Scanning the atmosphere of planets with high spectral resolution terahertz radiometers

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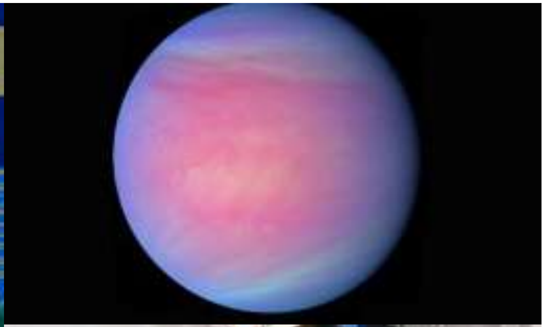
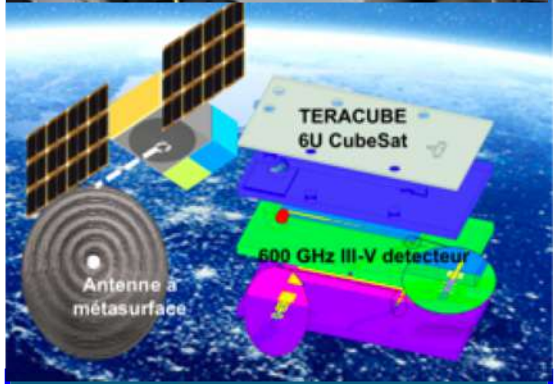
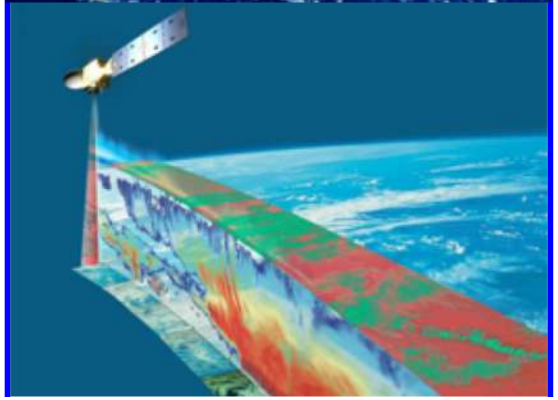
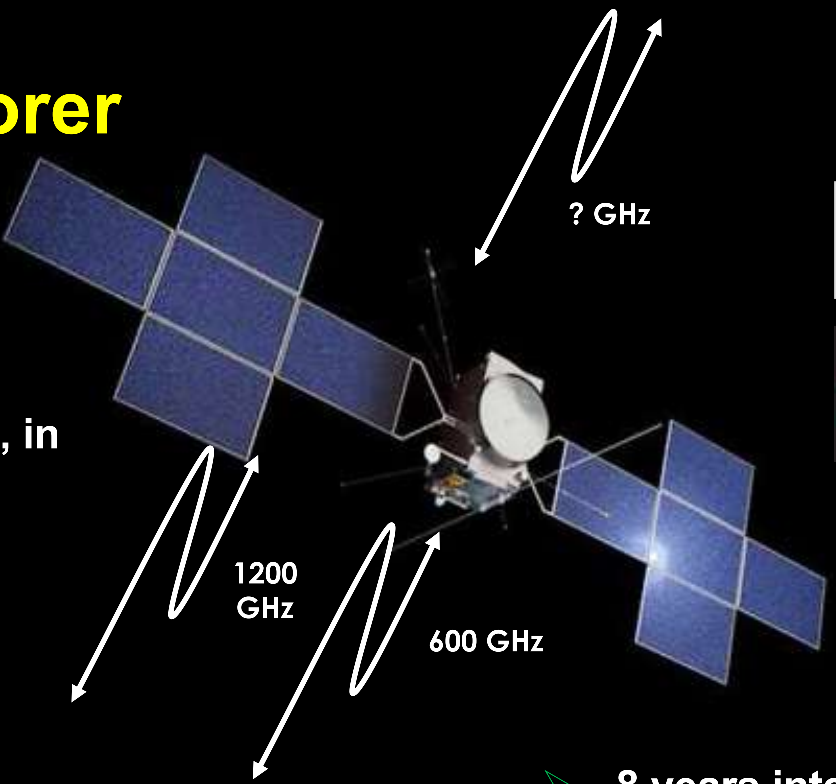






JUpiter ICy moons Explorer

First L Class mission ESA Cosmic Vision
Program 2015-2025



Detailed observations of the Jovian system, in particular Ganymede, Callisto and Europa.

What are the conditions surrounding the formation of planets and the emergence of life?

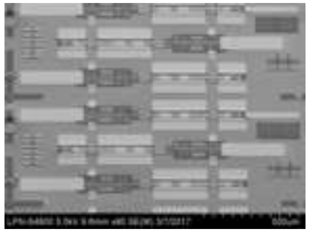
How does the Solar System work?

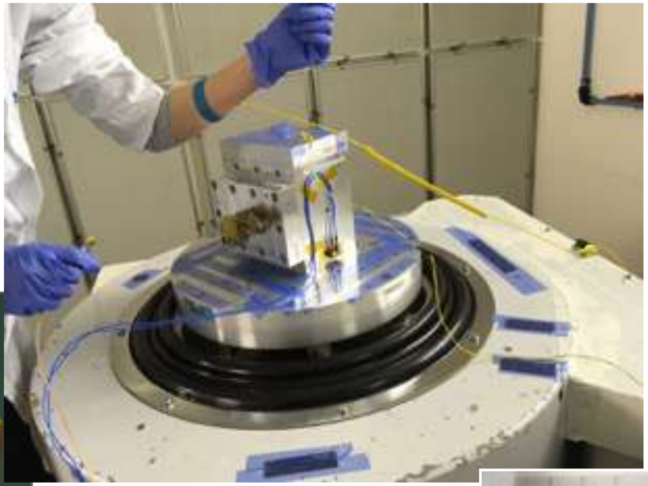
SUBMILLIMETER WAVE INSTRUMENT

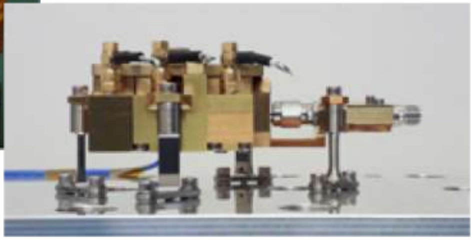
- 8 years interplanetary travel
- 2022 launch by Ariane V
- 5500kg spacecraft
- 97 m² solar generator, th largest ever built for an interplanetary mission
- 10 instruments for ~150 total payload including

General Procedure for Space-qualified Hardware delivery

i. Evaluation Program
ii. Qualification plan
iii. Assembly Integration Verification and Test process
iv. Performances and Pre-calibration tests.







