UFYS2010: Radio astronomy instrumentation and interferometry

Kaj Wiik

Tuorla Observatory

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Some of the figures are from Wilson, Rohlfs, Hüttemeister: 'Tools of Radio astronomy'

Outline

Recap from lecture 3

Receiver noise temperature

How to improve noise temperature?

Typical radio astronomy receivers

What is a receiver made of?

Mixers

Amplifiers

Linearity and intermodulation

Recap I

For aperture antennas (e.g. paraboloid- and horn antennas) the effective aperture can be calculated from the physical aperture and aperture efficiency:

$$A_e = \eta_e A \quad [\mathrm{m}^2] \tag{1}$$

Efficiency is a product of surface, blockage, spillover, illumination etc. efficiencies.

$$S = \frac{2kT_a}{A_e} \left[\frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{Hz}}\right] \tag{2}$$

where T_a is the *antenna temperature*, i.e. the increase of the temperature of a ‘resistor’ due to the source flux density.

Recap II

A convenient measure of antenna performance is the DPFU (Degrees Per Flux Unit) figure:

$$DPFU = \frac{A_e}{2k} 10^{-26} \left[\frac{\mathrm{K}}{\mathrm{J}y}\right] \tag{3}$$

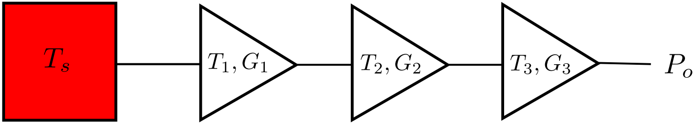
The minimum detectable noise difference *for ideal radiometer* is

$$\Delta T_{\mathrm{min}} = \frac{T_{\mathrm{sys}}}{\sqrt{\Delta\nu\tau}}. \tag{4}$$

Receivers

- Bolometer i.e. thermometer
- Direct detecting receiver
  - Amplifier and detector, no frequency conversion
- Heterodyne receiver
  - Frequency conversion and amplifier optionally before and after the mixer

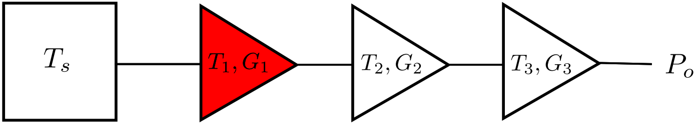
Equivalent noise of amplifier cascade



Assume that noise sources are always in input:

$$P_o = kB(T_s G_1 G_2 G_3 + ...)$$

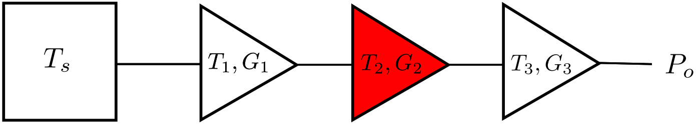
Equivalent noise of amplifier cascade



Assume that noise sources are always in input:

$$P_o = kB(T_sG_1G_2G_3 + T_1G_1G_2G_3 + ...)$$

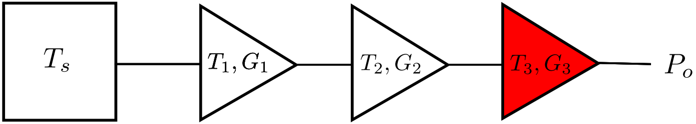
Equivalent noise of amplifier cascade



Assume that noise sources are always in input:

$$P_o = kB(T_sG_1G_2G_3 + T_1G_1G_2G_3 + T_2G_2G_3 + ...)$$

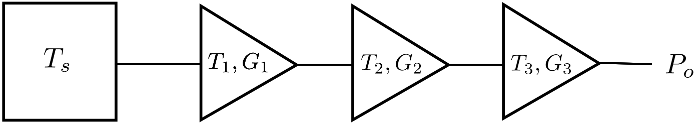
Equivalent noise of amplifier cascade



Assume that noise sources are always in input:

$$P_o = kB(T_sG_1G_2G_3 + T_1G_1G_2G_3 + T_2G_2G_3 + T_3G_3)$$

Equivalent noise of amplifier cascade



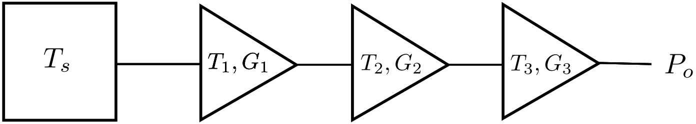
Assume that noise sources are always in input:

$$P_o = kB(T_sG_1G_2G_3 + T_1G_1G_2G_3 + T_2G_2G_3 + T_3G_3)$$

or

$$P_o = G_1G_2G_3kB(T_s + (T_1 + T_2/G_1 + T_3/(G_1G_2)))$$

Equivalent noise of amplifier cascade



Assume that noise sources are always in input:

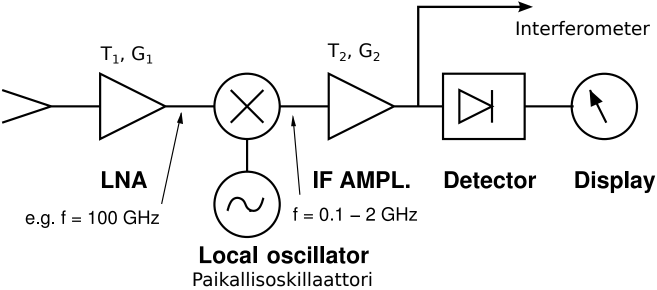
$$P_o = kB(T_s G_1 G_2 G_3 + T_1 G_1 G_2 G_3 + T_2 G_2 G_3 + T_3 G_3)$$

or

$$P_o = G_1 G_2 G_3 kB(T_s + \underbrace{(T_1 + T_2/G_1 + T_3/(G_1 G_2))}_{\text{Equivalent noise of the cascade}})$$

How to improve receiver noise temperature?

A typical heterodyne receiver:

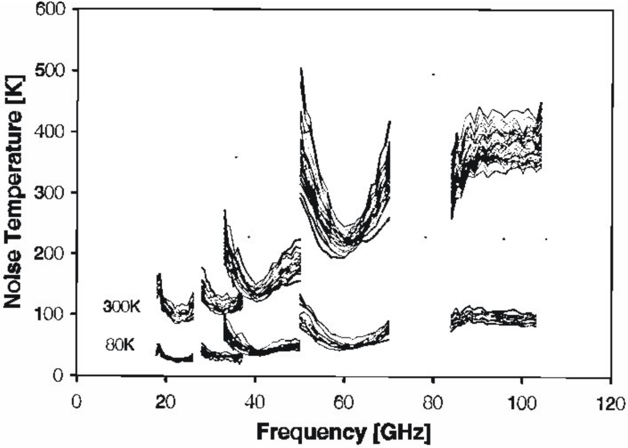


The system noise temperature of this receiver is

$$T_{\mathrm{sys}} = T_{\mathrm{atm}} + T_{\mathrm{src}} + T_{\mathrm{cmb}} + T_{\mathrm{tel}} + T_1 + T_2/G_1 + T_3/(G_1 G_2)\ldots \quad (5)$$

Therefore the first components before and including the first amplifier are decisive and they are *usually cooled* down to 4 - 15 K.

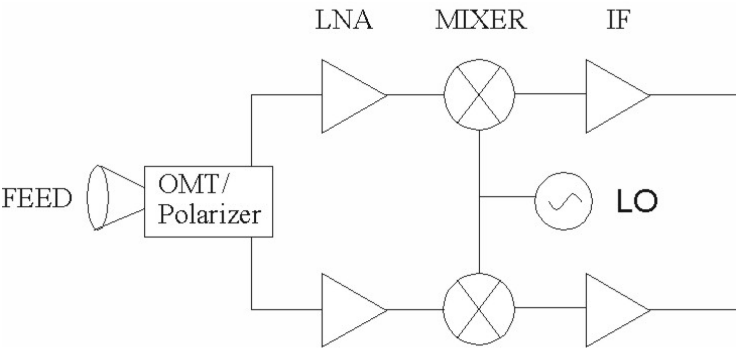
HFET Noise Temperature



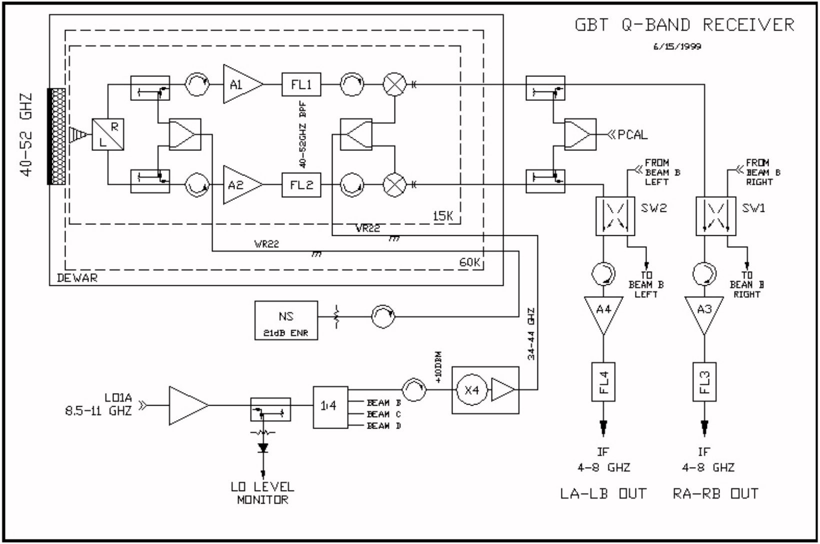
Data courtesy M. Pospieszalski of NRAO Central Development Laboratory

