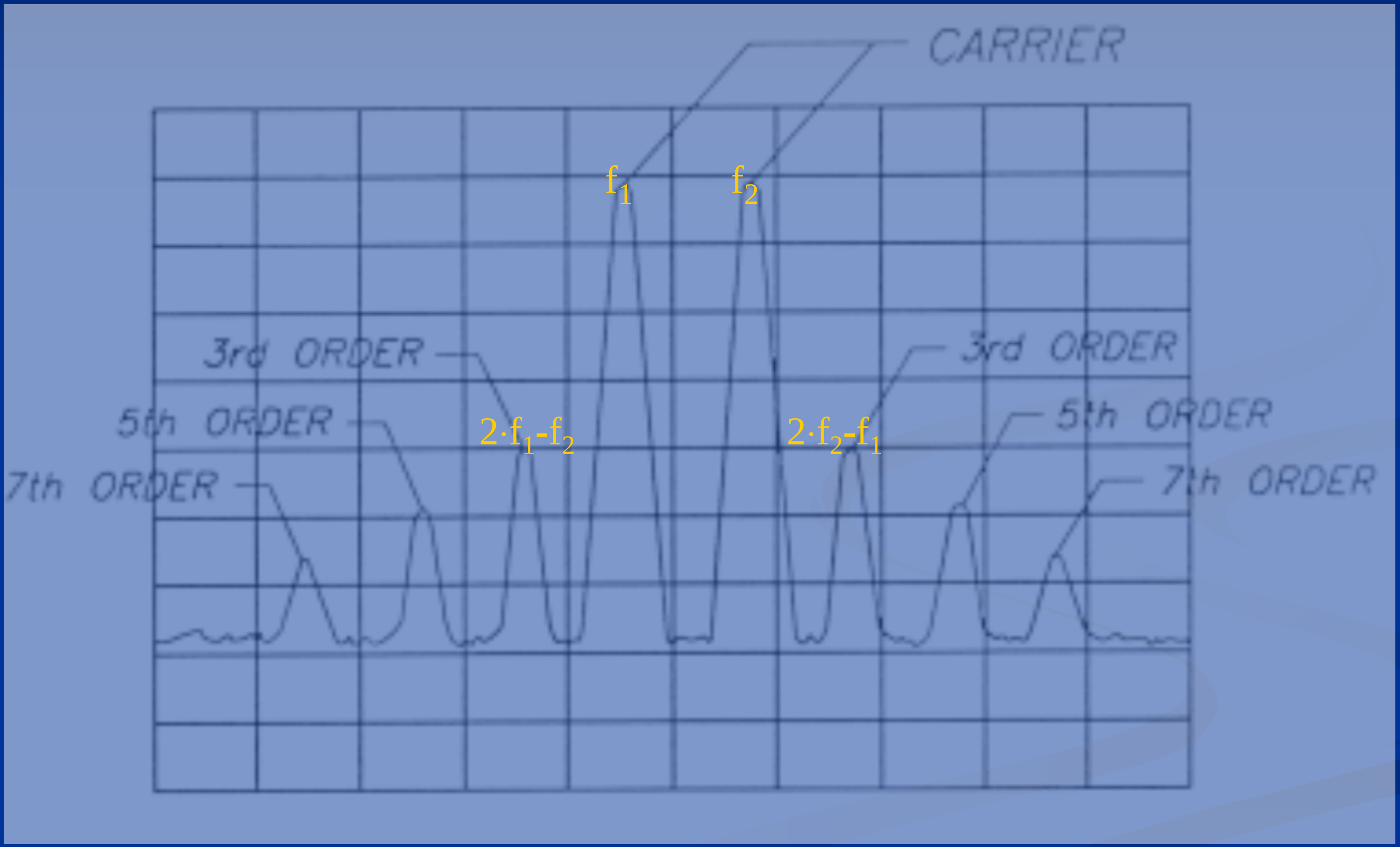
$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + ... + a_n \cdot x^n$$

- With two signals of the same amplitude and different frequency at the input of the form:

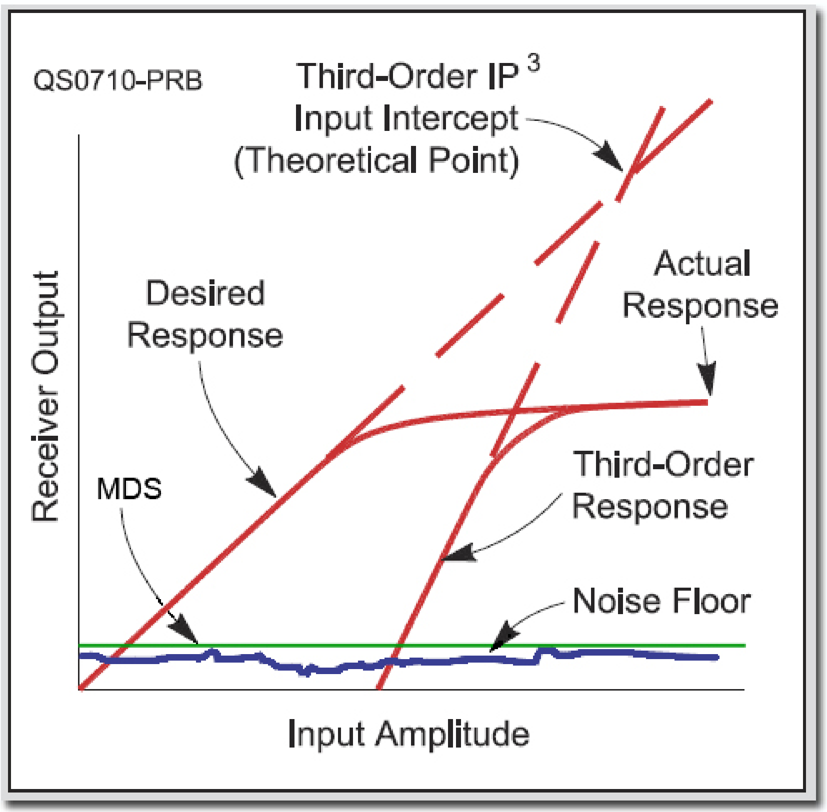
$$x(t) = A \cdot \cos(2 \cdot \pi \cdot f_1 \cdot t) + A \cdot \cos(2 \cdot \pi \cdot f_2 \cdot t)$$

- At the output many combination of frequencies will be found, in particular:
  - Fundamental (f_1, f_2)
  - 3rd order ($2 \cdot f_2 - f_1$, $2 \cdot f_1 - f_2$)
  - 5th order ($3 \cdot f_2 - 2 \cdot f_1$, $3 \cdot f_1 - 2 \cdot f_2$)
  - …

Intermodulation products



Interception point IP3



Source: QST, October, 2007 p. 70.

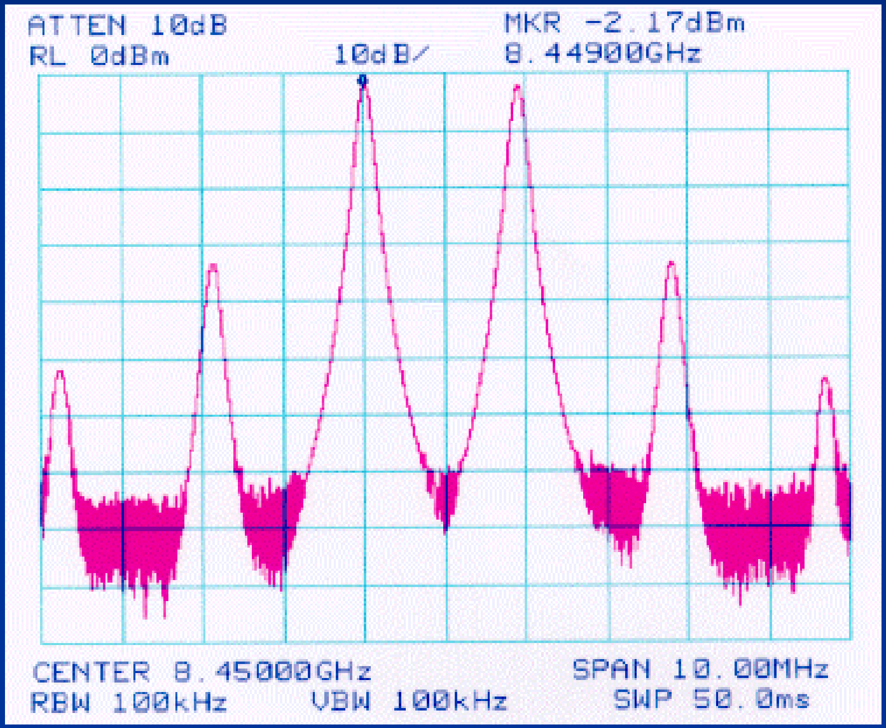
Slope of fundamental = 1:1

Slope of third order = 3:1

IP3 is the value of power output at the theoretical interception point.

The value of IP3 allow the calculation of interference in presence of strong signals

IP3 measurement of X-Band DSN amplifier



$$IP3(dBm) = \frac{Suppression(dB)}{Order - 1} + P_{out}(dBm)$$

Measured IP3=19 dBm

(Usually IP3 is ~14 dB above 1dB compression)

Future of amplifiers for radio astronomy

- Better semiconductor materials
  - Metamorphic GaAs
  - New heterostructures? (InAs/AlSb)
  - New devices? (SiGe HBT)
- MMICs for Focal Plane Arrays
- Balanced amplifiers for decade bandwidth feeds
- Higher frequency?
- Wider instantaneous bandwidth?

Yebes Personnel & Installations
(for cryo LNA development)

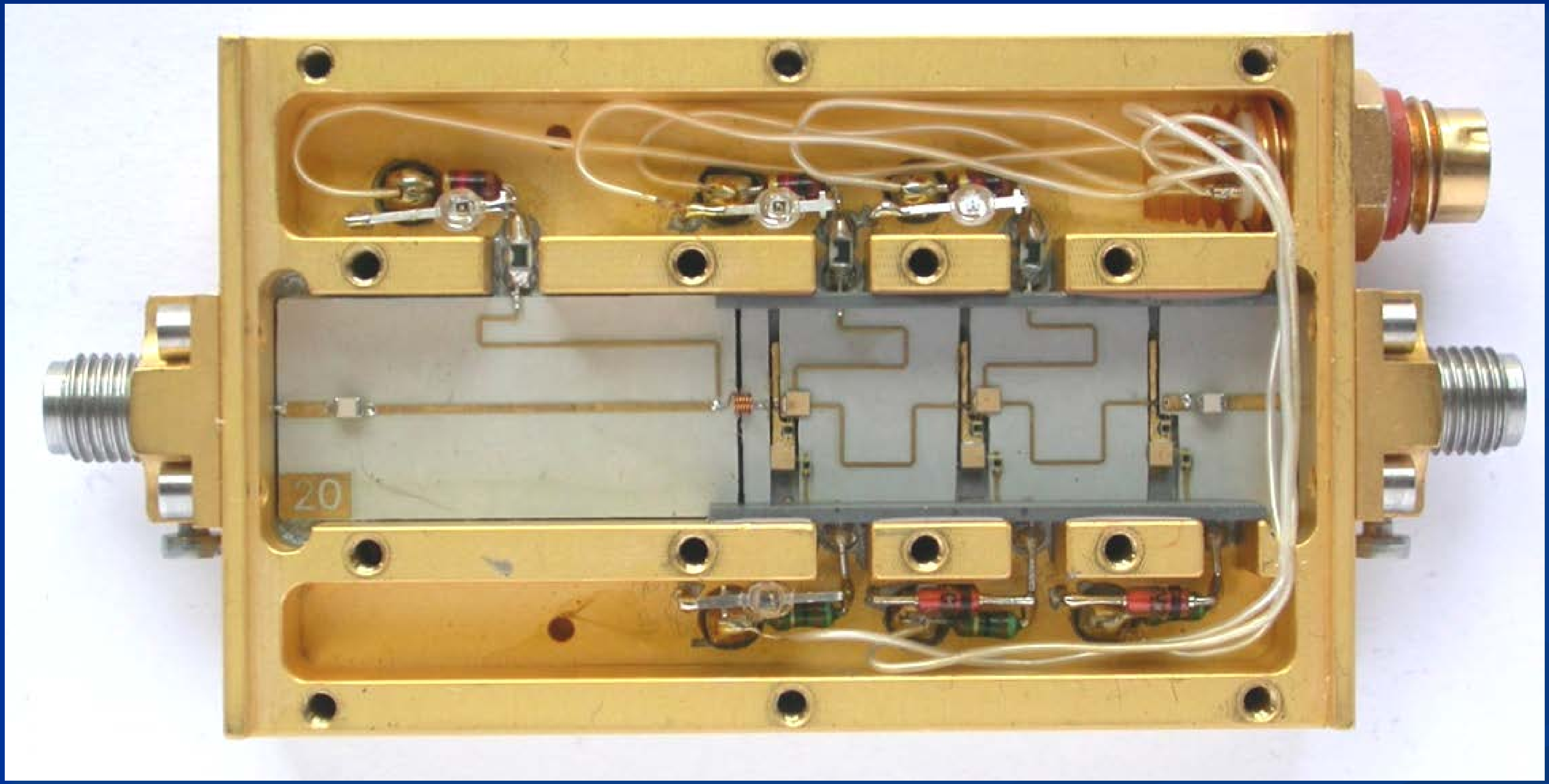
- Personnel
  - 5 engineers
  - 2 technicians
  - 1 chemistry LAB
- Installations
  - Microwave LAB
    - 4 Test Cryostats
    - VNAs, Spectrum Analyzers, Noise Figure Meters up to 50 (110) GHz
  - Assembly Lab
    - Microscopes
    - Bonding & welding machines
    - Pull test
    - Plasma cleaning
    - Laser milling machine
  - Mechanical Workshop (shared)
    - CNC milling machine
  - Chemistry lab
    - Electroplating (Au)
    - Substrate etching


HTBasic

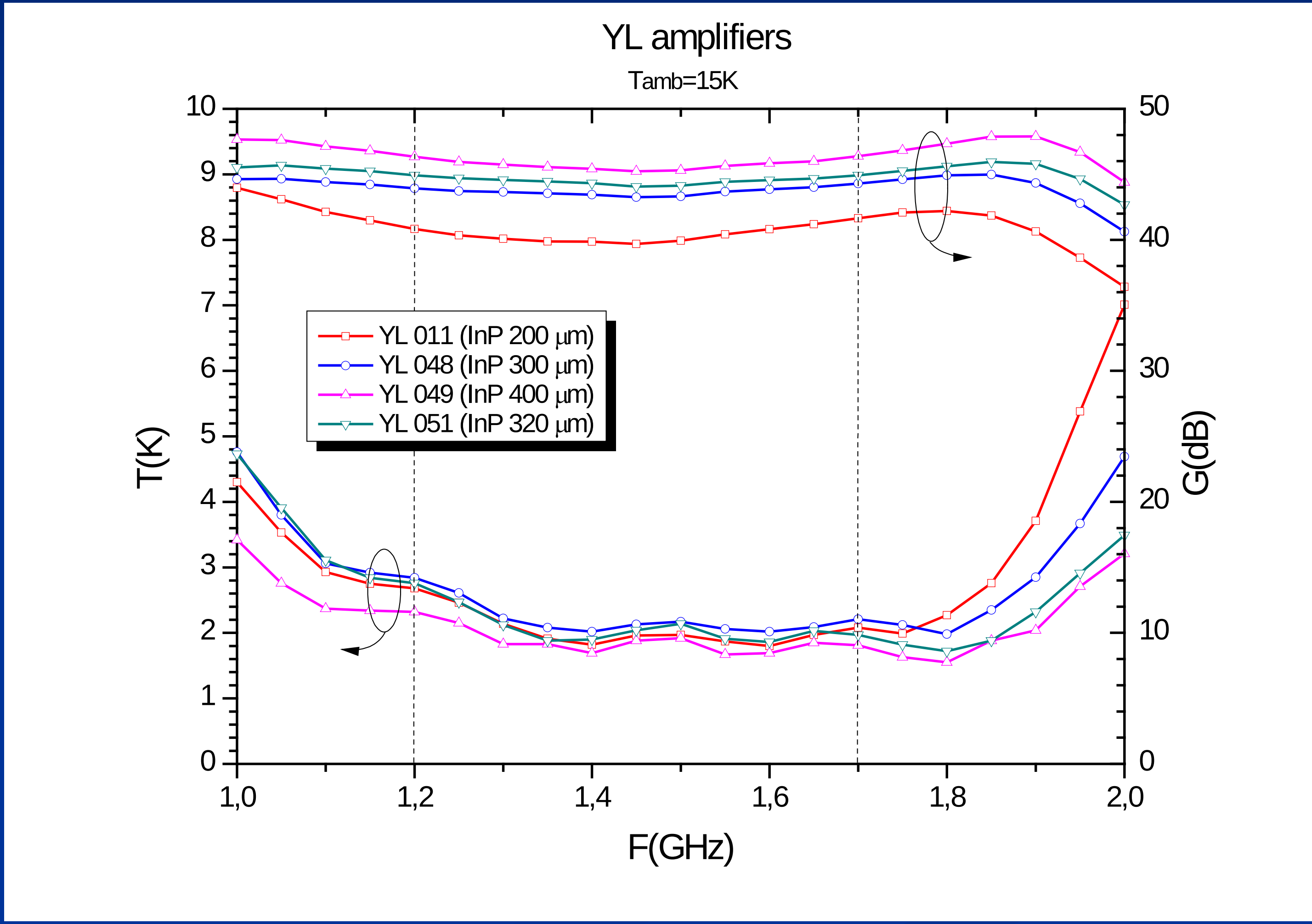
YEBES RECENT PROJECTS

- RT 40 m CAY → (bands from 2.2 GHz to 50 GHz)
- RAEGE (Geodetic VLBI) → (S, X and Ka Band tri-band receiver)
- 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 → (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)
  - FP7: AMSTAR+, AETHER (IF integrated with mixer), APRICOT (33-50 GHz multibeam receiver)
- Over 1000 cryogenic amplifiers delivered to different projects.

