Performance of a compact 557-GHz heterodyne receiver front-end

Components for future European space missions

ISSTT, Groningen, 10th April 2013

Philipp Neumaier

Performance of a compact 557-GHz heterodyne receiver front-end

Components for future European space missions

European Project: **TeraComp**

COOPERATION

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T. Bryllert, J. Hanning, L. Yan	*Wasa Millimeter Wave AB, Sweden*
V. Krozer	*Goethe-University Frankfurt, Germany*

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Motivation

Monitoring Earths' atmosphere

Water vapor, cloud ice water content

→ Strong H_2O absorption line @557GHz

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Other planets, moons

NO_2, N_2O, SO_2, H_2S, NH_3, CH_4, HCN

Motivation

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→ Strong H_2O absorption line @557GHz

Other planets, moons

NO_2, N_2O, SO_2, H_2S, NH_3, CH_4, HCN

Security application

THz-Imaging

Performance

Overview

17cm

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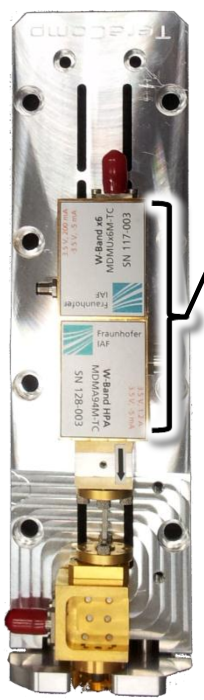
OMNISYS INSTRUMENTS
Fraunhofer IAF
DTU
Wasa MilliMeter Wave
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Performance

Overview



Fraunhofer IAF

x6 W-band mHEMT MMIC module

100mW between 88 - 97GHz @P_{input} -3dBm

@f_{input} 14.6 - 16GHz

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@f_{input} 14.6 - 16GHz

Wasa

x3 HBV

1-5 mW between 250 - 305GHz

Performance

Overview

Fraunhofer IAF

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100mW between 88 - 97GHz @P_{input} -3dBm

@f_{input} 14.6 - 16GHz

Wasa

x3 HBV

1-5 mW between 250 - 305GHz

Chalmers, Omnisys

low noise subharmonic Schottky diode mixer (DSB)
around 557GHz

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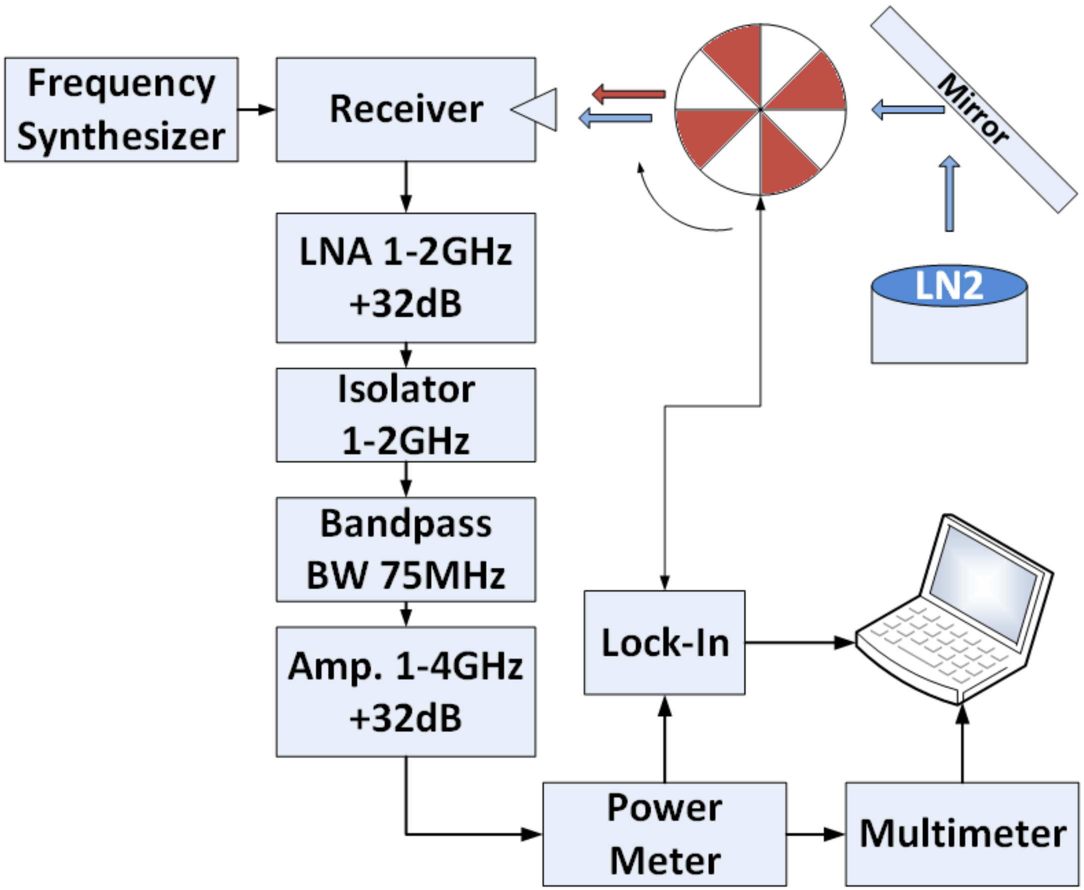
Performance

Noise Temperature

Setup

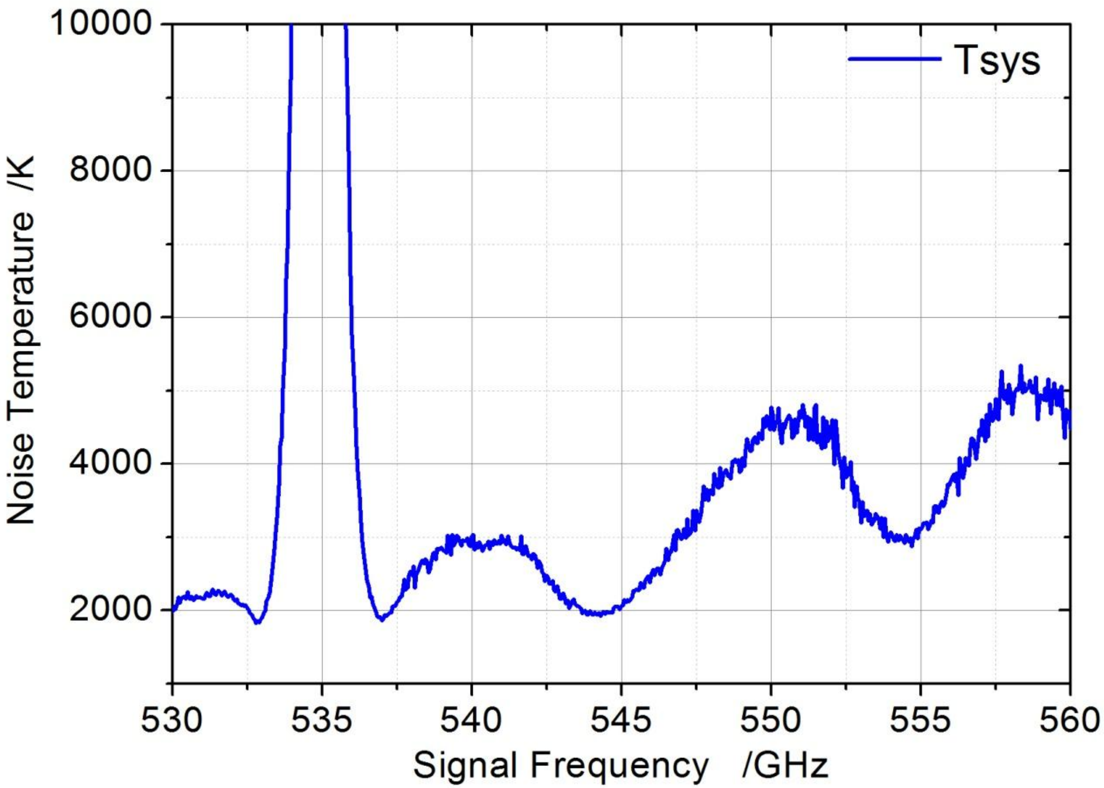


- Load, Eccosorb
  T_{Hot} = 296K
  T_{Cold} =77K
- Bandpass
  f_{center} = 1.43GHz
  Δf = 75MHz