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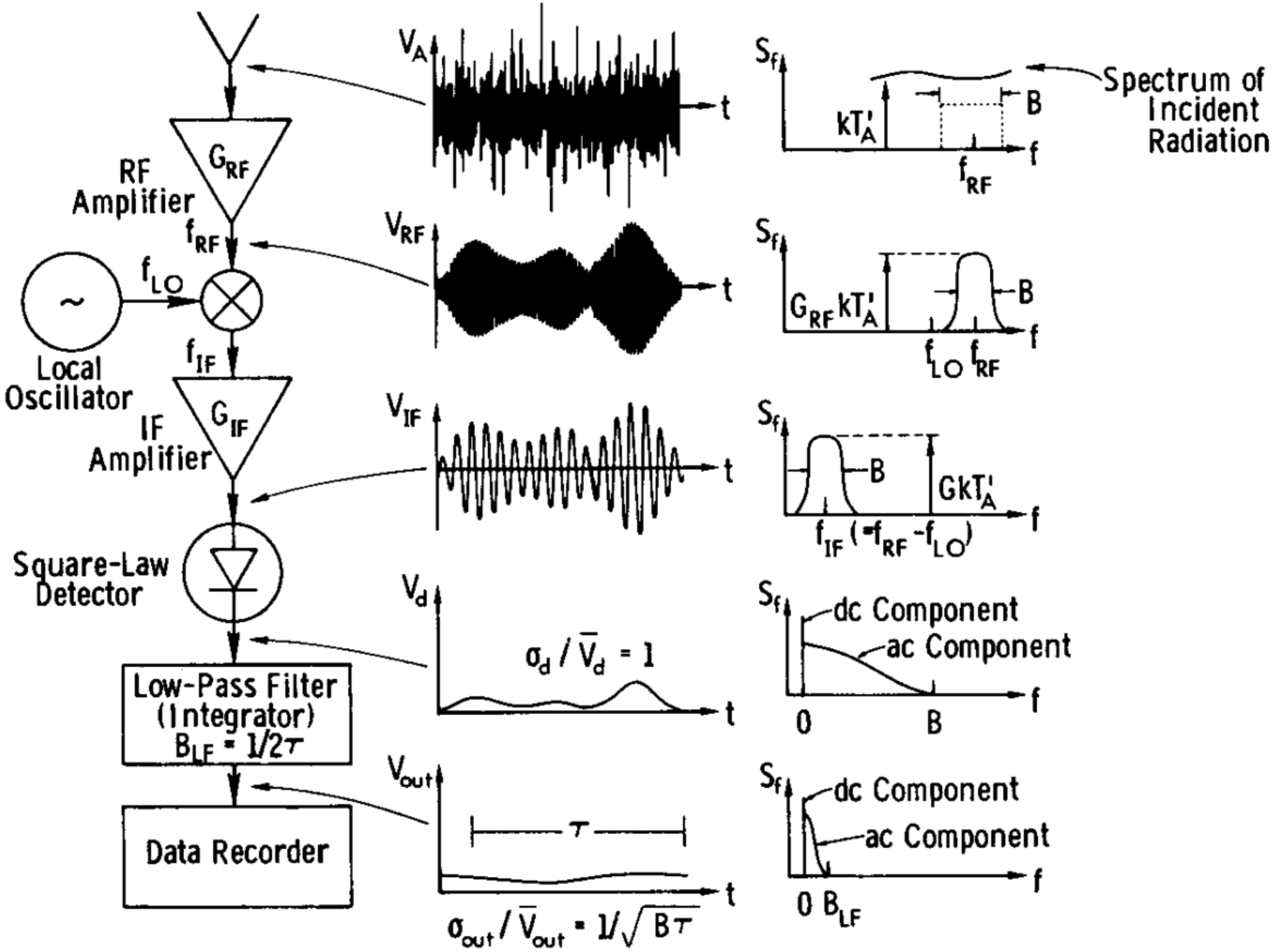
l'Observatoire de Paris | PSL



G = Power gain of predetection section (between RF amplifier input and IF amplifier output).

S_f = Power spectral density, W Hz^{-1}

Fig. 6.14 Total-power radiometer with a superheterodyne receiver. The signal voltage and corresponding spectrum are shown at various stages.

Equivalent-system noise power at the antenna terminals

- The total system input noise power is P_{SYS} where

$$P_{SYS} = P'_A + P'_{REC} = k\,T_{SYS}\,B$$

- Precision relates to ΔT, the radiometric resolution which is the smallest detectable change in T_A'.

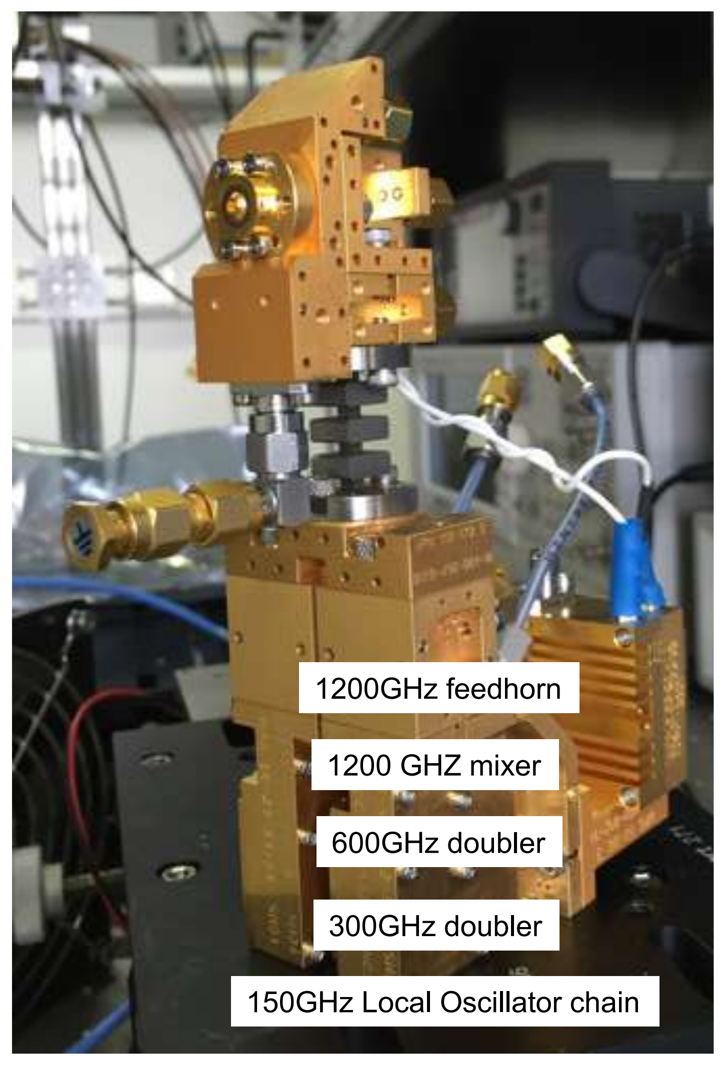
- Determination of ΔT requires an understanding of the signal's statistical properties. The ratio of the measurement uncertainty to the measured value is

$$\frac{\Delta T_{SYS}}{T_{SYS}} = \frac{1}{\sqrt{B\,\tau}}$$

- The measurement uncertainty due to noise processes, ΔT_N, is

$$\Delta T_N = \frac{T_{SYS}}{\sqrt{B\,\tau}}$$

JUICE-SWI 1080-1280GHz Schottky Receiver



- **performance exceeds by a factor 2 the specifications and by a factor 1.5 the instrument goal.**

Sensibility including calibration, gain variation, quantization factor:

$$\Delta T_{Min} = T_{sys}\left[\frac{1}{B\tau_s}+\frac{1}{B\tau_c}+\left(\frac{\Delta G}{G}\right)^2_{Th}+\left(\frac{\Delta G}{G}\right)^2_{n\_Th}+\chi^2+\left(\frac{\Delta T_{\mathrm{Re}\,c}}{T_A+T_{\mathrm{Re}\,c}}\right)^2\right]^{1/2}$$