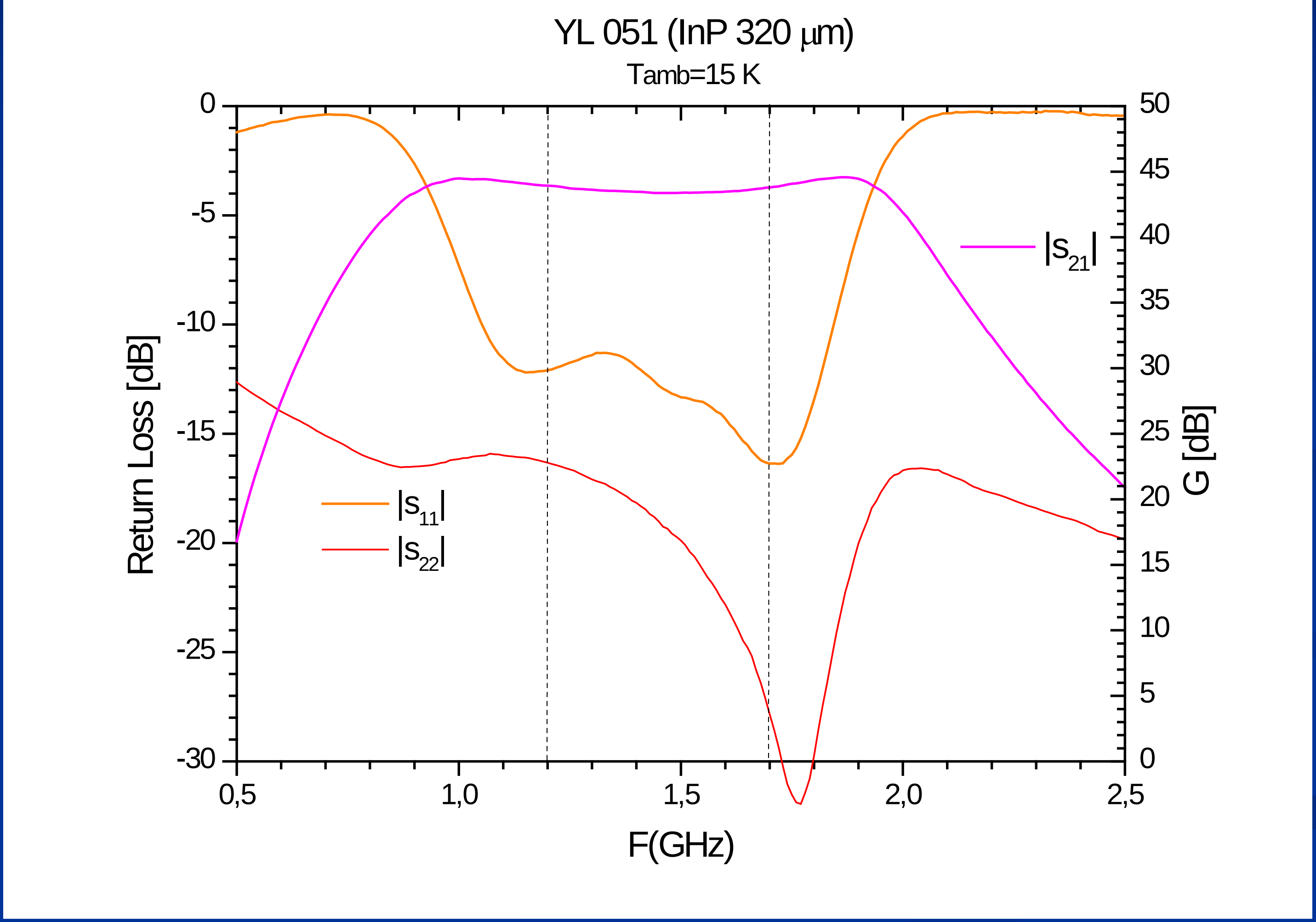
L-band YL series (for KIDs)



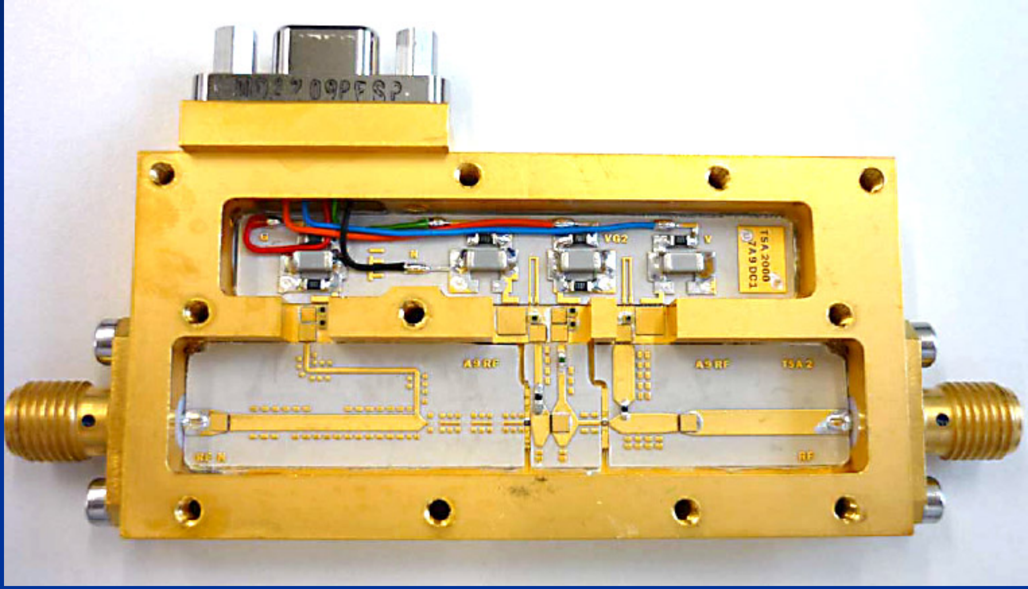
L-band YL series (for KIDs)

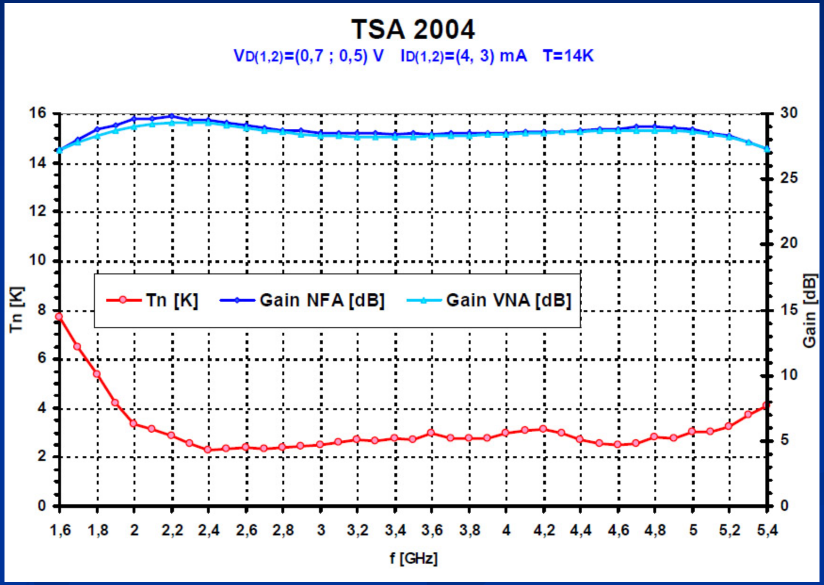


L-band YL series (for KIDs)



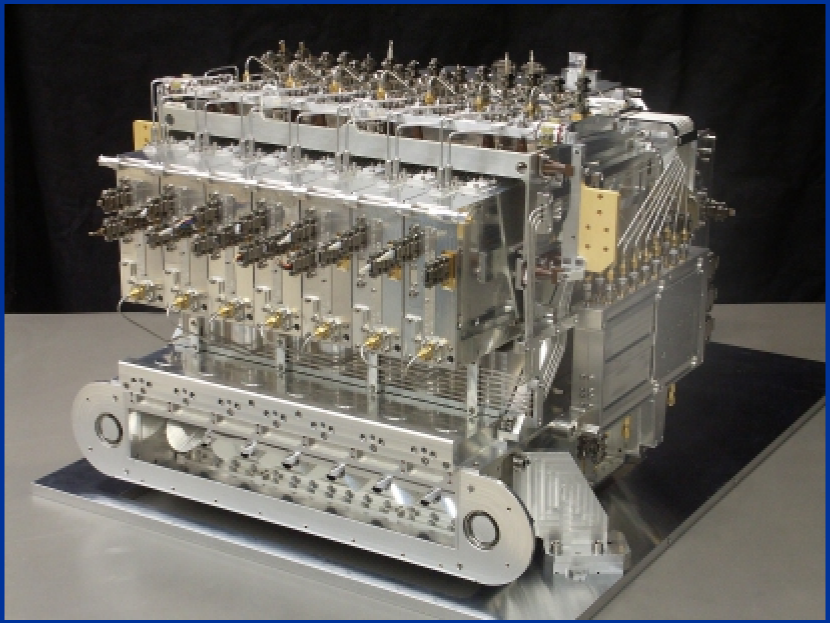
S-band Cryogenic Amplifier (sample)

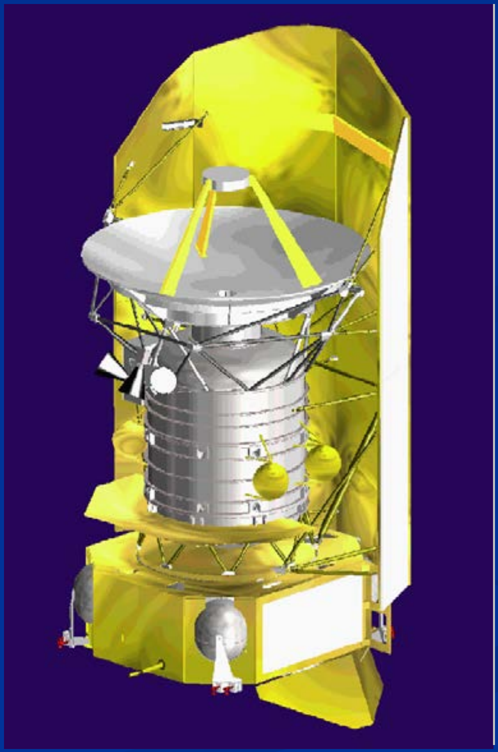




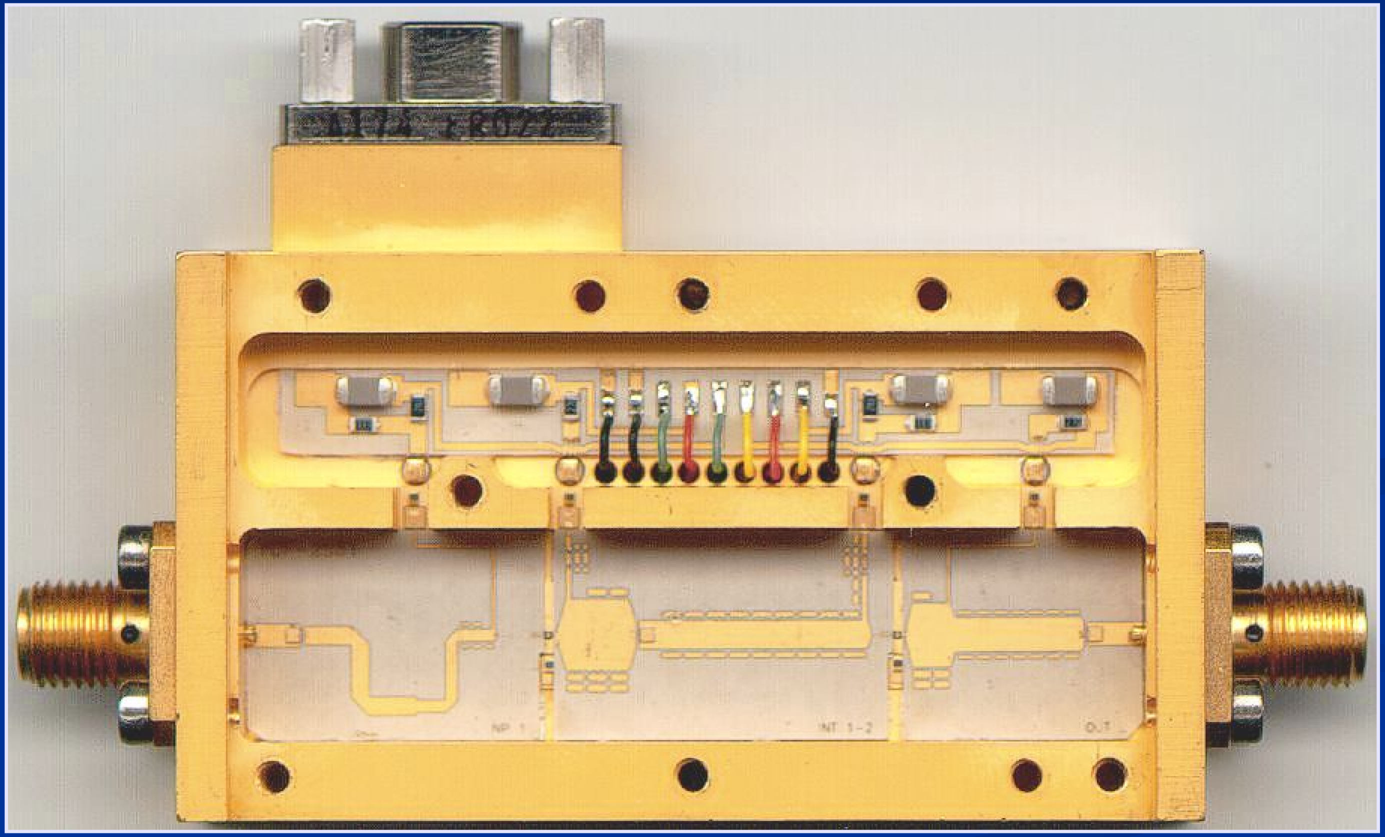
Technical Specification	Requirement	Test	Equipment	Result
Frequency Range	2.2 – 4.8 GHz	-	-	2.2-4.8 GHz
Noise Temperature	< 10K	Noise	N8975A	< 3.11 K
Average Gain	> 26 dB	Scattering Parameters based on VNA	N5230A	> 28.59 dB
Gain Flatness	2dB p-p		N5230A	<1.11dB p-p
Input VSWR	< 10 dB		N5230A	< 12.1 dB
Output VSWR	< 10 dB		N5230A	< 19.4 dB
Power Consumption	< 10mW	-	34970A	< 4.3 mW

HERSCHEL (HIFI)