Performance

Noise Temperature

Results



- Y-Factor

$$Y = \frac{P_{hot}}{P_{cold}}$$

- System Noise Temperature

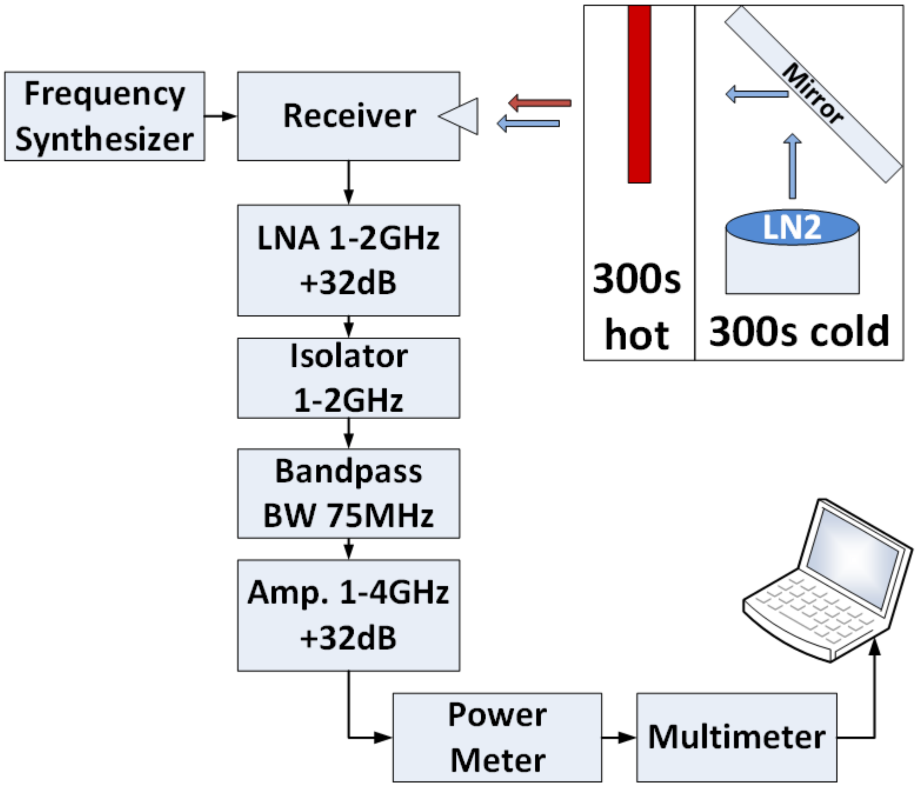
$$T_{sys} = \frac{T_{hot} - YT_{cold}}{Y - 1}$$

$$T_{sys}(545GHz) = 2000K$$

Performance

Temperature Resolution

Setup



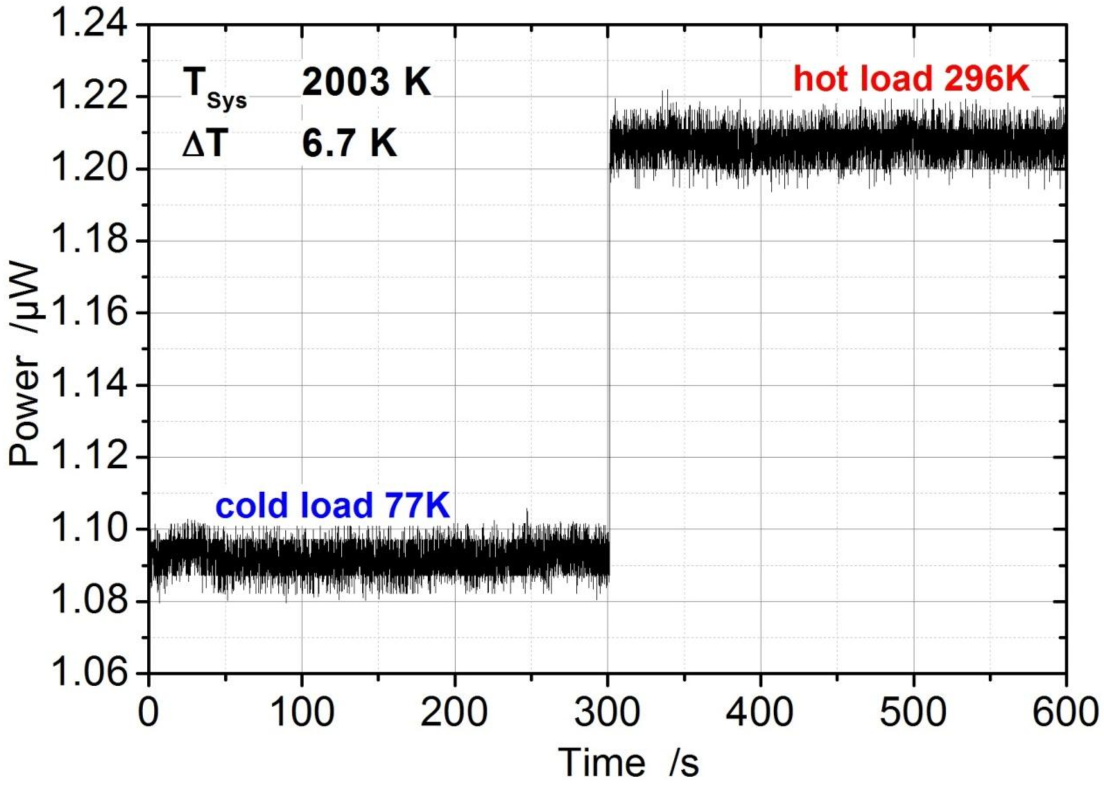
- LO-Chain
  f_{LO}=15.138GHz (545GHz)

- Load, Eccosorb
  T_{Hot} = 296K
  T_{Cold} =77K

Performance

Temperature Resolution

Results



- Radiometric Equation

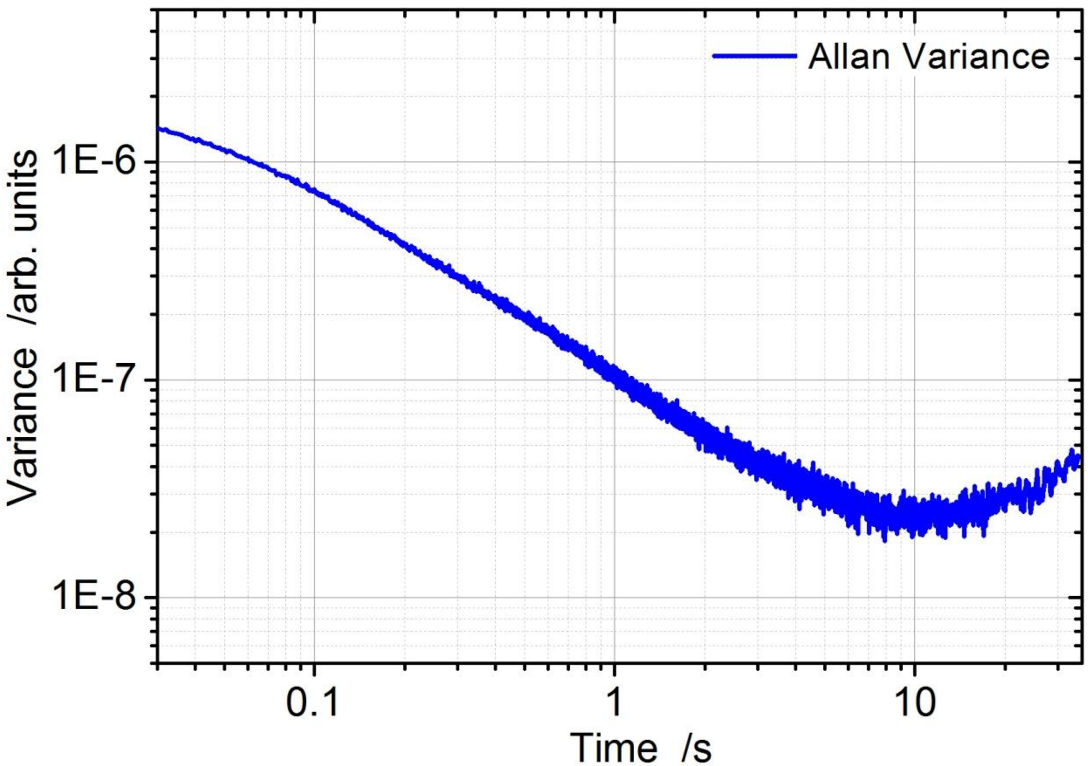
$$\Delta T = \frac{T_{sys}}{\sqrt{B \cdot t_{int}}} \approx 1.8K$$