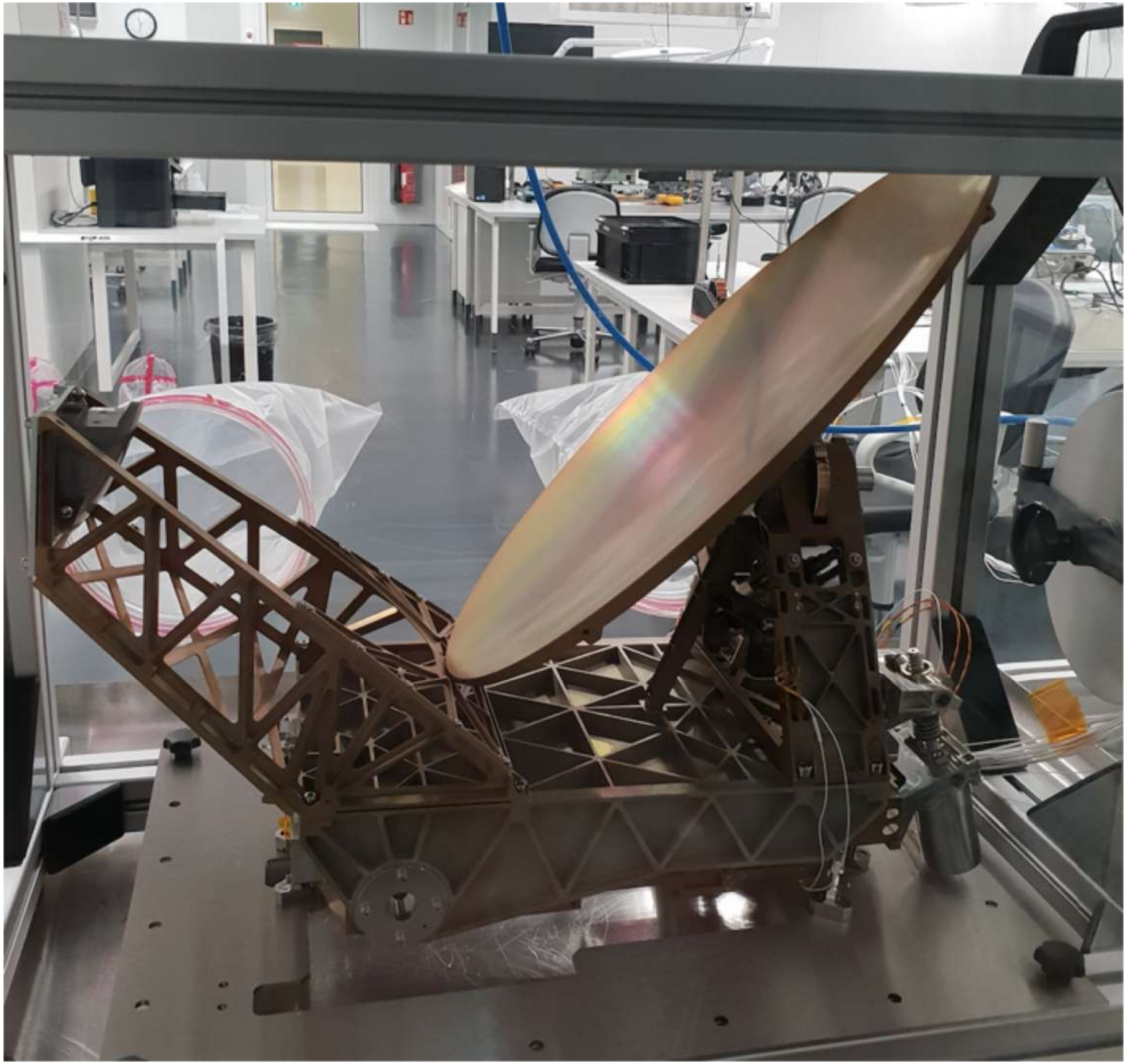
Gain stability has to be measured and the observation method defined by the scientists & engineers.

AND / OR

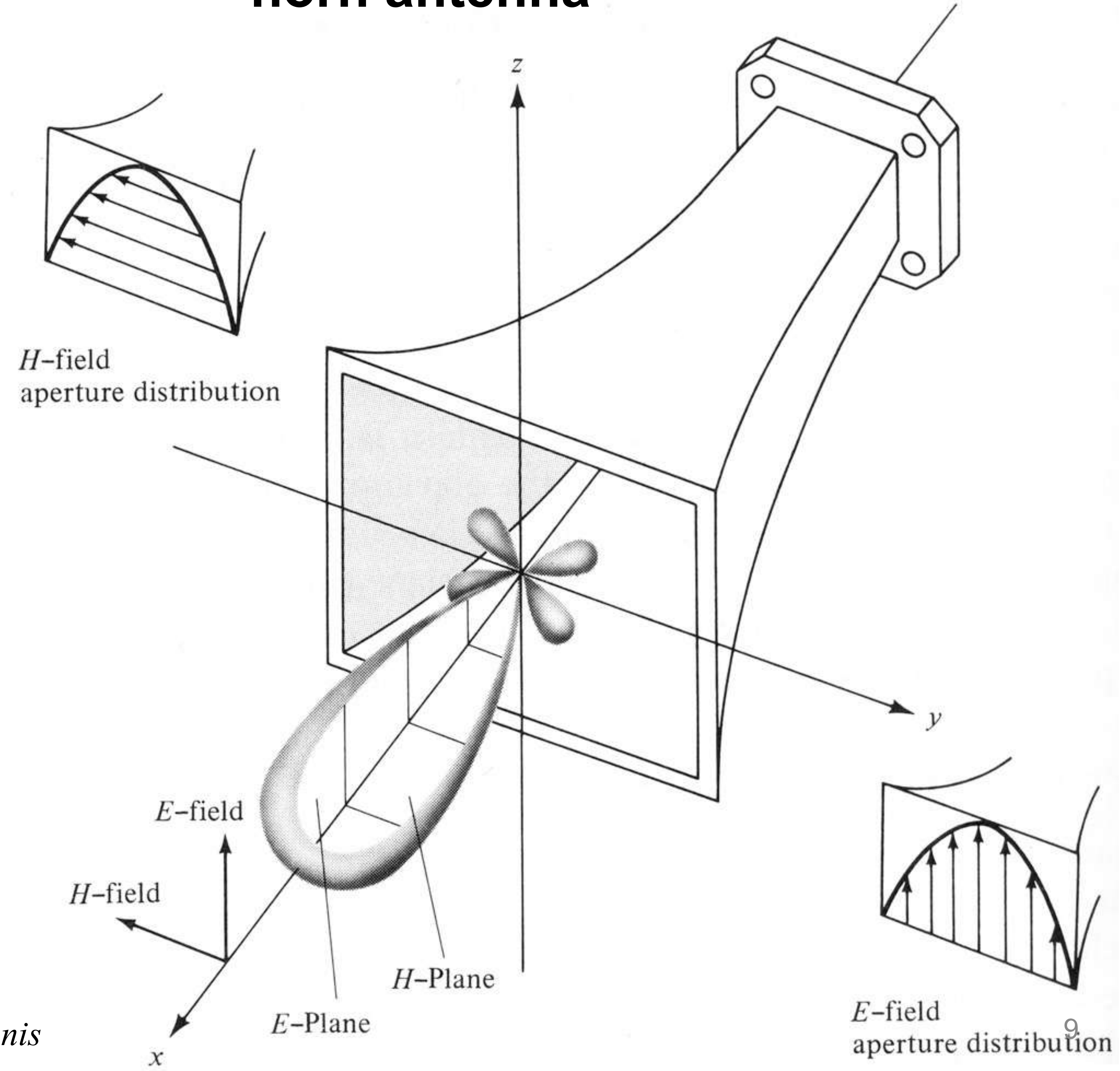
Optimize Tsys = Ta + Tmixer + TLNA / Gmixer + TIF/GLNA + …

↓

Marx Planck Institute, Radiometer Physics, Institut d’électronique et de télécommunication de Rennes (IETR), Observatory of Paris, Laboratory in Tunisia…