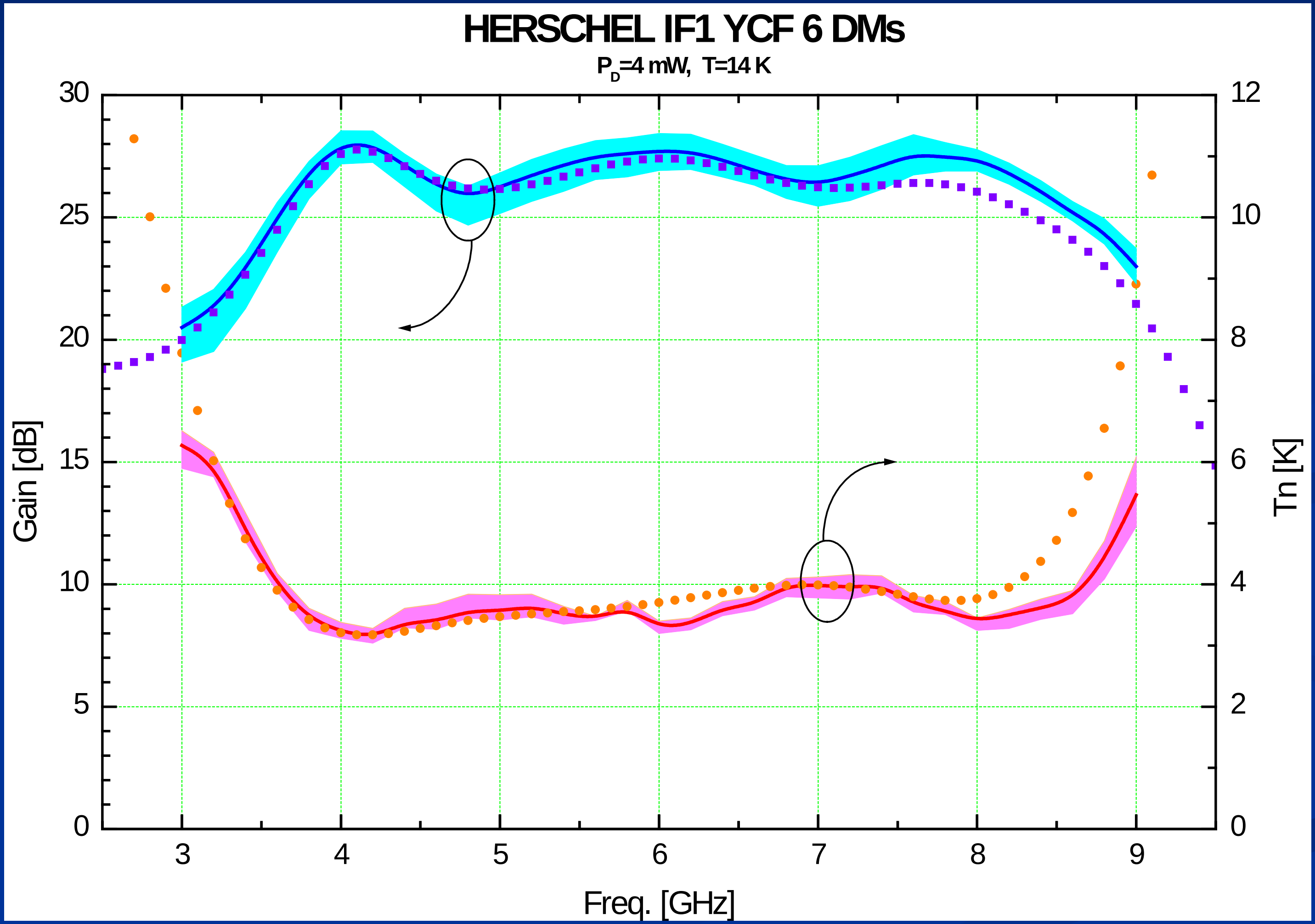


HIFI YCF 6004 (4-8 GHz)

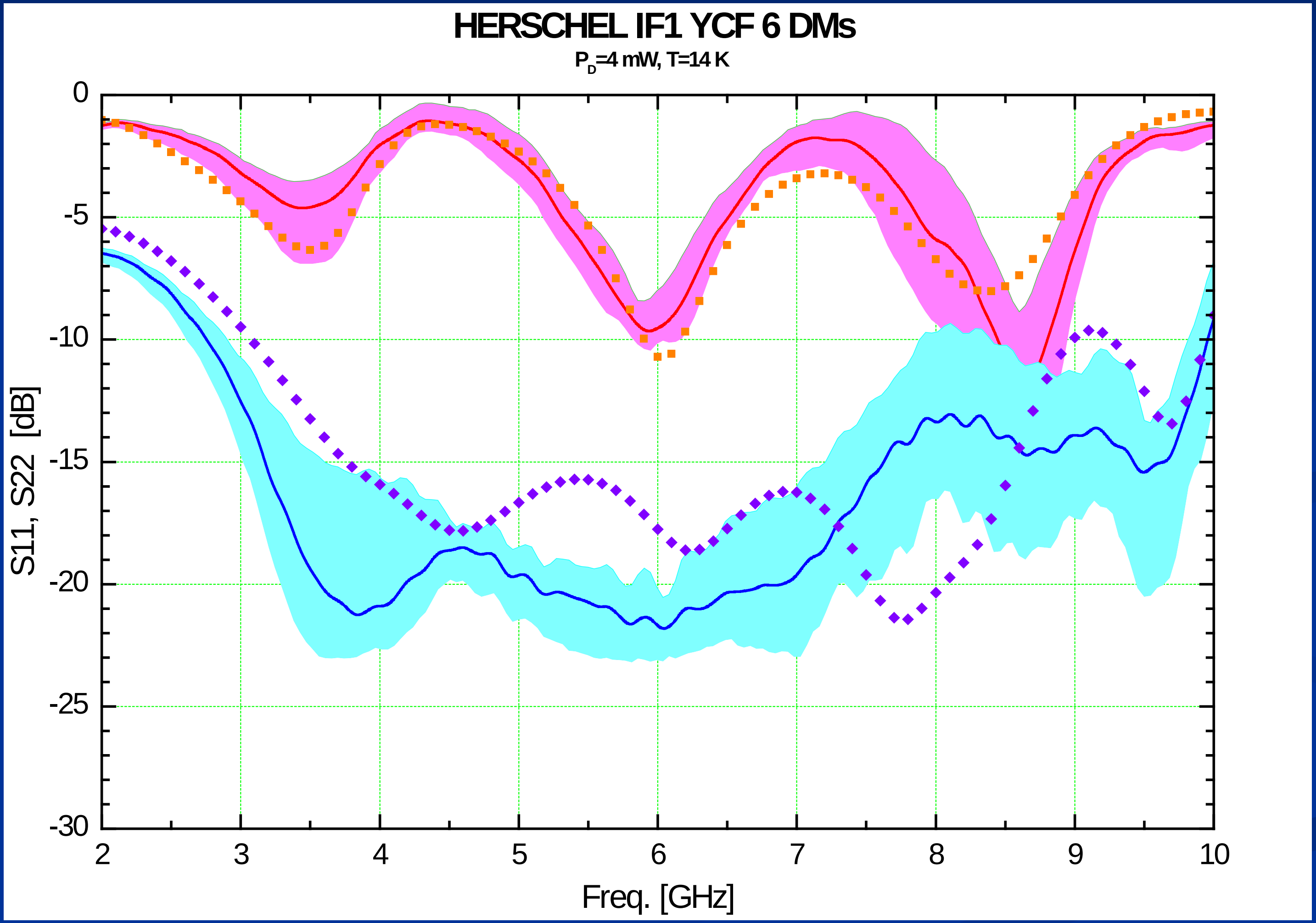


m=65 g   58 x 32 x 15 mm

HIFI YCF 6000 (Noise and Gain)

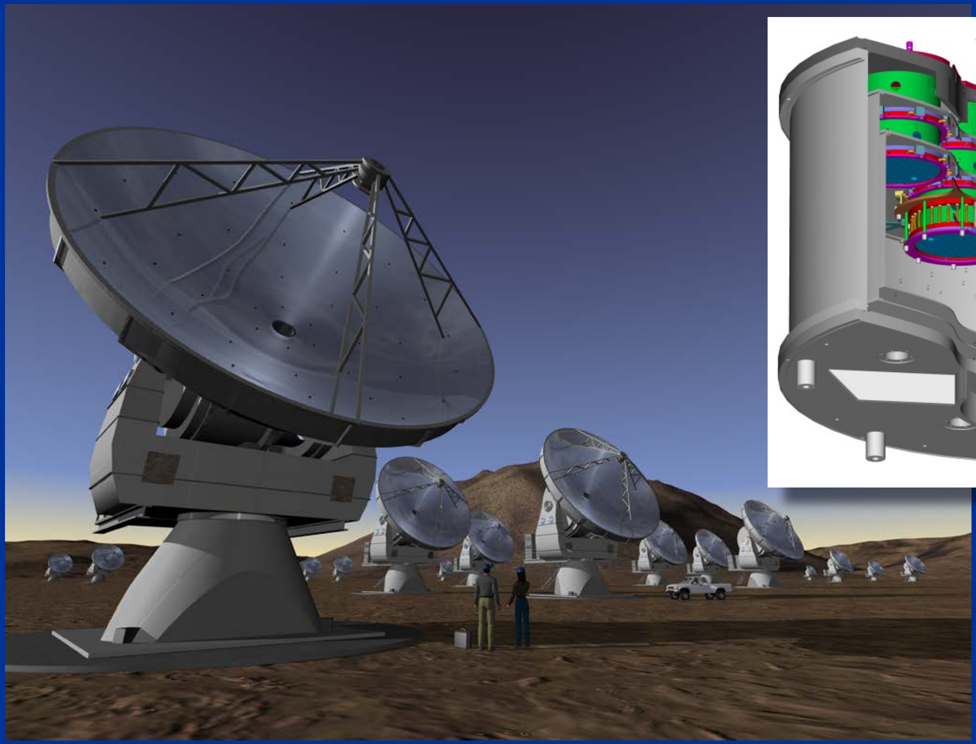


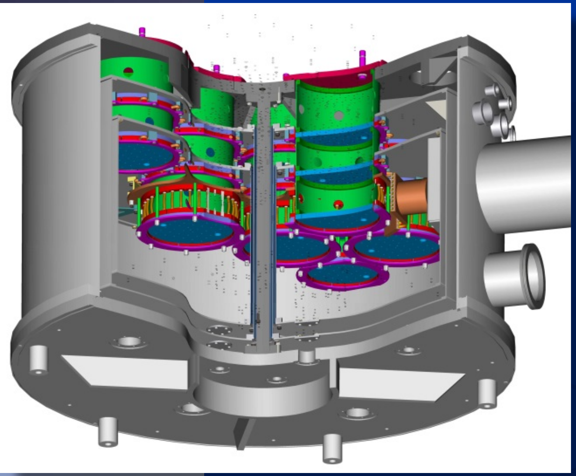
HIFI YCF 6000 (I/O Reflection)



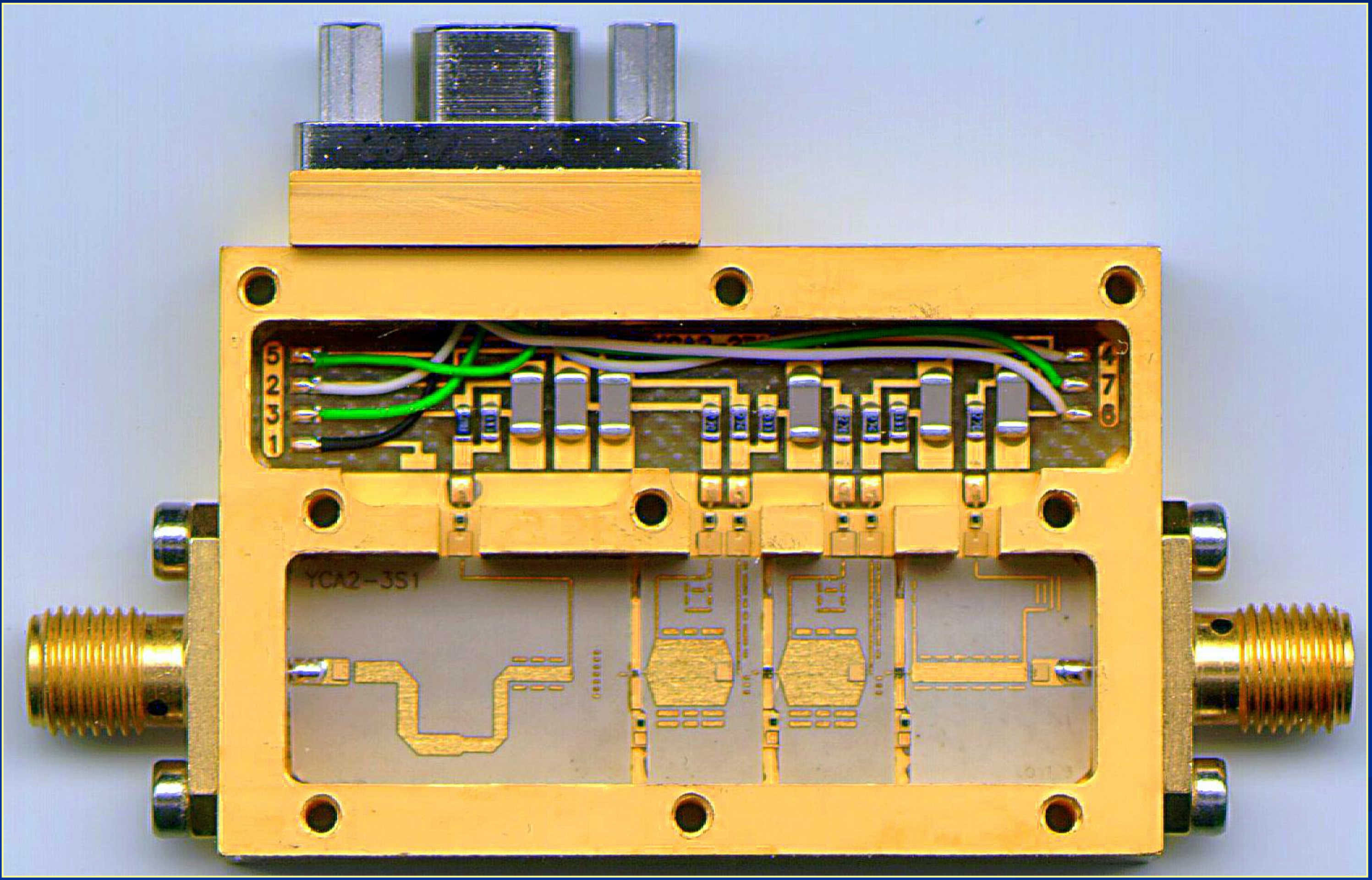
ALMA

- 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)