B = 75MHz
t_{int} = 20ms

Performance

Allan Variance

Results



- Allan Variance

$$\sigma_A^2(t) = at^{\beta} + \frac{b}{t} + c$$

- Allan Time

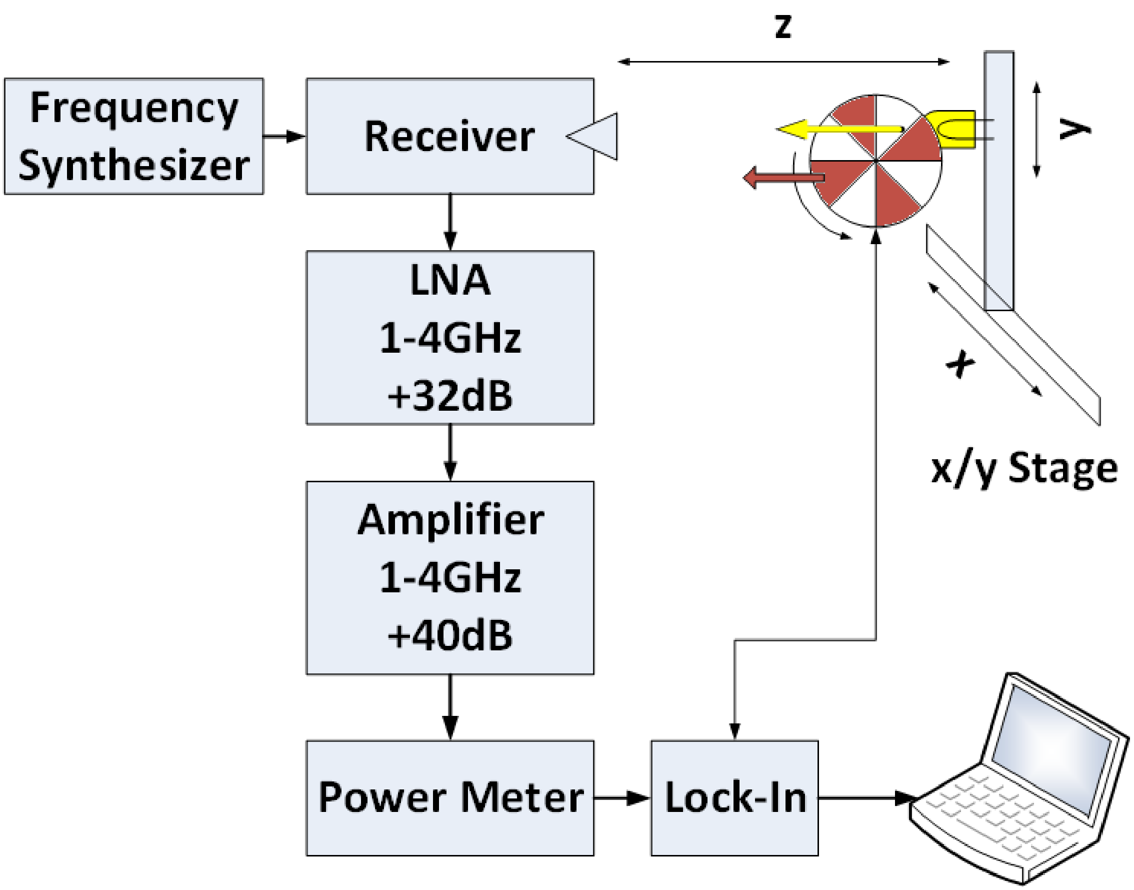
$$t_{Allan} \cong 10s$$

$$t_{Measurement} = 900s$$

Performance

Antenna Profile

Setup

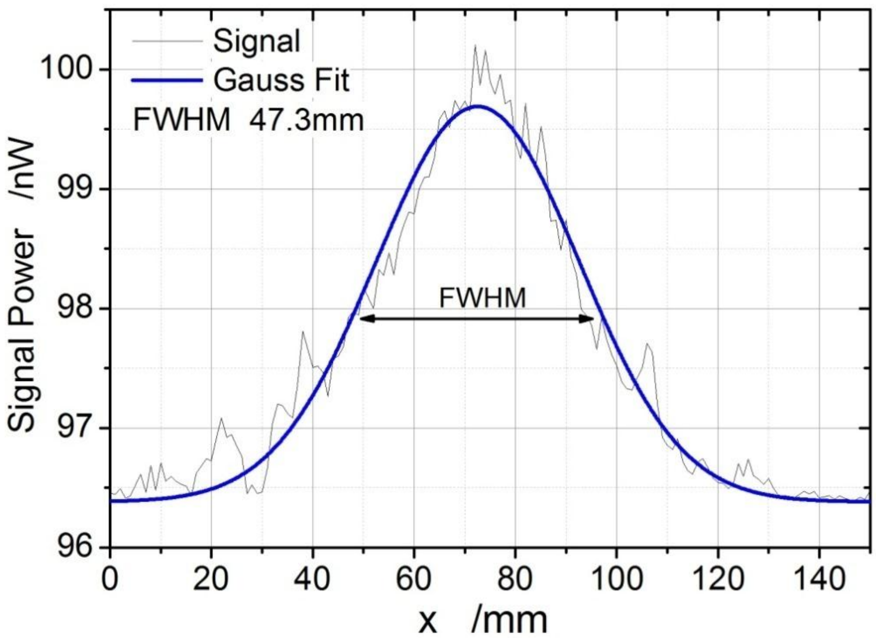


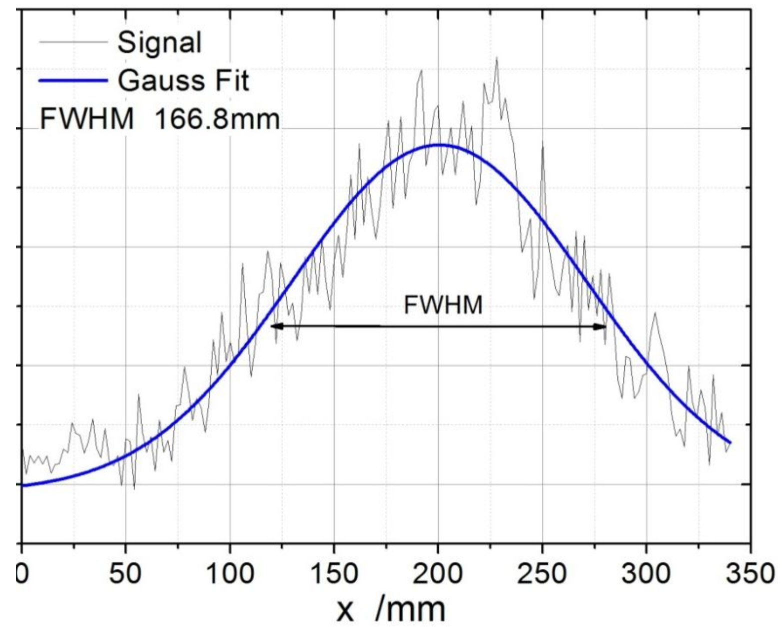
- LO-Chain
  f_{LO}=15.138GHz (545GHz)
- Loads, Eccosorb, Hg-Lamp
  T_{RT} = 296K
  T_{hot} ≈ 4000K