Principal E- and H-plane patterns for a pyramidal horn antenna

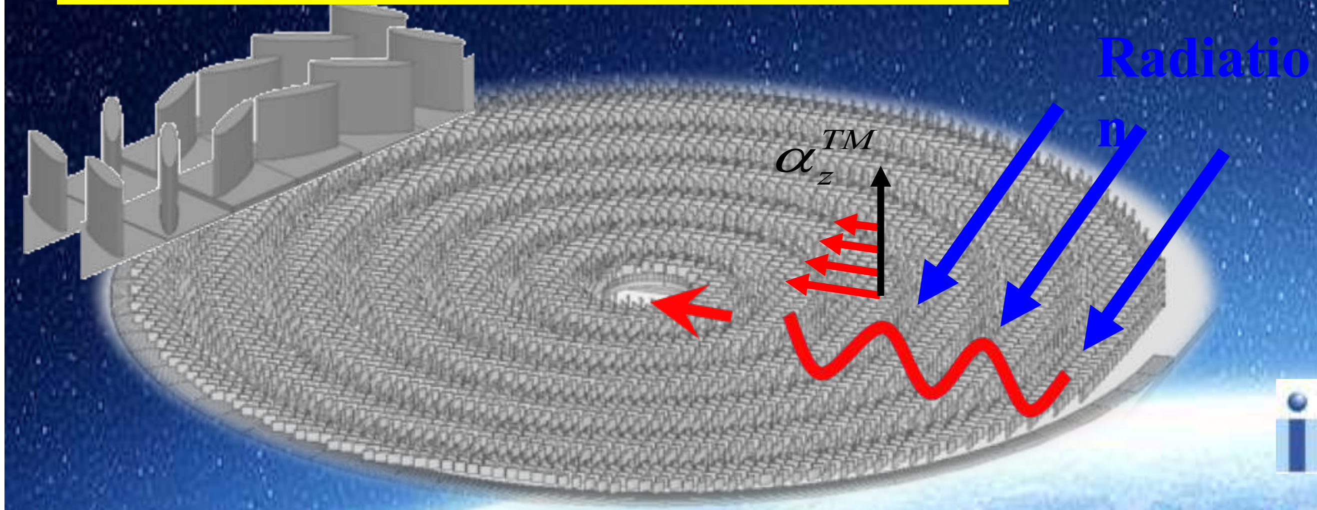


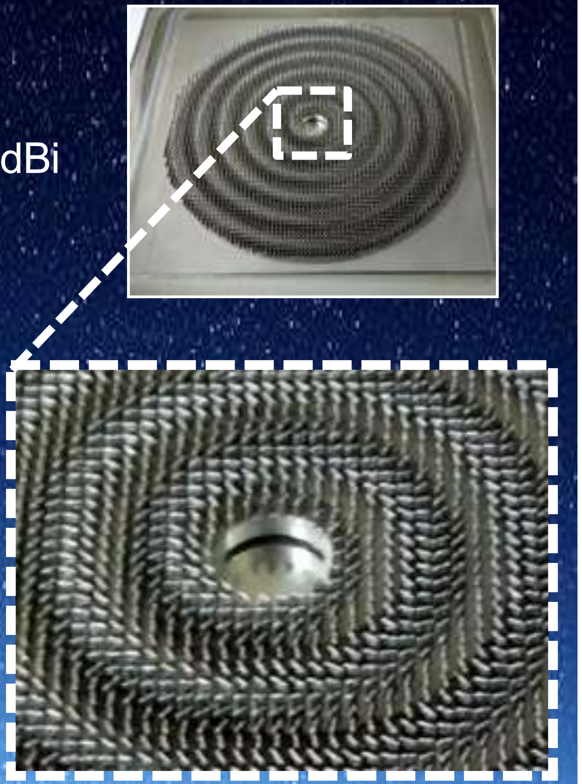
after Constantine A. Balanis

PRIMARY OPTICS: Metal-only Metasurface Antennas

D. González-Ovejero et al., *IEEE Trans. Antennas Propag.*, 66(11), Nov. 2018.

- ✓ **300 GHz (CNRS, IETR)**
- ✓ **664 GHz (DESIGN ON GOING)**





~32.5 dBi

Sensibility including calibration, gain variation, quantization factor:

$$\Delta T_{Min} = T_{sys}\left[\frac{1}{B\tau_s} + \frac{1}{B\tau_c} + \left(\frac{\Delta G}{G}\right)^2_{Th} + \left(\frac{\Delta G}{G}\right)^2_{n\_Th} + \chi^2 + \left(\frac{\Delta T_{\mathrm{Re}\,c}}{T_A + T_{\mathrm{Re}\,c}}\right)^2\right]^{1/2}$$

Gain stability has to be measured and the observation method defined by the scientists & engineers.

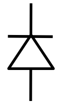
AND / OR

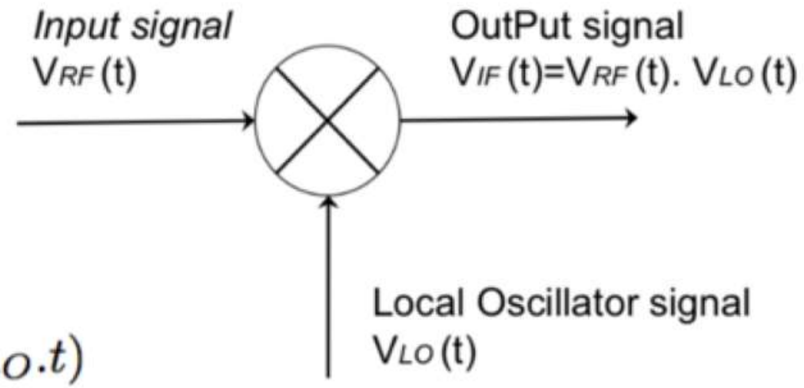
Optimize Tsys = Ta + Tmixer + TLNA / Gmixer + TIF/GLNA + …