Credit: Roger Norrod, NRAO

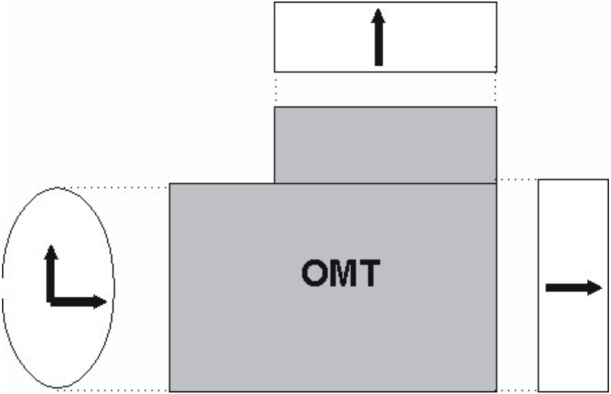
Typical Hetrodyne Receiver



Credit: Roger Norrod, NRAO


GBT Q-BAND RECEIVER
6/15/1999
40-52 GHZ
R
L
A1
A2
FL1
FL2
40-52GHZ BPF
15K
60K
DEWAR
WR22
WR22
PCAL
FROM BEAM B LEFT
FROM BEAM B RIGHT
SW2
SW1
TO BEAM B LEFT
TO BEAM B RIGHT
A4
A3
FL4
FL3
IF 4-8 GHZ
IF 4-8 GHZ
LA-LB OUT
RA-RB OUT
NS
21dB ENR
34-44 GHZ
+10DBM
X4
1:4
BEAM B
BEAM C
BEAM D
LO1A 8.5-11 GHZ
LO LEVEL MONITOR