Performance

Antenna Profile

Results





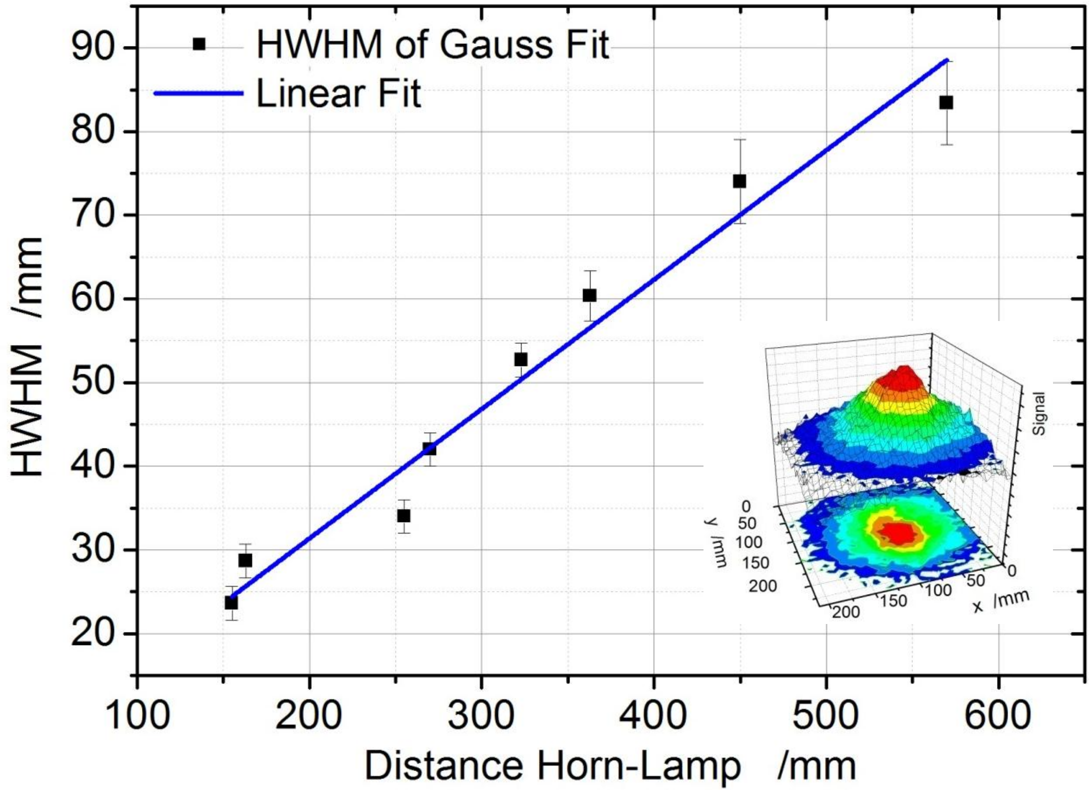
Beam Pattern z = 115mm

Beam Pattern z = 570mm

Performance

Antenna Profile

Results

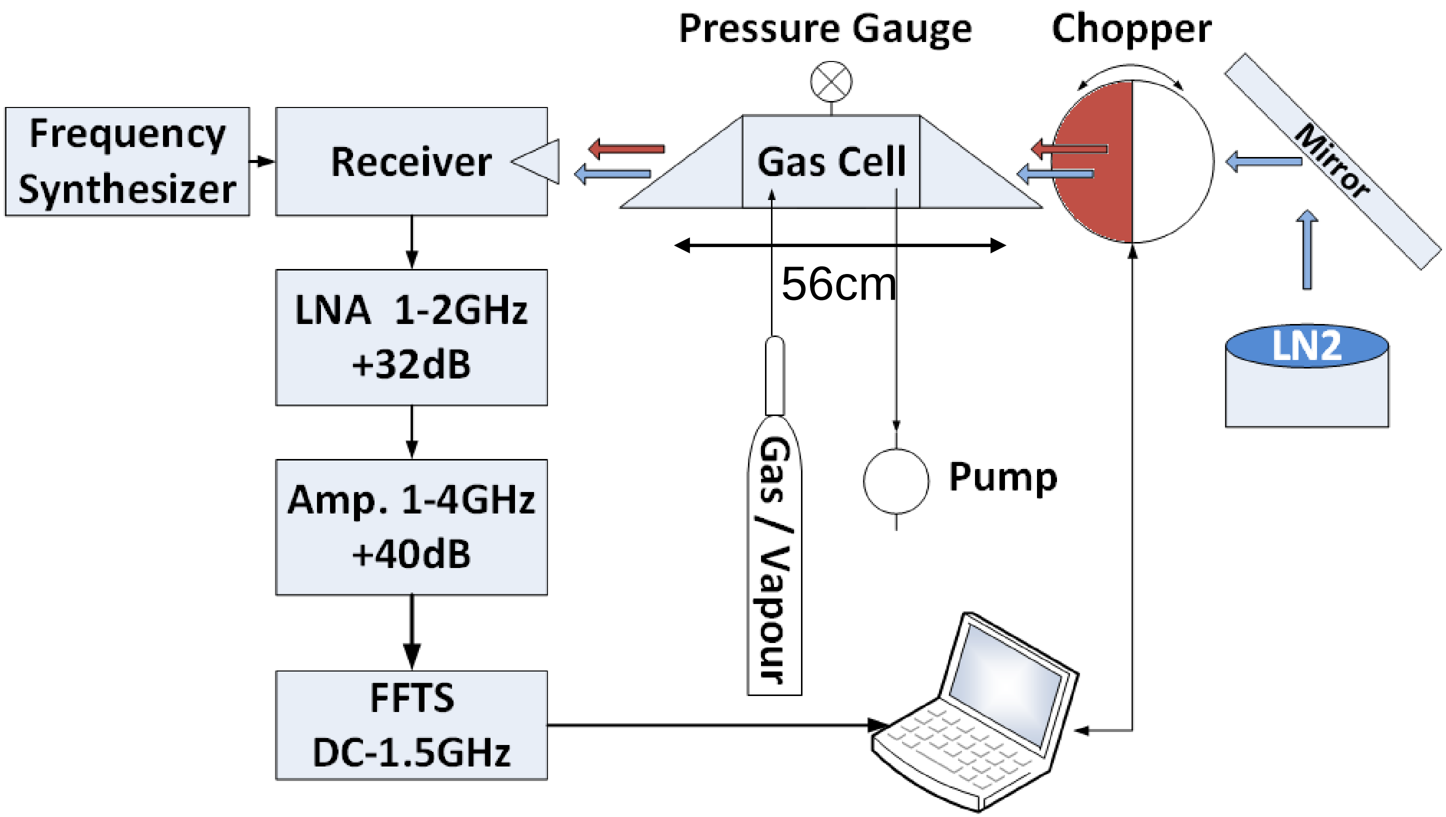


- confocal distance
  $$z_c = \frac{\pi w_0^2}{\lambda} \cong 7.4mm$$
- waist
  $$w_0 \cong 1.14mm$$
- asymptotic beam growth angle
  $$\Theta \cong \frac{\lambda}{\pi w_0} \cong 8.8°$$

Application

Spectroscopy

Setup

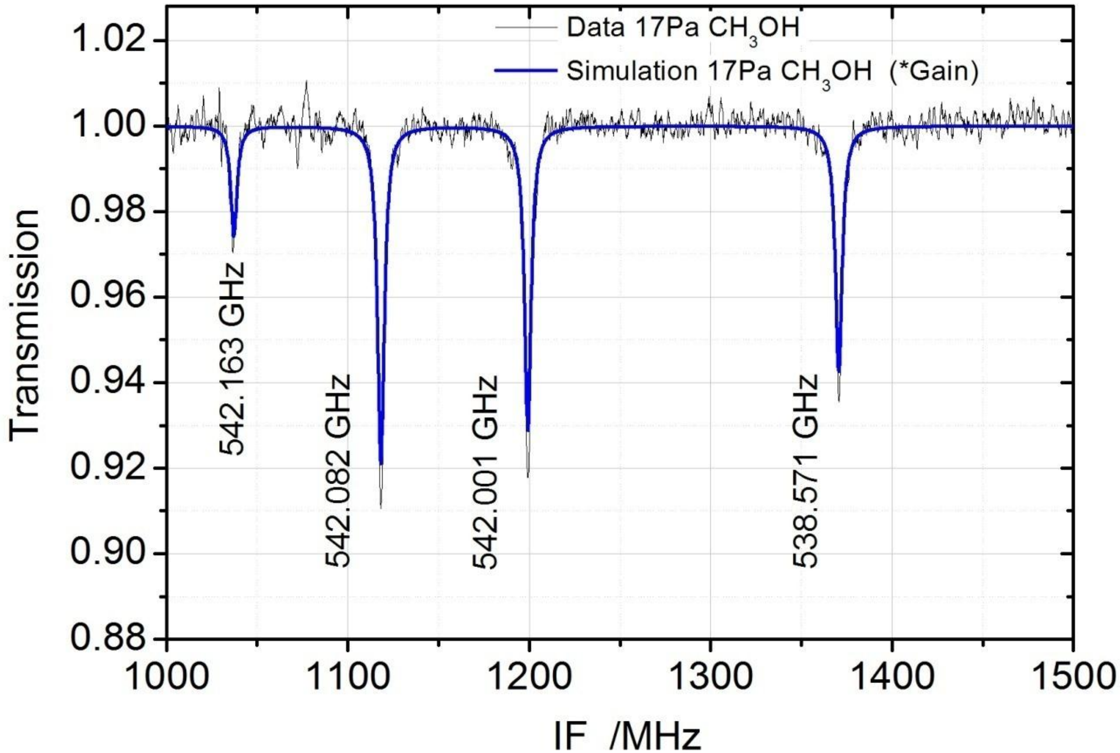


Application

Spectroscopy

Results

CH_3OH Spectroscopy



CH_3OH

$$T = \frac{S_{gas}^{hot} - S_{gas}^{cold}}{S_{empty}^{hot} - S_{empty}^{cold}}$$

t_{int} = 9.96 s

P = 17 Pa

f_{LO} = 15 GHz

f_{Signal} = 540.2 GHz

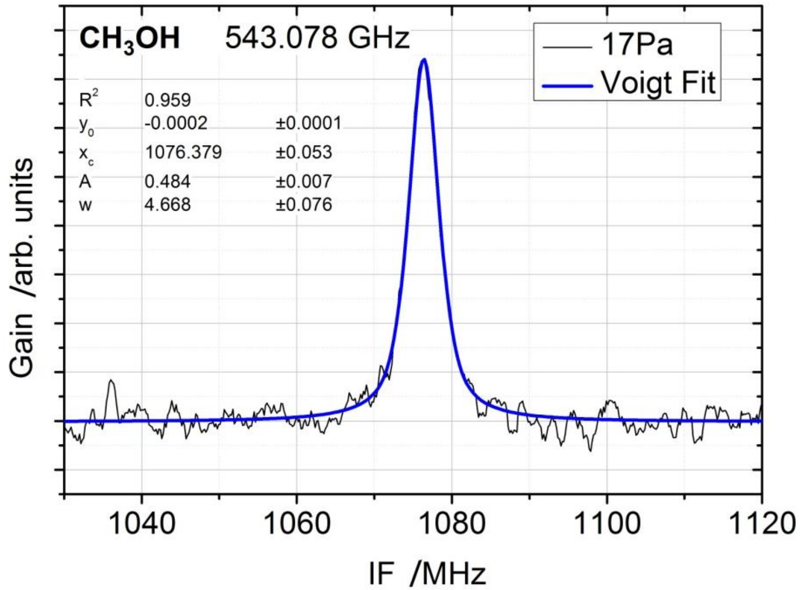
Simulation with HITRAN

Application

Spectroscopy

Results

CH_3OH Line Broadening



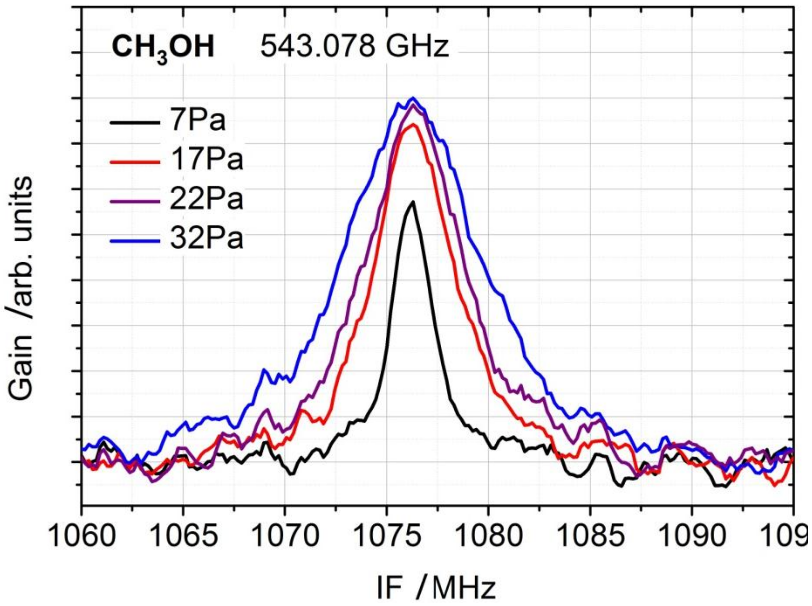
$$G = \frac{S_{empty}^{hot} - S_{empty}^{cold}}{S_{gas}^{hot} - S_{gas}^{cold}} - 1$$