↓

Observatory of Paris – LERMA + C2N

Mixer operation





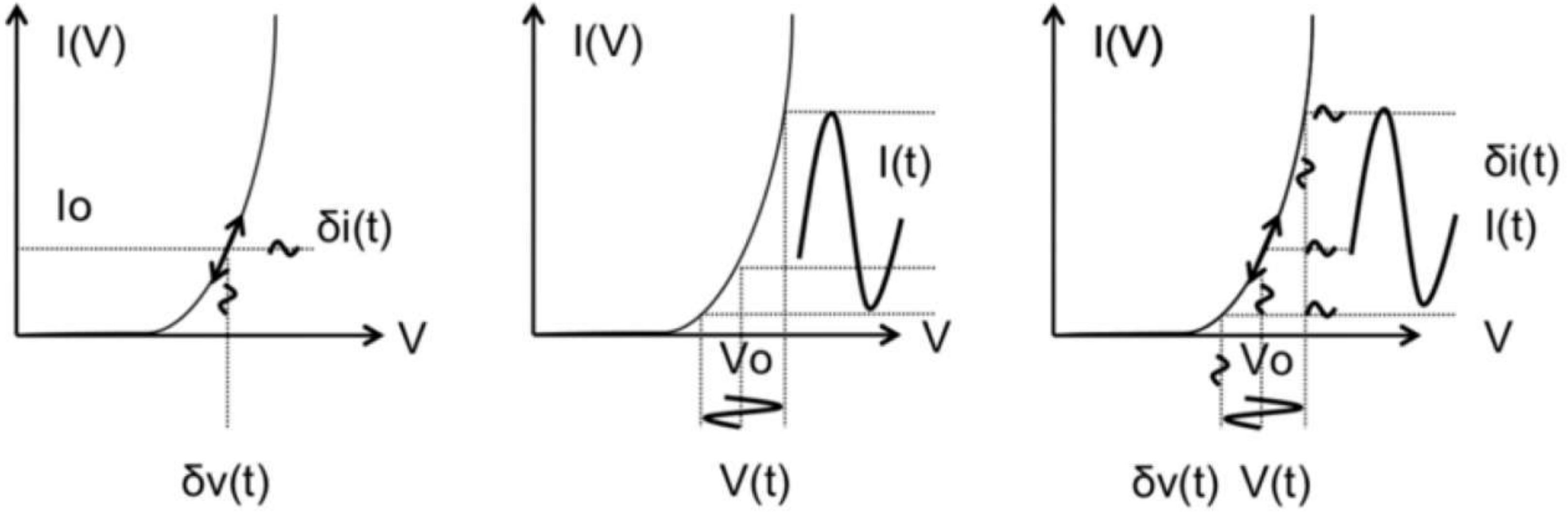
Input signal
$V_{RF}(t)$

OutPut signal
$V_{IF}(t) = V_{RF}(t).\ V_{LO}(t)$

Local Oscillator signal
$V_{LO}(t)$

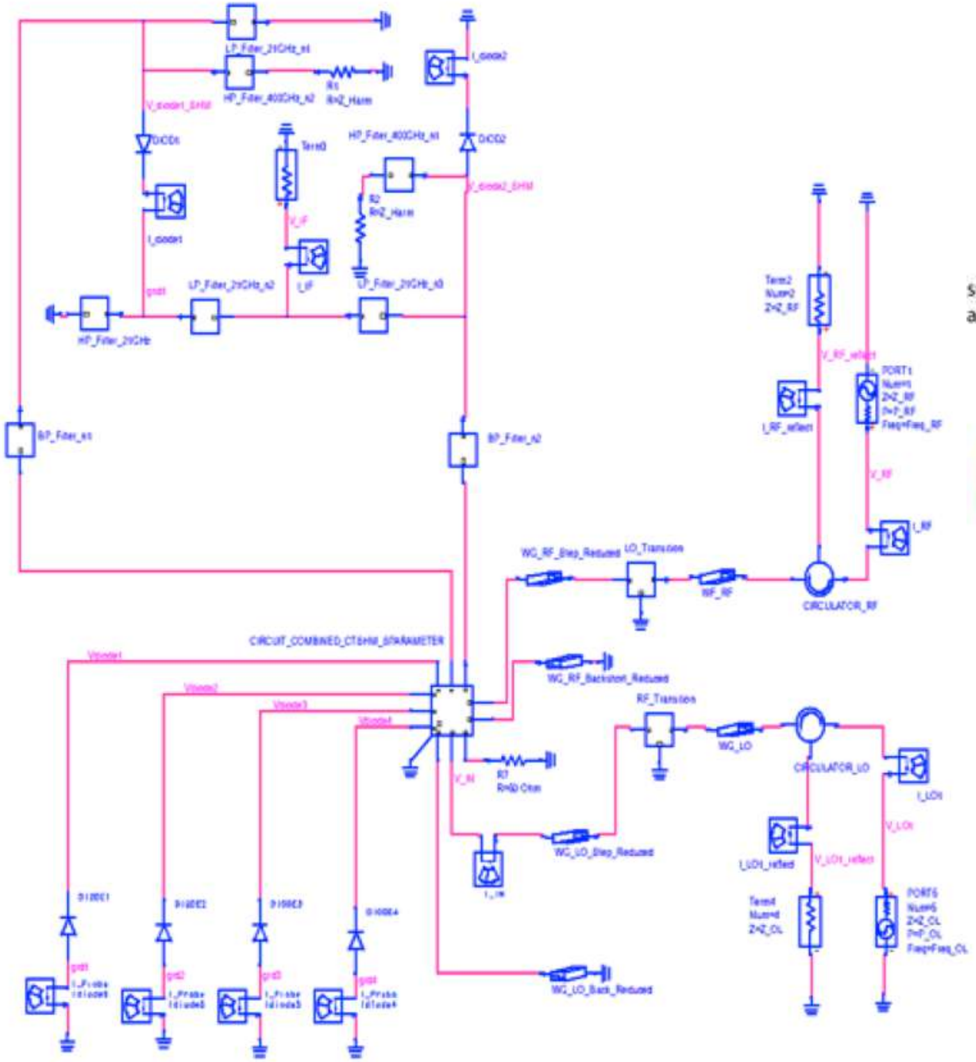
$$V_{RF}(t) = A(t).cos(\omega_{RF}.t) \qquad V_{LO}(t) = B.cos(\omega_{LO}.t)$$

$$V_{IF}(t) = A(t).cos(\omega_{RF}.t) \times B.cos(\omega_{LO}.t) = \frac{B.A(t)}{2} \times (cos(\omega_{LO} + \omega_{RF}).t + cos(\omega_{LO} - \omega_{RF}).t)$$

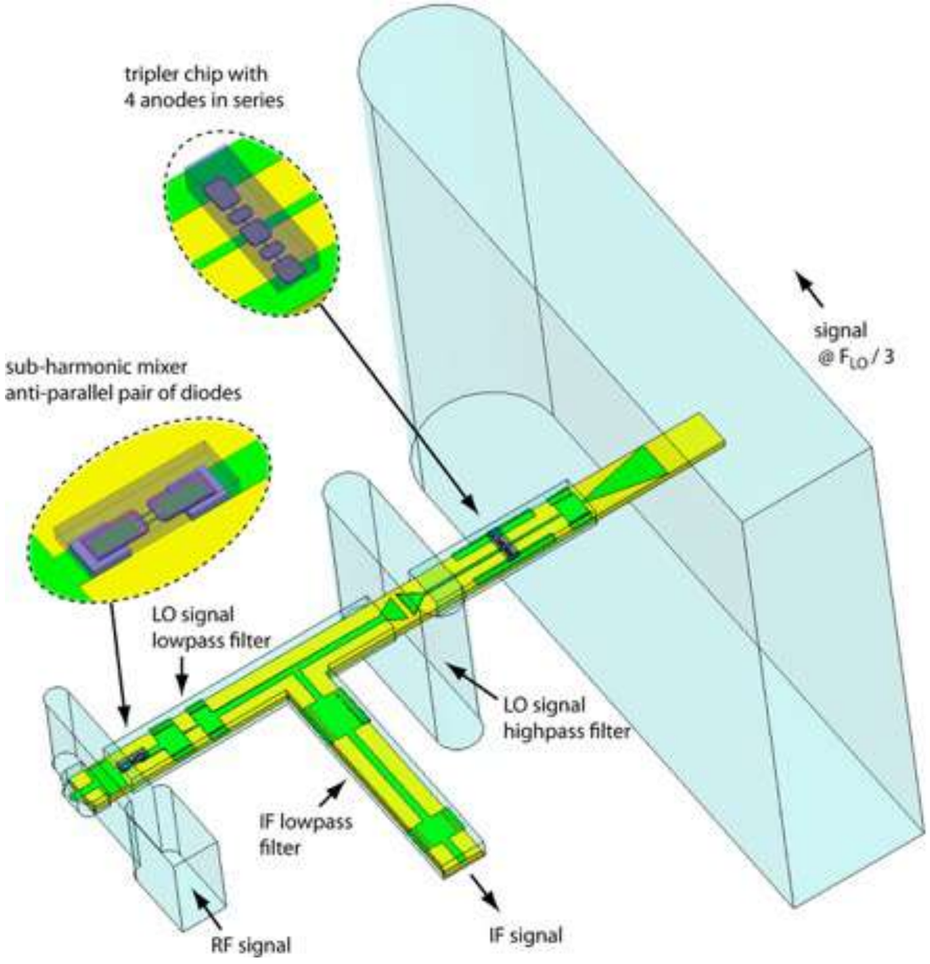


Excitation of the diode :
- small signal
- large signal (multiplier operation)
- small and large signal (mixer operation)

CIRCUIT OPTIMIZATION - DESIGN TOOLS



Harmonic balance simulation tool (ADS)



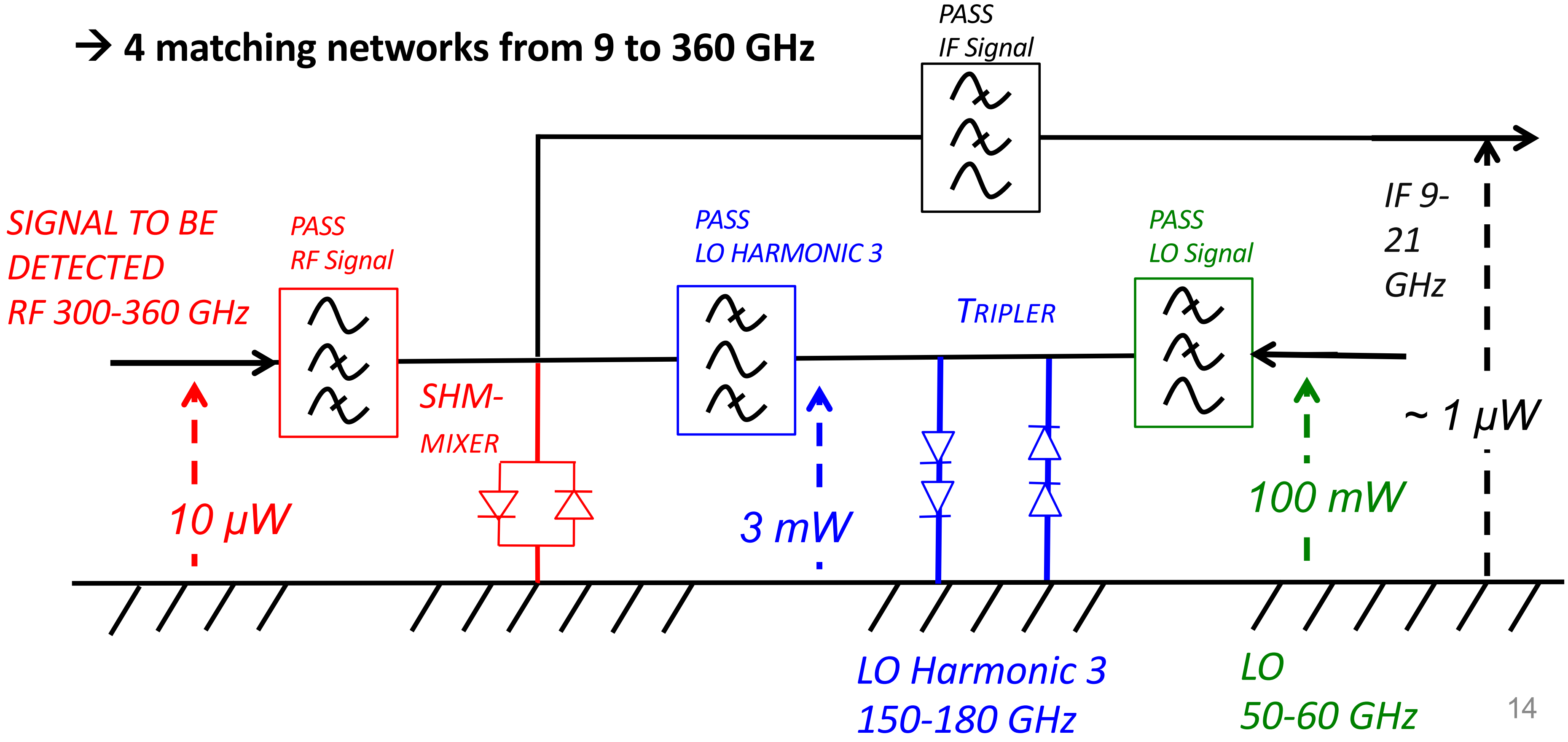
HFSS – 3D electro-magnetic sofware
Smallest dimension range 1 um
Biggest dimension range 2500 um