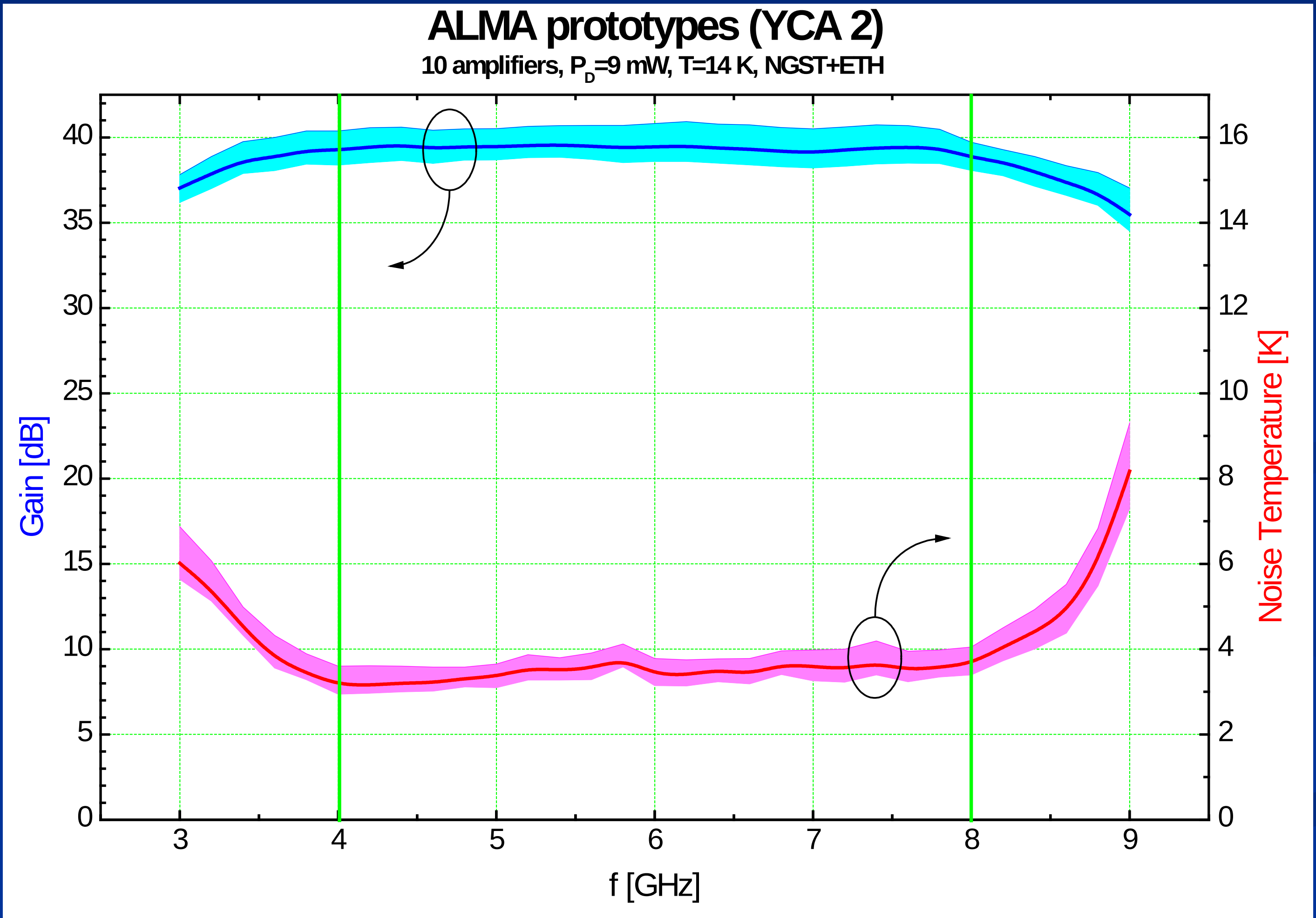




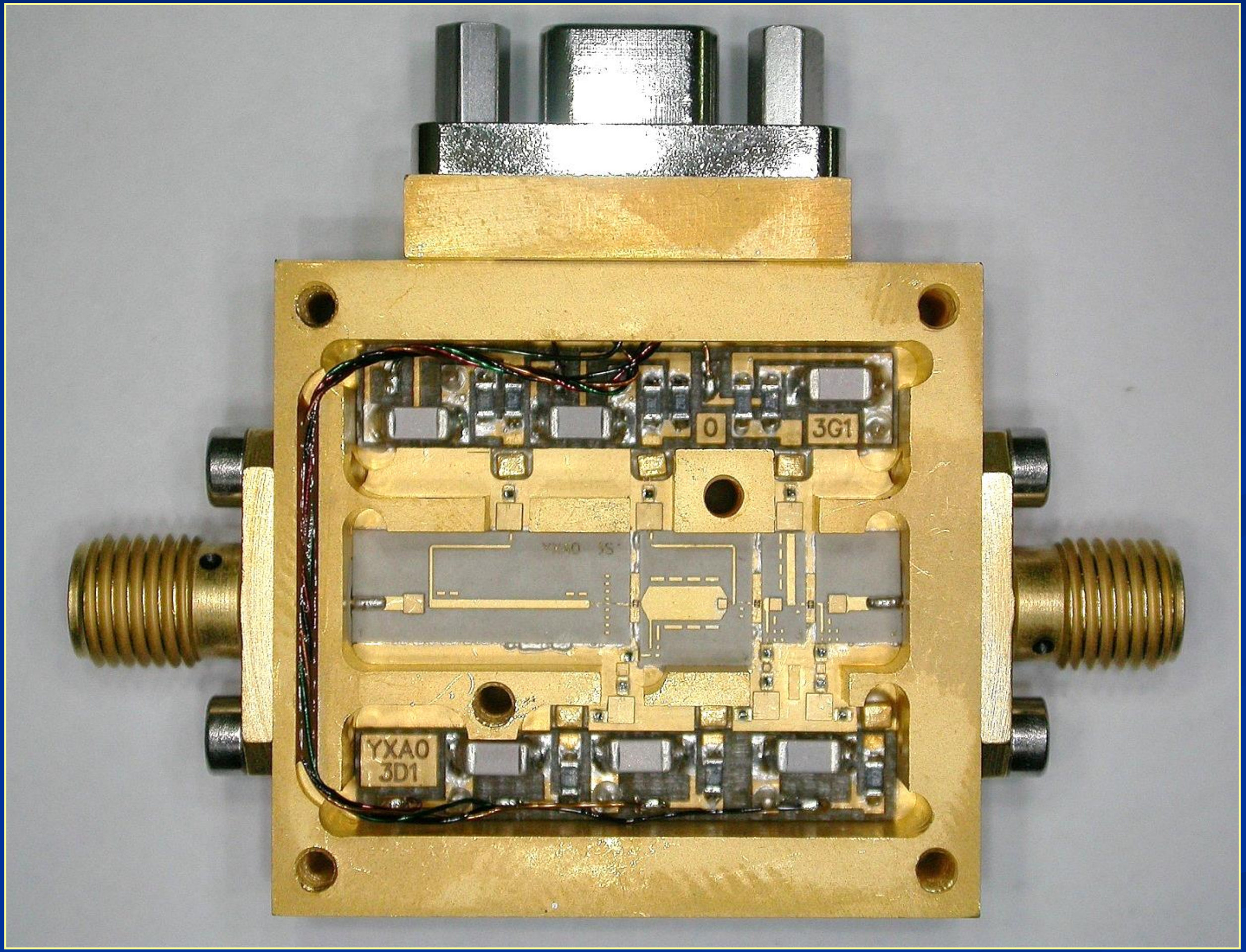
4-8 GHz ALMA amplifiers (Band 7)



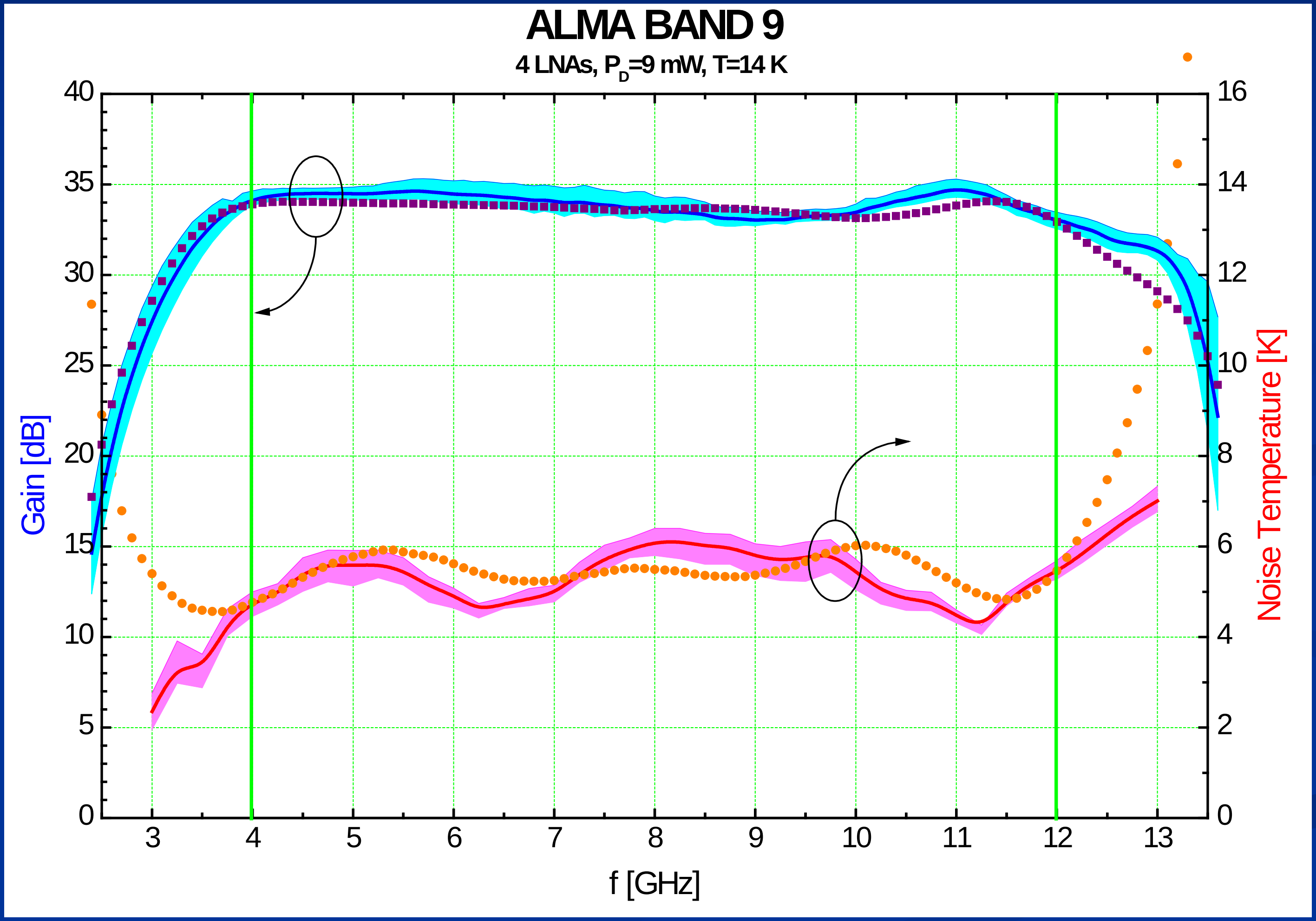
4-8 GHz ALMA amplifiers (Band 7)



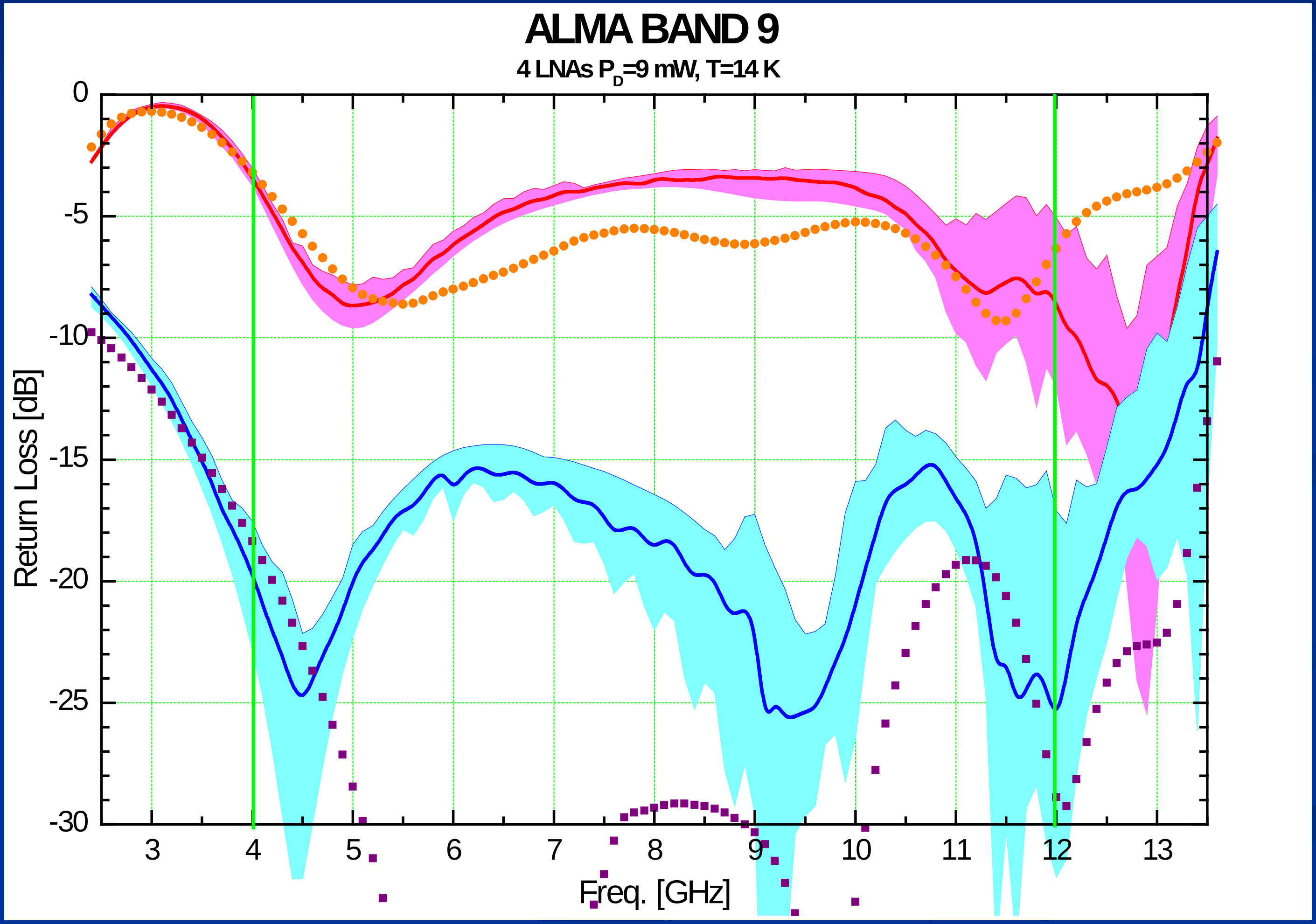
4-12 GHz ALMA amplifiers (Band 9)



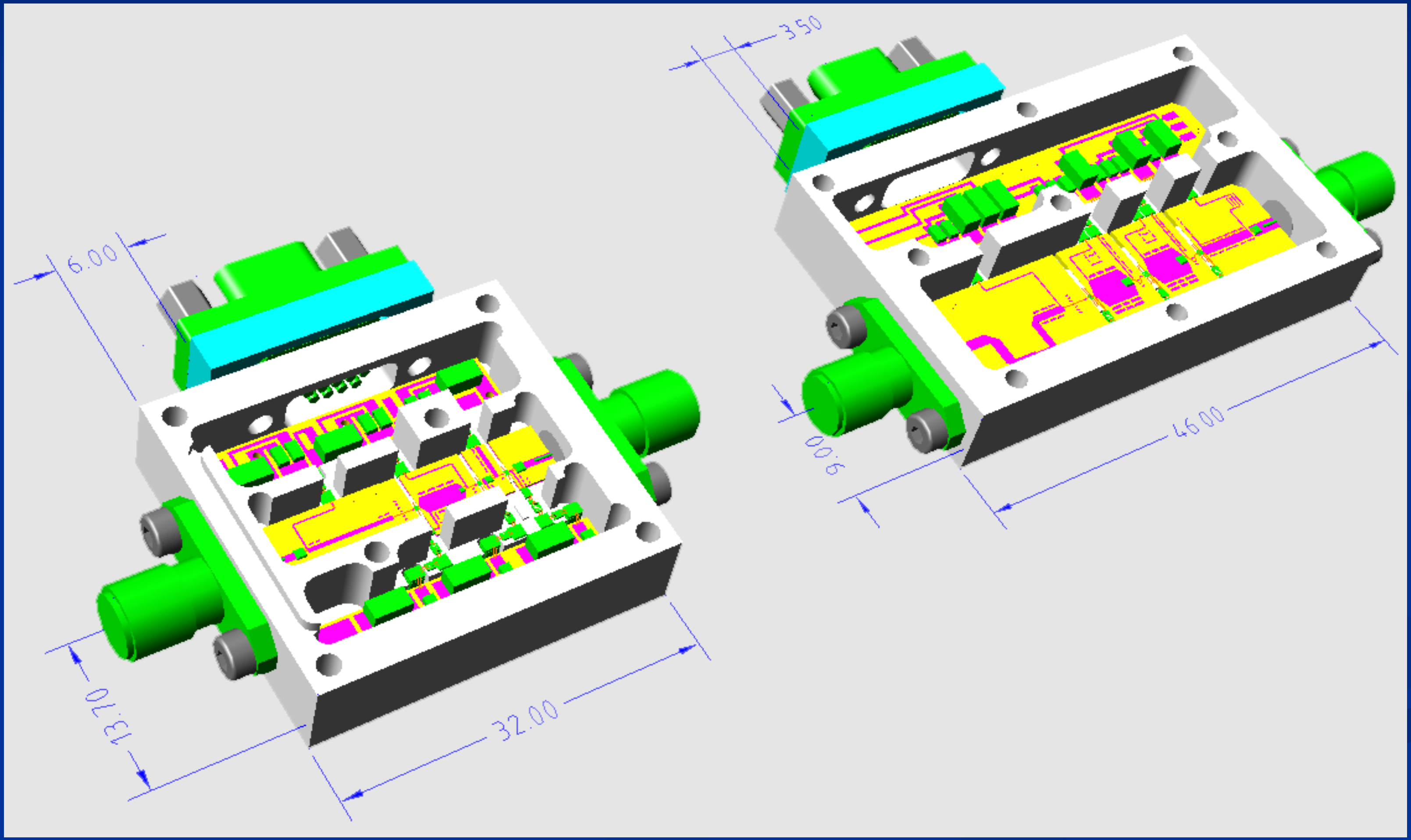
4-12 GHz ALMA amplifiers (Band 9)



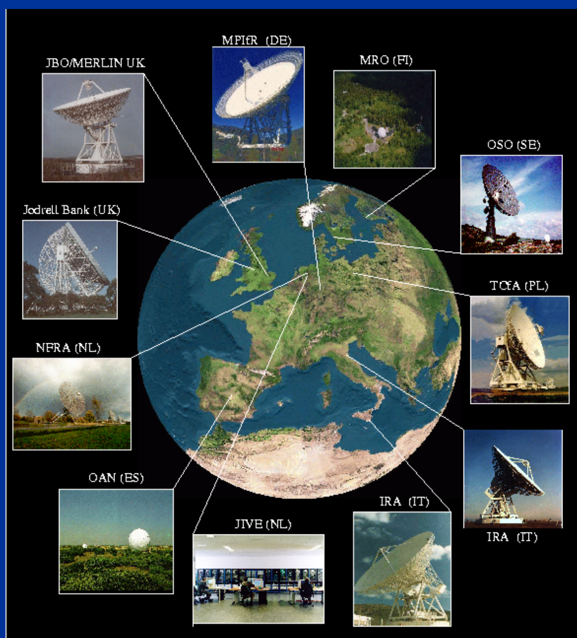
4-12 GHz ALMA amplifiers (Band 9)



