Superconducting Integrated Submm Wave Receiver

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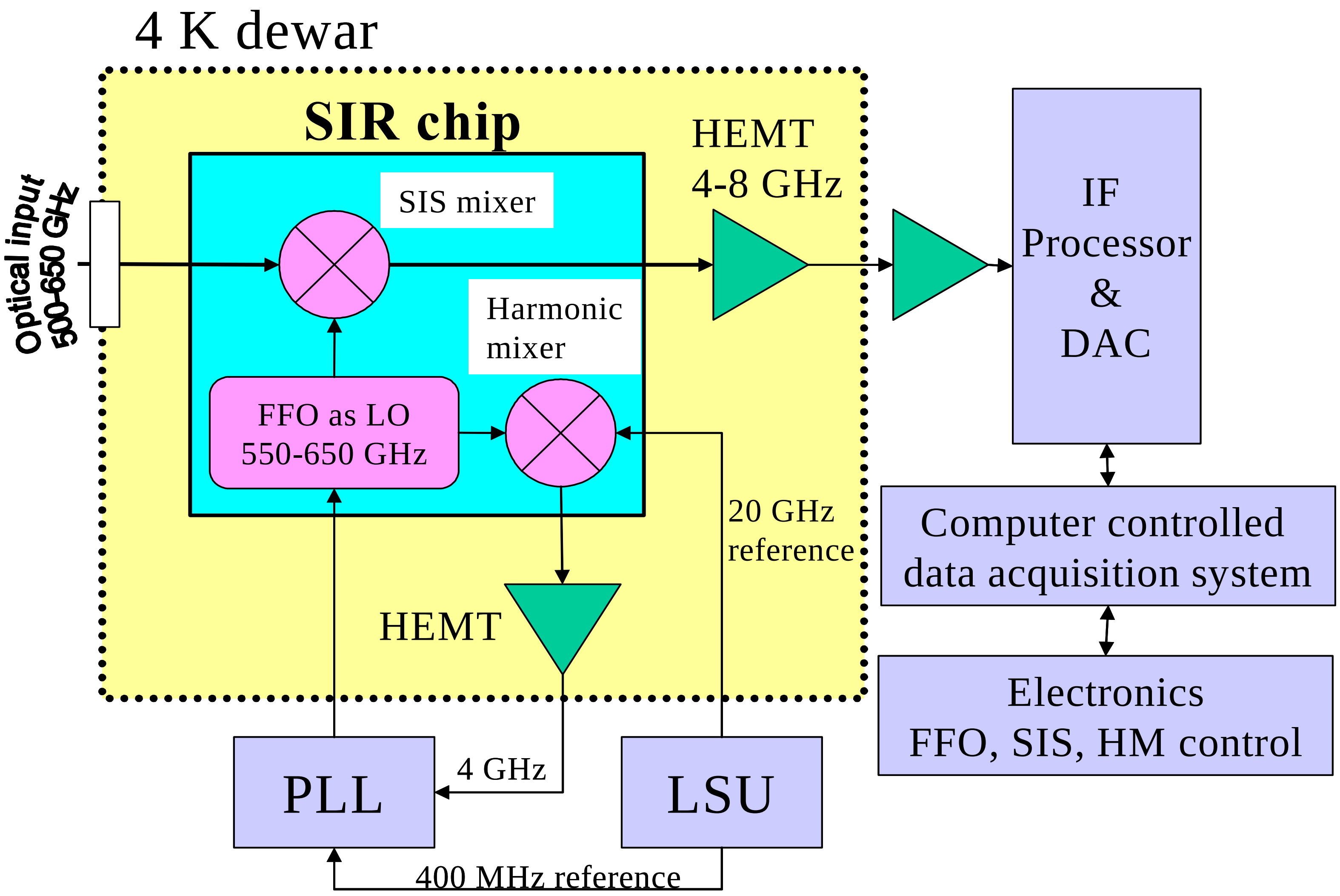
Superconducting Integrated Submm Wave Receiver

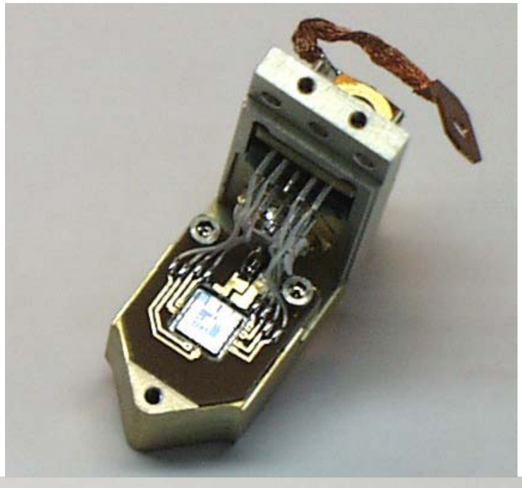
Outline

- Superconducting Integrated Receiver (SIR)
- Flux Flow Oscillator (FFO) for SIR
- Nb-AlN-NbN FFO – first implementation
- TErahertz LImb Sounder (TELIS) project
- TELIS SIR channel design
- SIR channel performance
- Future applications
- Conclusion

Superconducting Integrated Receiver (SIR) with phase-locked FFO



Superconducting Integrated Receiver (SIR)



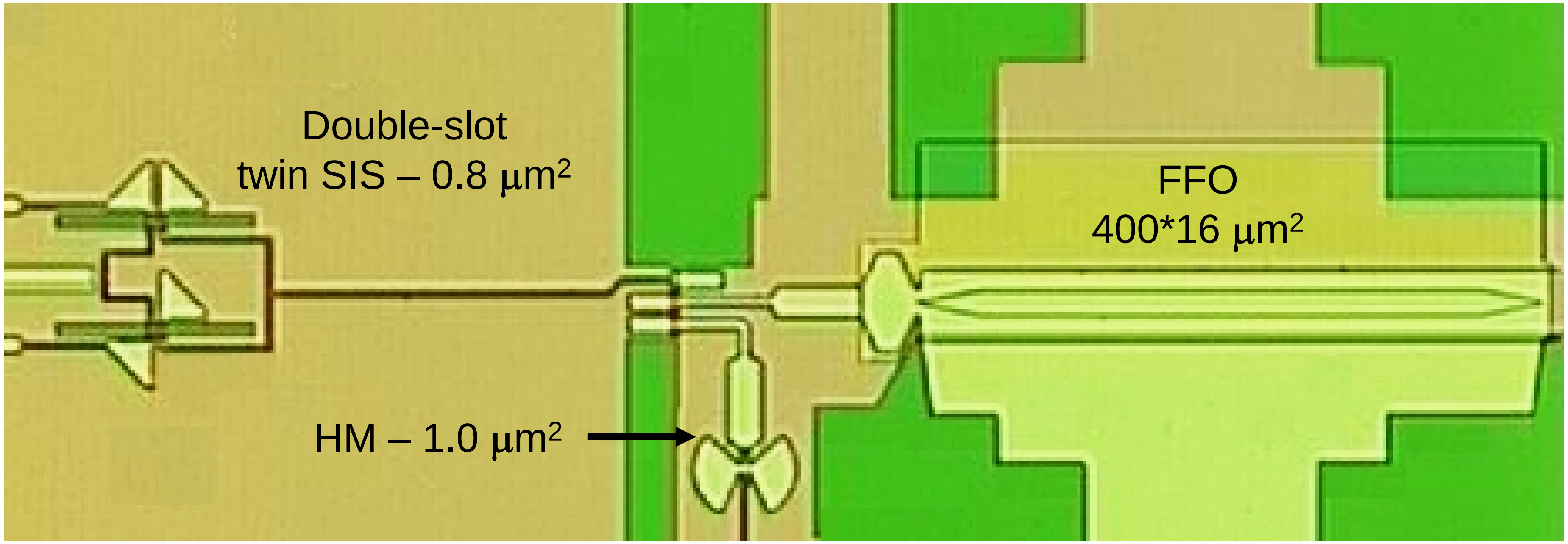
STATE OF THE ART (2002)

- **Single chip Nb-AlOx-Nb SIS receivers with superconducting FFO have been studied at frequencies from 100 to 700 GHz;**
- **A DSB receiver noise temperature as low as 90 K has been achieved at 500 GHz;**
- **9-pixel Imaging Array Receiver has been successfully tested;**
- **FFO Phase Locking (PLL) up to 700 GHz.**

APPLICATIONS

- **Airborne Receiver for Atmospheric Research and Environmental Monitoring; Radio Astronomy**
- **Focal Plane Array Receivers;**
- **Laboratory submm wave Spectrometers.**

Internal part of the SIR Microcircuit

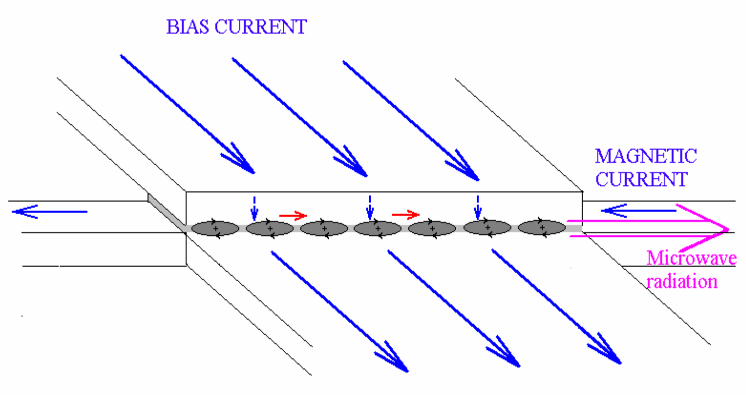


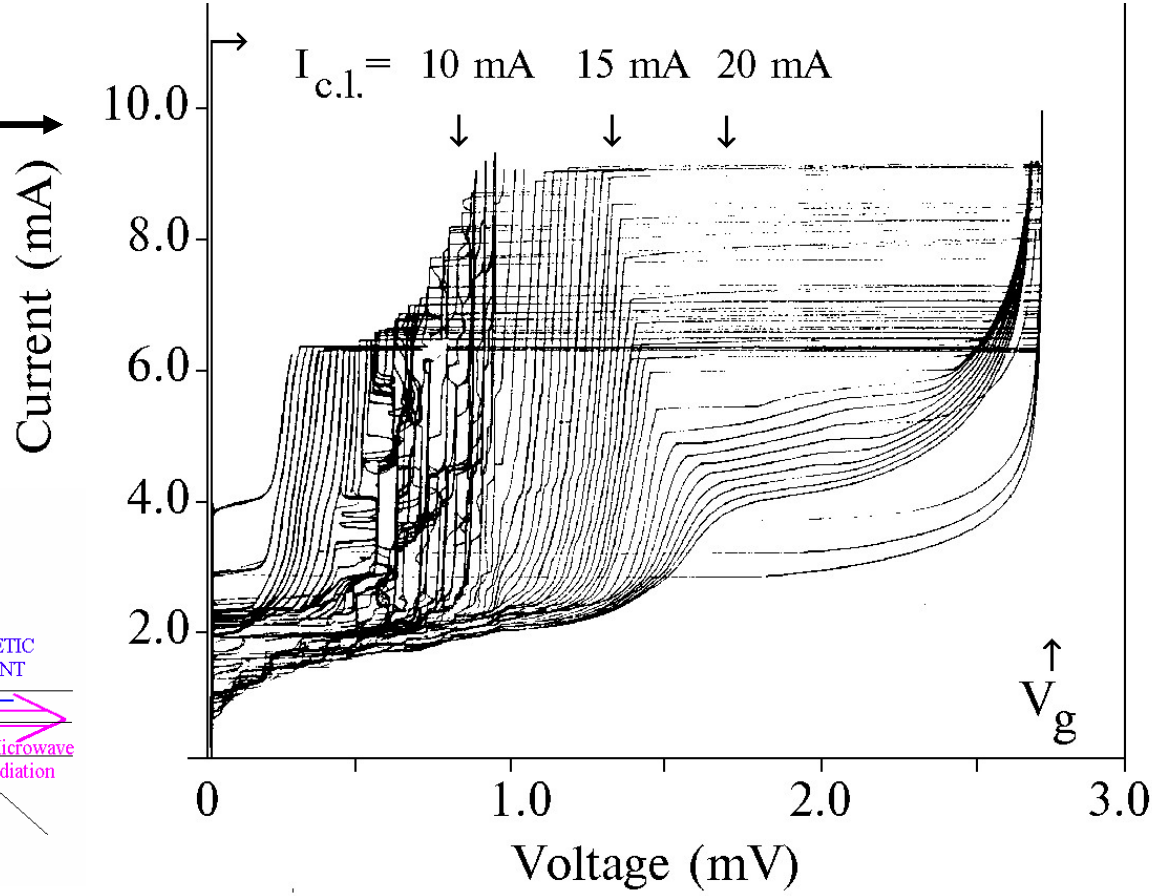
Nb-AlOx-Nb or Nb-AlN-NbN;   Jc = 5 - 10 kA/cm^2

Optionally: SIS – Jc = 8 kA/cm^2; FFO + HM = 4 kA/cm^2

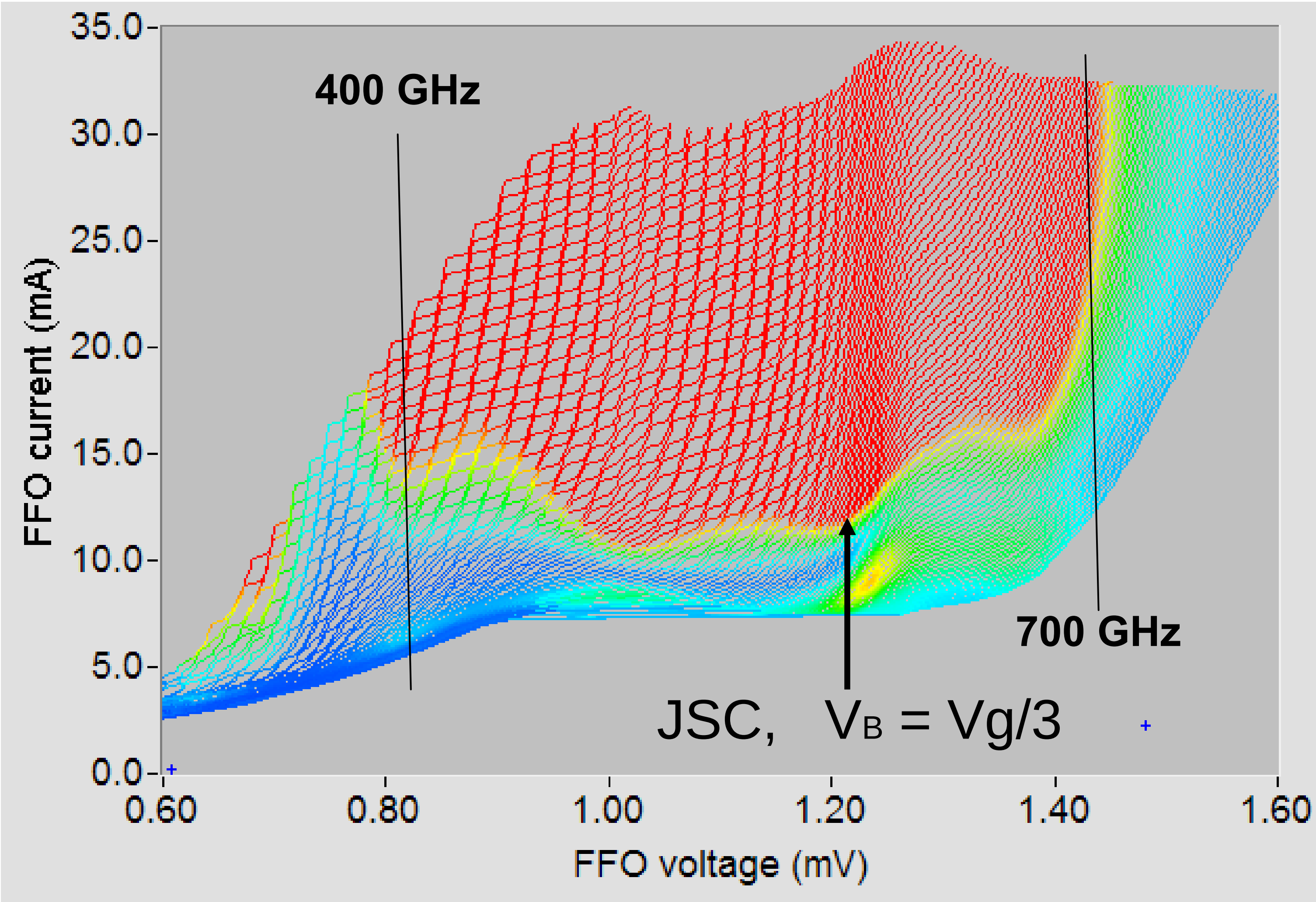
IVCs of the FFO measured at different magnetic fields

International Conference on Nonlinear Superconducting Devices and HTc Materials, Capri-94