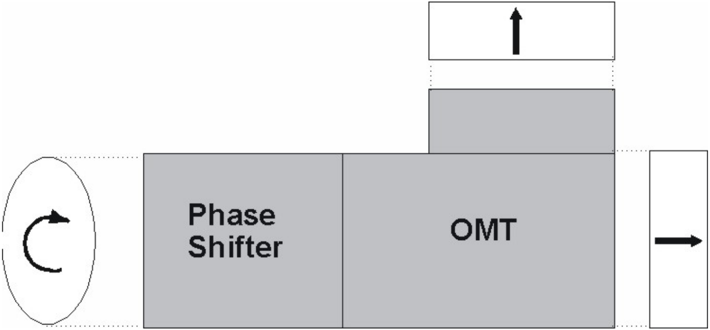
Linear Polarization



Orthomode Transducer

Credit: Roger Norrod, NRAO

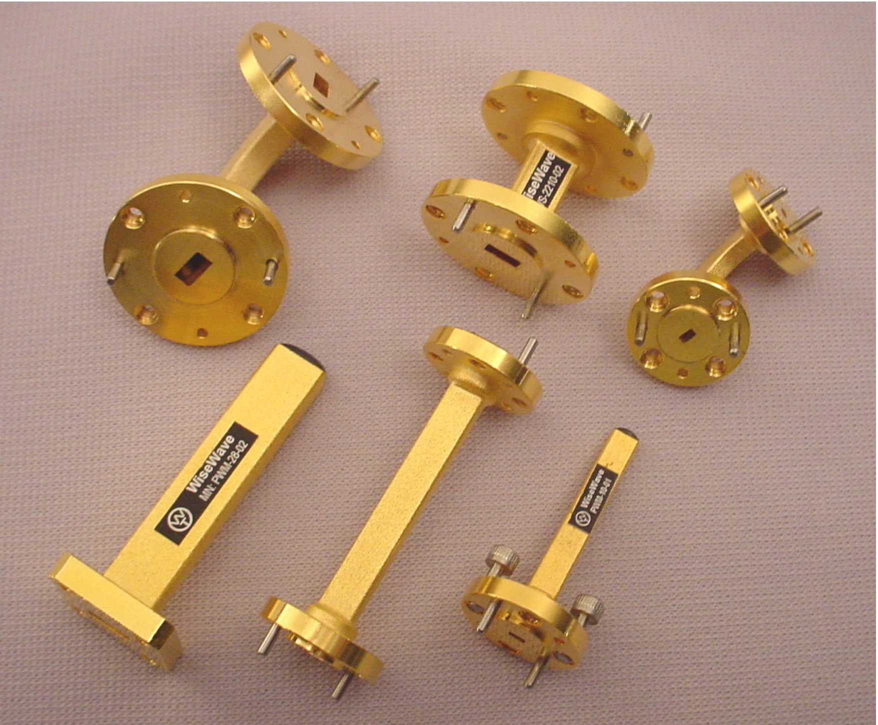
Circular Polarization

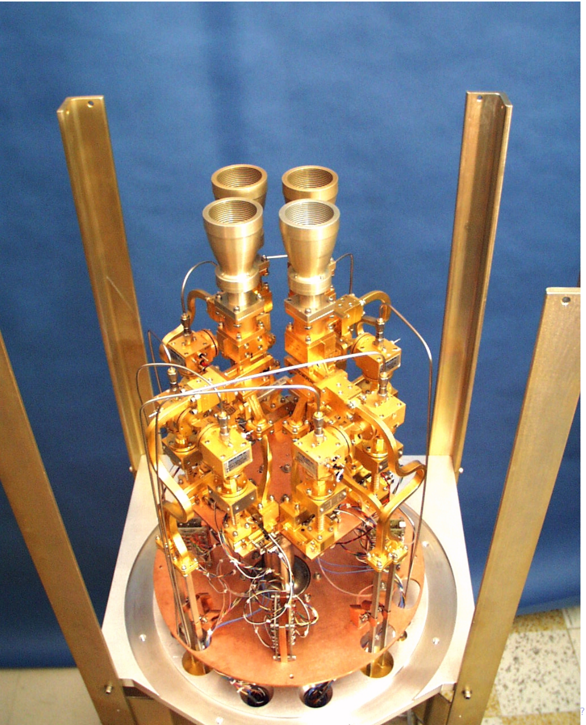


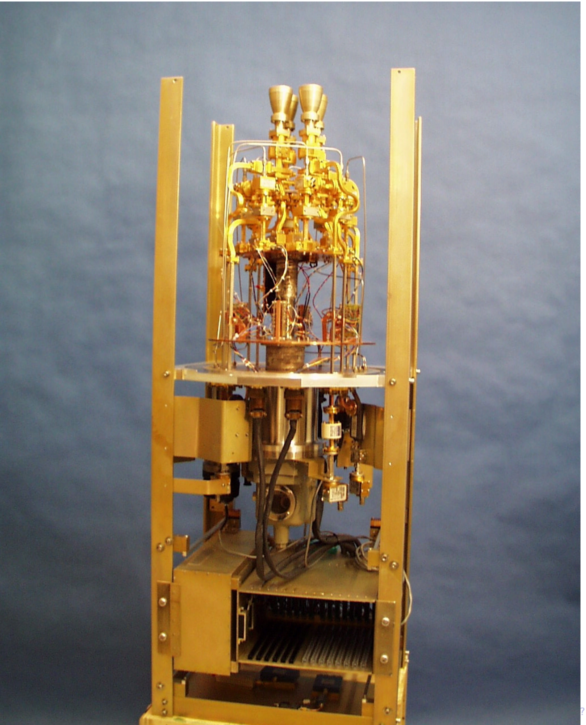
Credit: Roger Norrod, NRAO

A Variety of OMTs

Credit: Roger Norrod, NRAO


WiseWave
MN: PWM-28-02
iseWave
S-2210-02
WiseWave
PWM-10-01





How do mixers work?

Mixing (or down/upconverting in frequency) is accomplished using a nonlinear device that acts as a voltage multiplier. Schottky diodes and superconducting devices (SIS) are most common in radio astronomy.