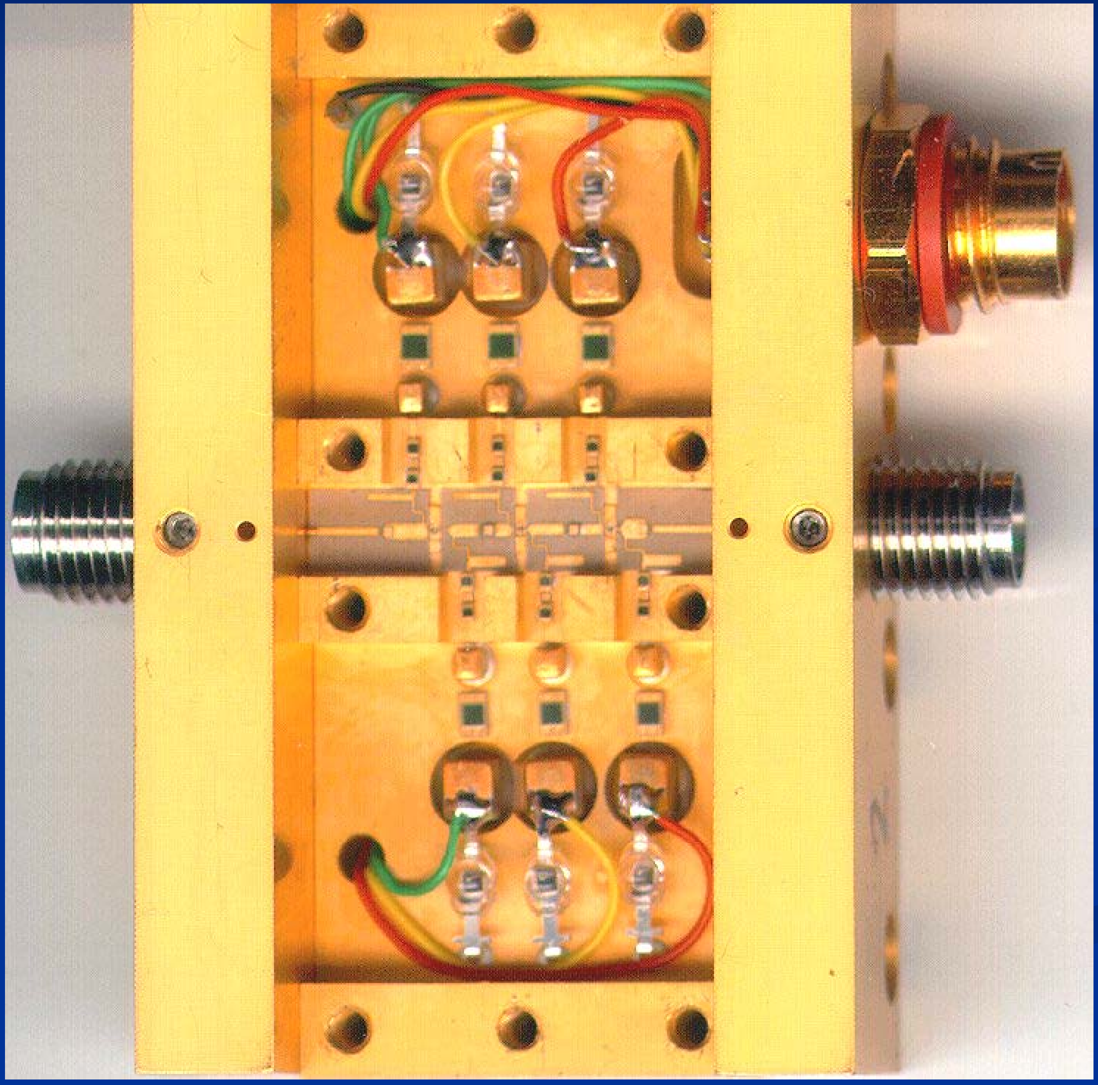
4-8 GHz/4-12 GHz amplifiers



K-BAND (20.5-24.5) VLBI



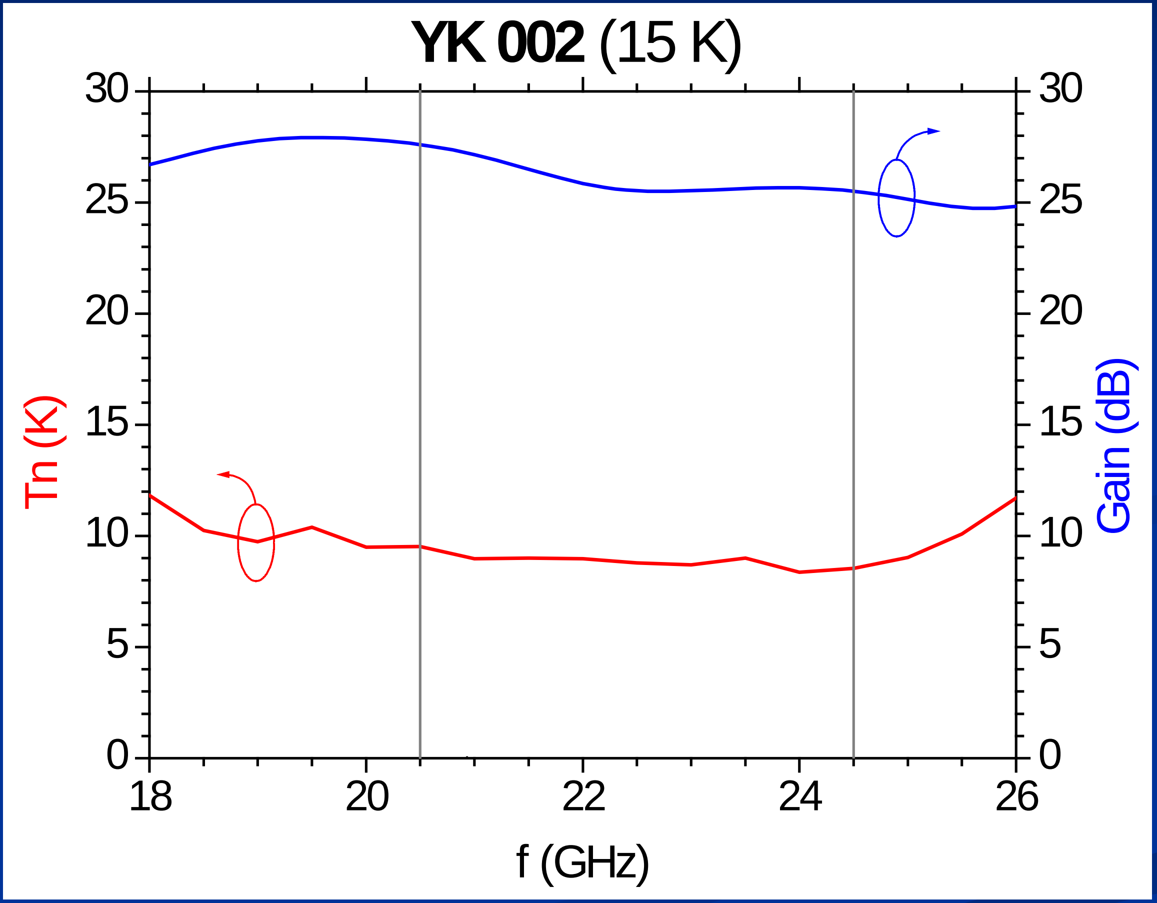
K-BAND (20.5-24.5) VLBI



K-BAND (20.5-24.5) VLBI

CHARACTERISTICS	
External Dimensions	32 × 48 × 13 mm
Total Weight	143 g
Material	Gold plated brass
Operating Temperature	15 K (-258 ºC)
Input/Output connectors	2.92 mm (K)
Bias connector	MICROTECH 7 pin

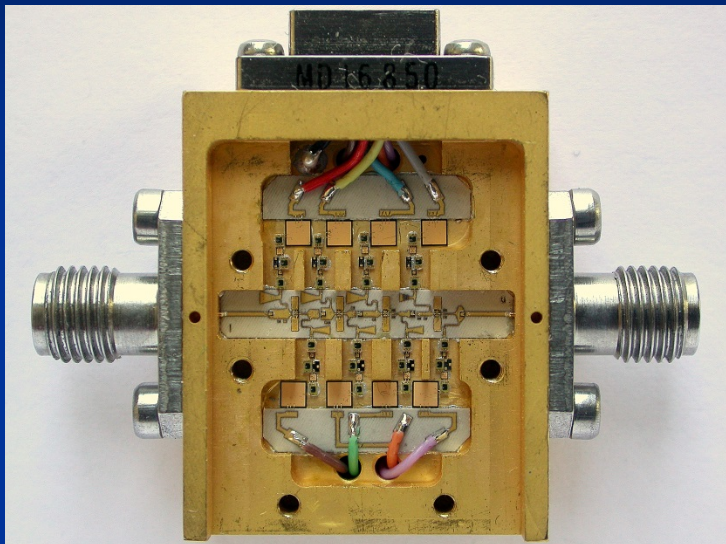
RESULTS 20.5-24.5 GHz @ 15 K (1 unit)	
Average Noise Temperature / NF	8.9 K / 0.130 dB
Gain (gain excursion)	26.1 dB (2)
Input Reflection	< -7.0 dB
Output Reflection	< -8.1 dB
Gain Fluctuations @1 Hz	1.2×10^{-4} $Hz^{-½}$
Power dissipation	26.6 mW

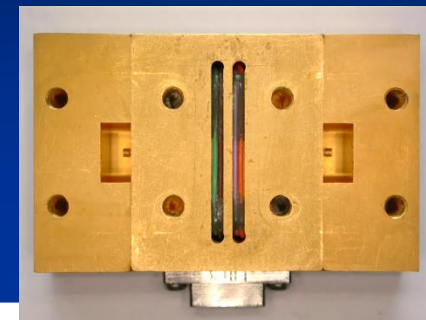


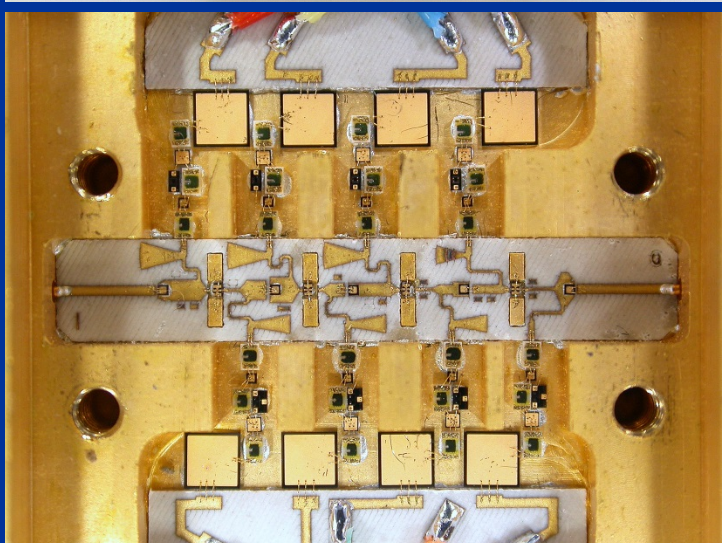
ESOC (ESA)

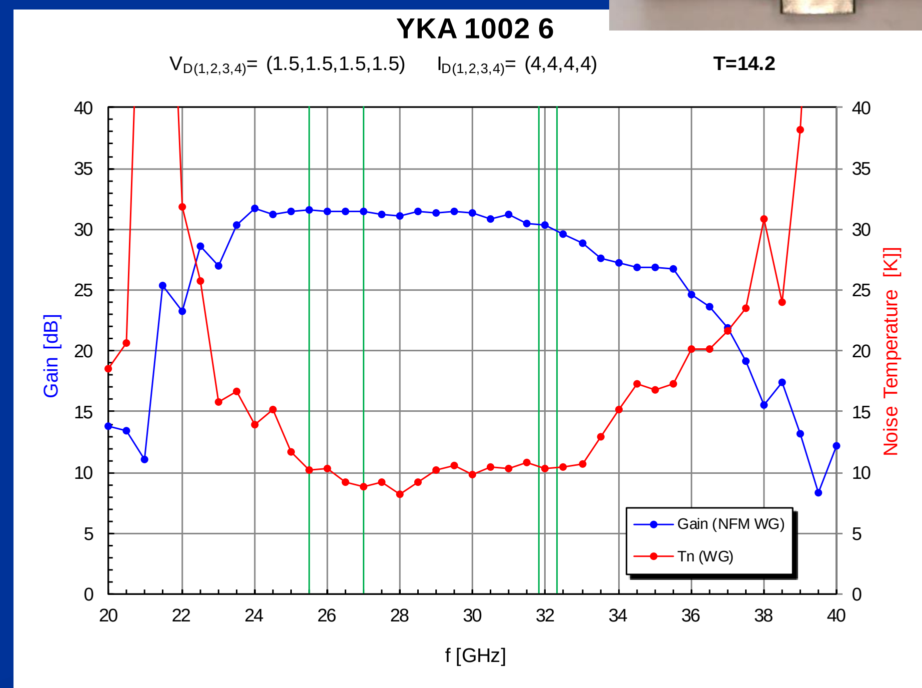
- Deep Space Network
- Needed for missions like: Venus express, Mars express, Rosetta, Herschel, Plank
  - X-Band → (8.1-9.0 GHz)
  - Ka-Band → (25.5- 34 GHz)

Ka band (25-34 GHz) design for ESOC using ETH InP HEMTs





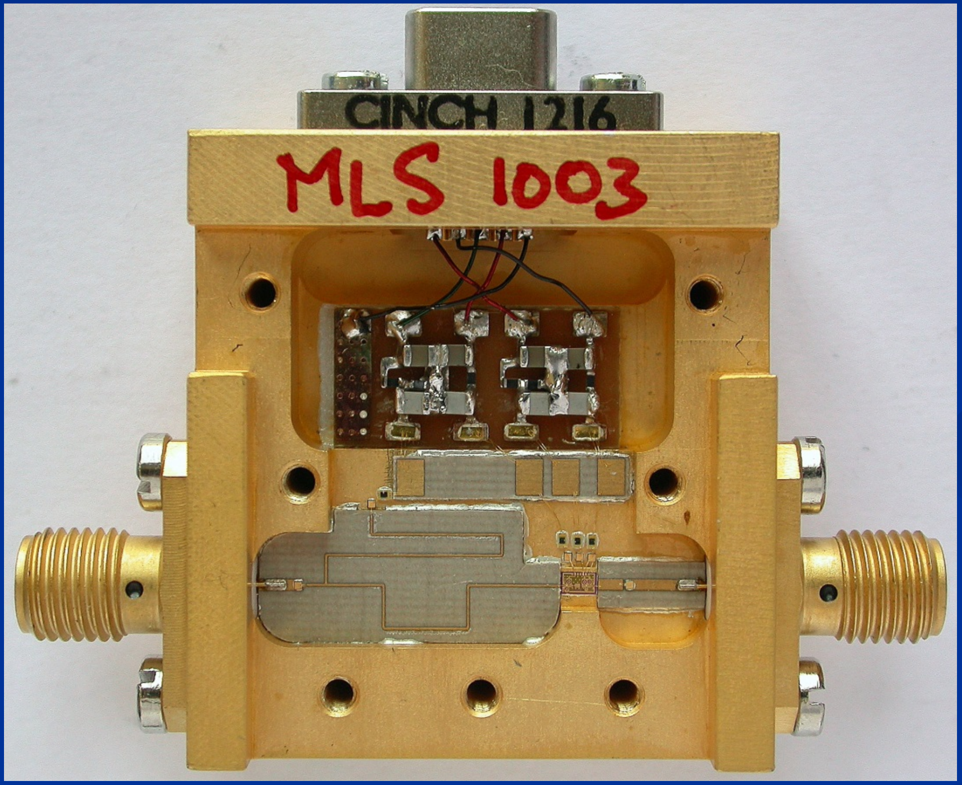




Cryo MMICs developments (IAF-YEBES-UCAN)