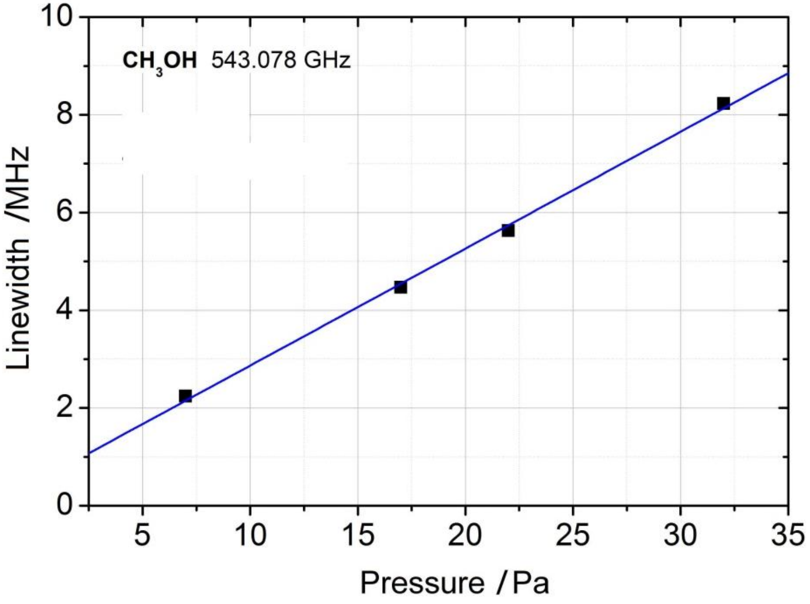
Application

Spectroscopy

Results

CH_3OH Line Broadening





$$G = \frac{S_{empty}^{hot} - S_{empty}^{cold}}{S_{gas}^{hot} - S_{gas}^{cold}} - 1$$

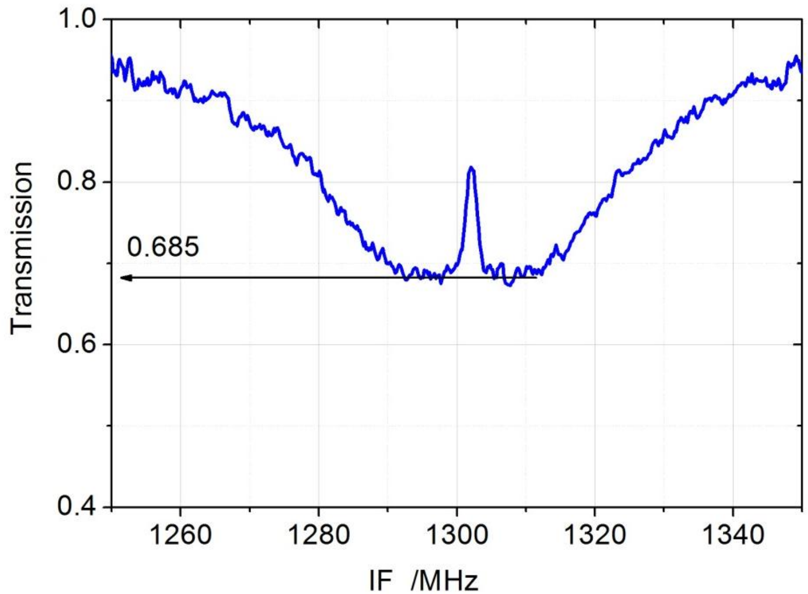
$$\gamma = 240 \, \frac{kHz}{Pa}$$

Application

Spectroscopy

Results

H_2O Spectroscopy / Sideband Gain



H_2O

$$T = \frac{S_{gas}^{hot} - S_{gas}^{cold}}{S_{empty}^{hot} - S_{empty}^{cold}}$$

t_{int} = 9.96 s

P = 22 Pa

f_{LO} = 15.43 GHz

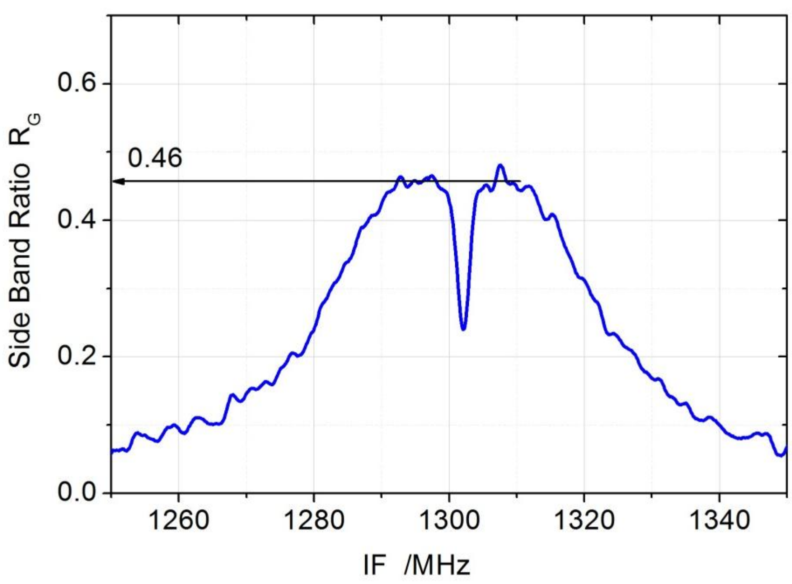
f_{Signal} = 555.6 GHz

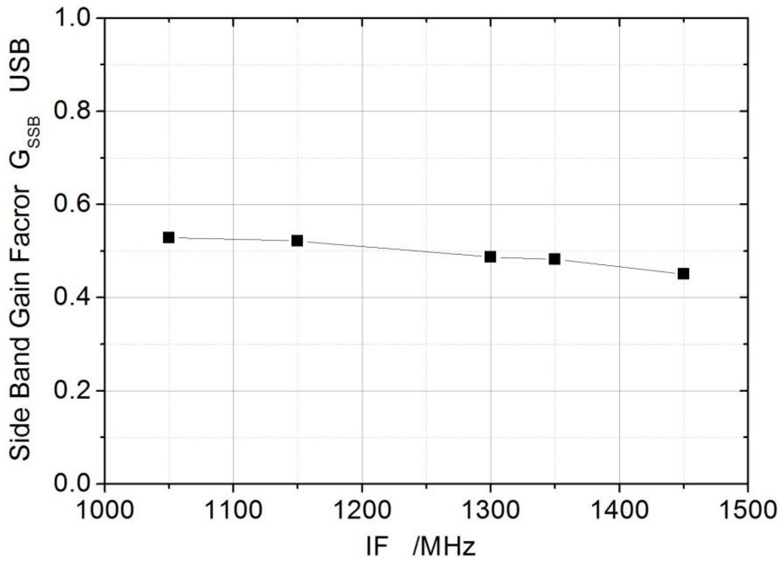
Application

Spectroscopy

Results

H_2O Spectroscopy / Sideband Gain





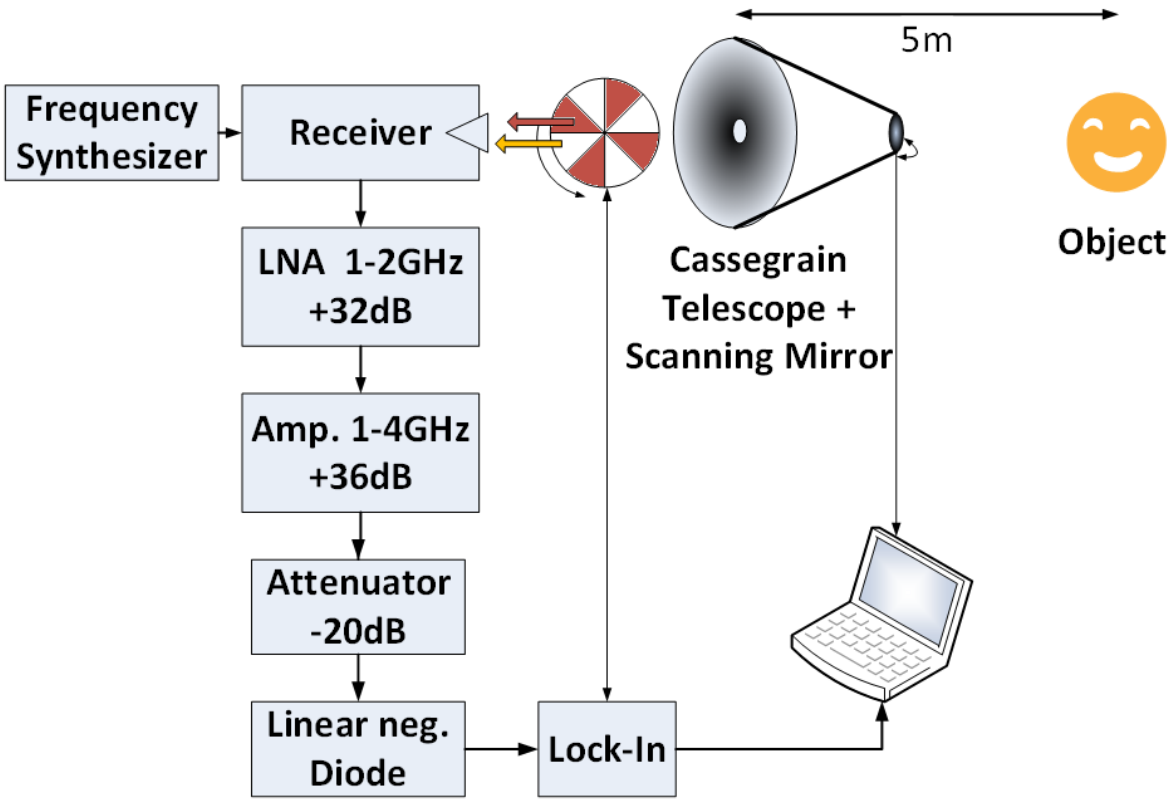
$$R_G = \frac{S_{empty}^{hot} - S_{empty}^{cold}}{S_{gas}^{hot} - S_{gas}^{cold}} - 1$$