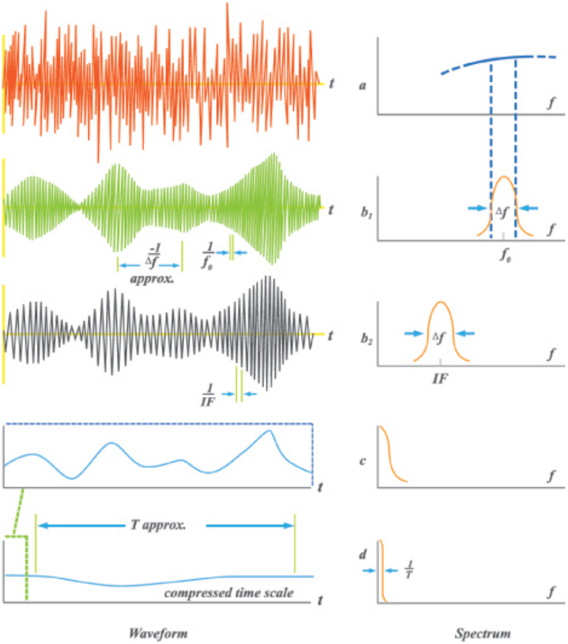
Mixing is based on the identity

$$\sin\theta\sin\varphi = \frac{1}{2}\cos(\theta-\varphi) - \frac{1}{2}\cos(\theta+\varphi) \tag{6}$$

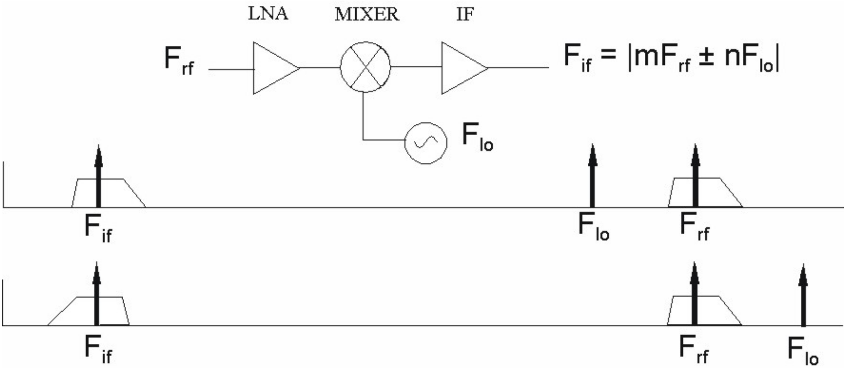
Multiplying two sinusoids results

$$\sin(2\pi\nu_1 t)\sin(2\pi\nu_2 t) = \frac{1}{2}\cos[2\pi(\nu_1-\nu_2)t] - \frac{1}{2}\cos[2\pi(\nu_1+\nu_2)t], \tag{7}$$

i.e. we get *sum and difference* frequencies. Usually in radio astronomy we need the difference, so the higher sum frequency is filtered out.


a
t
f
b₁
Δf
f₀
-1/Δf
approx.
1/f₀
b₂
Δf
IF
1/IF
c
f
T approx.
d
1/T
compressed time scale
Waveform
Spectrum

Frequency Conversion



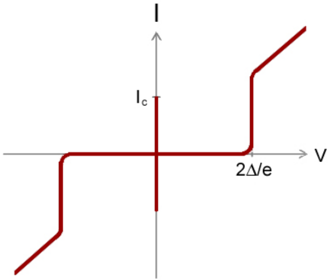
Credit: Roger Norrod, NRAO

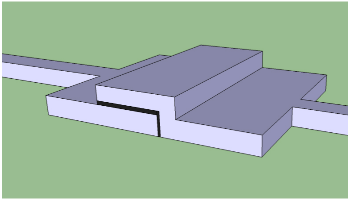
Mixer types: SIS & Schottky

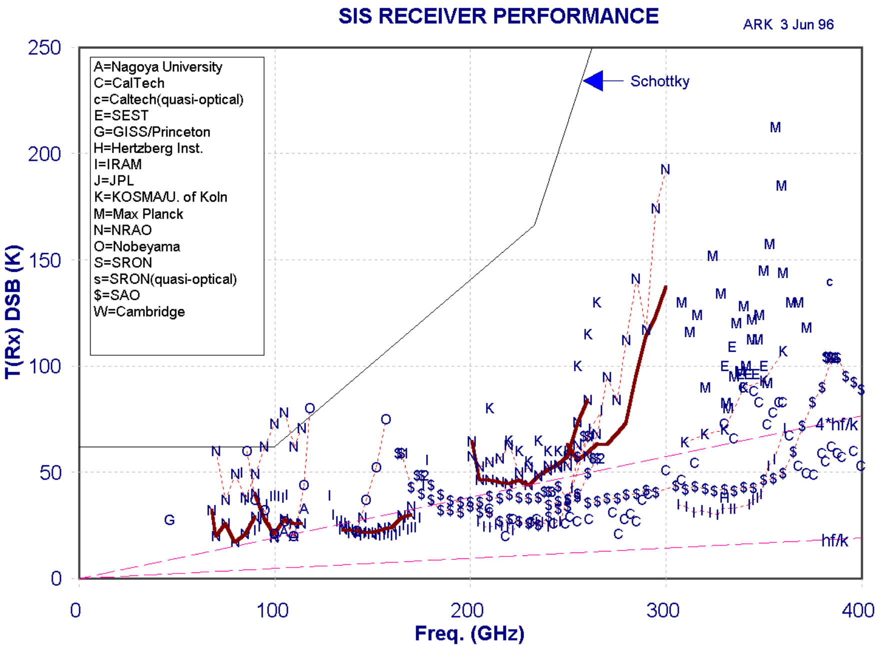
The first mm-mixers were based on *Schottky diode* junction. Schottky diodes are fast but otherwise quite normal diodes.