EXAMPLE CIRCUIT DEFINITION

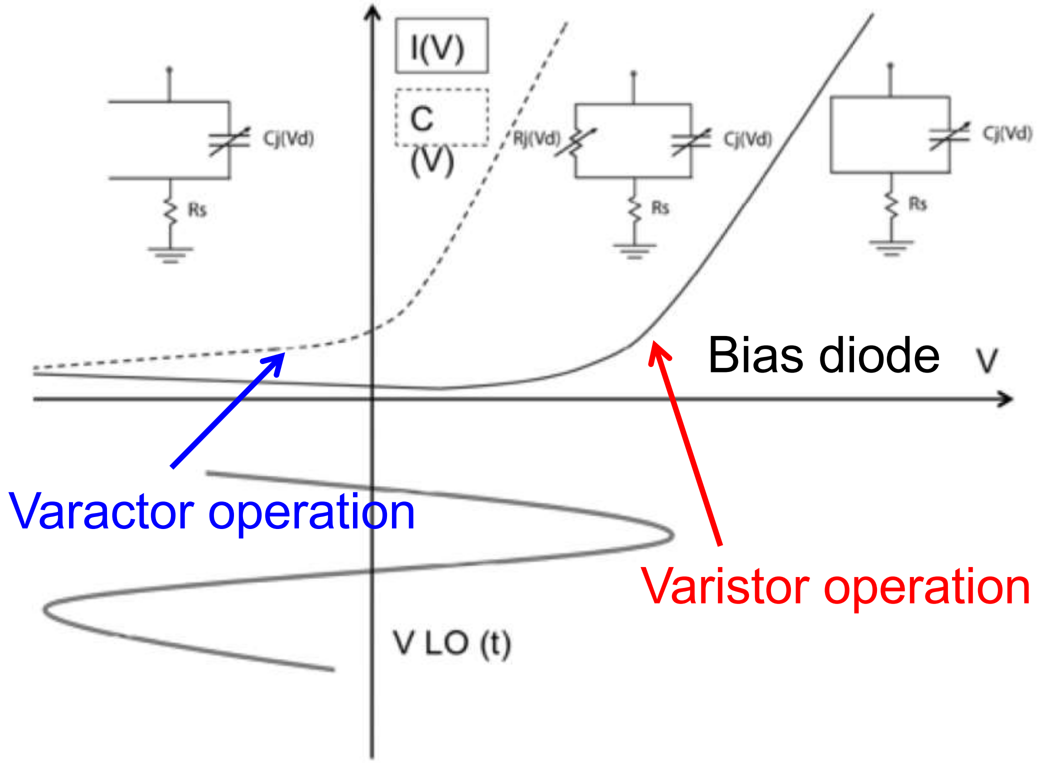
→ 6 non linear elements : Anti-parallel configuration sub-harmonic mixer (2 diodes)
Balanced configuration tripler (4 diodes)

→ **Power 10 µW to 100 mW (40 dB dynamic range)**

→ **4 matching networks from 9 to 360 GHz**



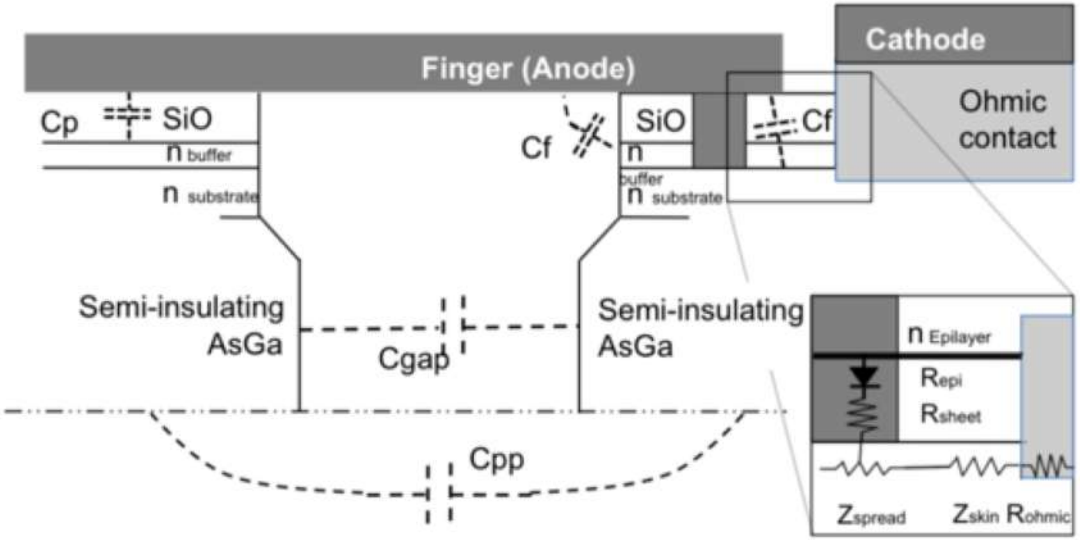
Mixer-multiplier operation



Varactor operation

Varistor operation

…at Terahertz frequencies



$$f_{Cutoff} = \frac{1}{r_j} = \frac{1}{2\pi R_s C_{Tot}}$$

$$\boxed{C_j(V_j) = A.\gamma_c \frac{\varepsilon}{W(V_d)} = (A.\gamma_c(\frac{q.N_d.\varepsilon_{epi}}{2.V_{bi}})^{\frac{1}{2}})_{V_d=0}}$$

$$\boxed{\gamma_c(V_d) = (1 + 4b_1 \frac{W(V_d)}{R_o} + \frac{3b_2}{\pi} \frac{W(V_d)^2}{R_o^2})}$$

Determination of the capacitance of the schottky junction :
Correction factor of the geometry
Analytical + 3D EM software