$$G_{ssb}^{upper} = \frac{1}{1 + R_G}$$

Application

Passive Imaging

Setup



- LO-Frequency
  f_{LO}=15.138GHz (545GHz)
- Cassegrain Telescope
  $Ø_{prime}$ = 76cm
  $Ø_{second}$ = 11cm
  $Ø_{Field\ of\ View}$ = 1m

  x_{Object} = 5m

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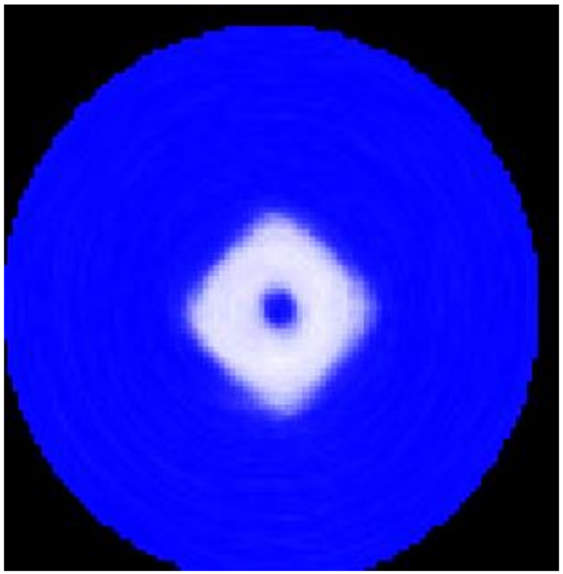
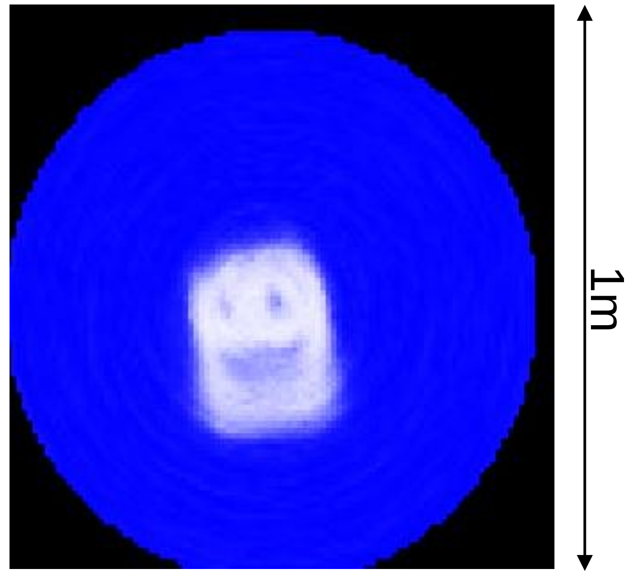
Application

Passive Imaging

Results



cold Ecosorb square with hole



cold Ecosorb face with eyes and mouth

Conclusion

Mixer	RT heterodyne receiver
	Subharmonic Schottky diode mixer
	Compact, light weight
	T_{sys} (545GHz) = 2000 K
LO	Power Amplifier mHEMT MMIC
	HBV tripler
Appl.	Spectroscopy CH_3OH, H_2O
	Passive Imaging

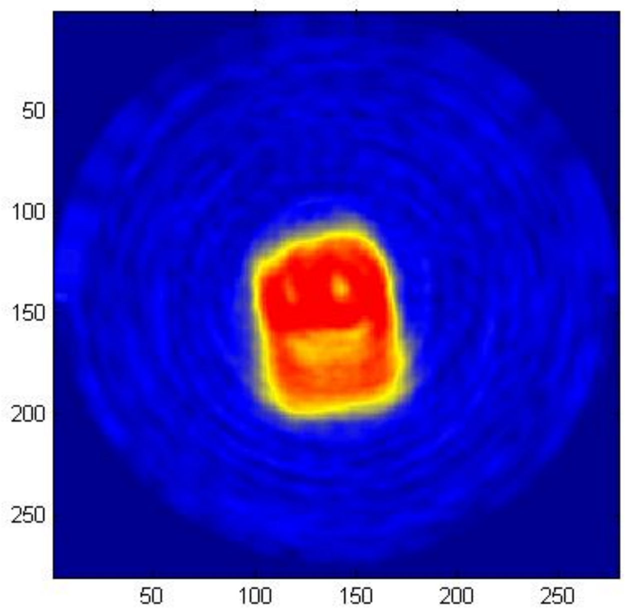
Thank you

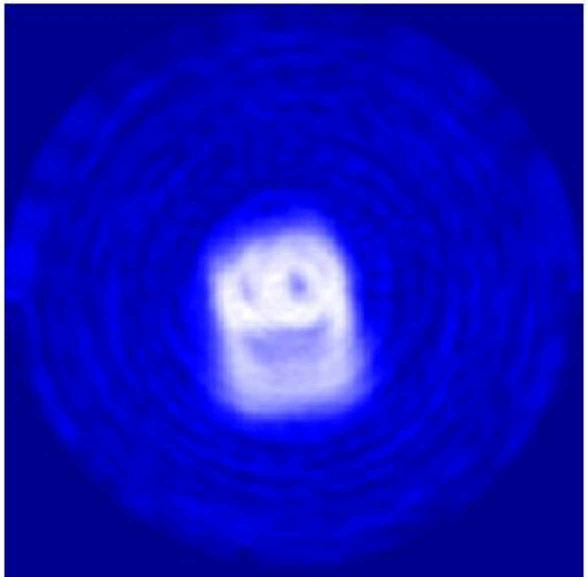
for your attention

www.fp7-teracomp.eu (Grant agreement no.: 242424)

Passive Imaging

Results



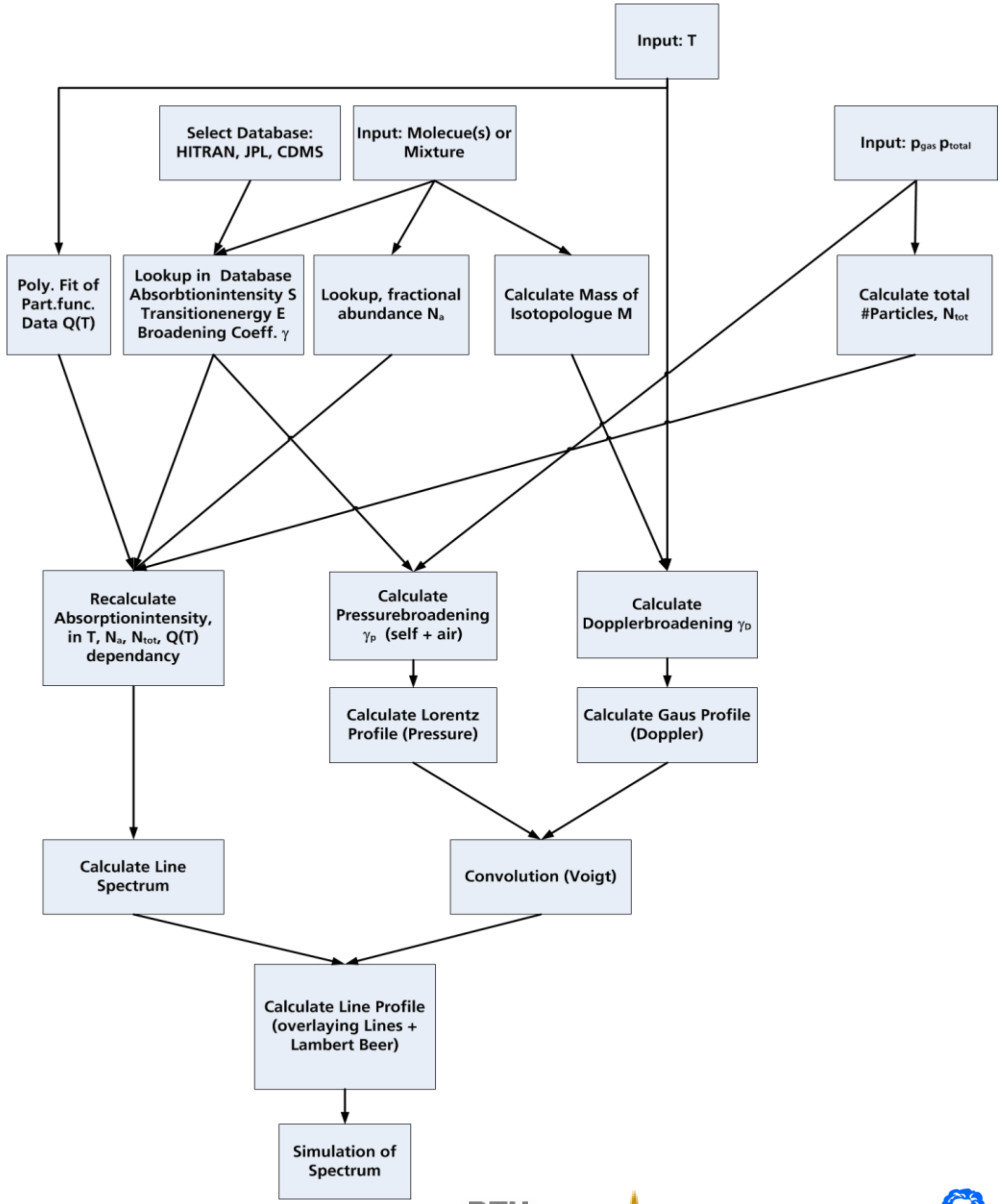


cold Ecosorb face with eyes and mouth

Flowchart

Simulation

Programme



Spectroscopy *Lineprofile, Broadening, Fitting*

Pressure (Lorentz) $\delta\upsilon_{Lorentz} = \gamma_{self} \cdot P$

Doppler (Gauß) $\delta\upsilon_{Doppler} = \frac{\upsilon_0}{c}\sqrt{\frac{2(\ln 2)k_B T}{M}}$