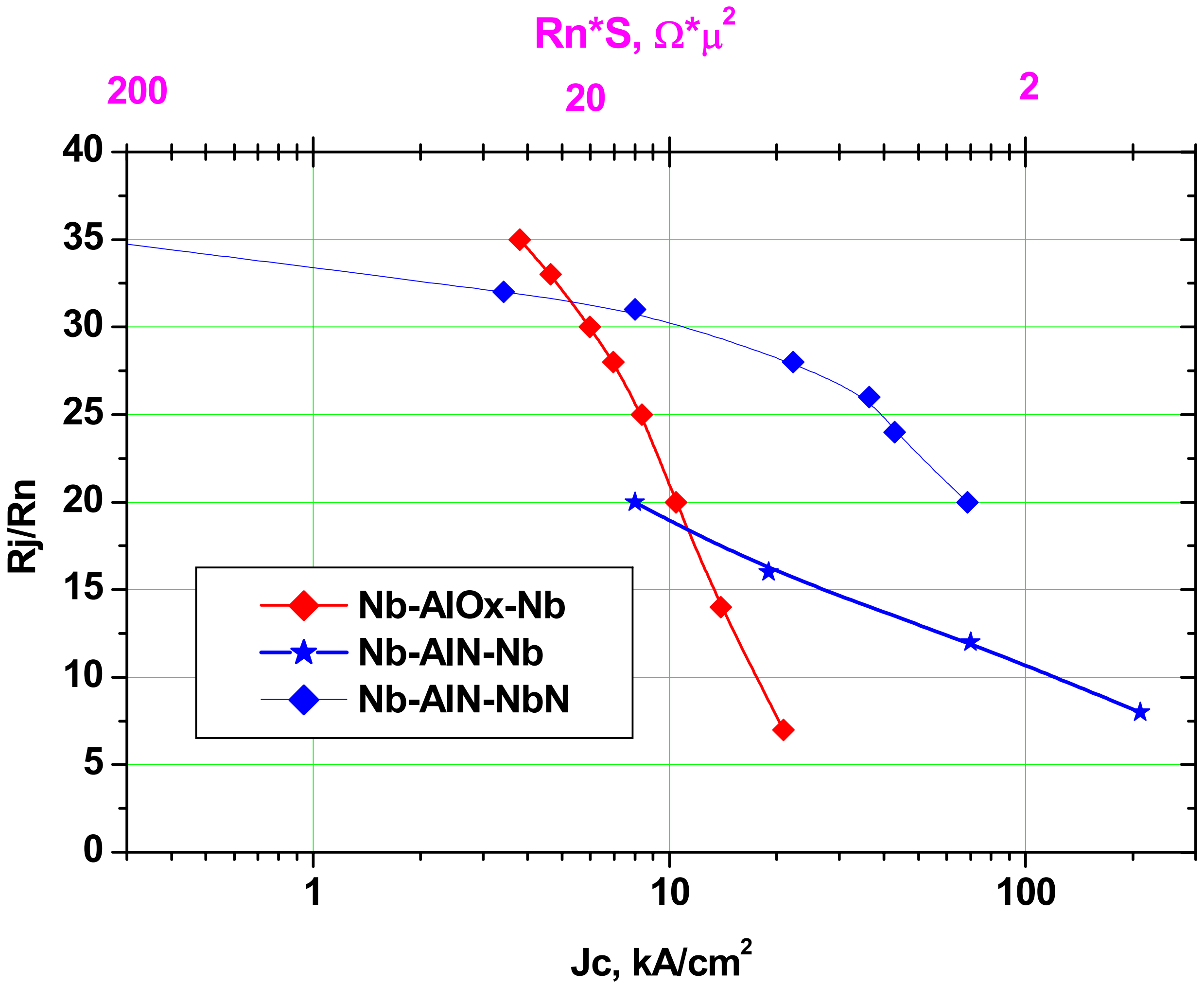




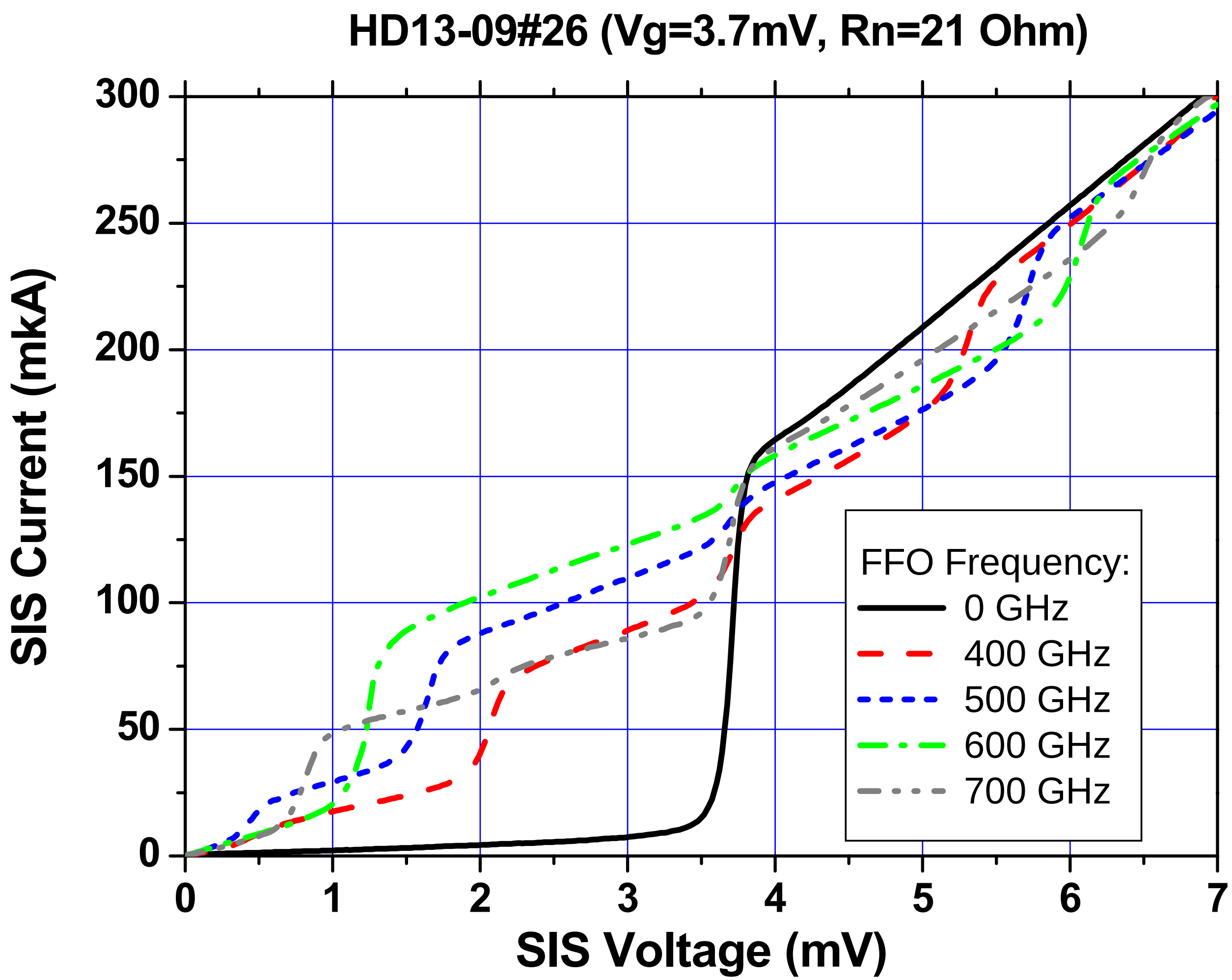
Nb-AlN-NbN FFO for SIR; new features



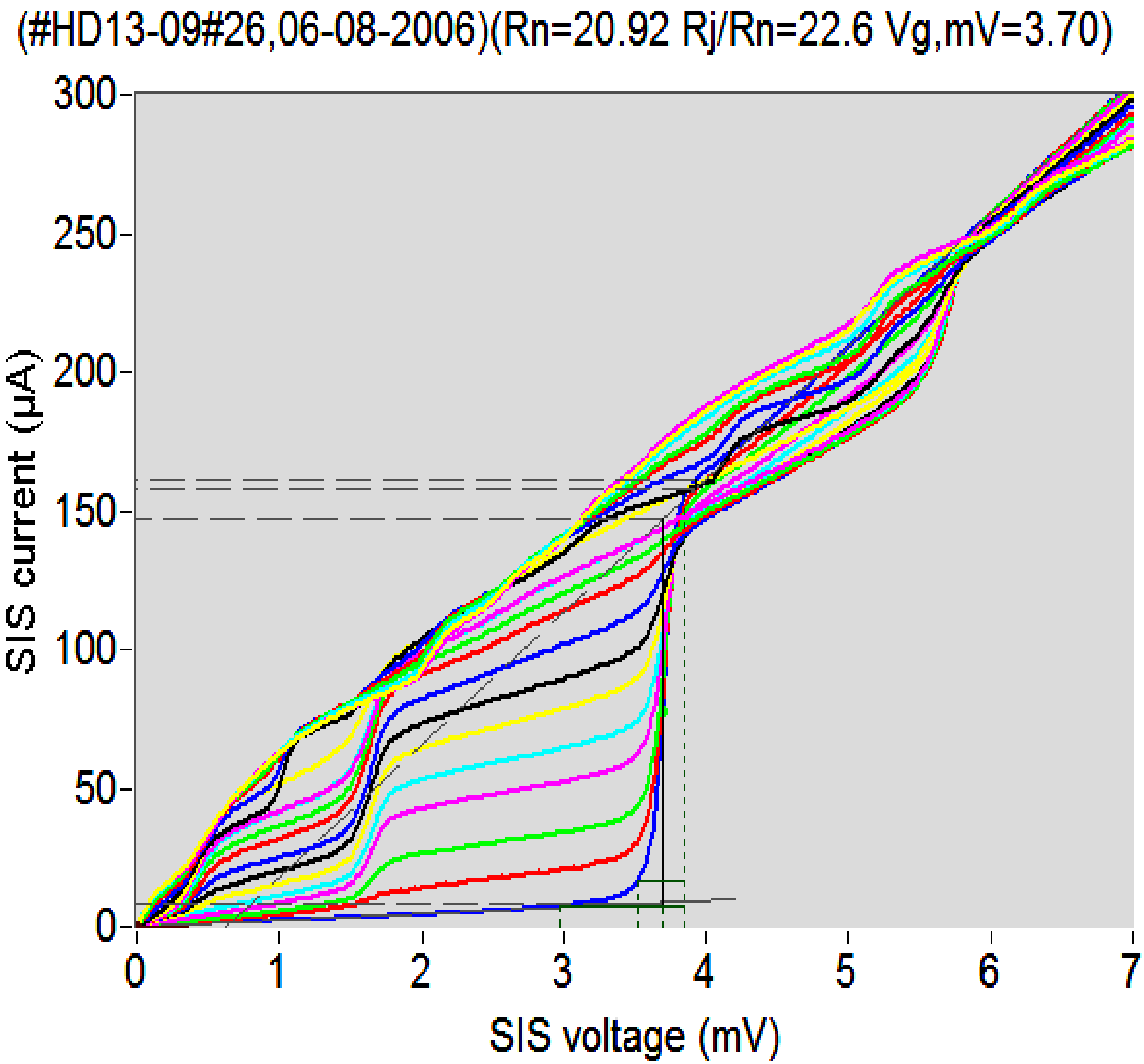
Quality of the AlOx and AlN tunnel barriers on the current density



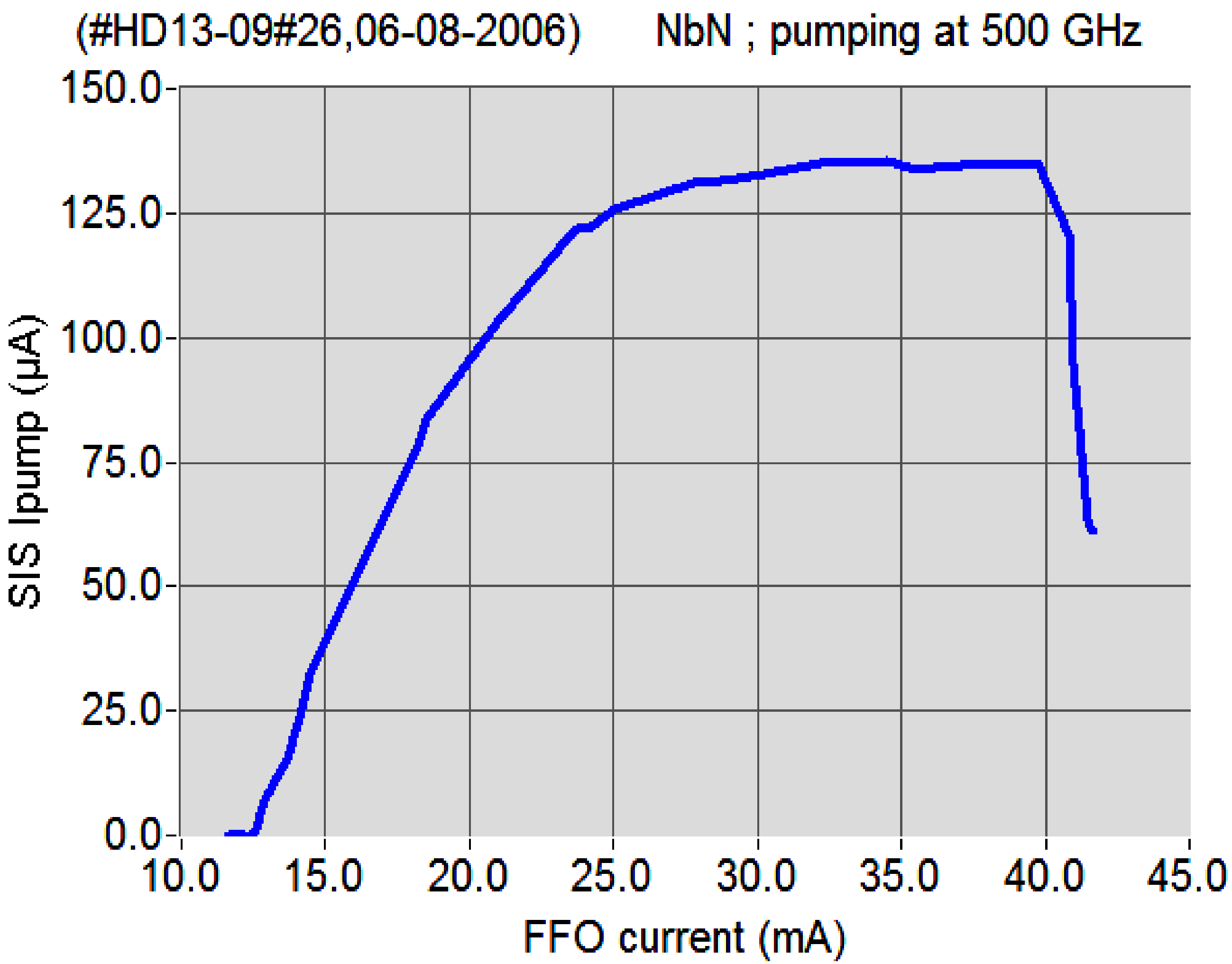
Nb-AlN-NbN SIS pumped by FFO; FFO frequency tuning



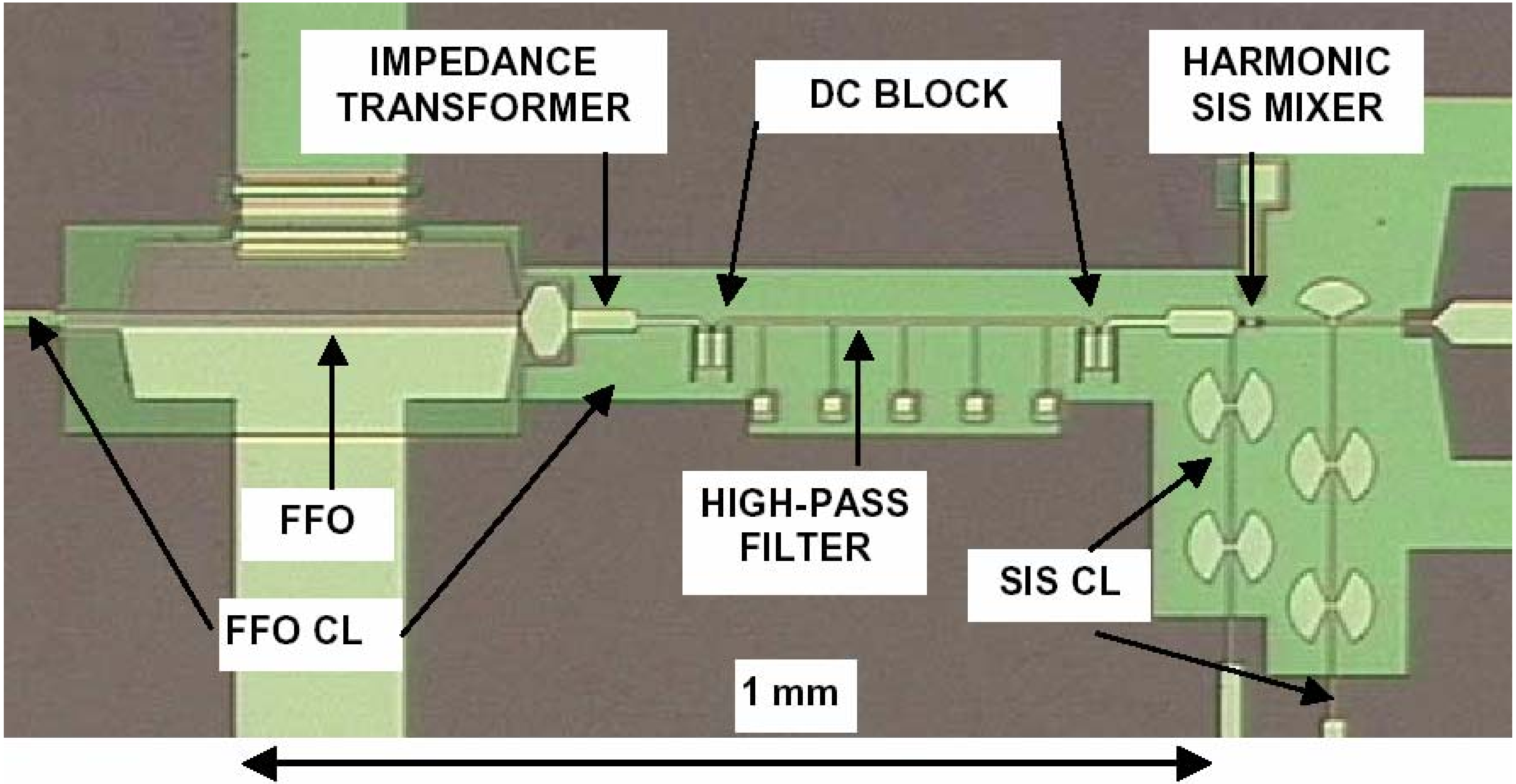
A set of the SIS IV-curves, pumped by FFO at 500 GHz