- **600 GHz GaAs Schottky mixer**

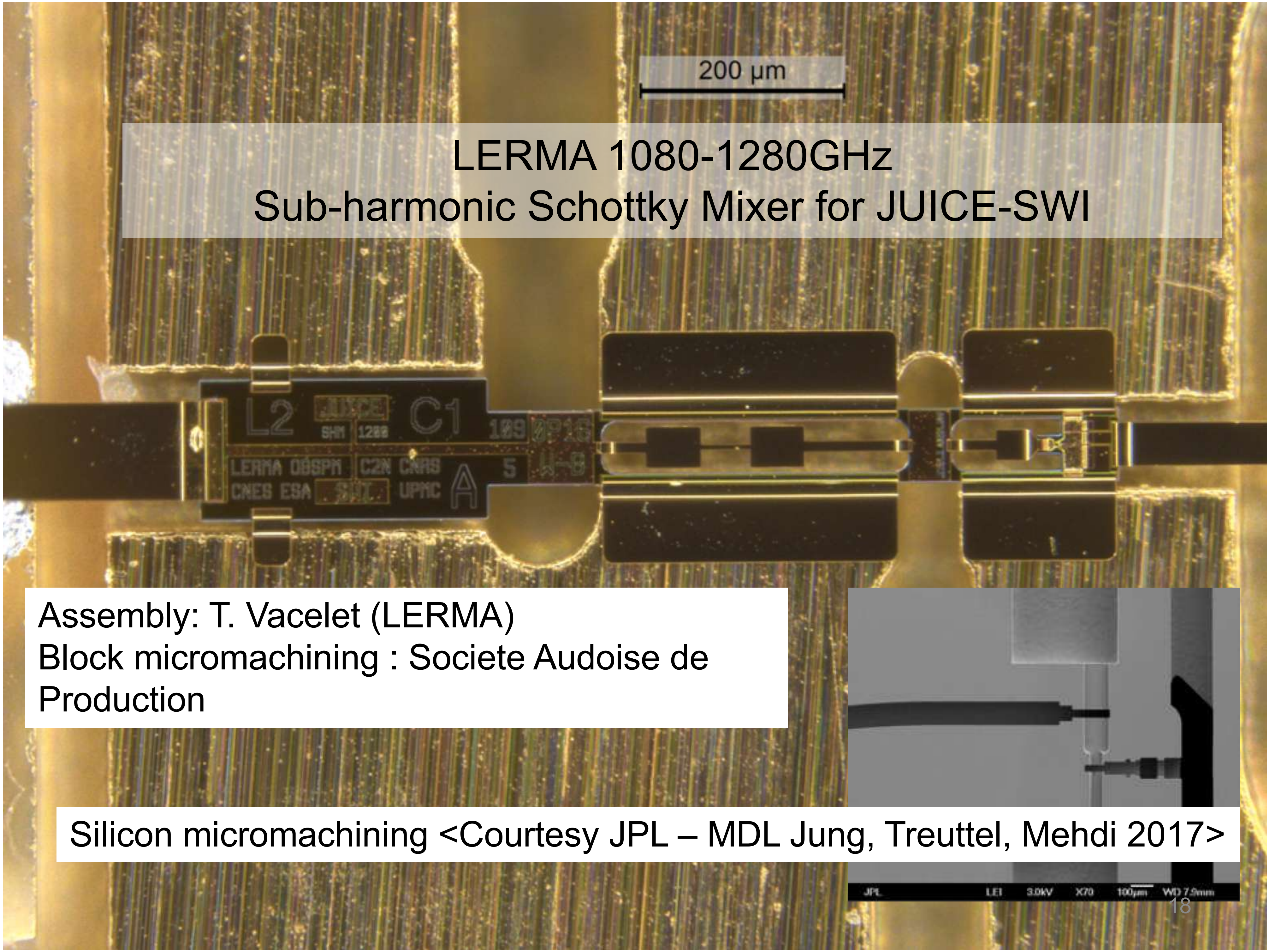
Design: Treuttel - Fabrication 2015 : Gatilova

- **1200 GHz GaAs Schottky mixer**

Design : Maestrini/Treuttel/Moro.Melgar – Fabrication 2017 : Gatilova

S-o-A Schottky MIXERS

LERMA 1080-1280GHz
Sub-harmonic Schottky Mixer for JUICE-SWI

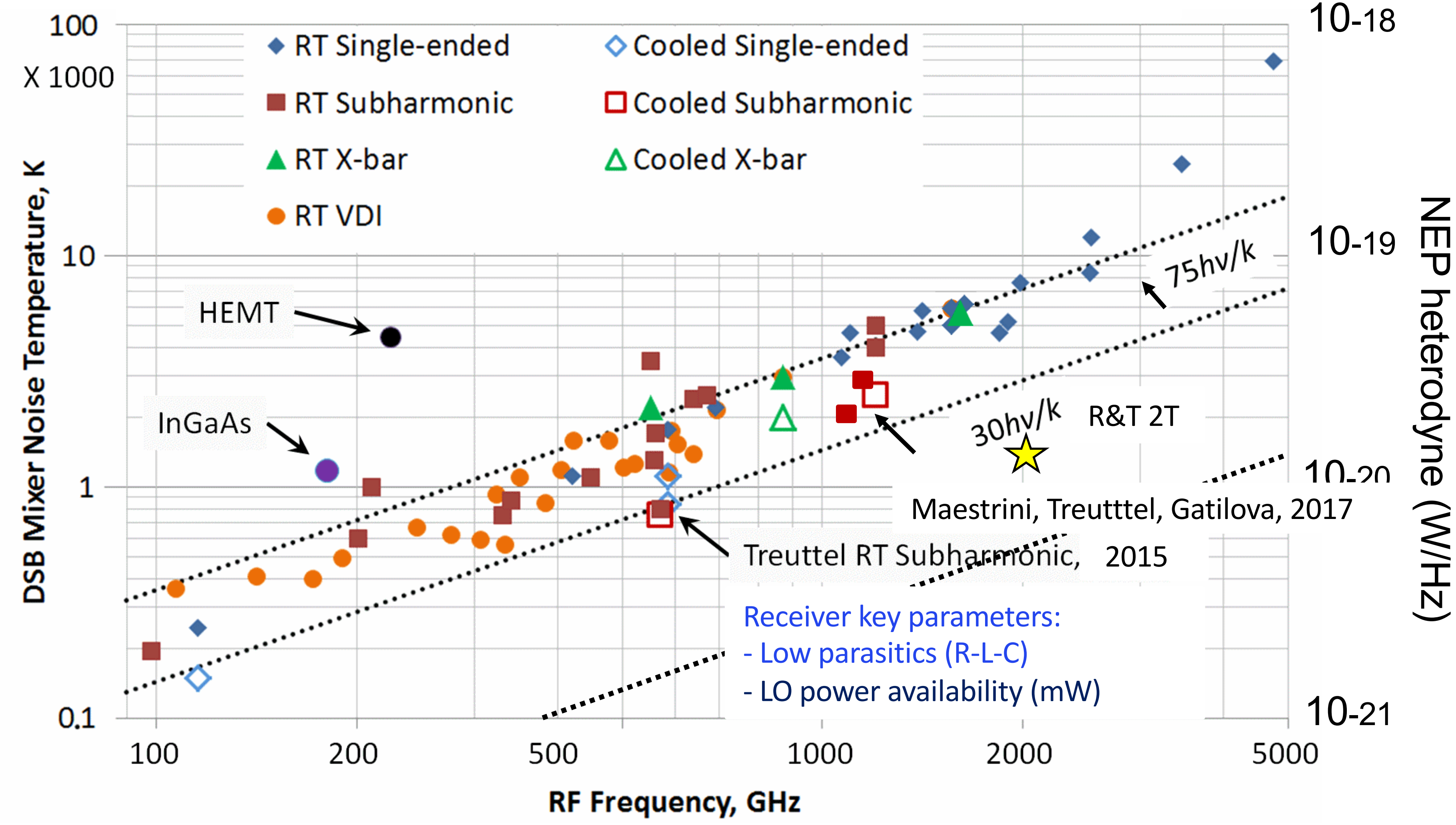


Assembly: T. Vacelet (LERMA)
Block micromachining : Societe Audoise de Production

Silicon micromachining <Courtesy JPL – MDL Jung, Treuttel, Mehdi 2017>

State of the art Schottky mixers

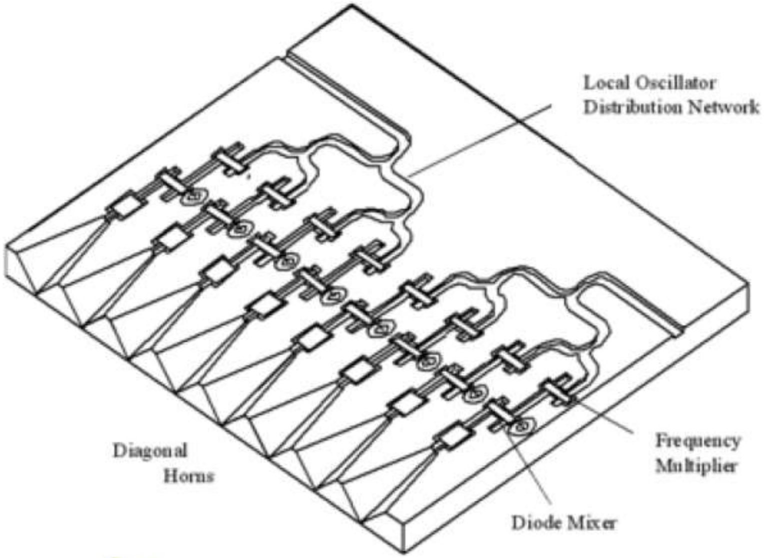
Heterodyne detection / Room temperature operation