} Voigt

Integrated Abs.-Intensity S_{DB}

Abs.coef. $\alpha \propto \frac{S_{DB} \cdot P}{T \cdot \delta\upsilon_{Lorentz}}$

Lambert Beer Law $\frac{I}{I_0} = \exp\left(-\alpha \cdot L\right)$

Formulas

HITRAN Calculation

HITRAN Intensity

$$S = S_V^N \cdot N = \frac{h\upsilon_{if}}{c}\left[1-\exp\left(-\frac{c_2\upsilon_{if}}{T}\right)\right]\cdot\frac{g_i I_a}{Q(T)}\exp\left(-\frac{c_2 E_i}{T}\right)B_{if}\cdot N$$

$$[S] = \frac{1}{cm^2}$$

Lambert Beer Law

$$I = I_0 \exp(-\alpha \cdot L)$$

$$[S_V^N] = \frac{cm}{\# Molec}$$

Voigt-Profile (normalized)

$$\int_{-\infty}^{\infty}\phi(\upsilon-\upsilon_0)d(\upsilon-\upsilon_0)\overset{!}{=}1$$

$$[N] = \frac{\# Molec}{cm^3}$$

Absorption Coefficient

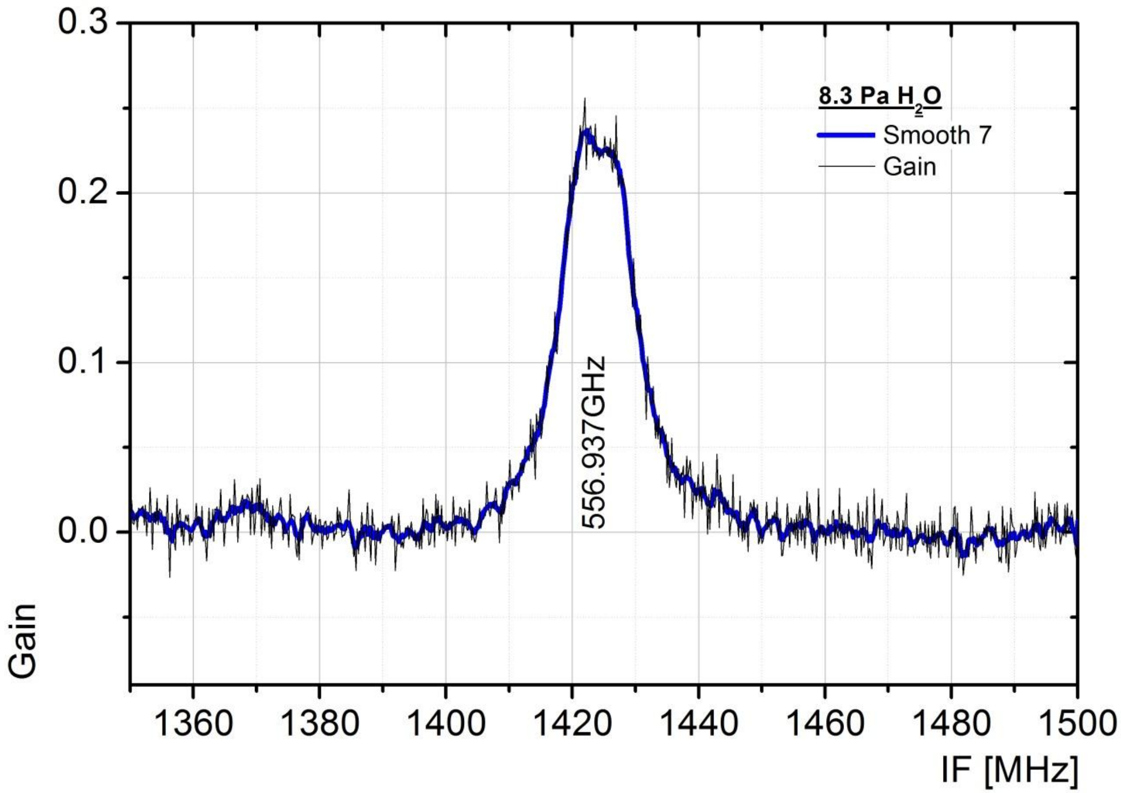
$$\alpha(\upsilon-\upsilon_0) = S\cdot\phi(\upsilon-\upsilon_0)$$

$$[\phi] = cm$$

Application

Spectroscopy

Results



H_2O

$$G = \frac{S_{empty}^{hot} - S_{empty}^{cold}}{S_{gas}^{hot} - S_{gas}^{cold}} - 1$$