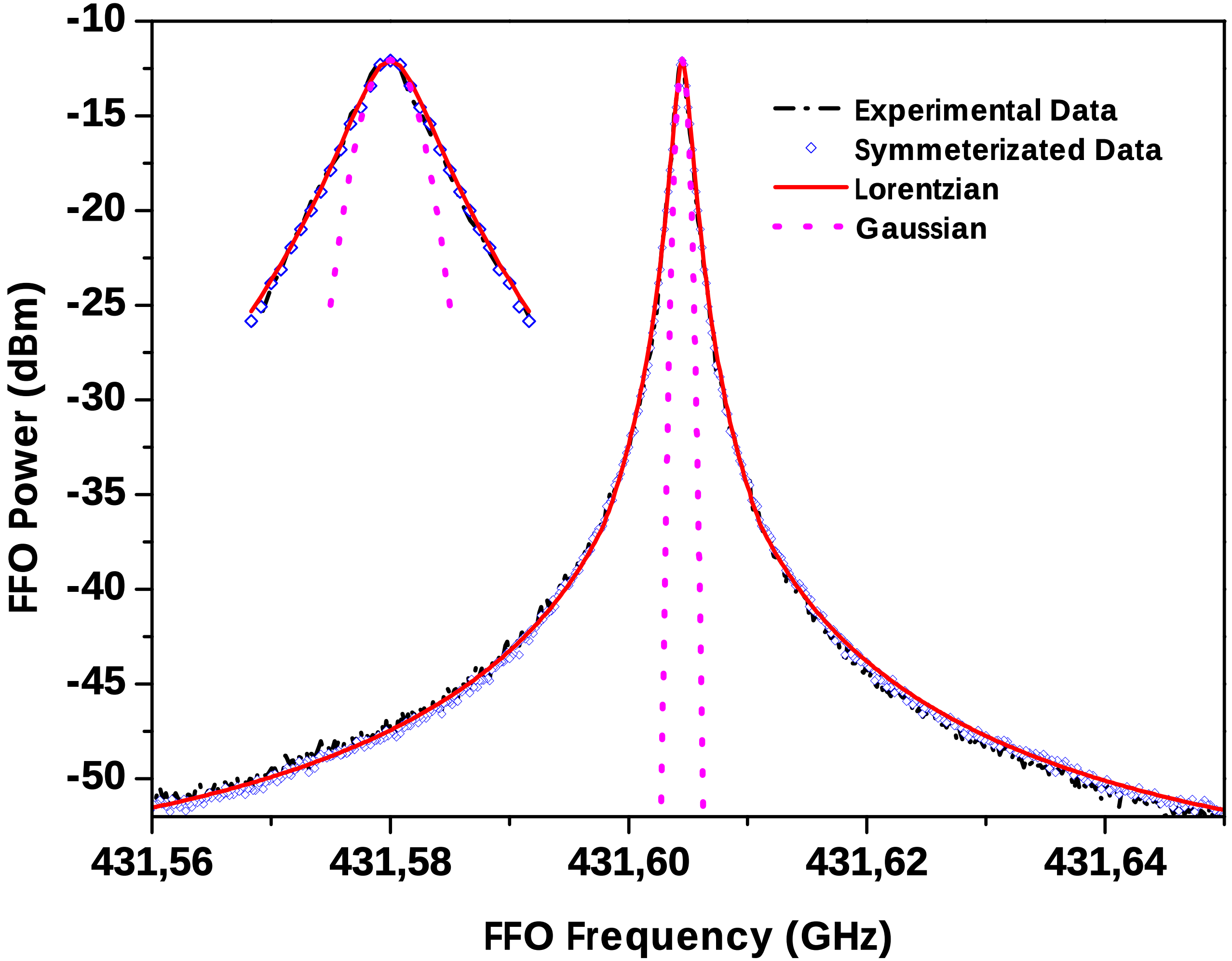
SIS mixer pumping at different Nb-AlN-NbN FFO bias (output power) setting



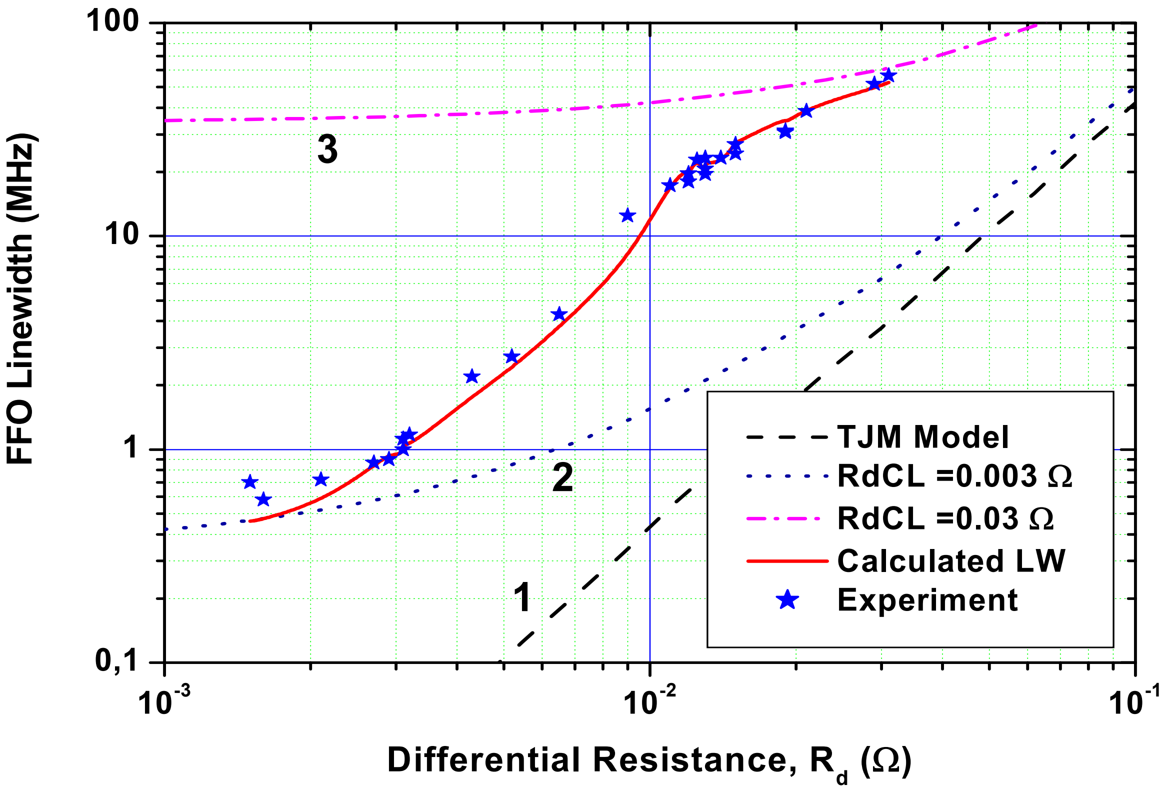
Circuit for FFO Linewidth Study & PL



Example of FFO Spectrum



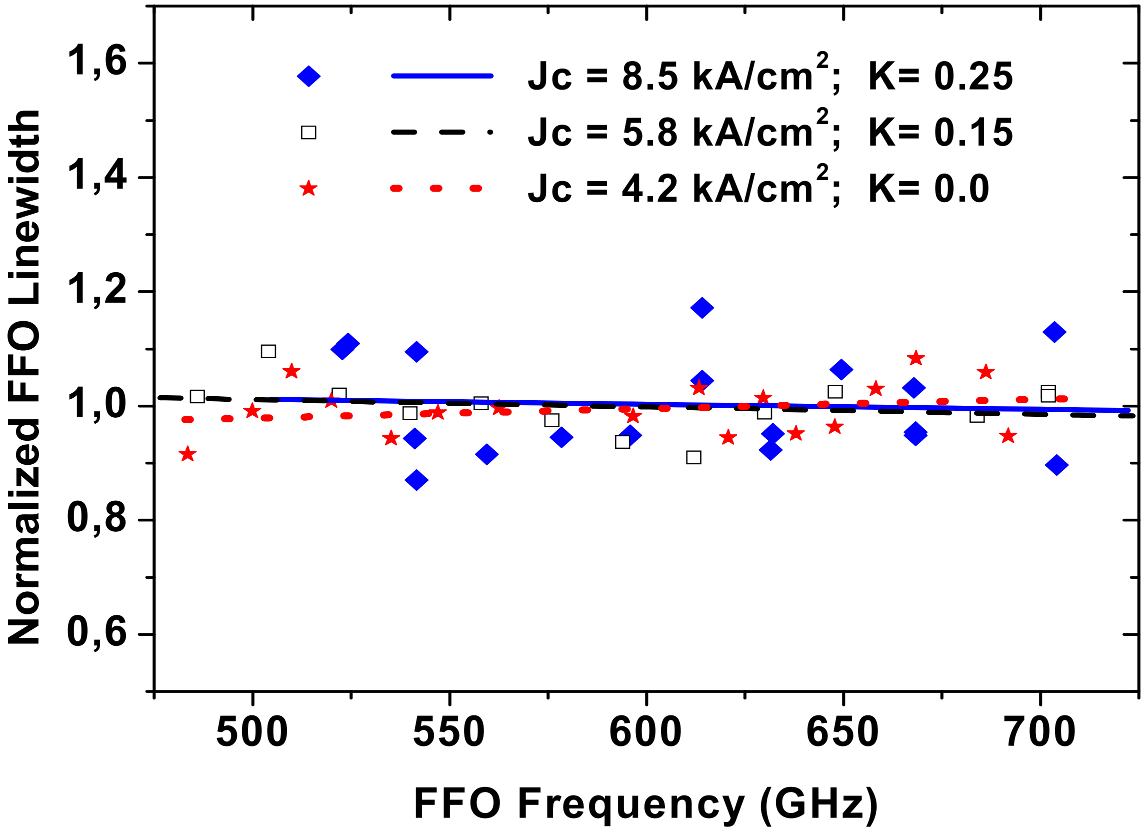
FFO linewidth



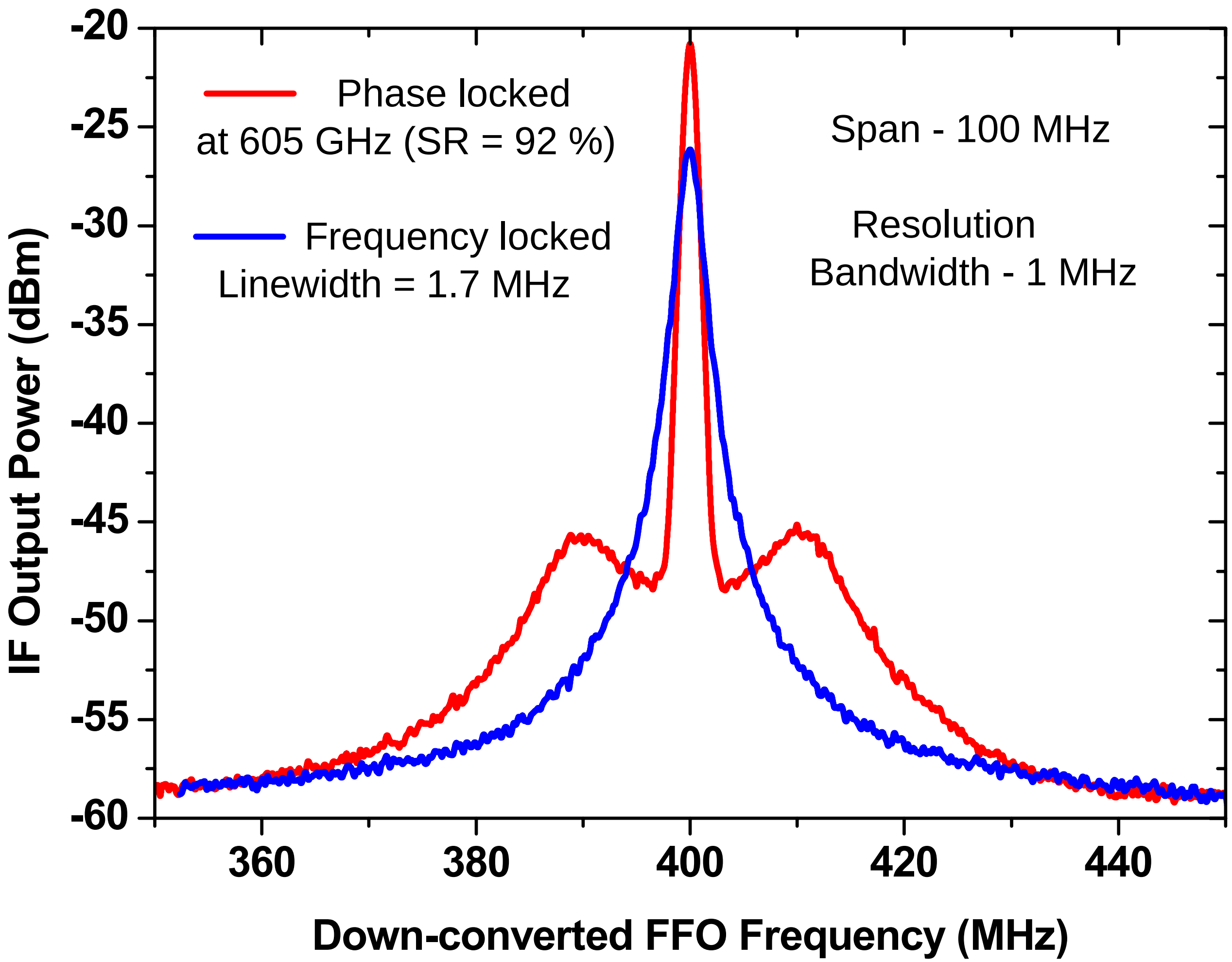
$$\Delta f = (Rd_B + K * Rd_{CL})^2 \left(\frac{2e}{h}\right)^2 \left[\frac{e * I_{qp}}{2\pi} \coth\left(\tfrac{eV}{2kT}\right) + \frac{e * I_S}{\pi} \coth\left(\tfrac{eV}{kT}\right)\right]$$

Normalized FFO Linewidth

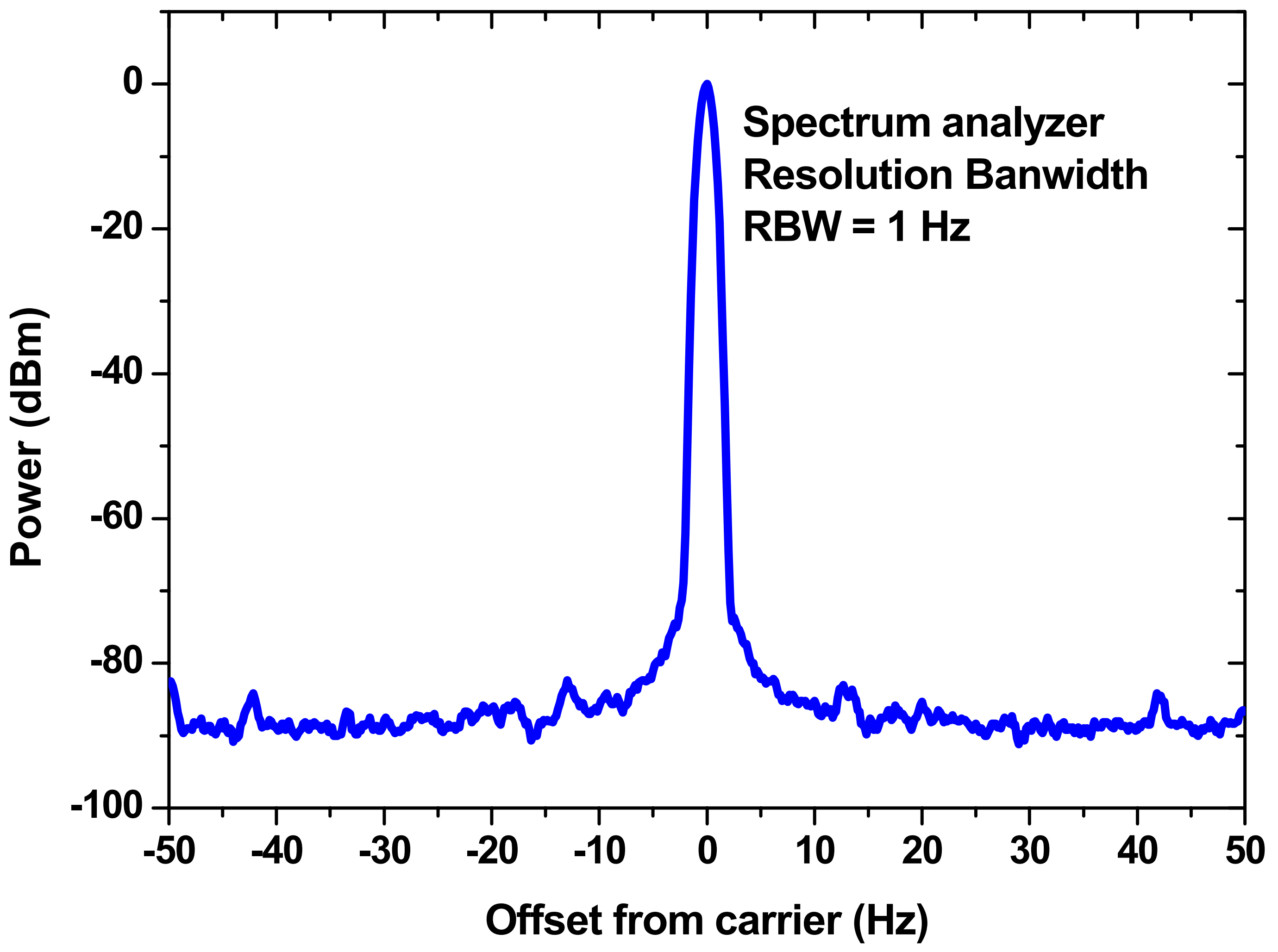
$$\Delta f := \left(\frac{2\cdot e}{h}\right)^2 \cdot \left(R_d + K\cdot R_{dCL}\right)^2 \cdot \left[\frac{e\cdot(Iqp)}{2\cdot\pi}\cdot\coth\left(\frac{e\cdot V}{2\cdot k_b\cdot T}\right) + \frac{2\cdot e\cdot(Is)}{2\cdot\pi}\cdot\coth\left(\frac{e\ V}{k_b\cdot T}\right)\right] + \frac{1}{\pi}\cdot\left(\frac{2\cdot e}{h}\right)\cdot\left(R_d + R_{dCL}\right)\cdot I_{lf}$$