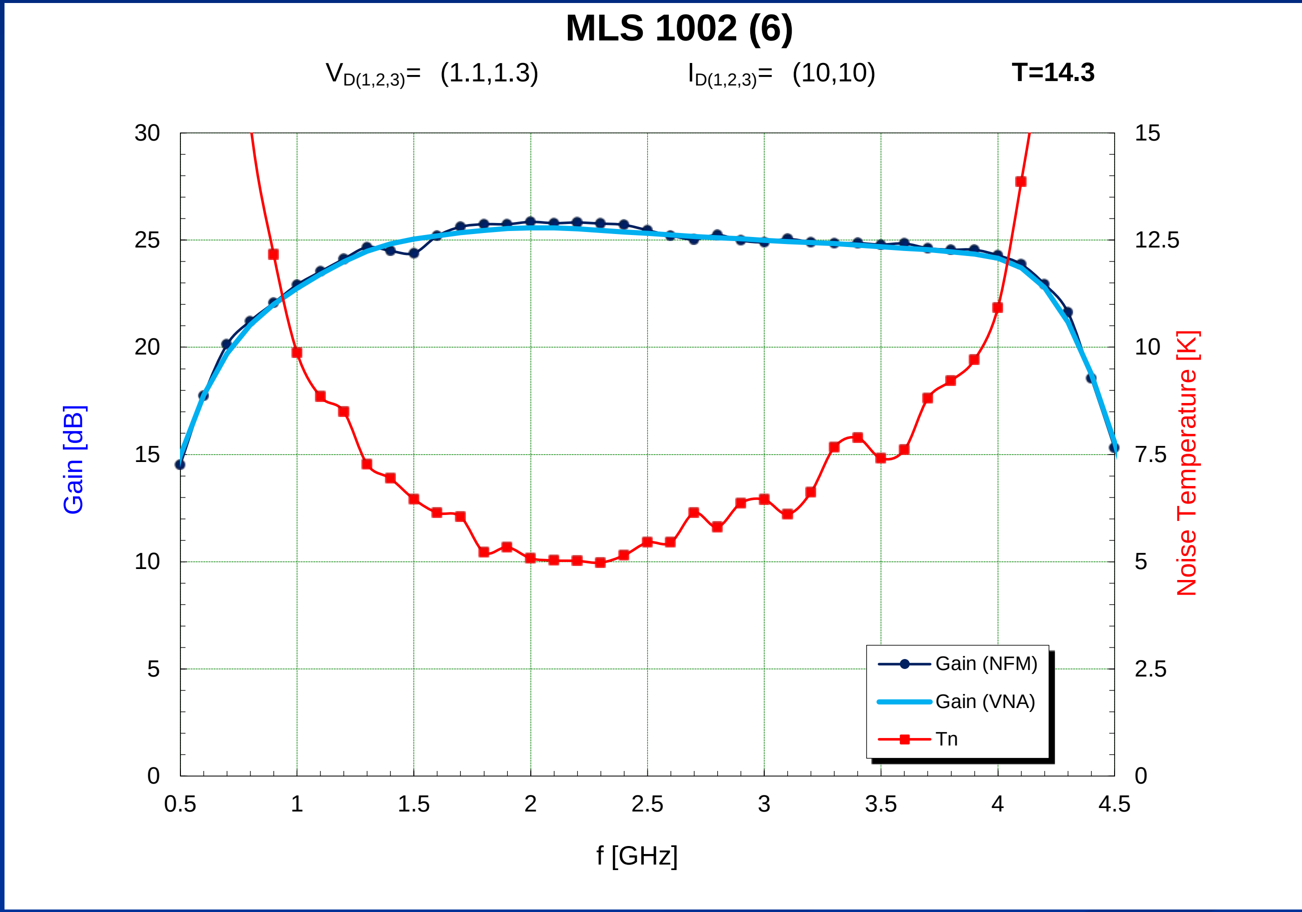
- Cooperation agreements with IAF and UCAN since 2008 recently extended (and funded) until 2015
- Tests of discrete mHEMTs (GaAs)
- Several design iterations of MMICs
    - Different gate sizes (50, 100 nm)
    - Coplanar and microstrip versions
  - 4-12 GHz
  - 25-35 GHz
  - 30-50 GHz
- Wide band LNA (2-14 GHz) can be the next development

1-4 GHz MMICs (MPIfR design)
Coplanar, 100 nm - Run 721



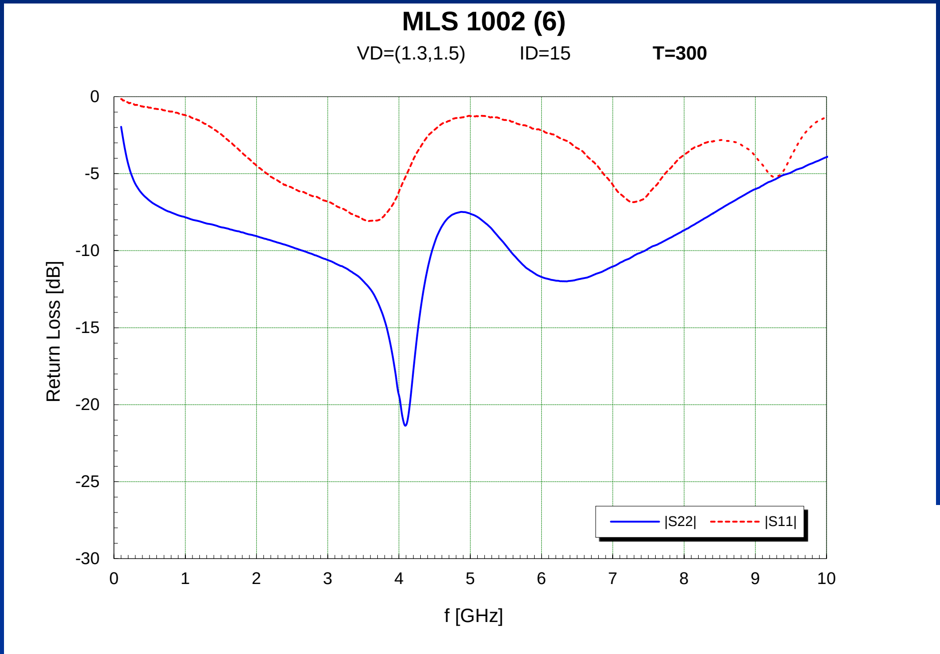
	R721 C12	R721 C38	R721 C39
T_{avg} (K)	**6.9**	**7.3**	**7.3**
T_{min} (K)	5	5.2	5.1
G_{avg} (dB)	24.9	23.4	22.6
ΔG (dB)	2.8	3.6	3
S11 max (dB)	-1.4	-1.6	-1.5
S22 max (dB)	-8.5	-8.5	-8.1

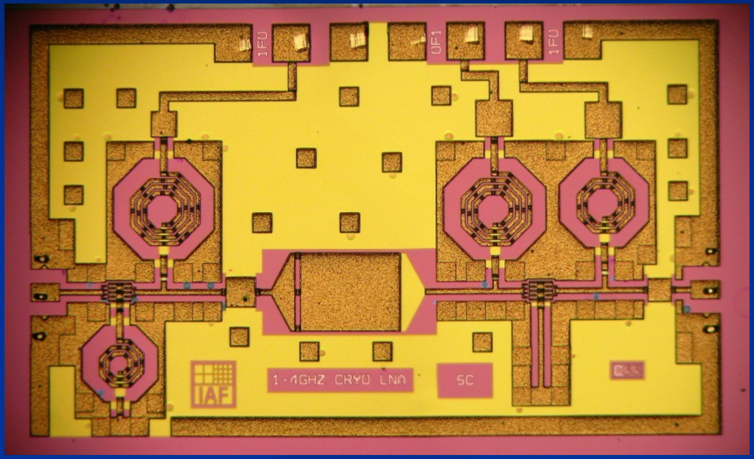
1-4 GHz MMICs (MPIfR design)
Coplanar, 100 nm - Run 721

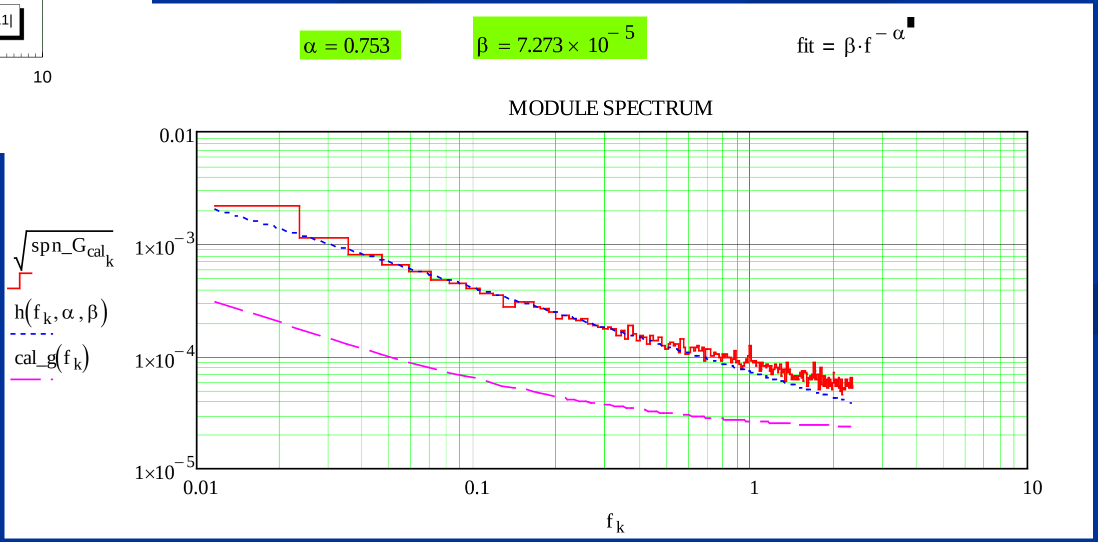


1-4 GHz MMICs (MPIfR design)

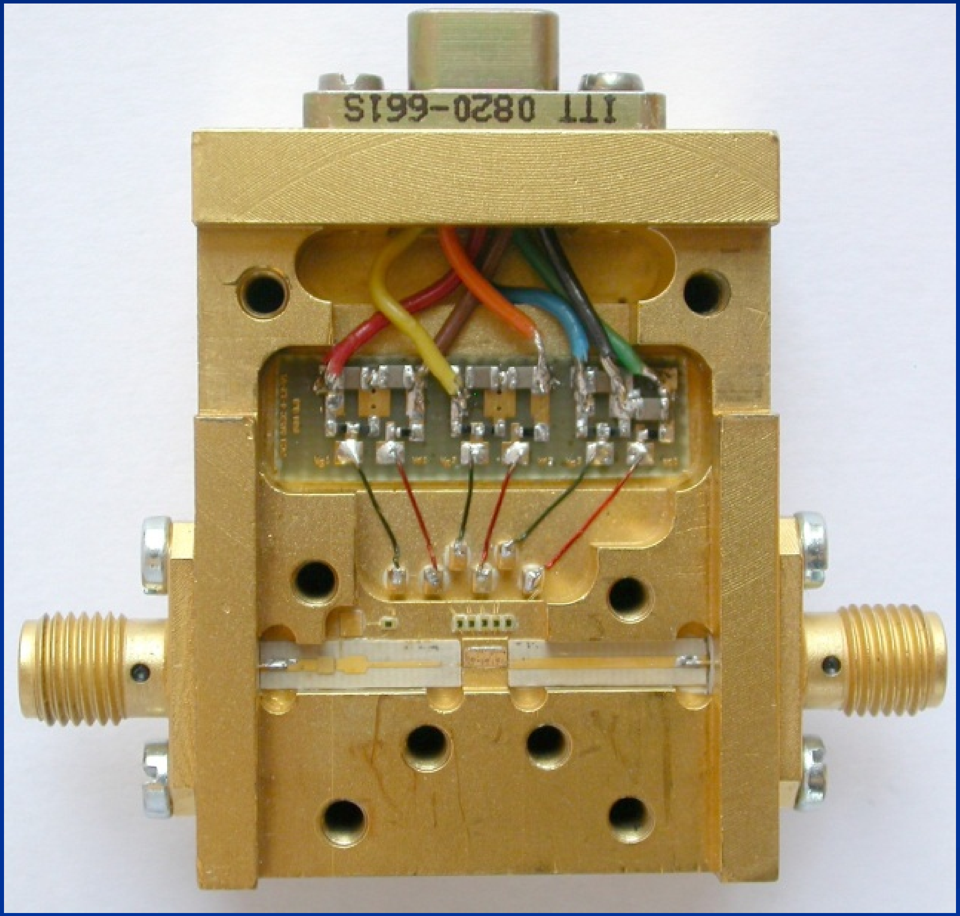
Coplanar, 100 nm - Run 721





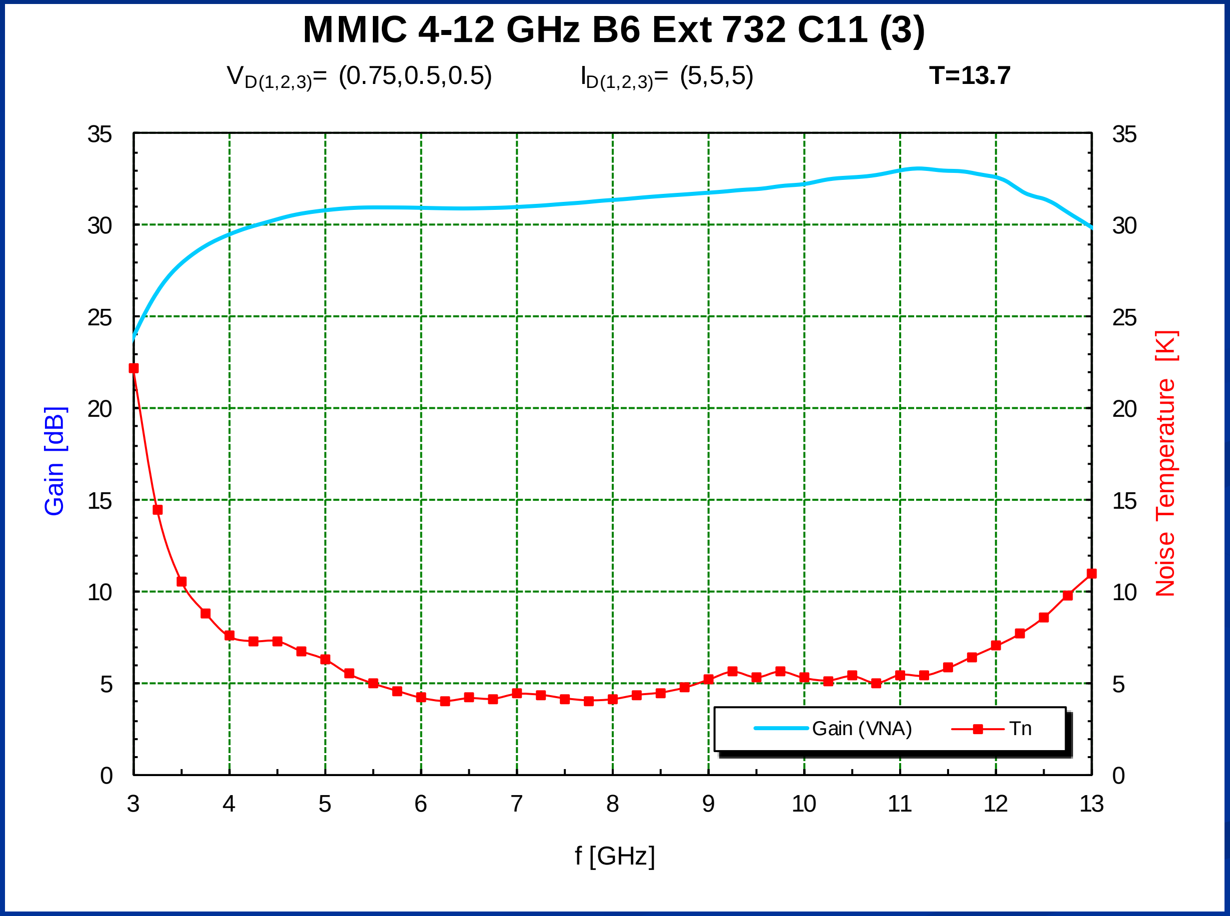


4-12 GHz MMICs
Coplanar, 100 nm - Run 732b

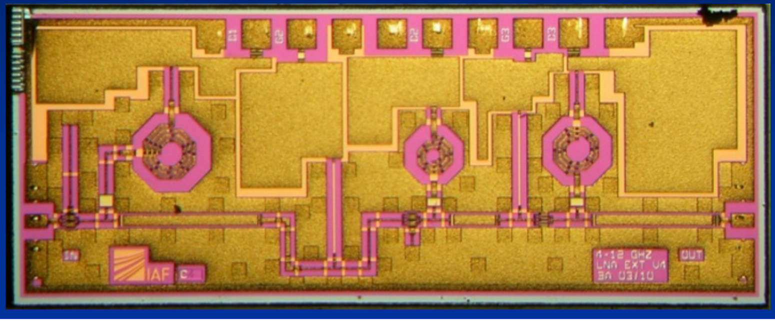


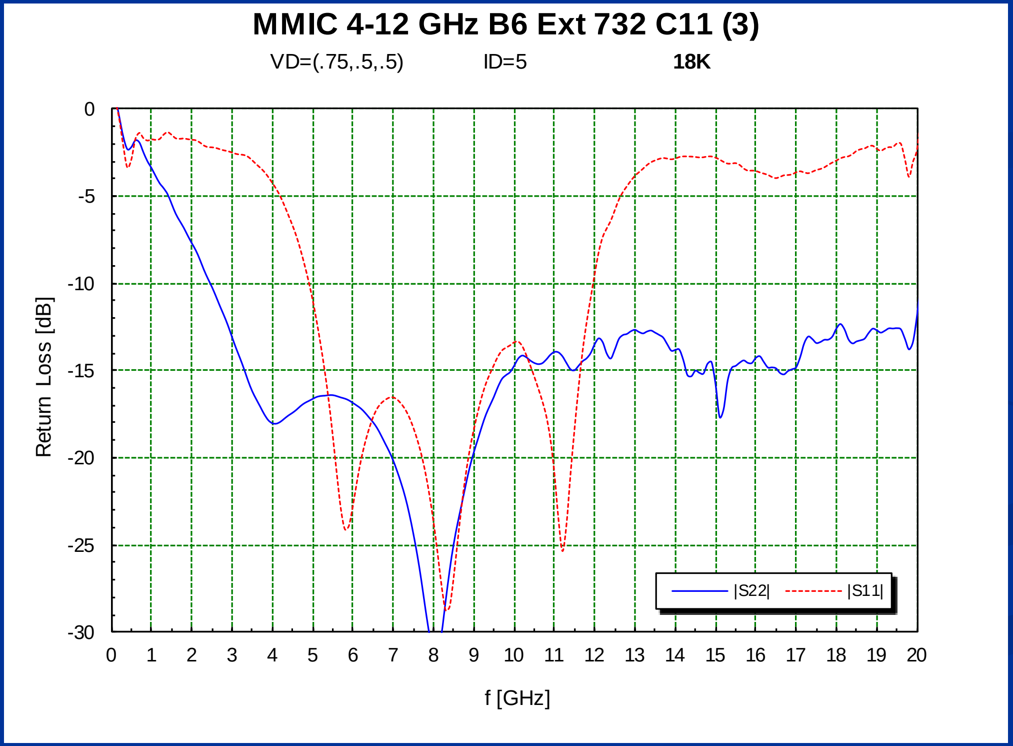
	R732b C11
T_{avg} (K)	**5.3**
T_{min} (K)	4.1
G_{avg} (dB)	31.5
ΔG (dB)	3.6
S11 max (dB)	-4.2
S22 max (dB)	-13.5