SIS (Superconductor Insulator Superconductor) tunneling junction is commonly used in mm- and submm-receivers without a preamplifier.

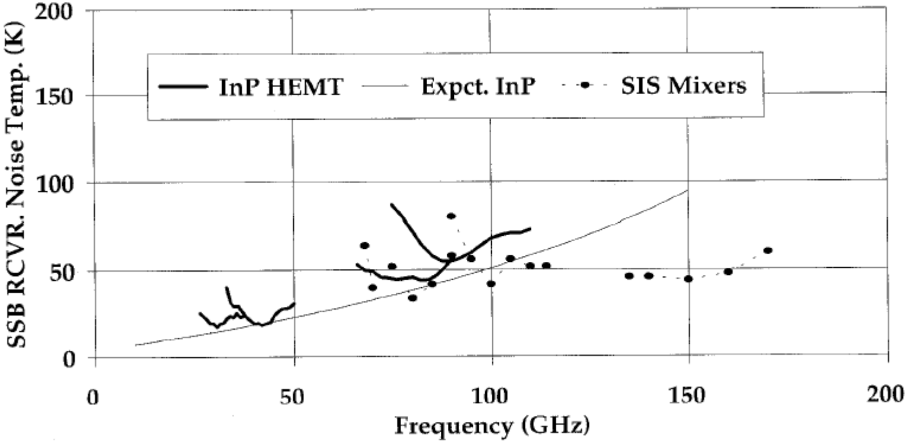
The characteristic voltage-current function is very nonlinear. If the junction is dc biased at a voltage just below the gap voltage ($V = 2\Delta/e$), the junction acts as a very sensitive mixer.



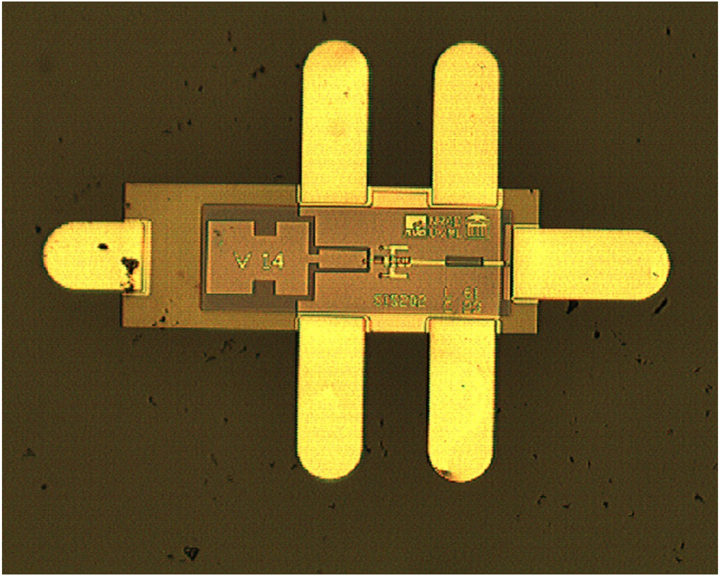



SIS RECEIVER PERFORMANCE
ARK 3 Jun 96
A=Nagoya University
C=CalTech
c=Caltech(quasi-optical)
E=SEST
G=GISS/Princeton
H=Hertzberg Inst.
I=IRAM
J=JPL
K=KOSMA/U. of Koln
M=Max Planck
N=NRAO
O=Nobeyama
S=SRON
s=SRON(quasi-optical)
$=SAO
W=Cambridge
Schottky
4*hf/k
hf/k
T(Rx) DSB (K)
0
50
100
150
200
250
Freq. (GHz)
0
100
200
300
400