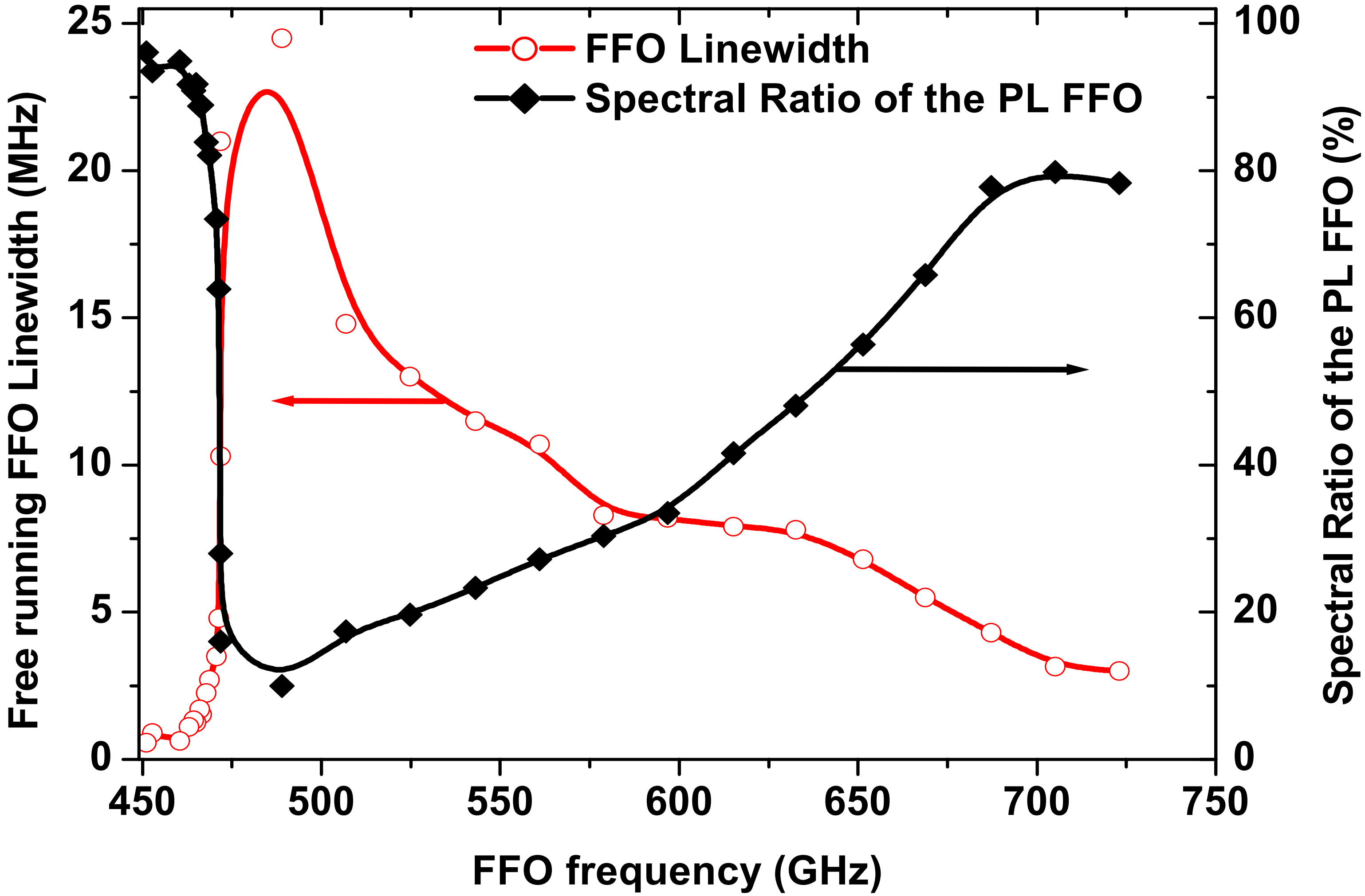
FL and PL spectra of the Nb-AlN-NbN FFO : frequency 605 GHz; LW = 1.7 MГц; SR = 92 %



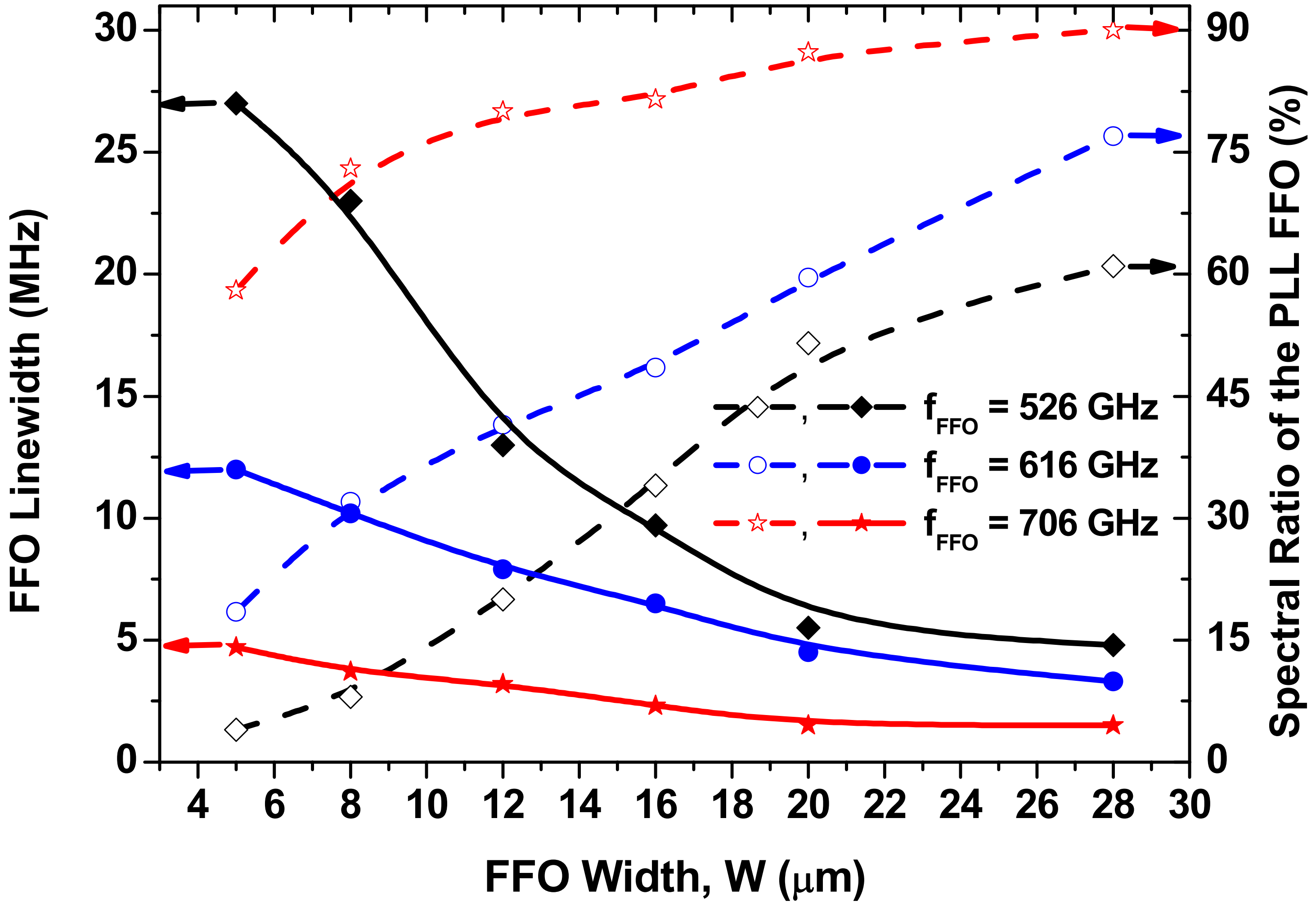
Down-converted spectra of the FFO operating at 671 GHz. Span – 100 Hz.



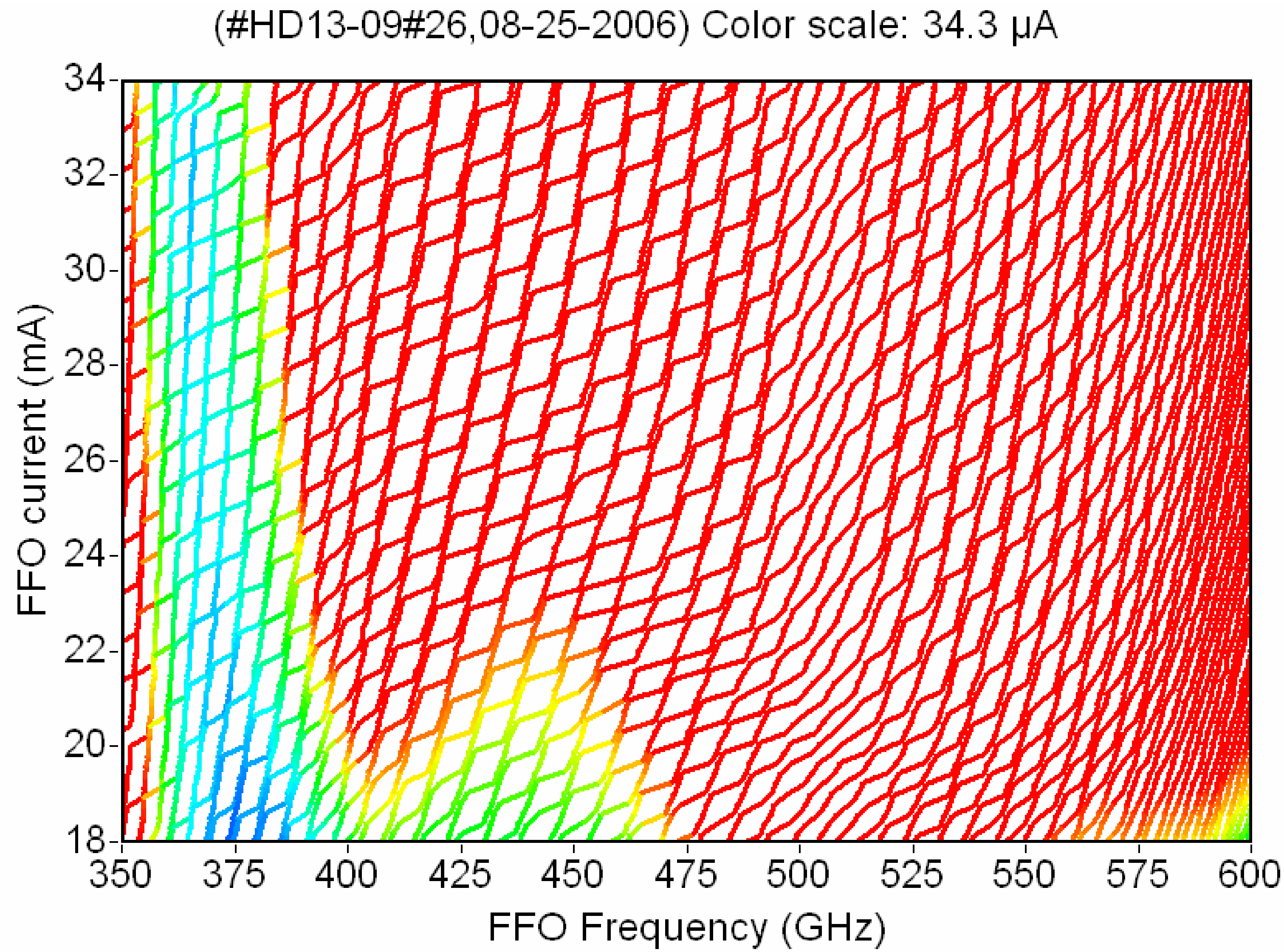
FFO linewidth and Spectral Ratio PL FFO on its oscillation frequency.



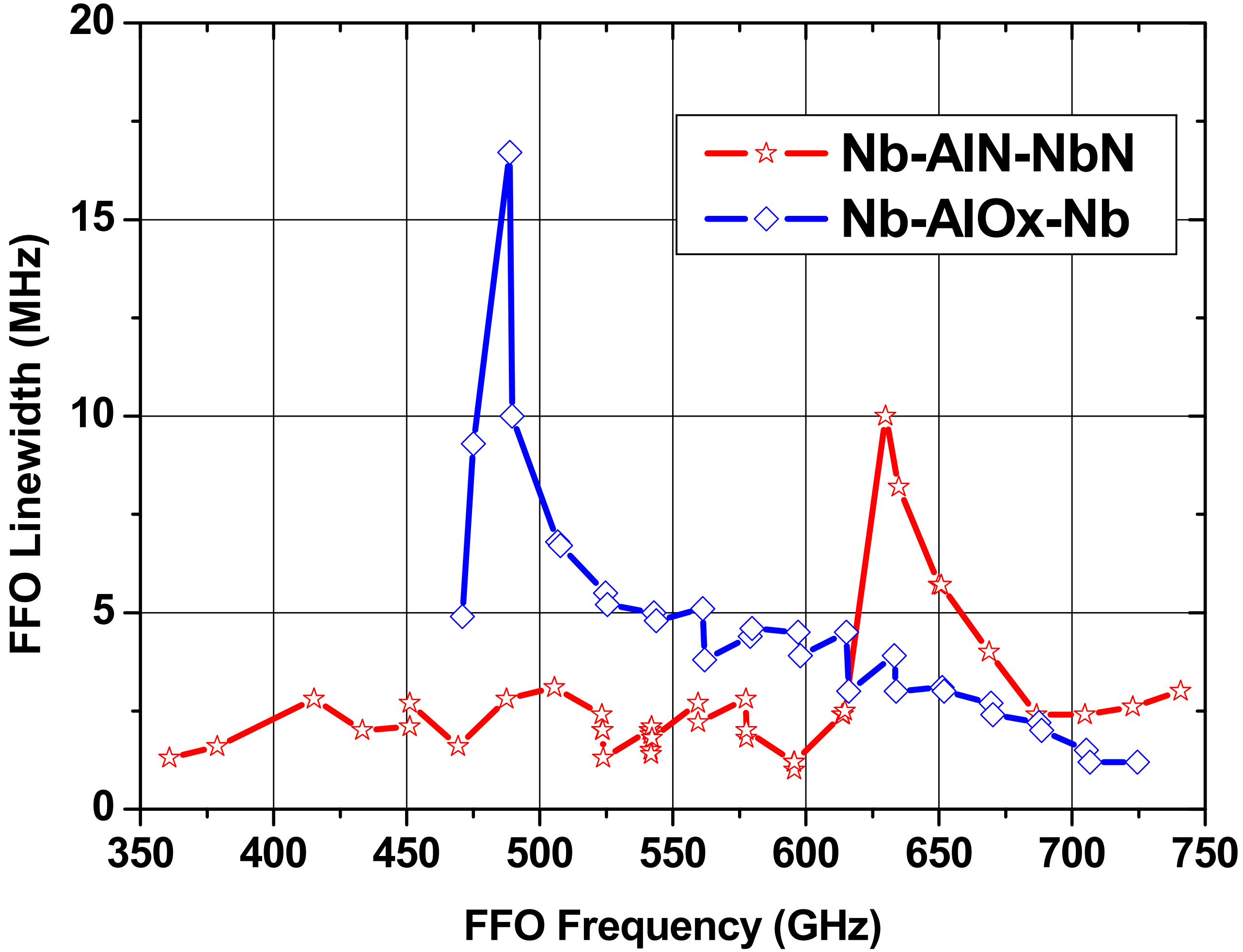
Linewidth of free-running FFOs and SR for the PL FFO as a function of FFO width (RnS =30 Ω*μm²)



A close-up of FFO IVC in Fiske steps region



Frequency dependence of the FFO: Nb-AlOx-Nb and Nb-AlN-NbN circuits



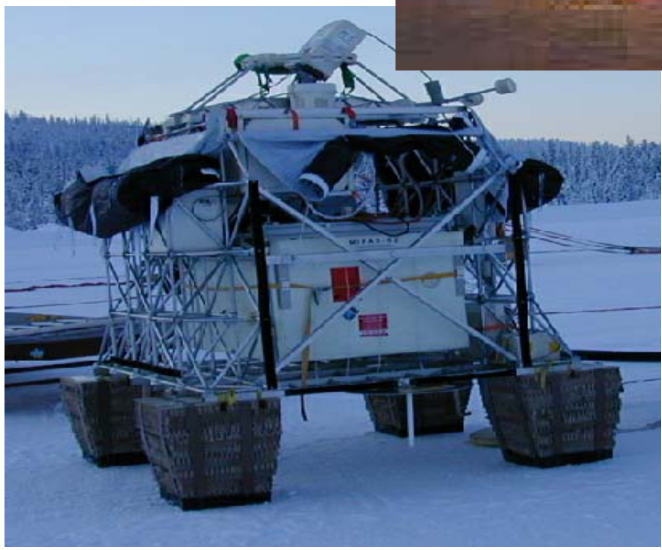
TELIS - TErahertz LImb Sounder

TELIS Objectives:

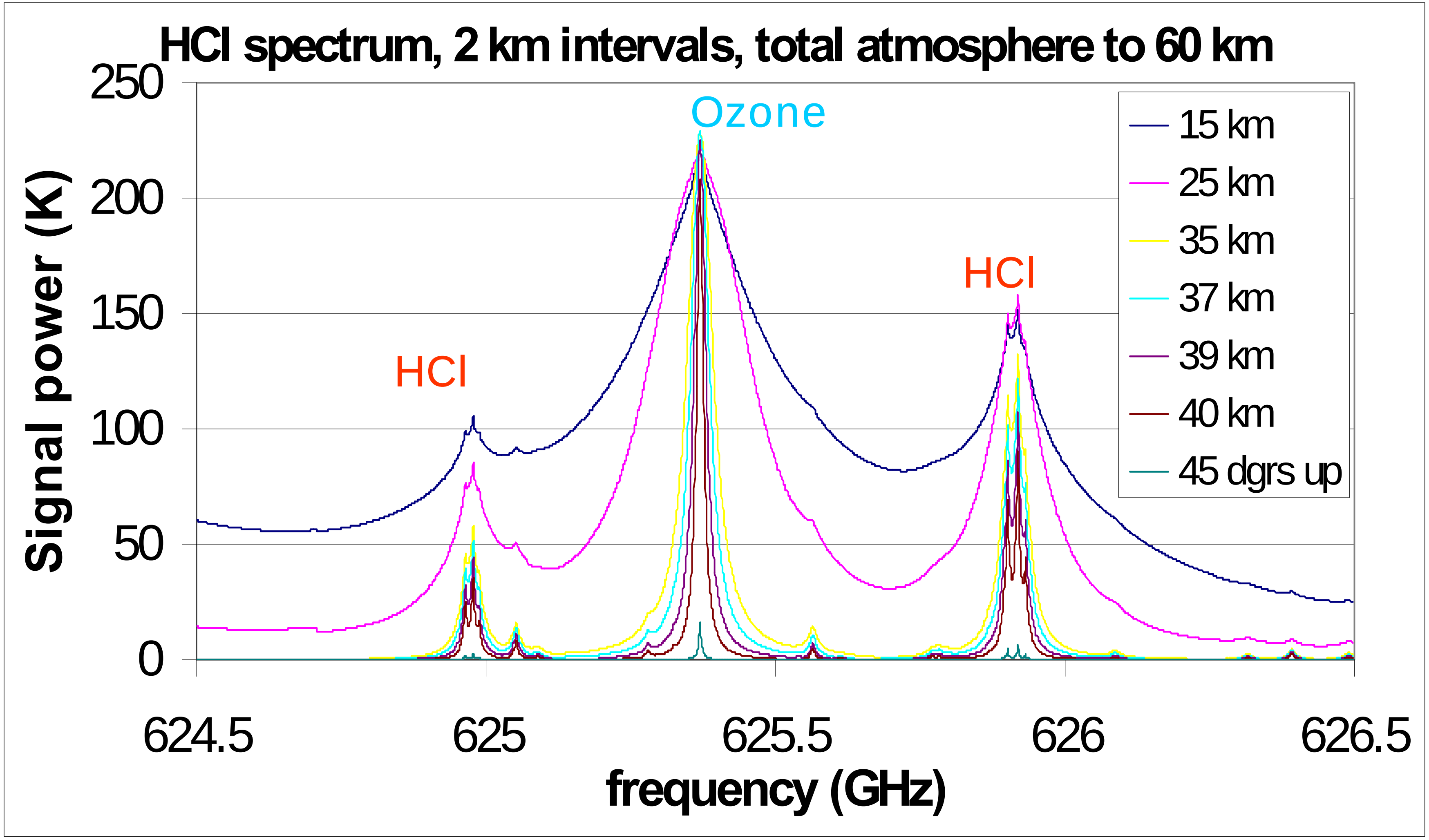
- Measure many species for atmospheric science (ClO, BrO, O_3, HCl, HOCl, etc);
  - Chemistry, Transport, Climate
- Serve as a test platform for new sensors
- Serve as validation tool for future satellite missions

Three independent frequency channels, cryogenic heterodyne receivers:

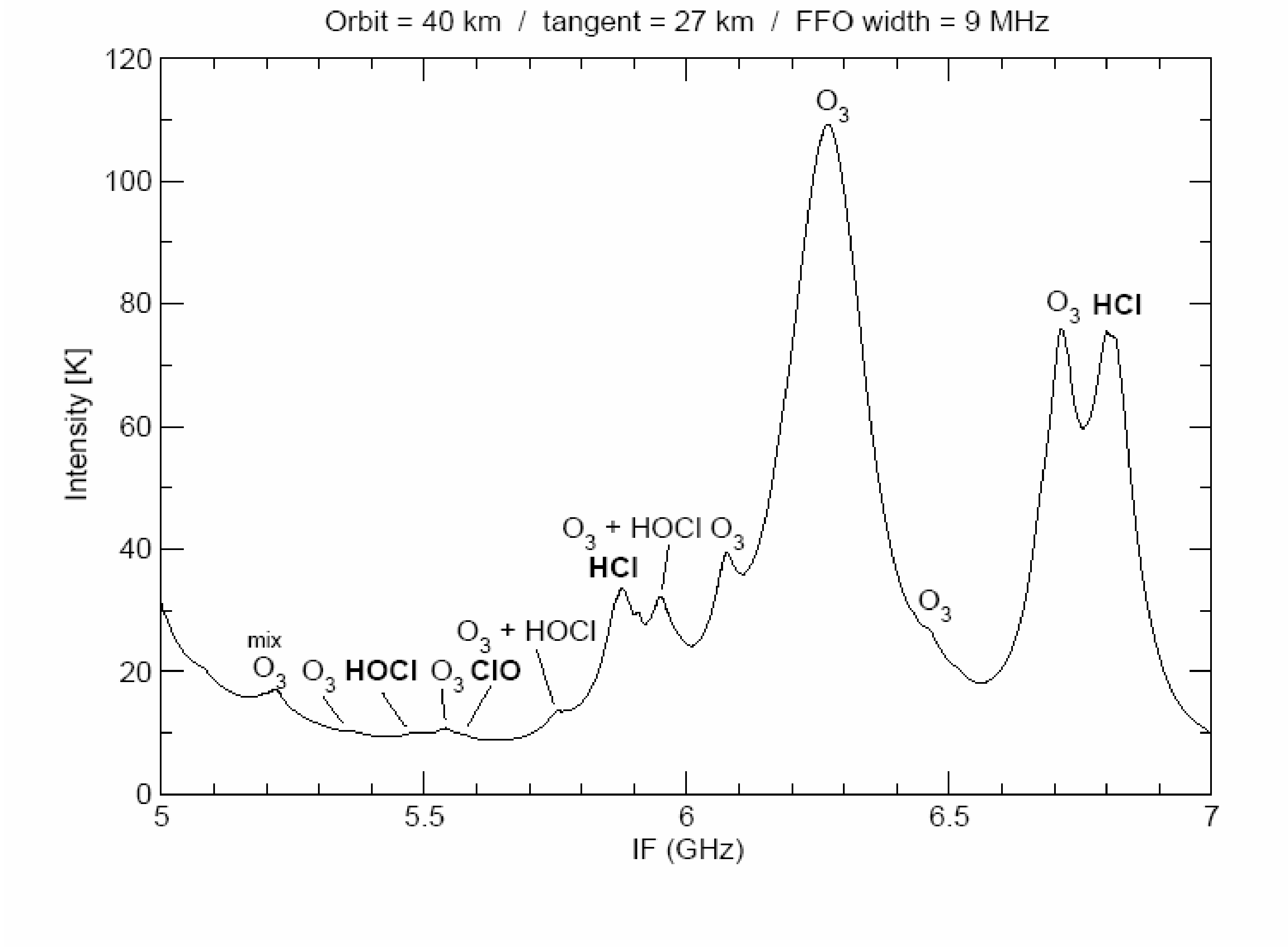
- 500 GHz by RAL
- **600-650 GHz by SRON-IREE**
- 1.8 THz by DLR (PI)



Simulated spectra for Ozone and HCl at 625 GHz



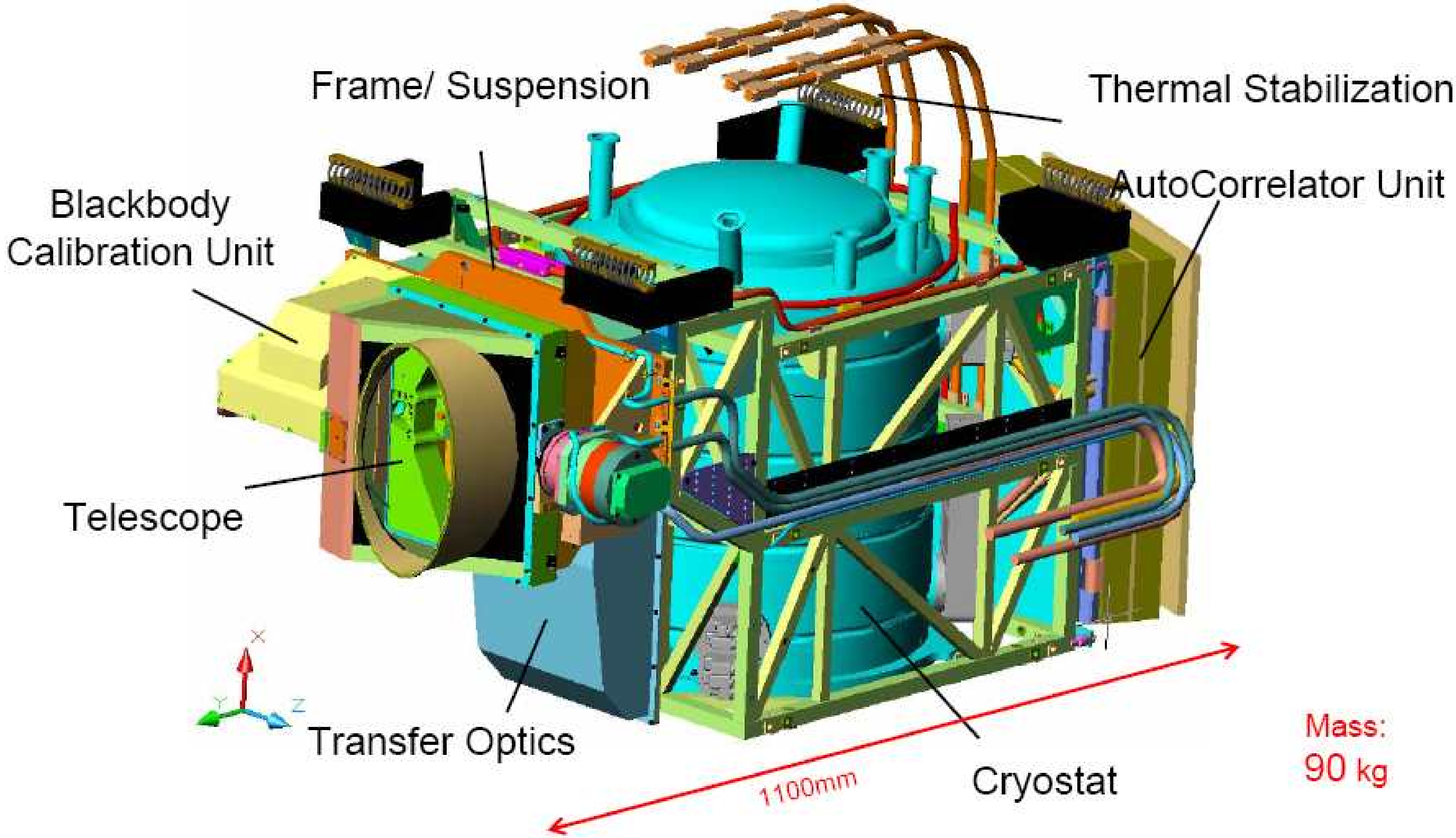
Simulated atmospheric spectra (DSB) at 619 GHz



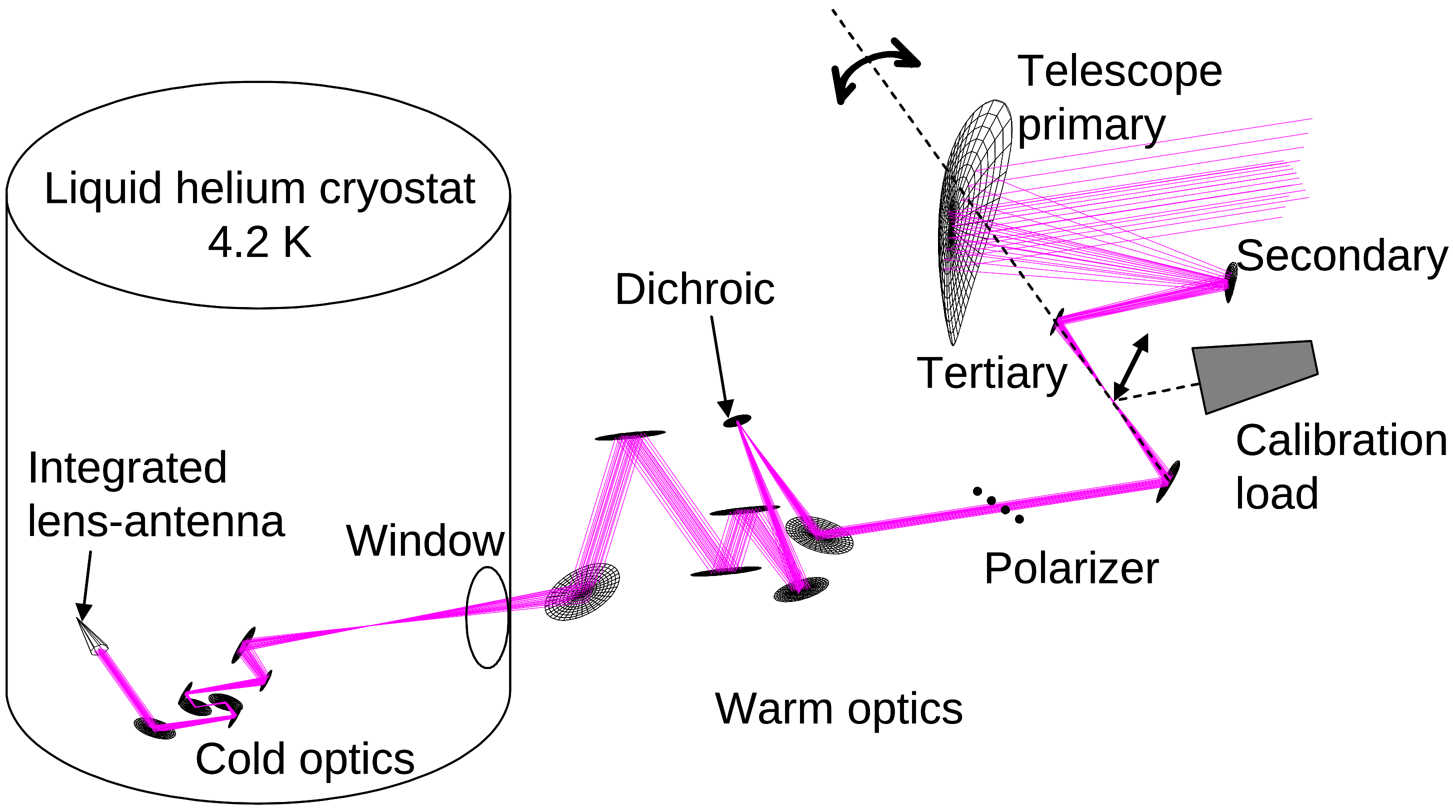
TELIS-SIR Main Parameters

##	Description	Value (Spec)
1	Input frequency range, GHz	500 – 650 (550 – 650)
2	Minimum noise temperature in the range (DSB), K	150 (250)
3	Output IF range, GHz	4 - 8 (5 - 7)
4	Spectral resolution (width of the spectral channel), MHz	< 1 (2)
5	LO frequency net, MHz	< 300
6	Dissipated power at 4.2 K stage (including IF amplifiers chain), mW	100
7	Operation temperature, K	< 4.5

TELIS – Instrument Model



Schematics of the 550-650 GHz channel optics



Wire grid polarizer and dichroic plate are used to separate this receiver from the two other frequency channels (not shown). The cold optics and mixer element are located inside the cryostat at the ambient temperature 4.2 K