4-12 GHz MMICs
Coplanar, 100 nm - Run 732b



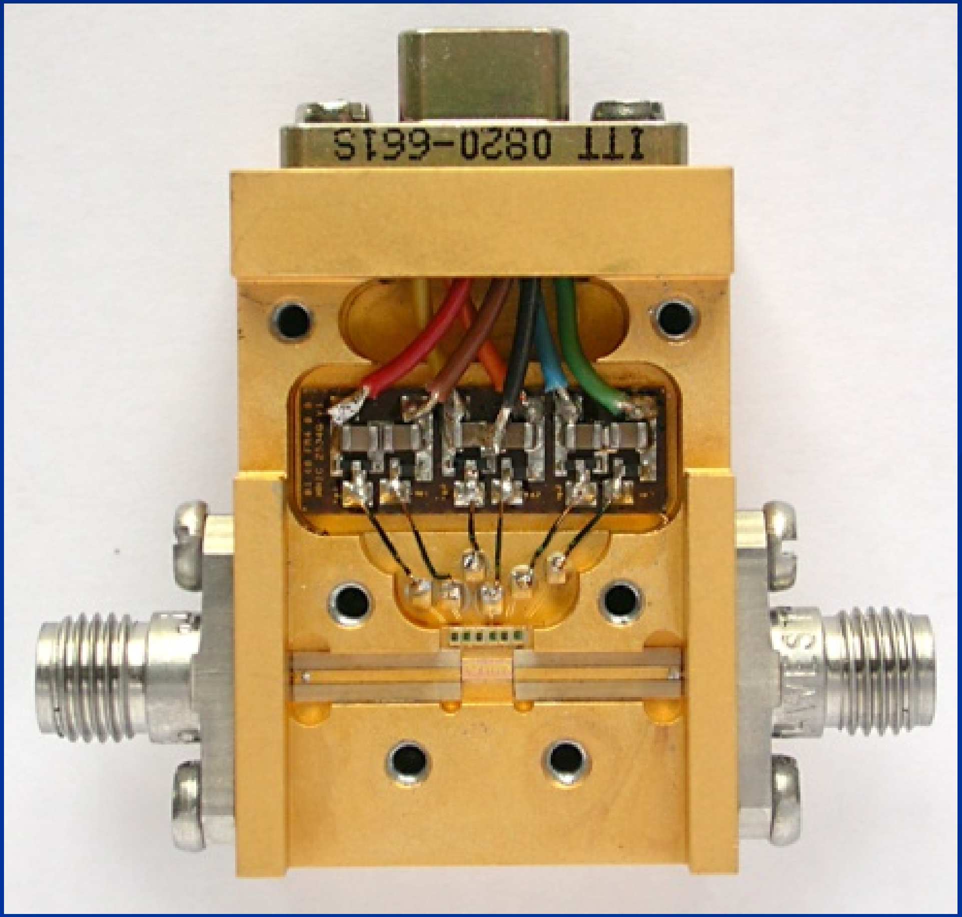
4-12 GHz MMICs
Coplanar, 100 nm - Run 732b





Ka band MMICs

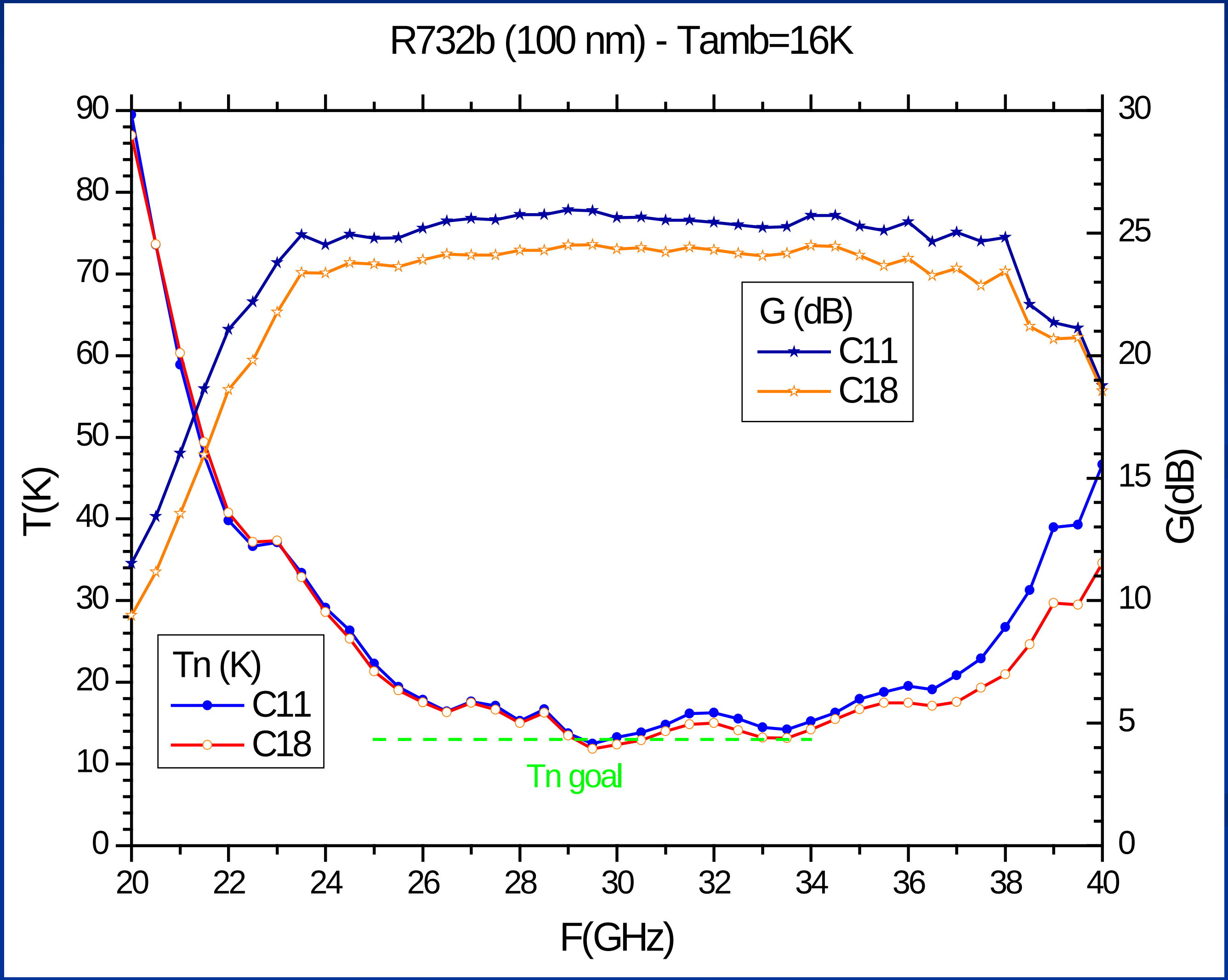
Coplanar, 100 nm - Run 732b



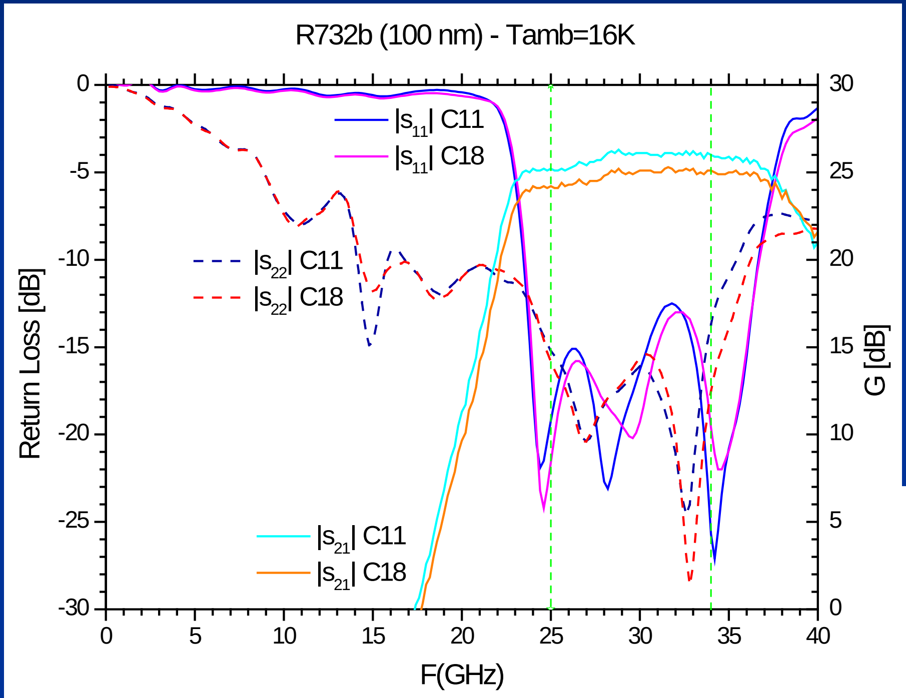
	R732b C11	R732b C18
T_{avg} (K)	**15.9**	**15.2**
T_{min} (K)	12.5	11.9
G_{avg} (dB)	25.5	24.2
ΔG (dB)	1.2	0.9
S11 max (dB)	-12.5	-13.0
S22 max (dB)	-13.7	-12.7

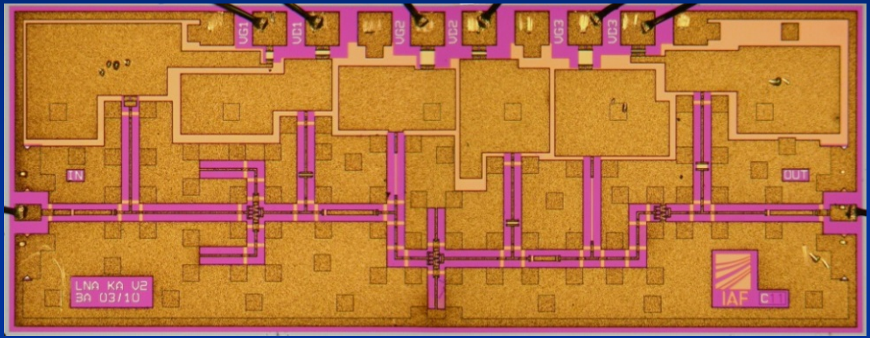
Ka band MMICs

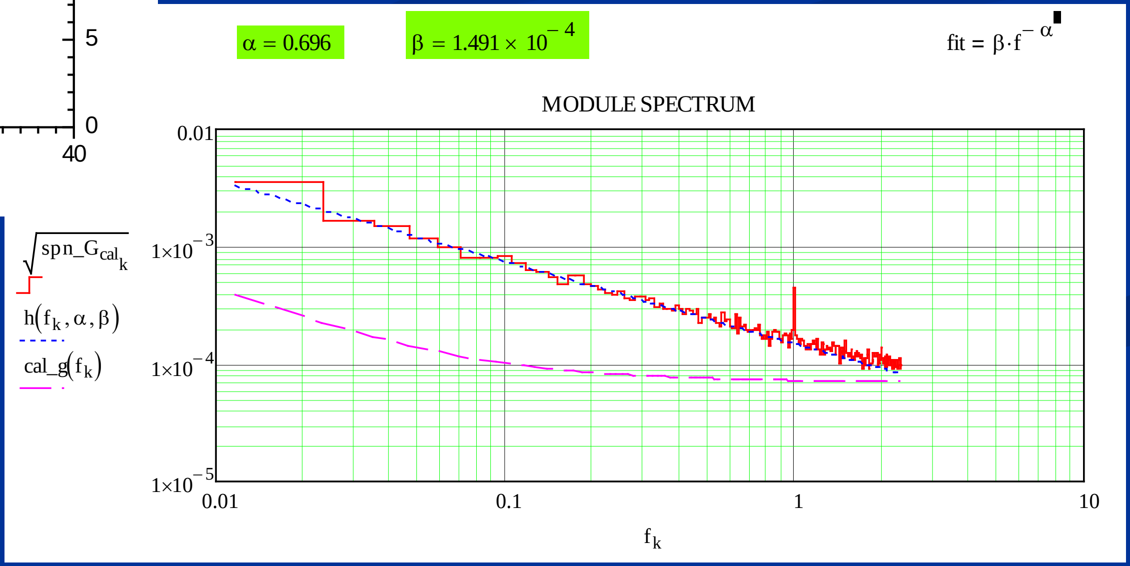
Coplanar, 100 nm - Run 732b



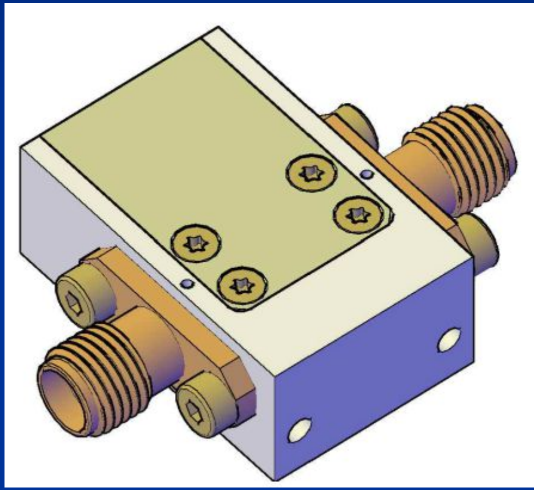
Ka band MMICs Coplanar, 100 nm - Run 732b

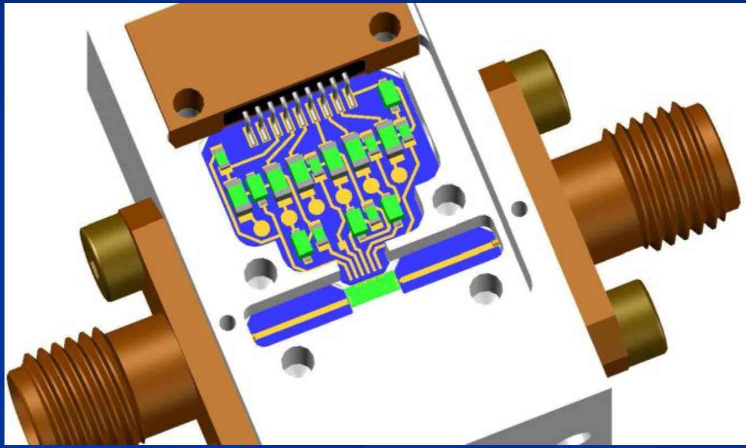


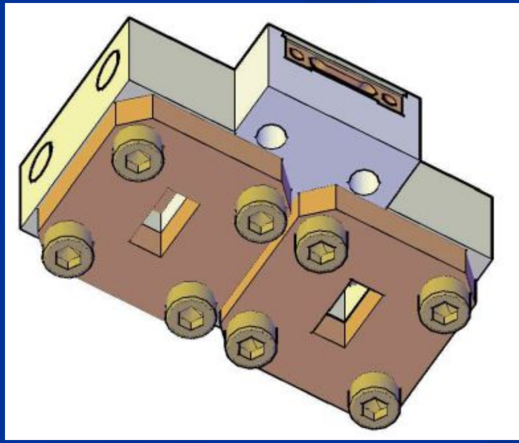




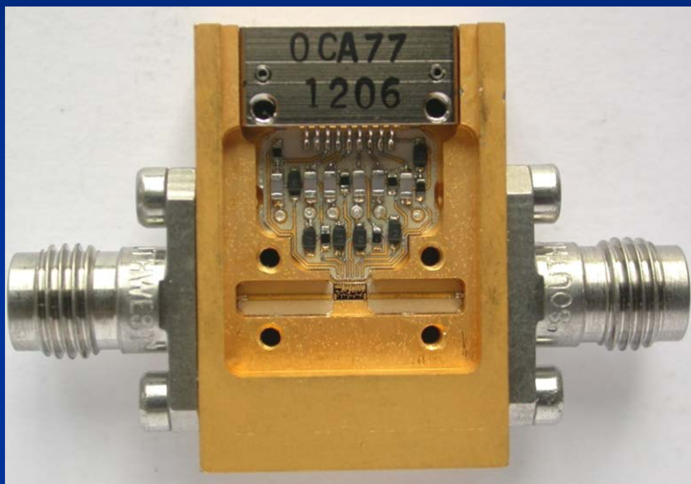
MMIC Ka Band (coax & WG)