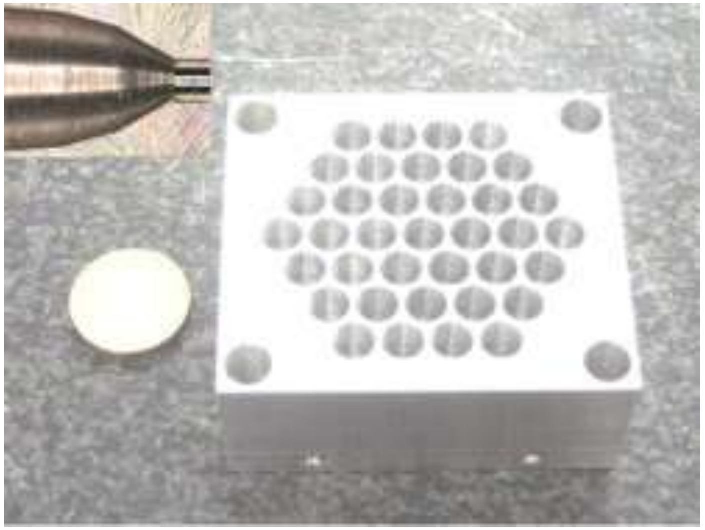
Receiver key parameters:
- Low parasitics (R-L-C)
- LO power availability (mW)

[Courtesy : JPL, VDI, LERMA-LPN, Chalmers, +…]

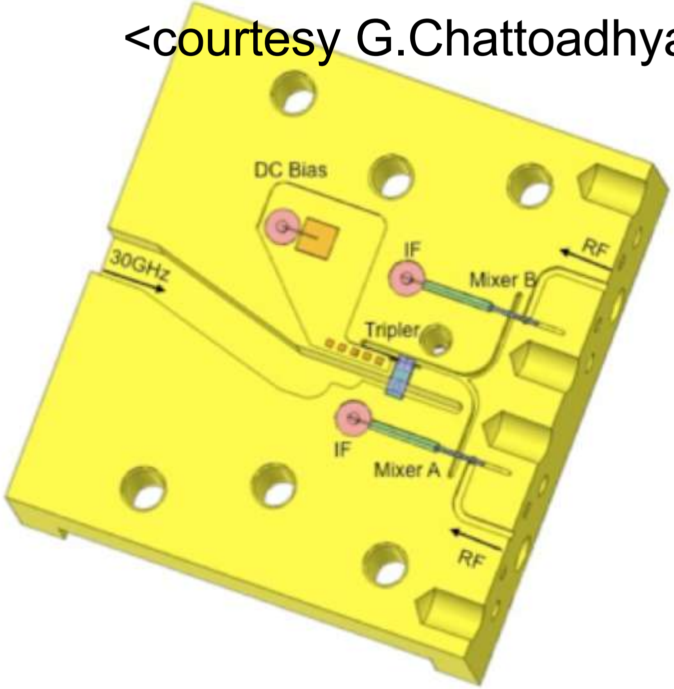
Arrays


Local Oscillator Distribution Network
Diagonal Horns
Frequency Multiplier
Diode Mixer

<courtesy G.Chattoadhyay, JPL>

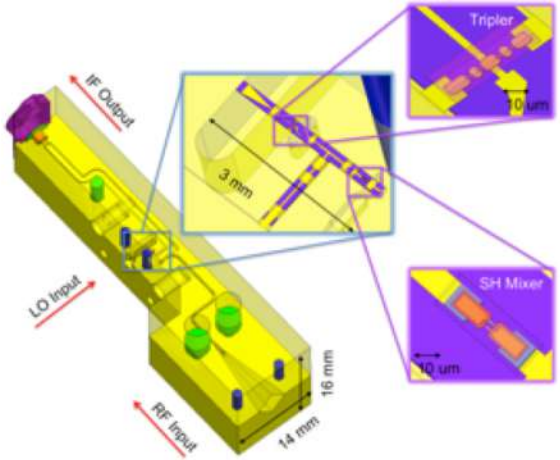


<Leech, A&A, 2011>


DC Bias
30GHz
IF
Mixer B
RF
Tripler
IF
Mixer A
RF

<H. Wang, PhD>

<B.Thomas JPL ISSTT – 2010>

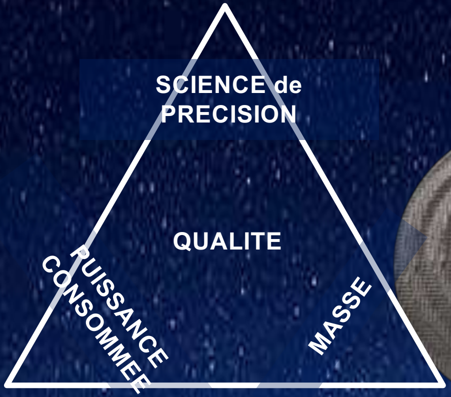

IF Output
LO Input
RF Input
3 mm
16 mm
14 mm
Tripler
10 um
SH Mixer
10 um

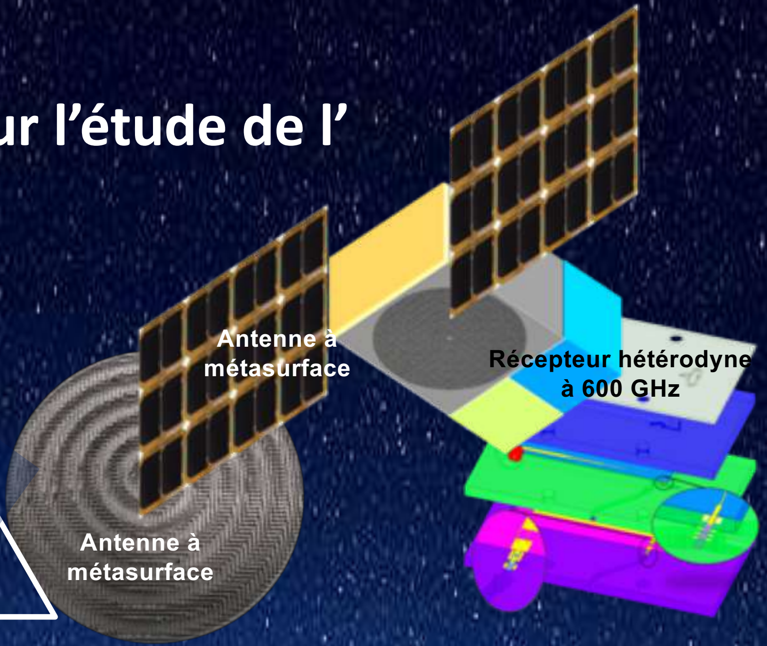
<J.Treuttel, PhD>

TERACUBE

Instrument Térahertz Embarqué sur Nano Satellite aux Fréquences Térahertz pour l’étude de l’ Atmosphère Vénusienne

Charge utile 6U CubeSat	Instrumentation Térahertz (antenne, récepteur)
Electronique de contrôle et calibration	Synthétiseur de fréquence Spectromètre digital Logiciel de vol
Electronique de puissance	Télémétrie de vol Communication





- ✓ **Preliminary study started at JPL 2 THz NPP Treuttel (power consumption, synthesizer and backend)**
- ✓ Metasurface antenna design at 664 GHz (IETR)
- ✓ Access to COTS and qualified components (JUICE-SWI)
- ✓ French Synthesizer and Back end

Interfaces système, Intégration du prototype Démonstrateur de vol