Layout of SIR cold channel

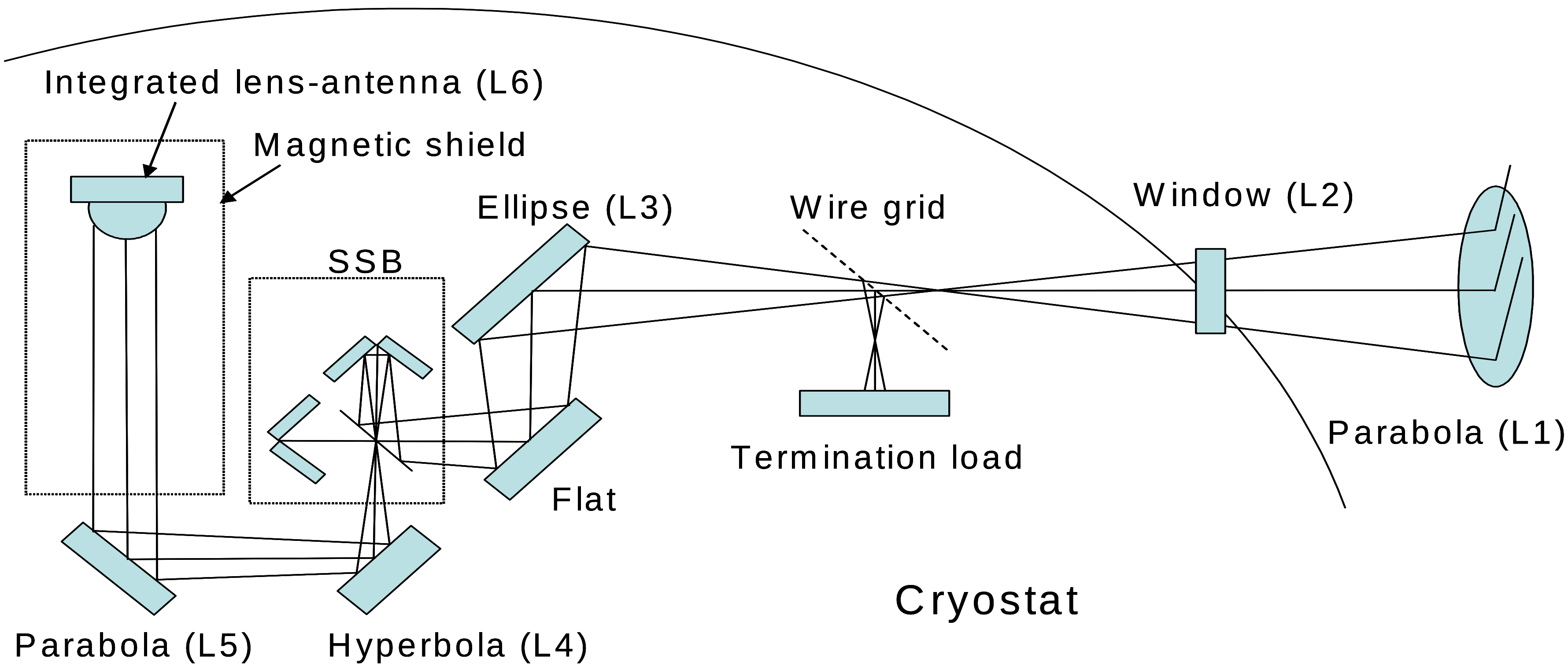
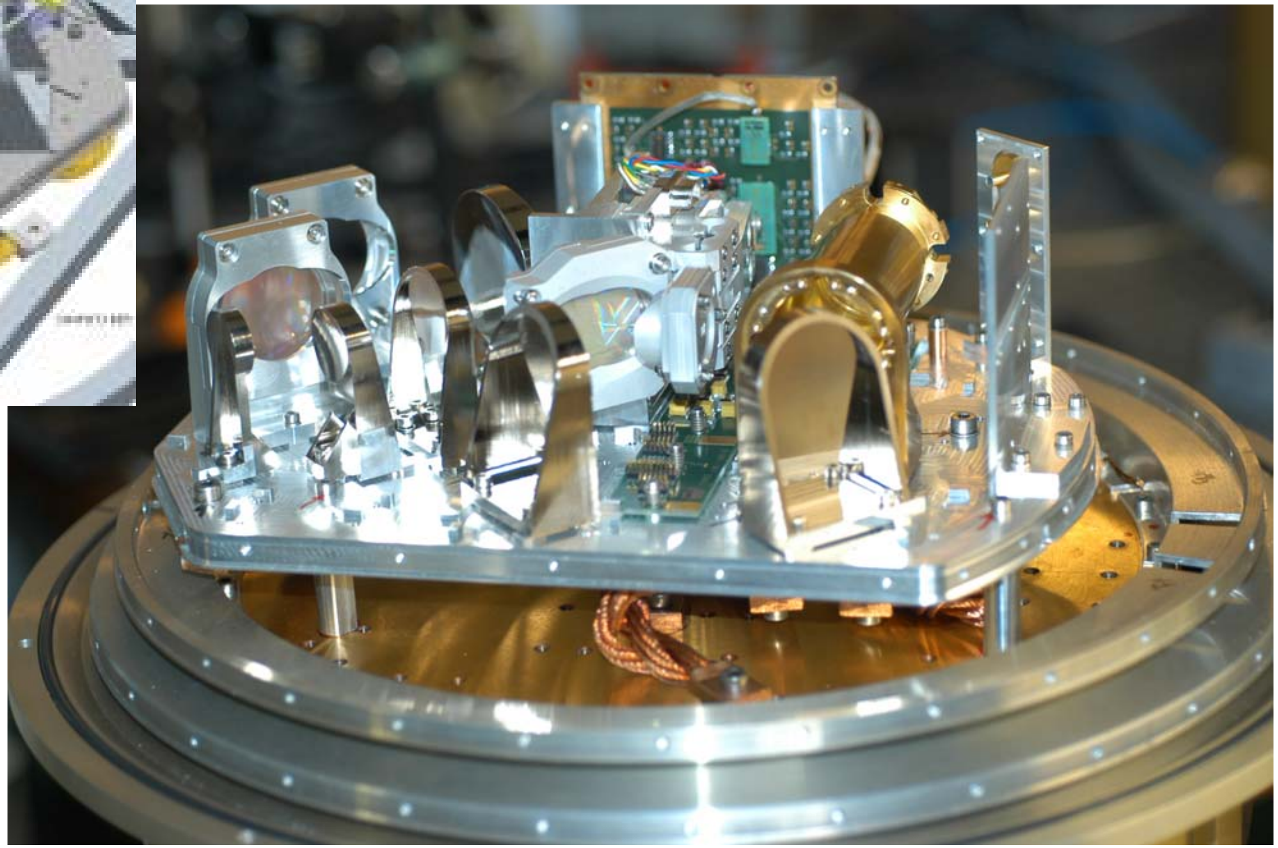
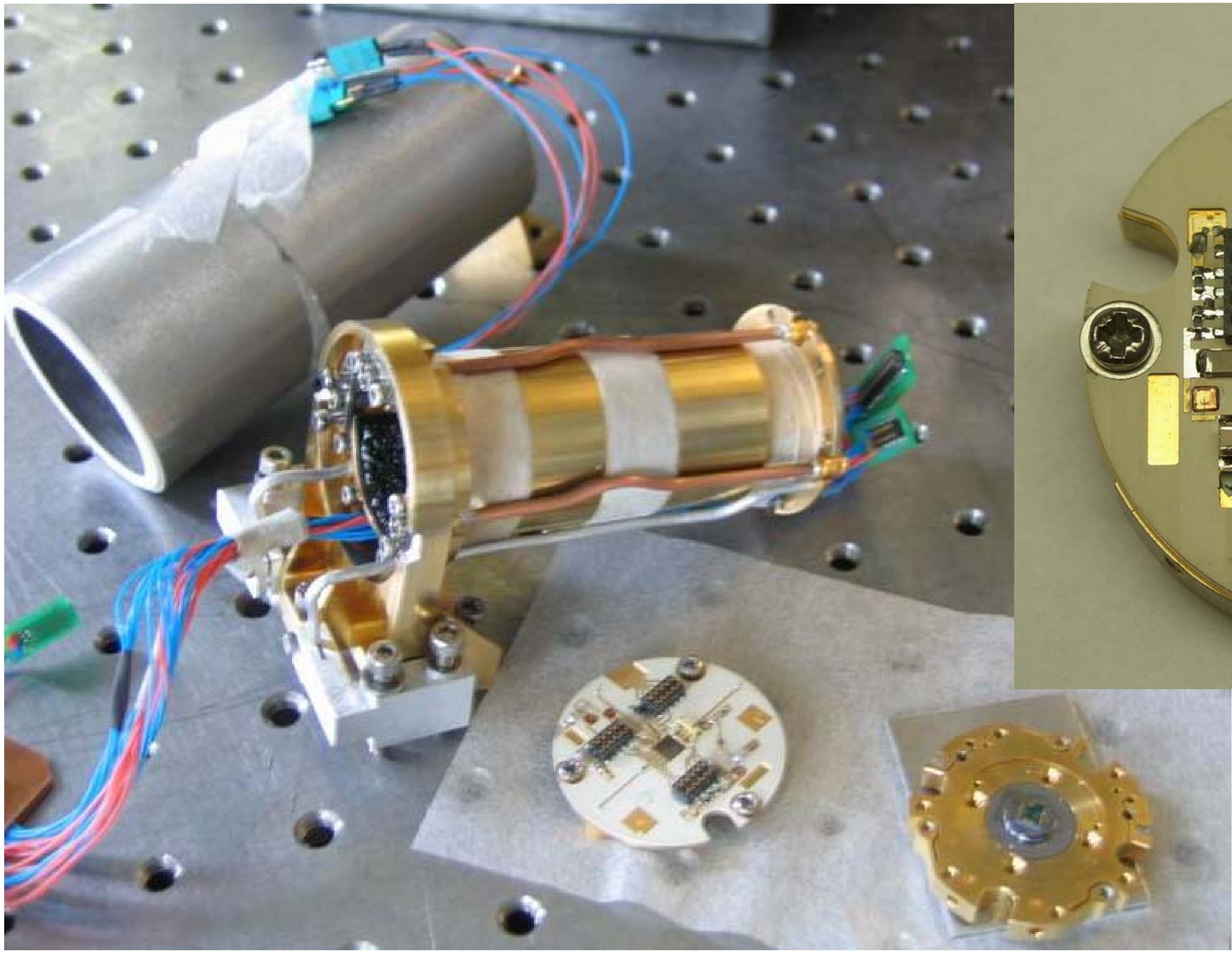


Photo of the SIR-TELIS channel



SIR Mixer Block with Shields



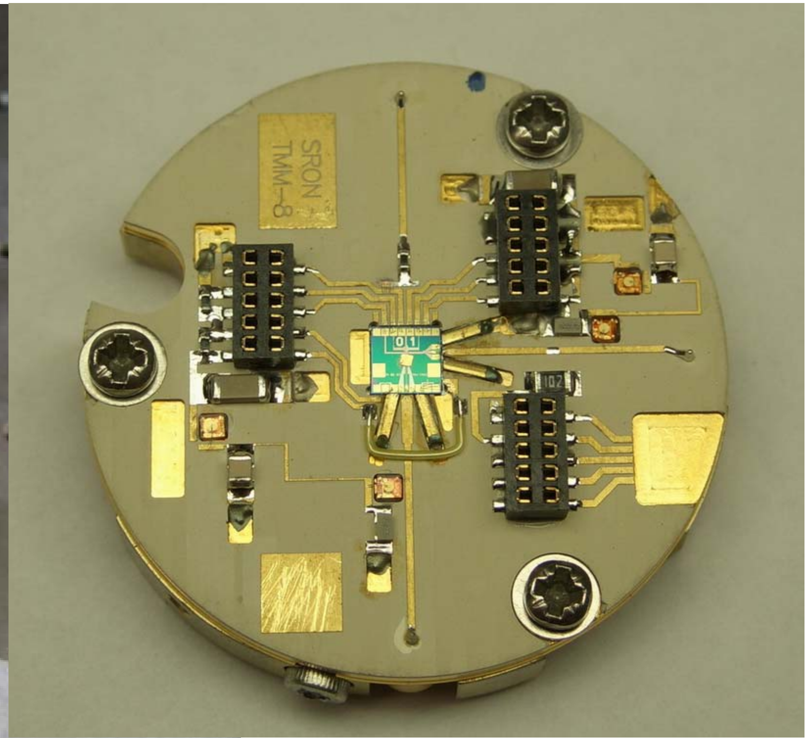


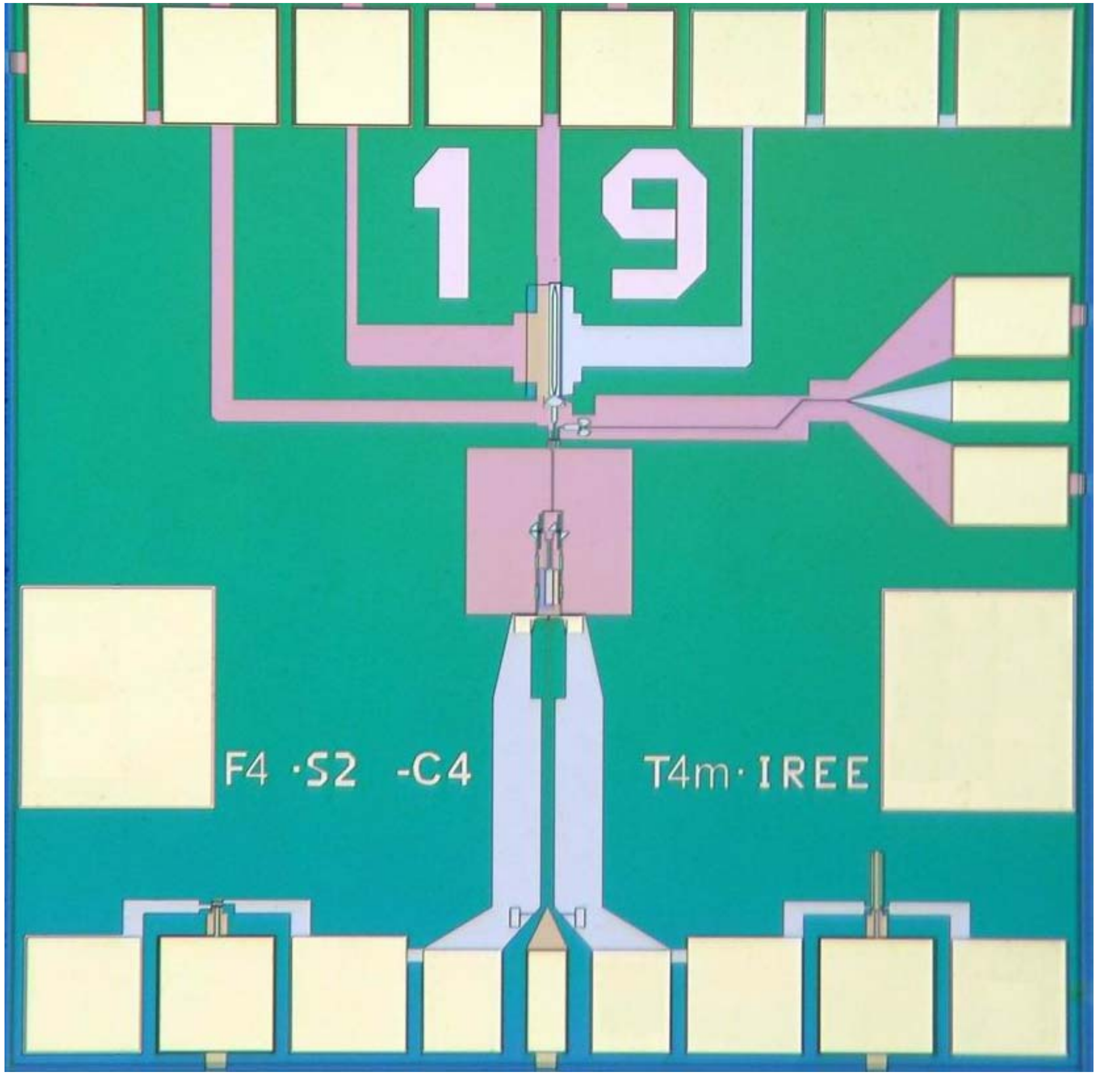
Photo of the T4m SIR chip

Silicon (Si);

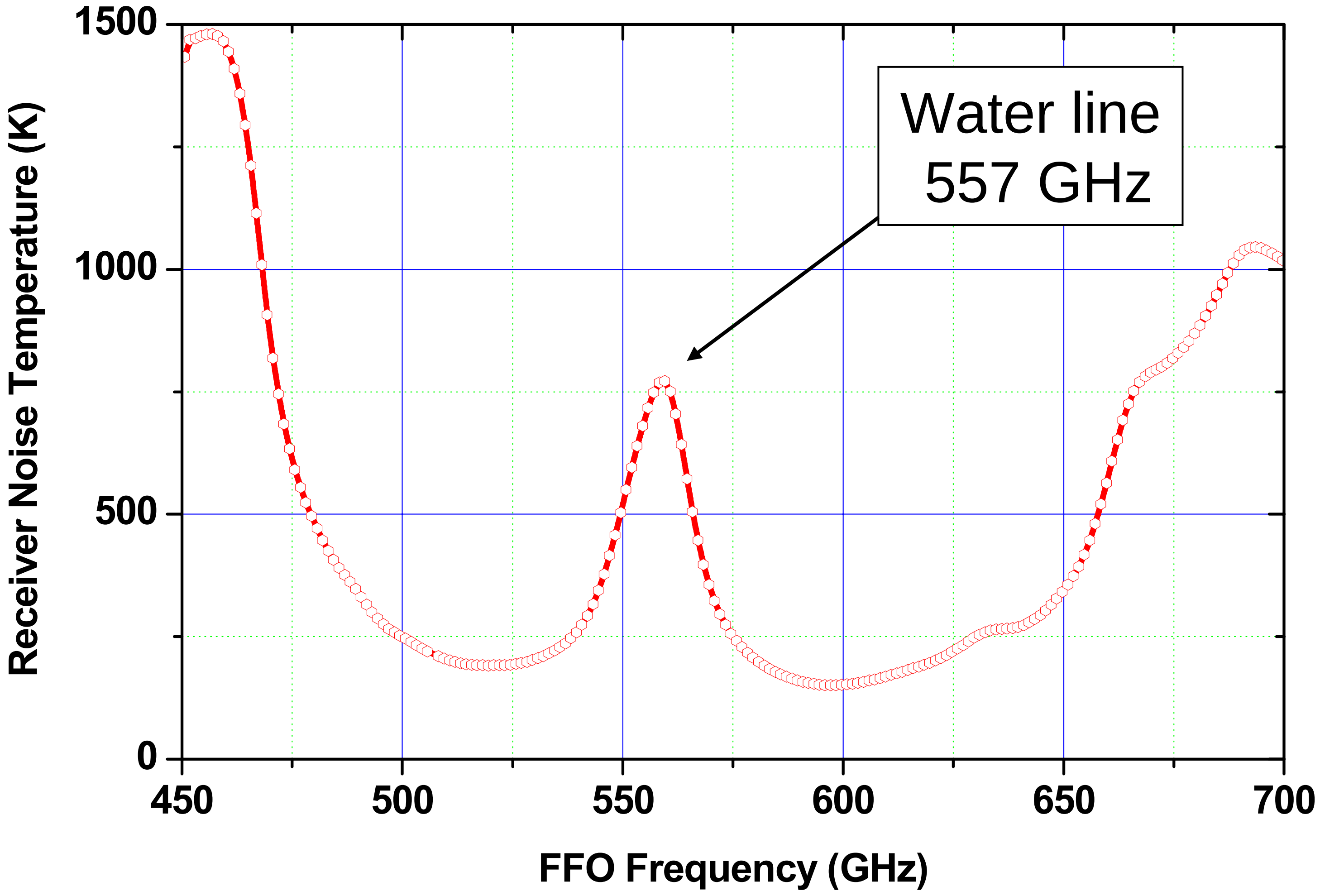
4 x 4 x 0.5 mm^3

Nb-AlOx-Nb or

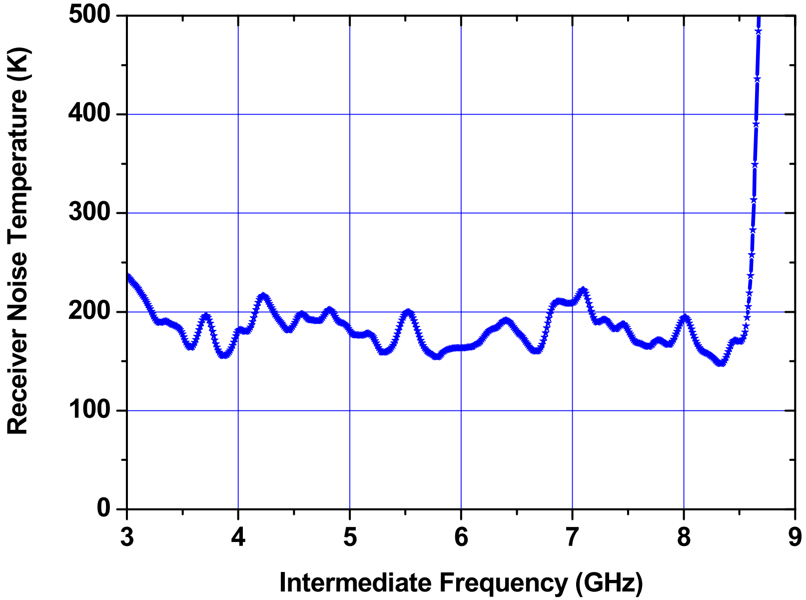
Nb-AlN-NbN;