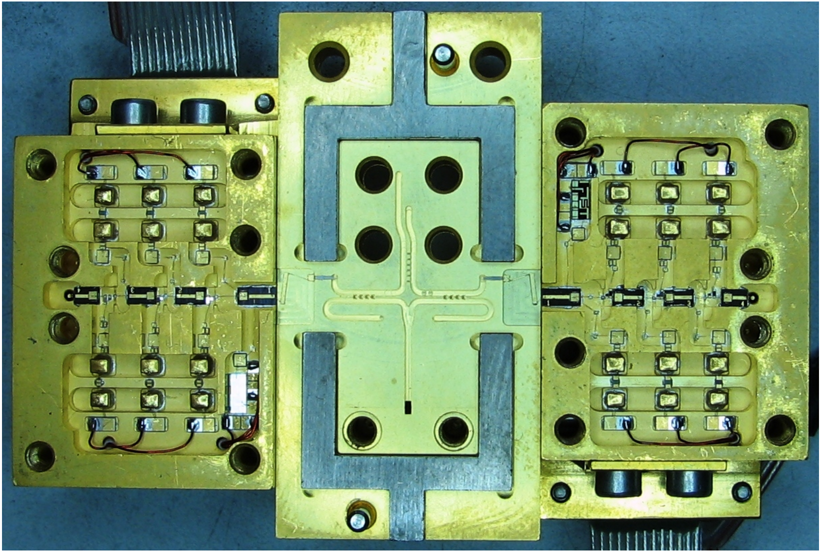
NRAO SIS MIXER AND InP AMPLIFIER RECEIVER PERFORMANCE



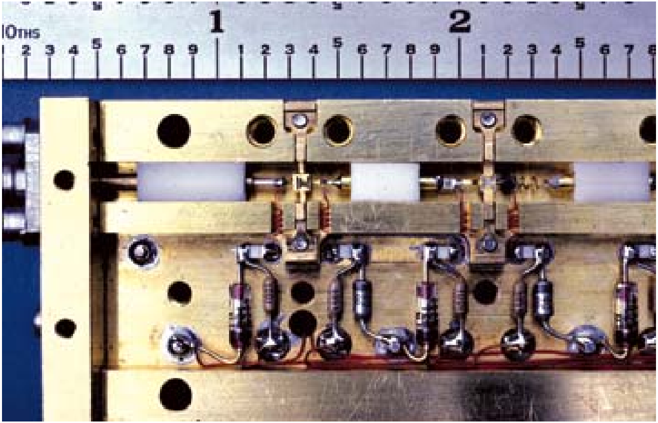
SIS mixer chip



SIS mixer block (two channel image reject)