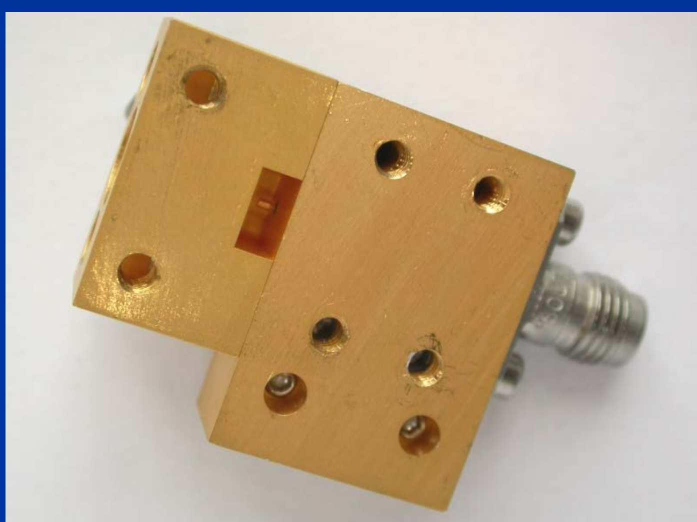


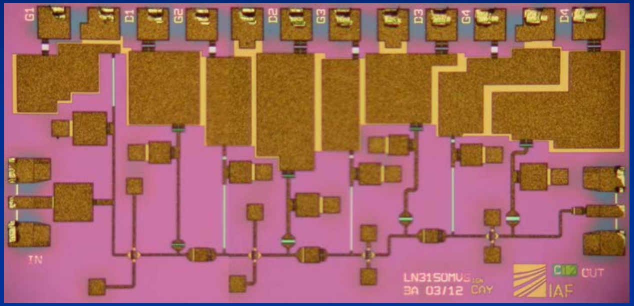




Q band MMICs
Microstrip, 50 nm - Run 745a





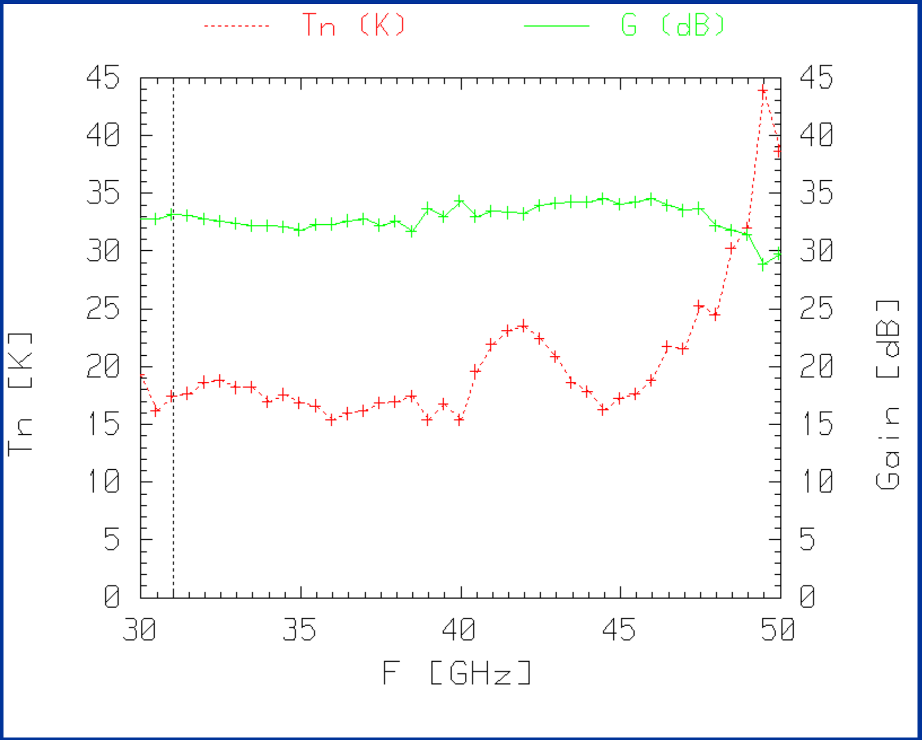


T=15K	YMQ 2002 (C16)	
	Coaxial input	WG input
T_{avg} (K)	**20.5**	**16.8**
T_{min} (K)	15.4	12.8
G_{avg} (dB)	32.8	33.4
ΔG (dB)	5.7	4.8
S11 max (dB)[1]	-5.8	-5.4
S22 max (dB)[1]	-11.3	-11.2

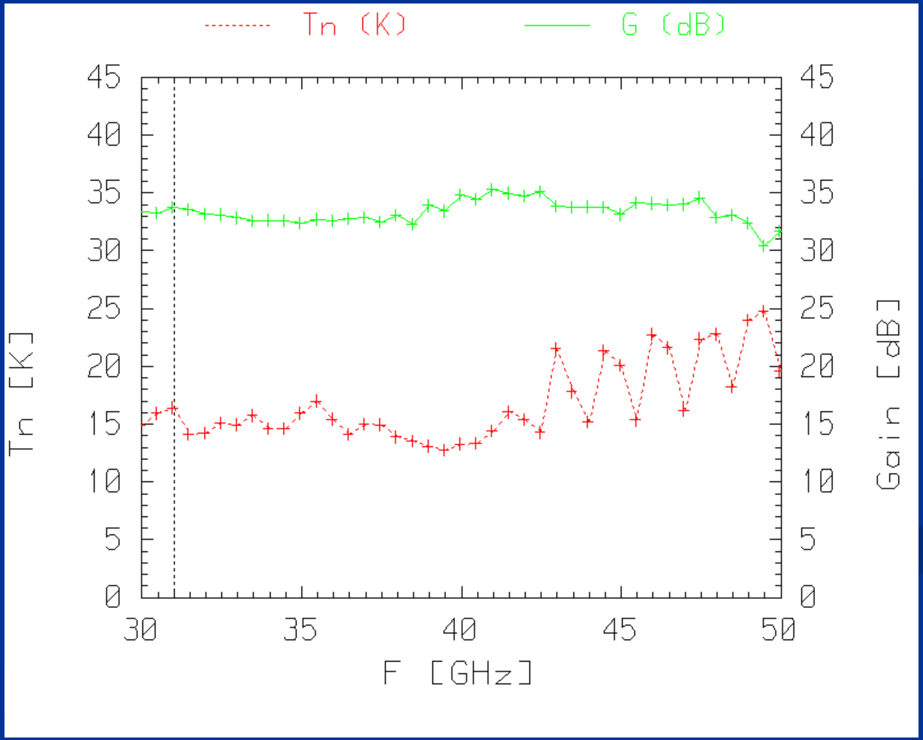
Q band MMICs

Microstrip, 50 nm - Run 745a

Coaxial Input



WG Input



Conclusions:

- Long experience in developments cryo LNAs
- Participation in large Radio Astronomy projects (IRAM, Herschel, ALMA…)
- Demonstrated experience in high reliability and QA, including Space Qualification
- Industrial production of cryogenic LNAs under tight budgets (with TTI)
- Ongoing cooperation agreements for Cryogenic MMICs developments (involving IAF & UC)
- Plans to develop ultra wide band cryo LNAs (VLBI 2010, SKA?)

Cryogenic cavity detector for a large-scale cold dark-matter axion search

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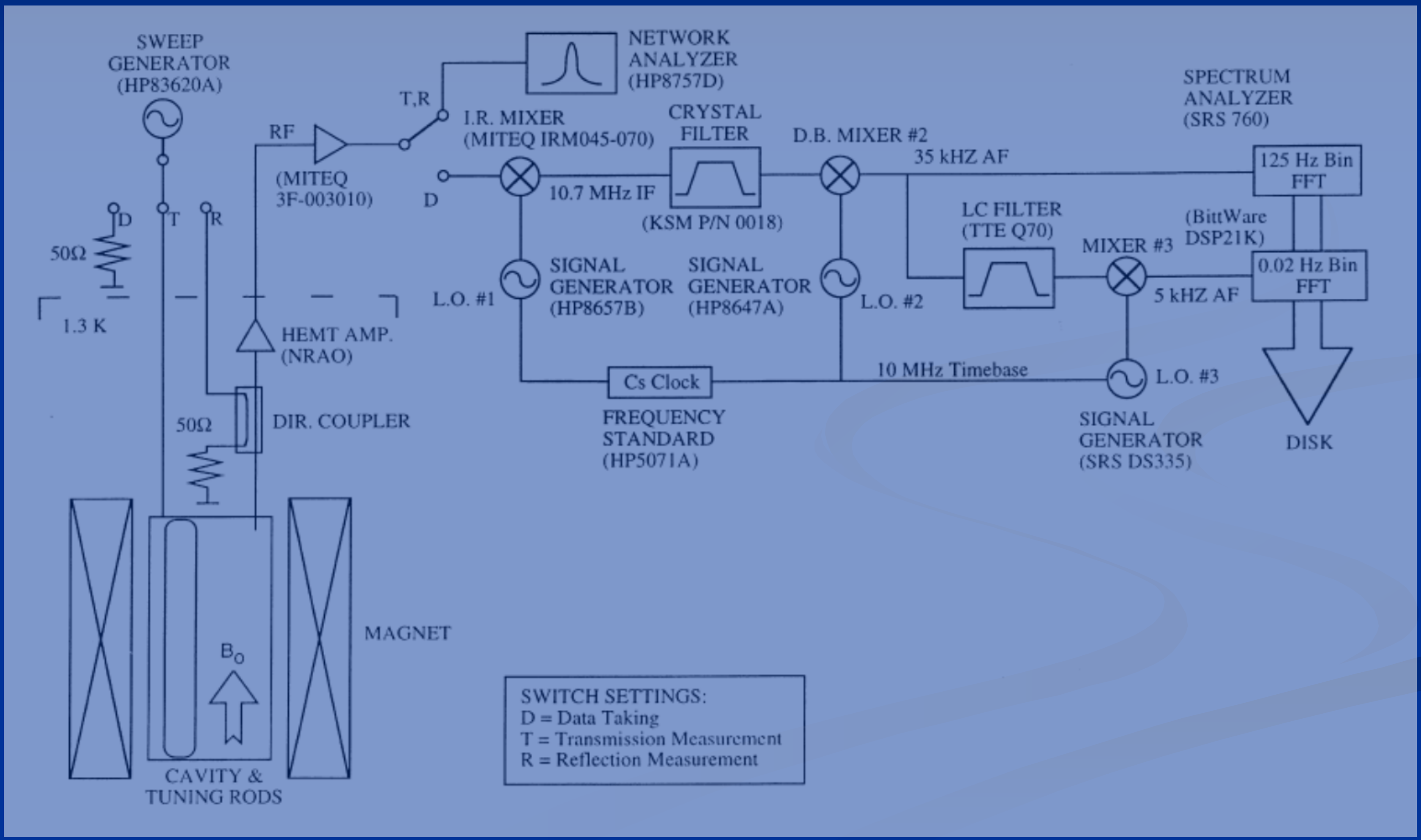

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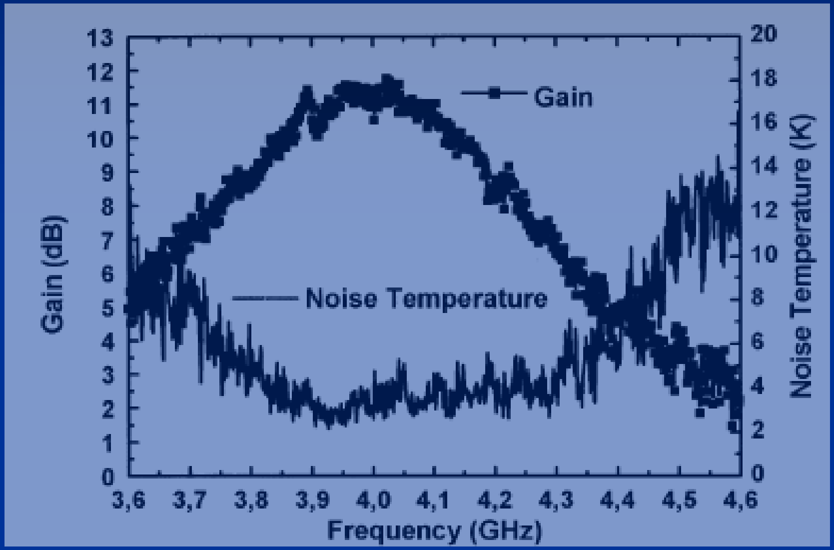
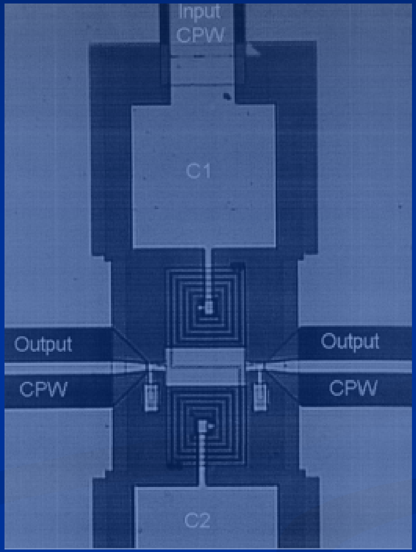
Dynamic Characteristics of S-Band DC SQUID Amplifier

Georgy V. Prokopenko, Sergey V. Shitov, Irina L. Lapitskaya, Valery P. Koshelets, and Jesper Mygind





IV. Conclusion

The study of the dynamic characteristics of SQA's at 4 GHz has demonstrated that this device can offer a low-noise operation providing $T_N \approx (1\text{–}2)$ K that is about state-of-the-art for coolable HEMT-amplifiers of this frequency range. The saturating signal temperature was found at the level of (100–150) K that, in combination with a bandwidth of about 500 MHz, makes SQA a promising intermediate frequency amplifier, which can be integrated with a SIS mixer or similar superconducting device, e.g., within the fully Superconducting Integrated Receiver.

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Noise performance of lumped element direct current superconducting quantum interference device amplifiers in the 4–8 GHz range

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We report on the noise of a lumped element direct current superconducting quantum interference device amplifier. We show that the noise temperature in the 4–8 GHz range over ranges of tens of megahertz is below 1 K (three photons of added noise), characterize the overall behavior of the

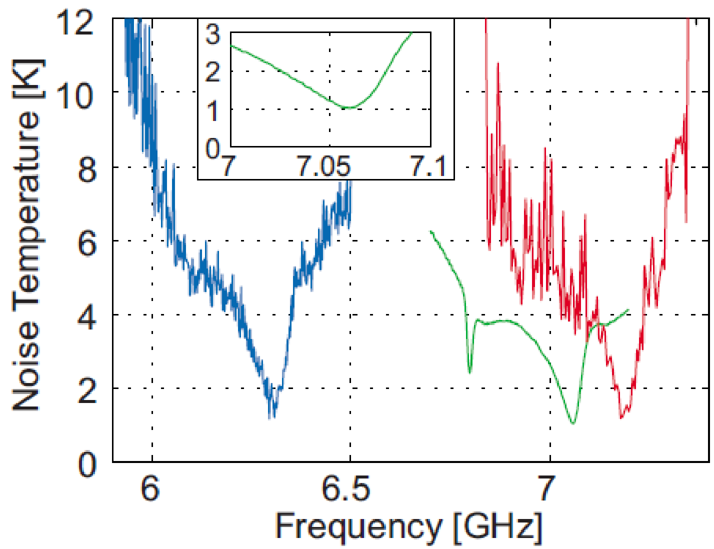

FIG. 2. (Color online) System noise temperature as a function of frequency at a good bias point for three amplifiers with different lengths of input resonator. The left—most line is a 2 mm long input resonator, the middle line is 1.6 mm, and the right—most line is 1.4 mm. Inset shows zoomed in noise temperature as a function of frequency around the optimal noise point for the 1.6 mm amplifier. These data were taken using the y-factor method for the 1.6 mm device and the SNTJ method for the other devices, with the configuration of double circulators, directional coupler, and transfer switch shown in Fig. 1.