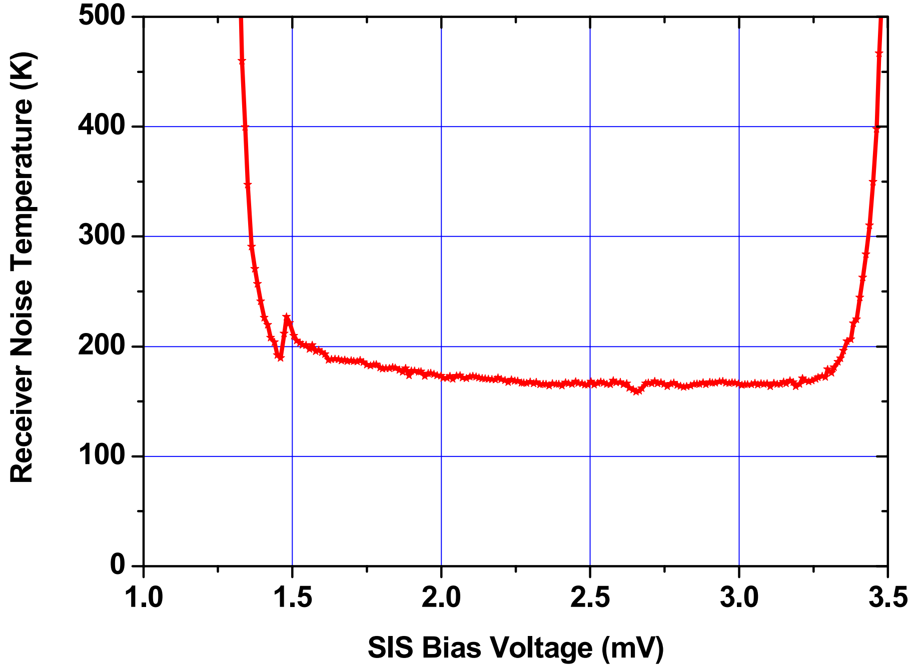


Uncorrected Receiver Noise Temperature (DSB)