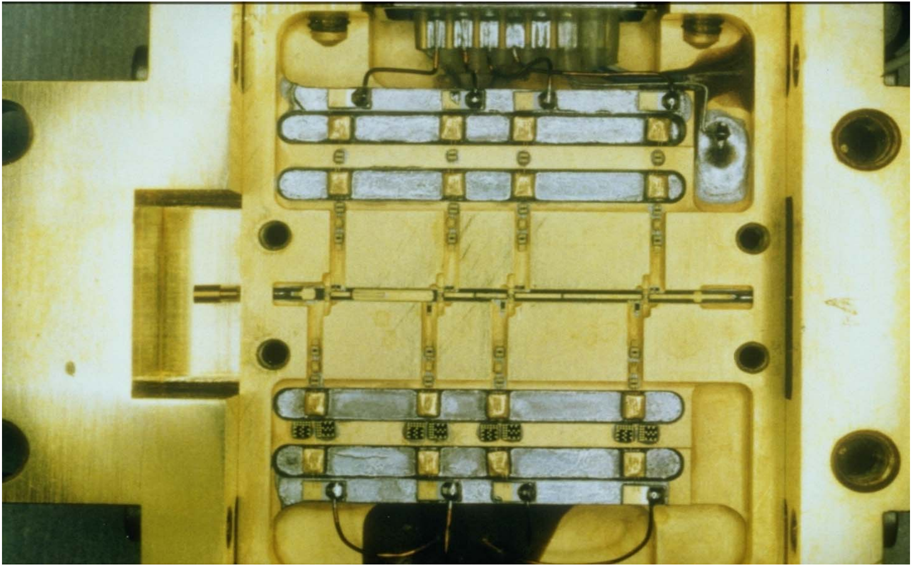


A HFET LNA



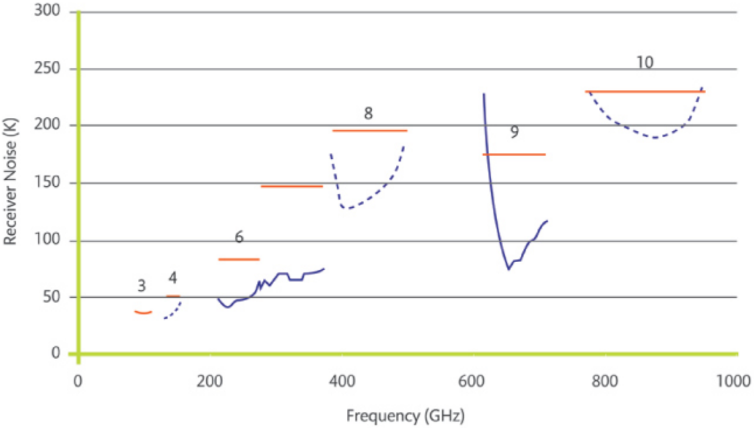
Credit: Roger Norrod, NRAO

K-band Map Amplifier

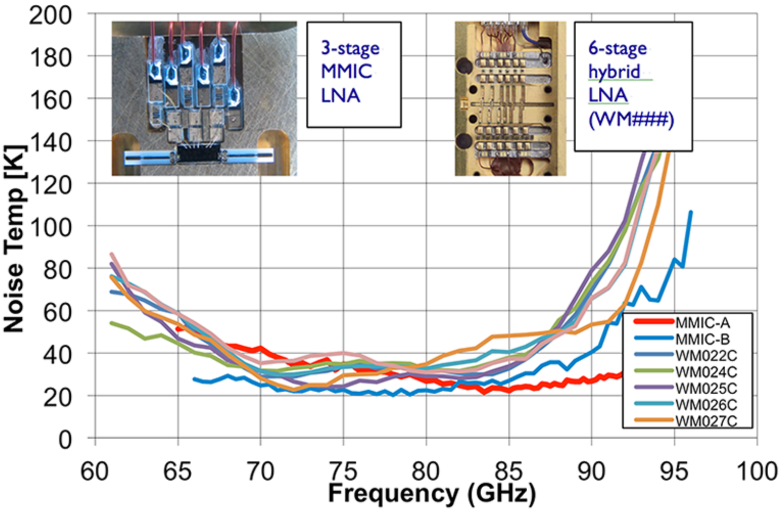


Credit: Roger Norrod, NRAO

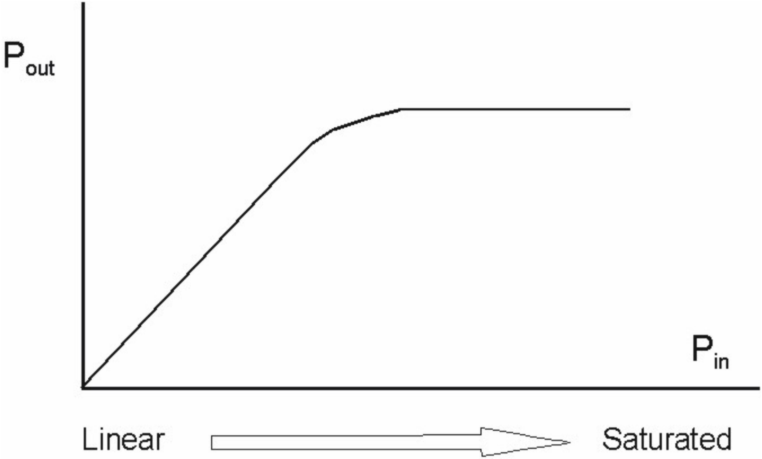
ALMA receivers, specs and reality



ALMA 'low' frequency HEMT amplifiers

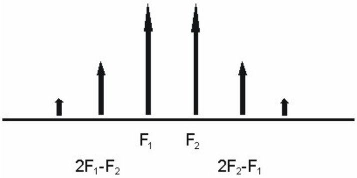


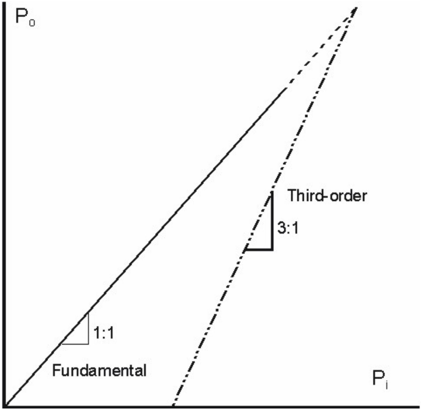
Linearity



Credit: Roger Norrod, NRAO

Intermodulation





Credit: Roger Norrod, NRAO

Wake up and thanks!