$$G = \frac{1}{T} - 1$$

t_{int} = 9.96 s

P = 8.3 Pa

Gain = 0.235

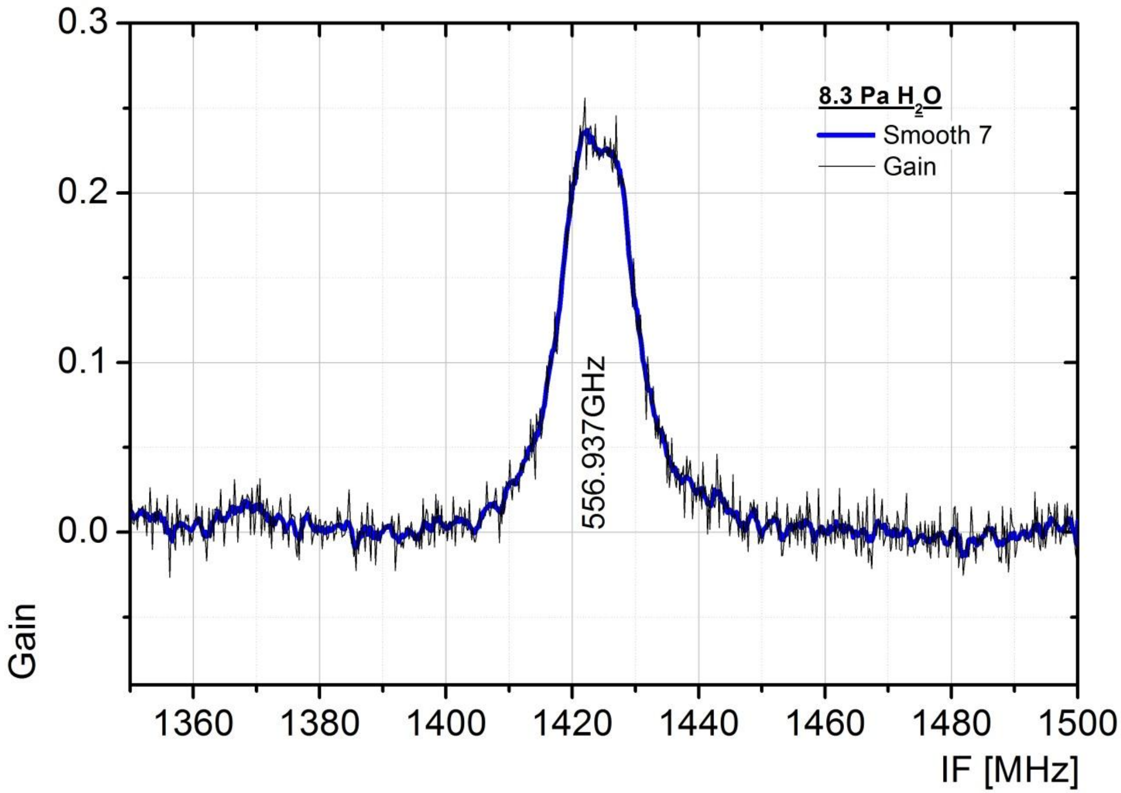
f_{LO} = 15.43089 MHz

f_{Signal} = 555.512 GHz

Application

Spectroscopy

Results



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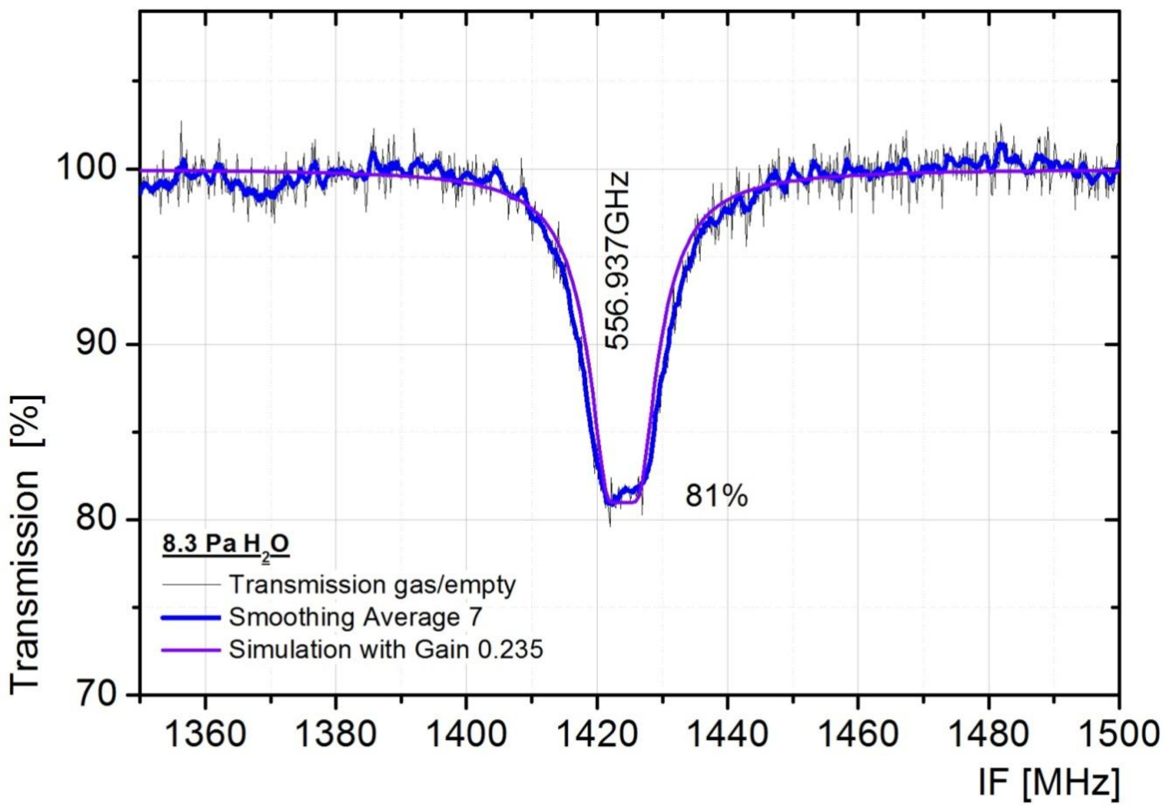
Application

Spectroscopy

Results



H_2O

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t_{int} = 9.96s

P = 8.3Pa

Gain = 0.235

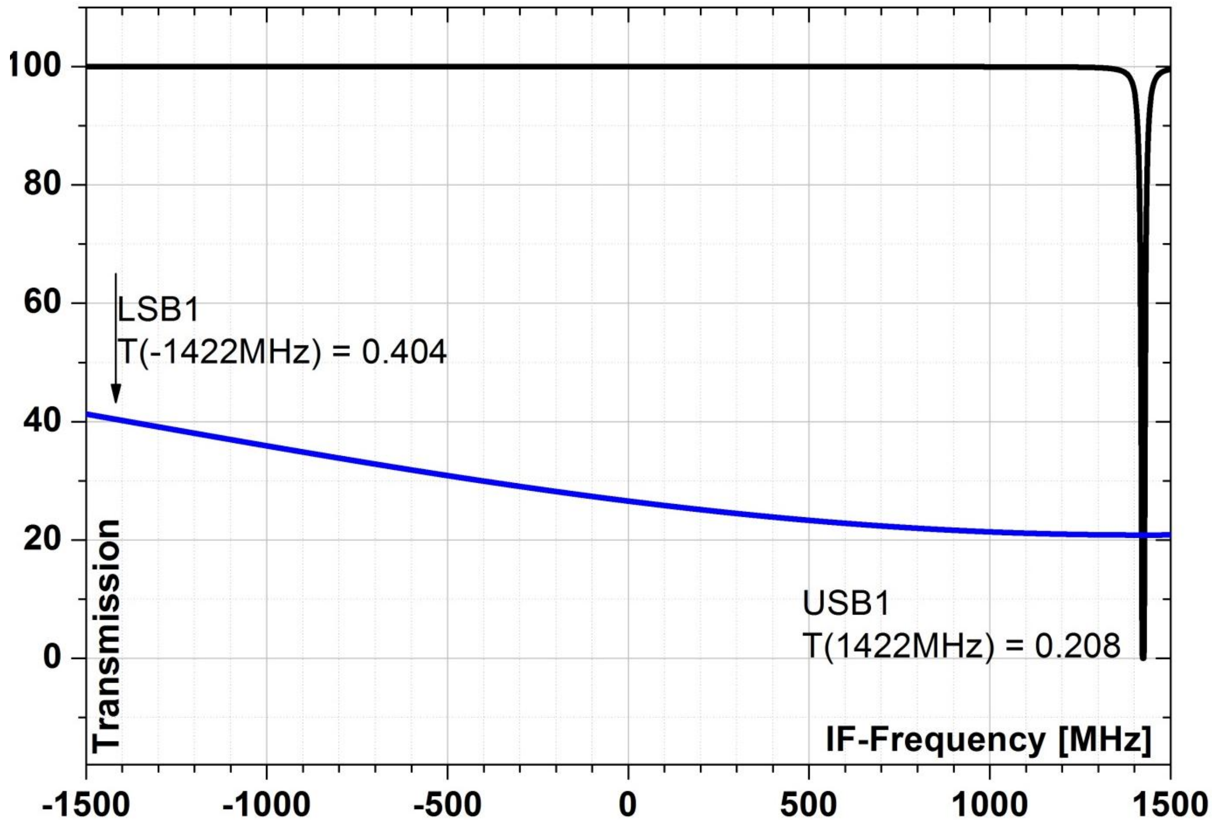
f_{LO} = 15.43MHz

f_{Signal} = 555.5GHz

Application

Spectroscopy

Results



H_2O

Simulation of 556.94 GHz H2O-Line in ambient air.

DB HITRAN

P_{H2O} = 2230Pa

P_{total} = 100500Pa

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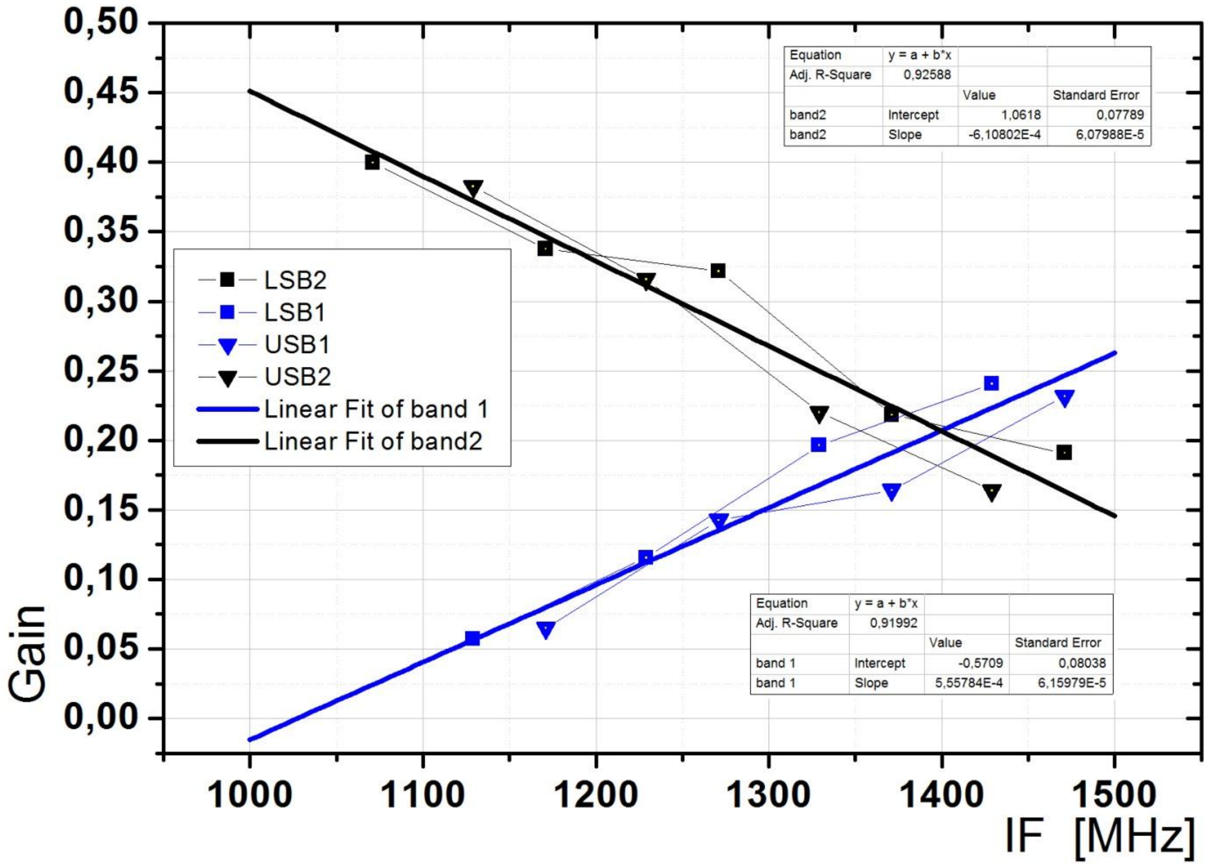
Application

Spectroscopy

Results



Sideband Gains

Upper / Lower

Sideband + aliasing

Spectroscopy

Gain