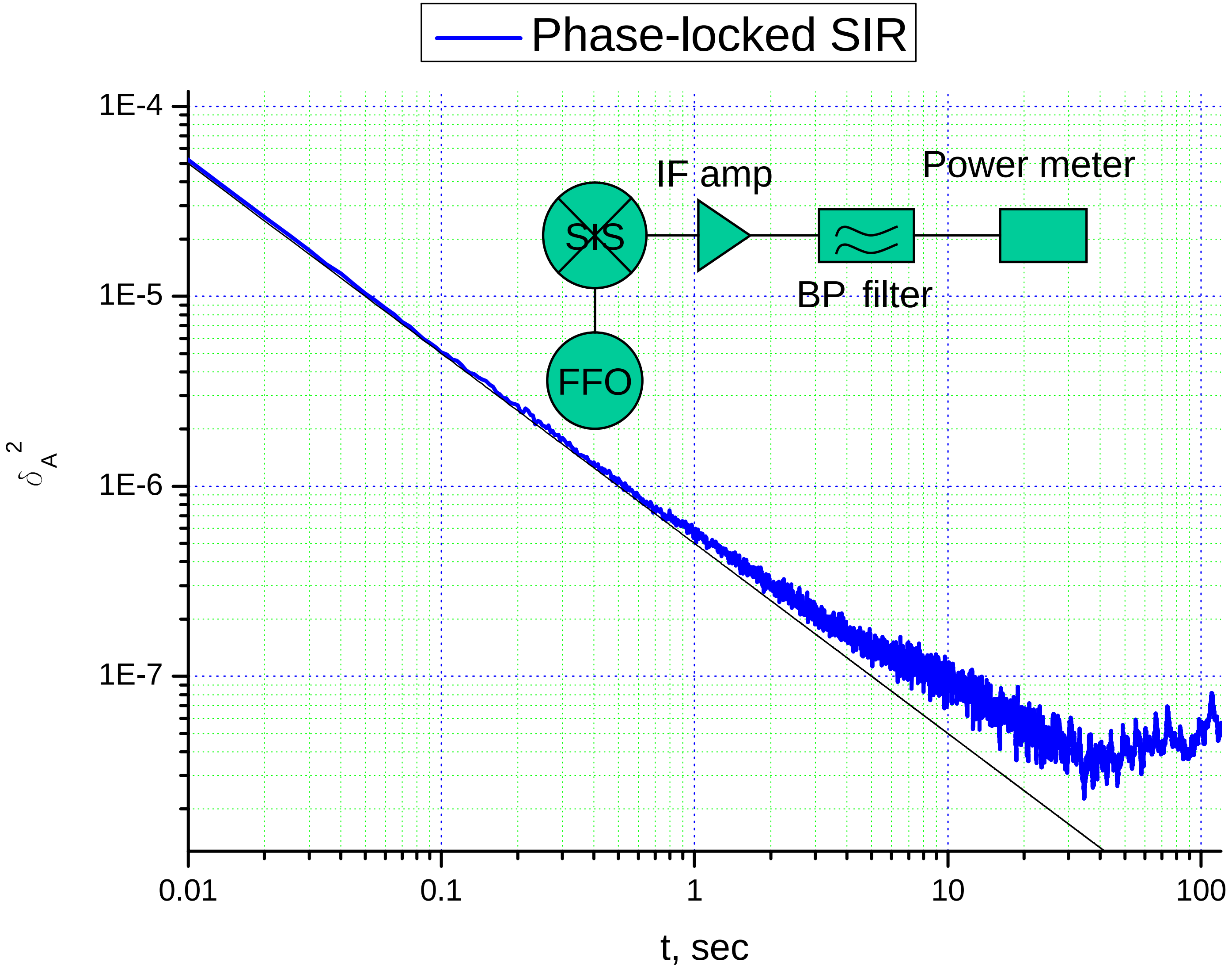


SIR Noise Temperature on Intermediate Frequency and SIS Bias

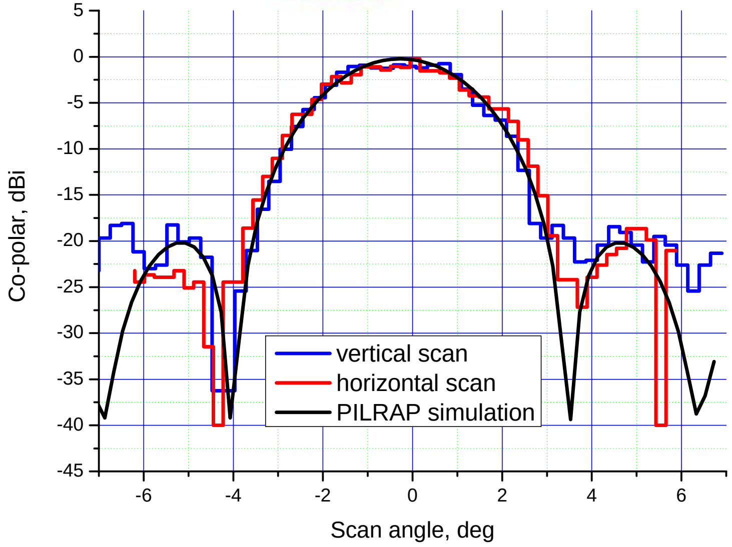


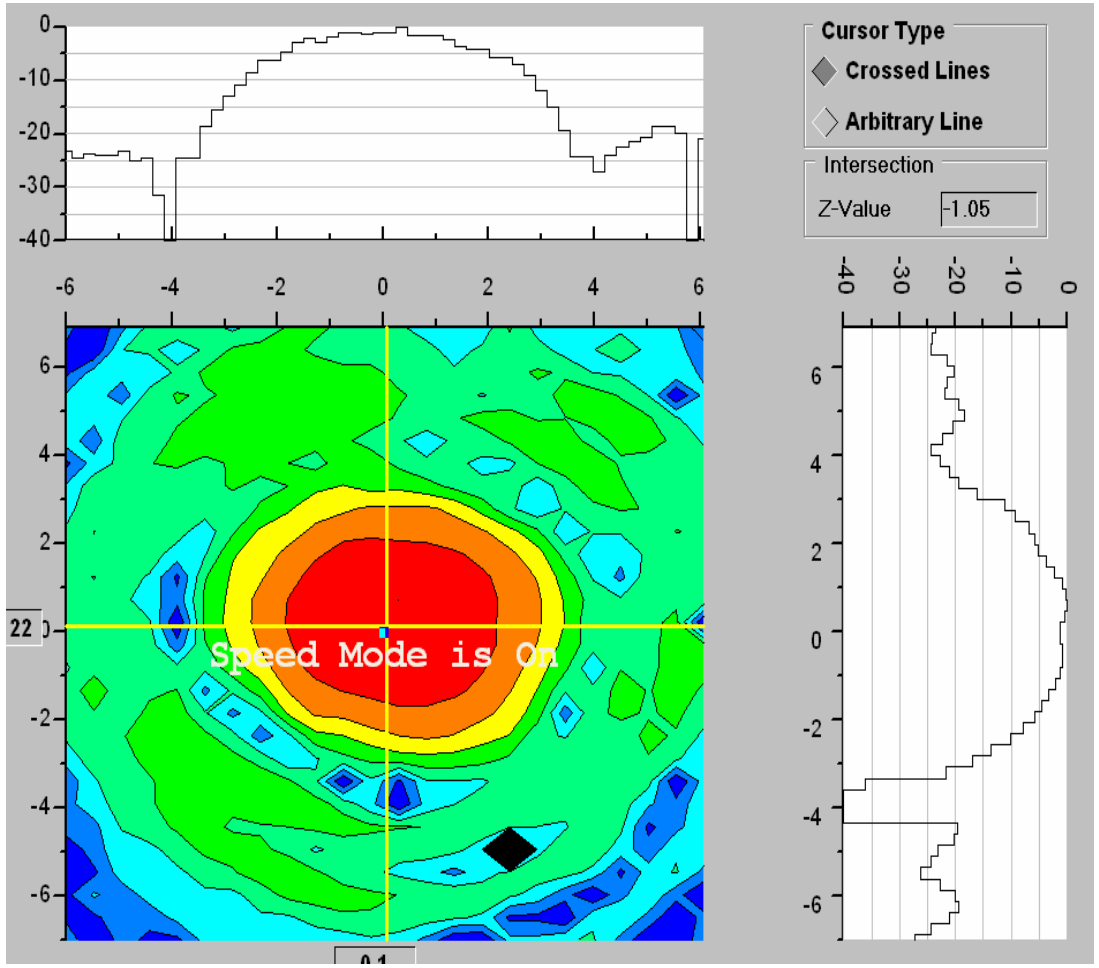


SIR Stability: Allan variance test

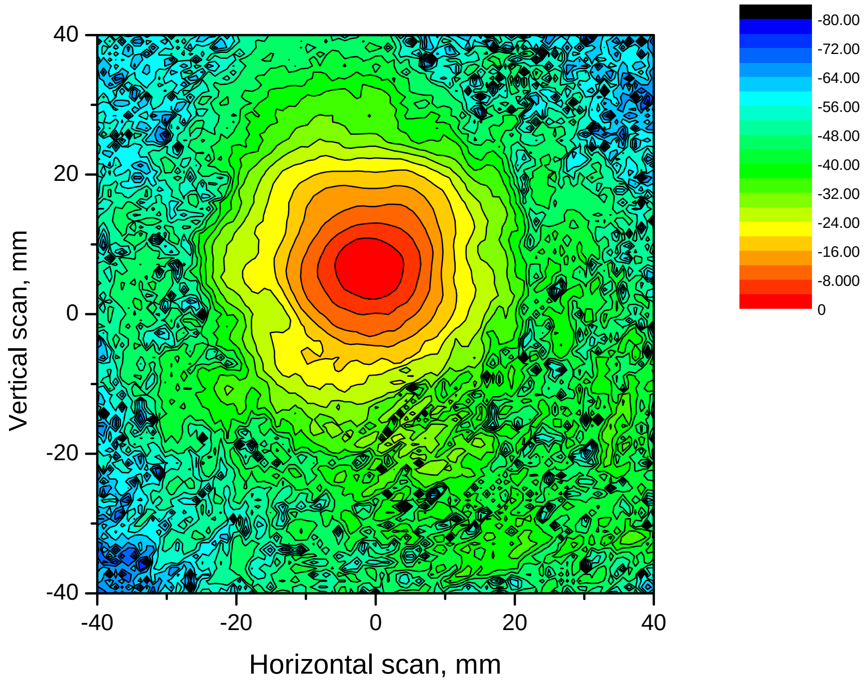


Antenna-Lens Beam Pattern of the SIR at 625 GHz

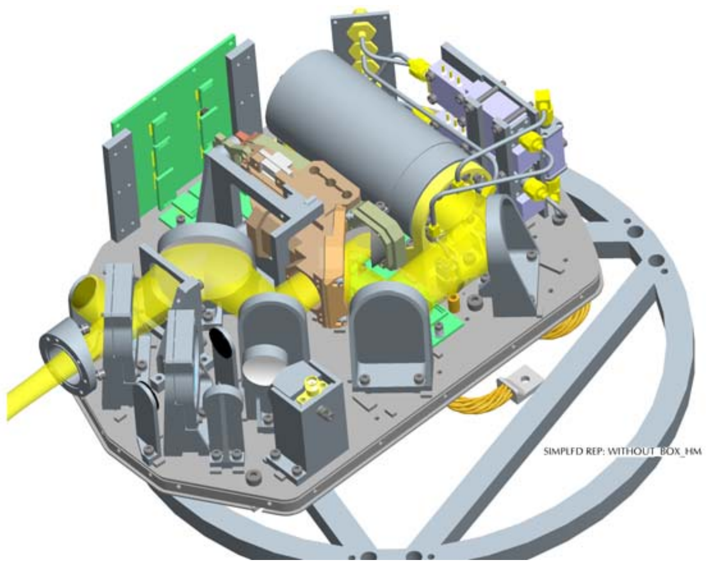


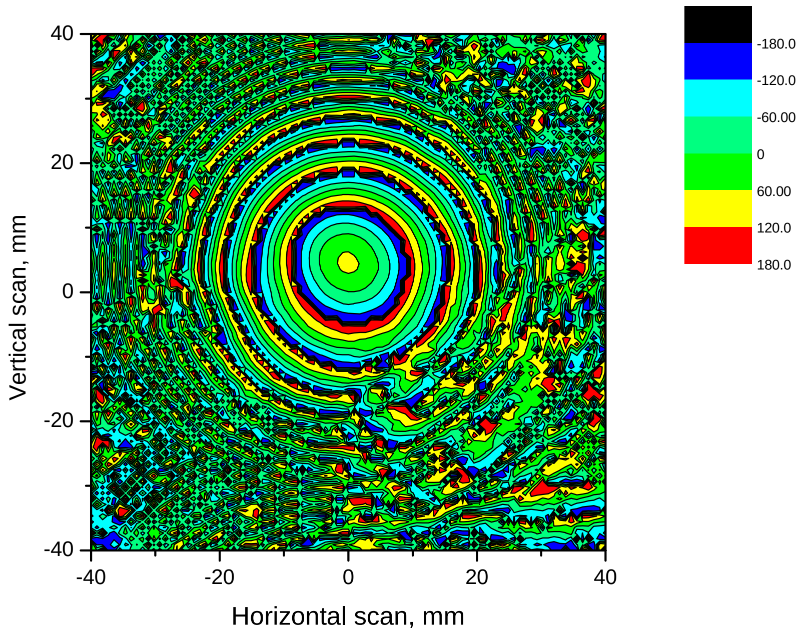


Amplitude and phase APB of the SIR with cold optics



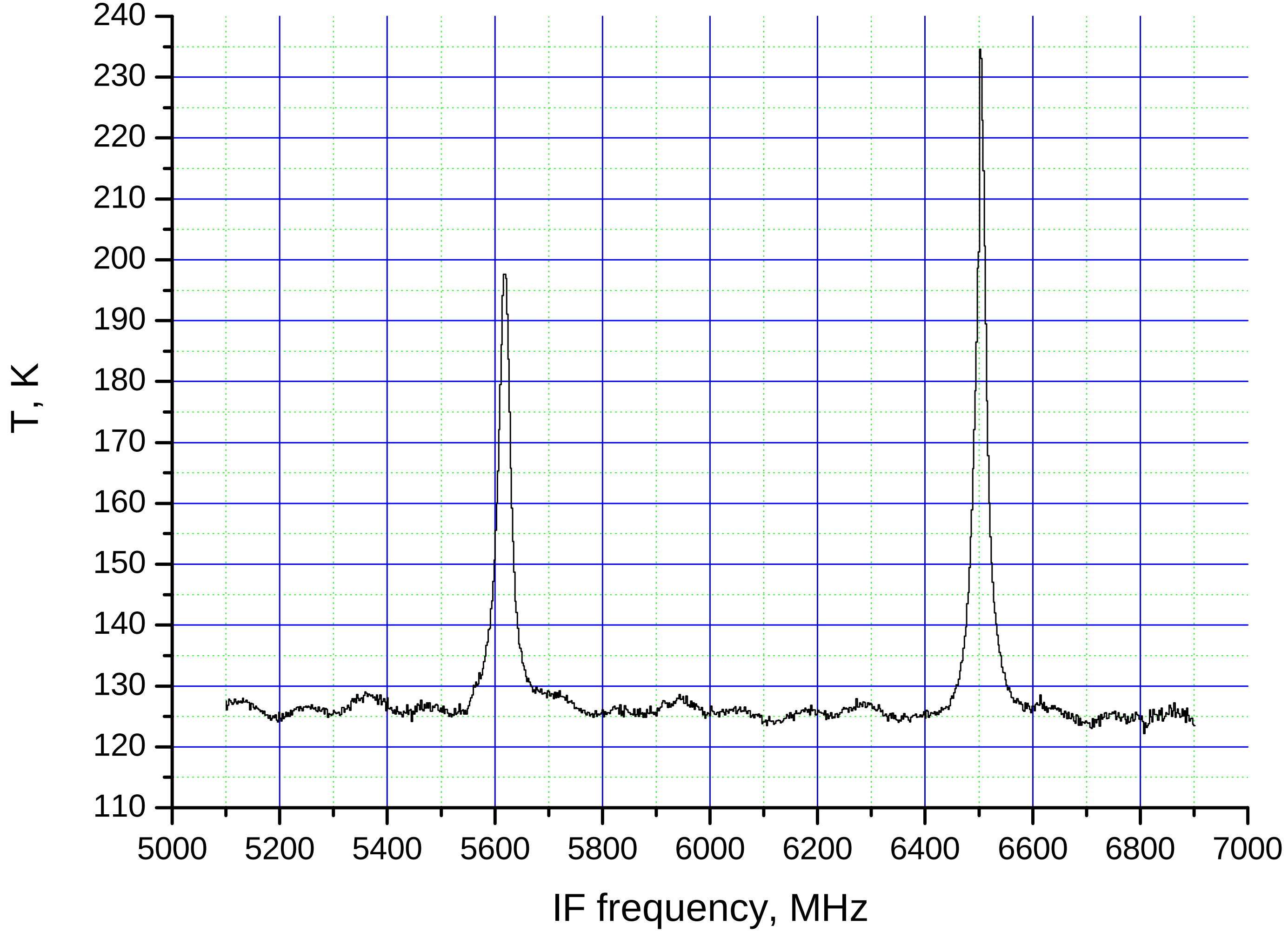
Amplitude



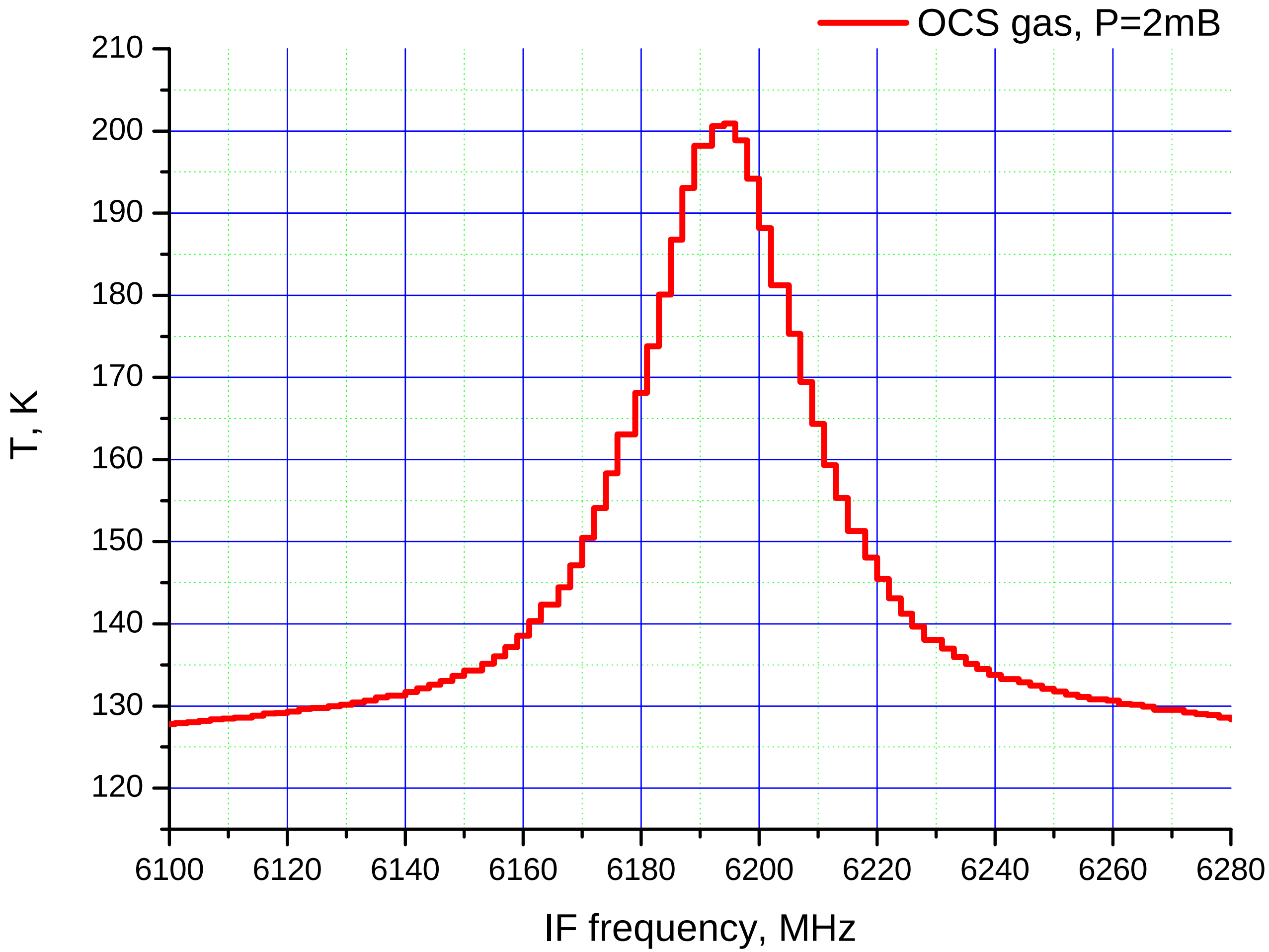


Phase

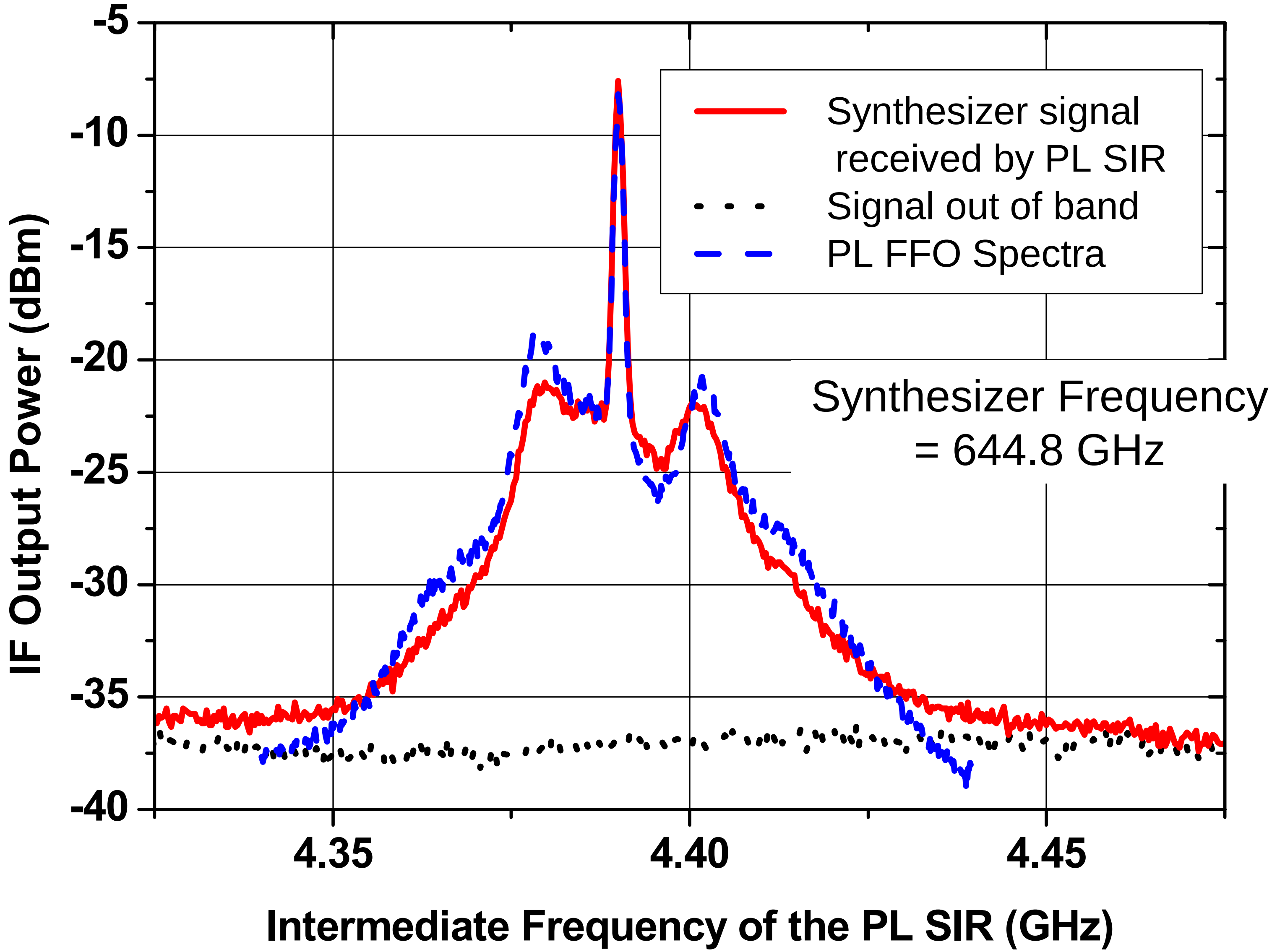
Deconvolved spectrum of two OCS emission lines (gas pressure 1.2 mBar; FFO frequency 625.24 GHz)



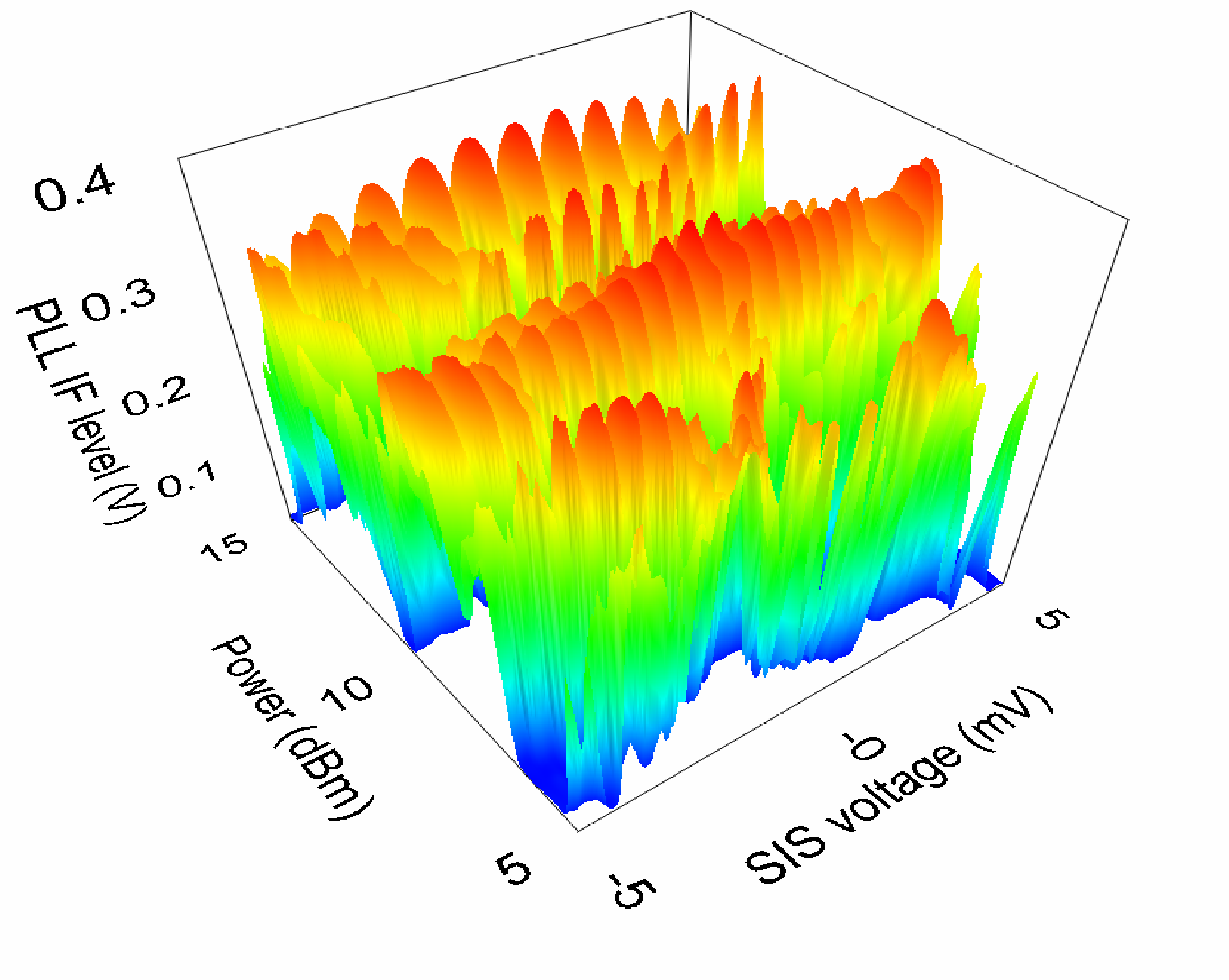
Gas cell measurements; resolution determined by DAC



Phase locked FFO; spectral resolution < 1 MHz



Remote optimization of the PLL SIR operation (3-D)

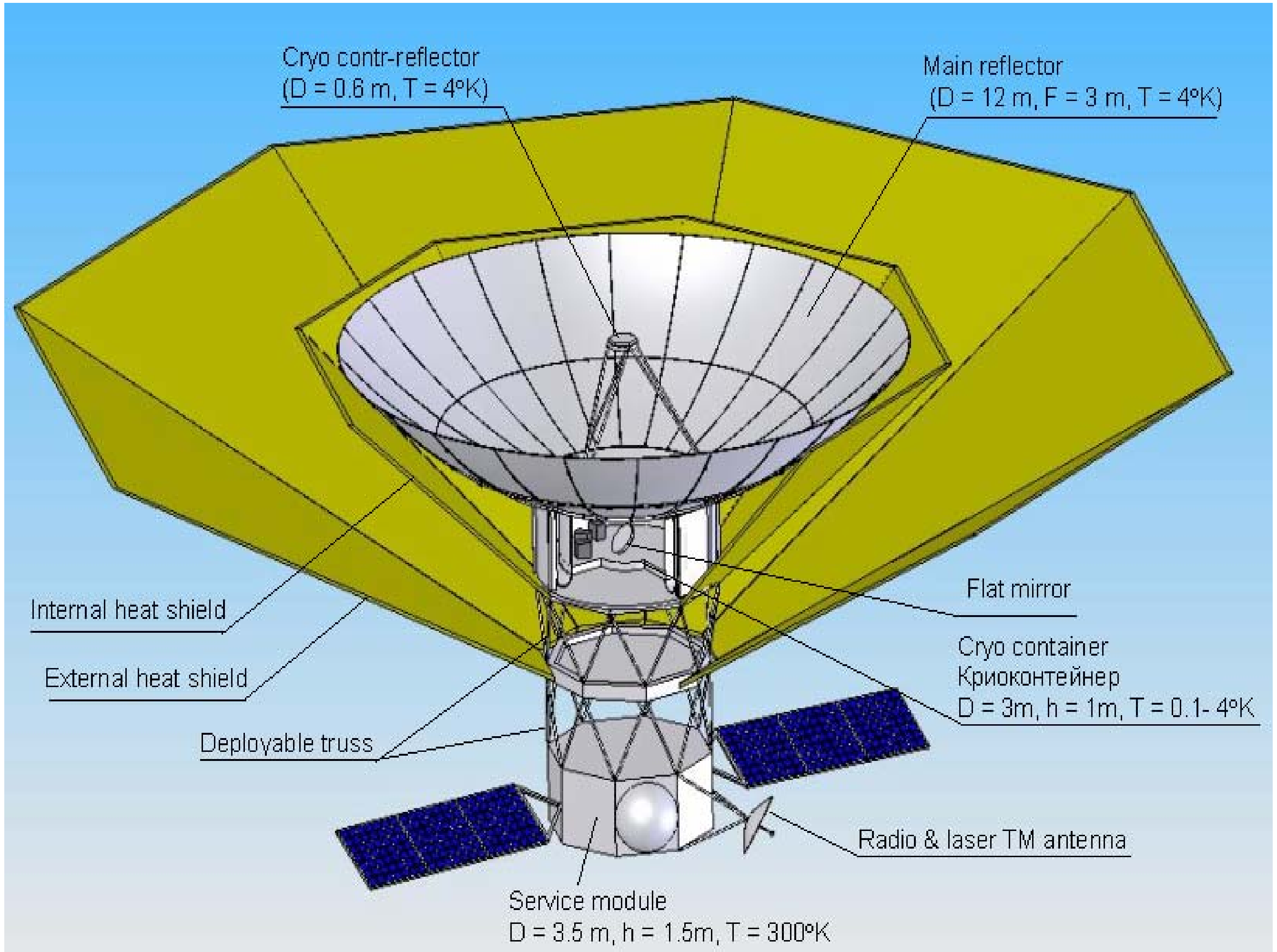


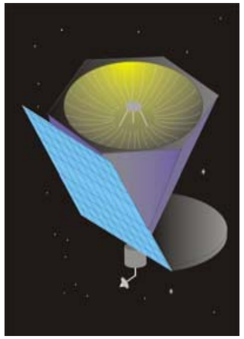
ESPRIT – Exploratory Submm Space Radio-Interferometric Telescope

The six elements of ESPRIT in an Ariane 5

- Telescope sizes ~ 3.5 meter ; off-axis
- Number of elements N = 6 (15 baselines)
- Projected baselines 200 - 1000 meter
- Frequencies:
  Spots in the range 0.5 – 6 THz
- Front Ends -
  (0.5 – 1.5 THz) SIS mixers, multiplier LO /
  SIR = FFO + SIS + HM
  (1.5 – 6 THz) HEB mixers, QCL as LO
- System temperature < 1000 K
- IF bandwidth > 4 GHz (goal 8 GHz)

“Millimetron” – Russian Space Agency (2017)
12 m cryogenic mirror; λ = 0,01- 20 mm.





Ground-space interferometer

Conclusion

- Concept of the Phase-locked SIR is developed and tested.
- Nb-AlN-NbN FFO and SIR have been successfully implemented.
- Improved design of the FFO for TELIS has been developed and optimized; free-running linewidth from 1 to 10 MHz recorded in the frequency range 350 – 740 GHz that allows to phase lock from 35 up to 95 % of the FFO power.
- 3-rd generation of the PL SIR for TELIS has been developed showing a possibility to realize TELIS requirements:
  Frequency range 500 – 650 ГГц; Noise Temperature 150 К;
  IF bandwidth 4 - 8 ГГц; Spectral resolution better 1 МГц;
  Beam Pattern - FWHM = 3 deg, with sidelobes < - 17 dB.
  Procedure for remote optimization of the PL SIR operation has been developed and experimentally proven.
- First TELIS flight is scheduled on April 2008.
- Future space missions are under consideration.