Integrated Submillimeter Receiver for TELIS

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ABSTRACT

We present results of a single-chip superconducting integrated receiver development for the Terahertz Limb Sounder (TELIS) balloon project. TELIS is a collaborative European project to build a three-channel heterodyne balloon-based spectrometer for measuring a variety of the stratosphere constituents. The Superconducting Integrated Receiver (SIR) comprises in one chip a planar antenna integrated with a superconductor-insulator-superconductor (SIS) mixer, a superconducting Flux Flow Oscillator (FFO) acting as Local Oscillator (LO) and a second SIS harmonic mixer (HM) for FFO phase locking. An improved design of the FFO for TELIS has been developed and optimized. A free-running linewidth between 9 and 2 MHz has been measured in the frequency range 500 – 710 GHz. As a result the spectral ratio of the phased-locked FFO varies from 35 to 90 % correspondingly, ensuring that at least half of the phase-locked FFO power in the primary frequency range for TELIS (550-650 GHz). The FFO performance required for successful TELIS operation and an influence of FFO linewidth imperfections on retrieval procedure are discussed.

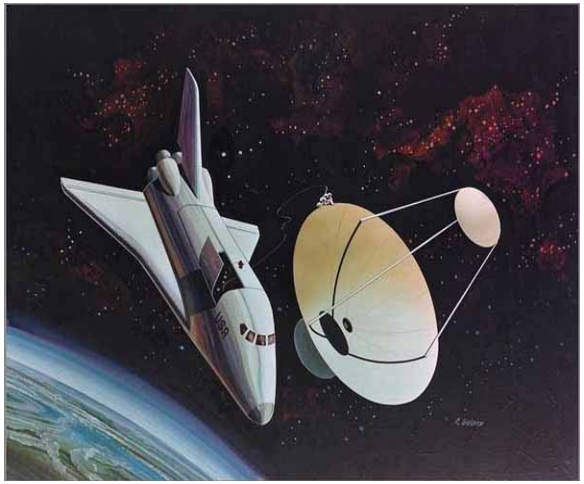
All receiver components (including input optical elements and Martin-Puplett polarization rotating interferometer for single side band operation) will be mounted on a single 4.2 K plate inside a 240x180x80 mm3 box. New generation of the SIR for TELIS with improved FFO performance has been developed and preliminary tested. First measurements give an uncorrected double side band (DSB) noise temperature below 250 K measured with the phase-locked FFO; more detailed results are presented at the conference. It is important to ensure that tuning of a phase-locked (PL) SIR can be performed remotely by telecommand. For this purpose a number of approaches for the PL SIR automatic computer control have been developed and tested.

Integrated Submillimeter Receiver for TELIS

Outline

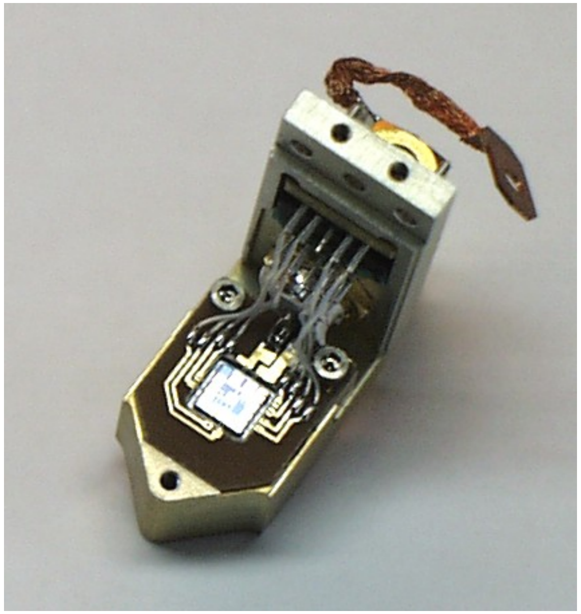
- Superconducting Integrated Receiver (SIR) with phased-locked FFO;
- TErahertz LImb Sounder (TELIS)
- FFO frequency and power tuning, Linewidth and Spectral Ratio of the PL FFO;
- SIR noise temperature and SIR remote operation;
- NbN FFO and SIR – first implementation;
- Cryogenic Phase Detector for SIR;
- Conclusion

Superconducting Integrated Receiver (SIR)



APPLICATIONS

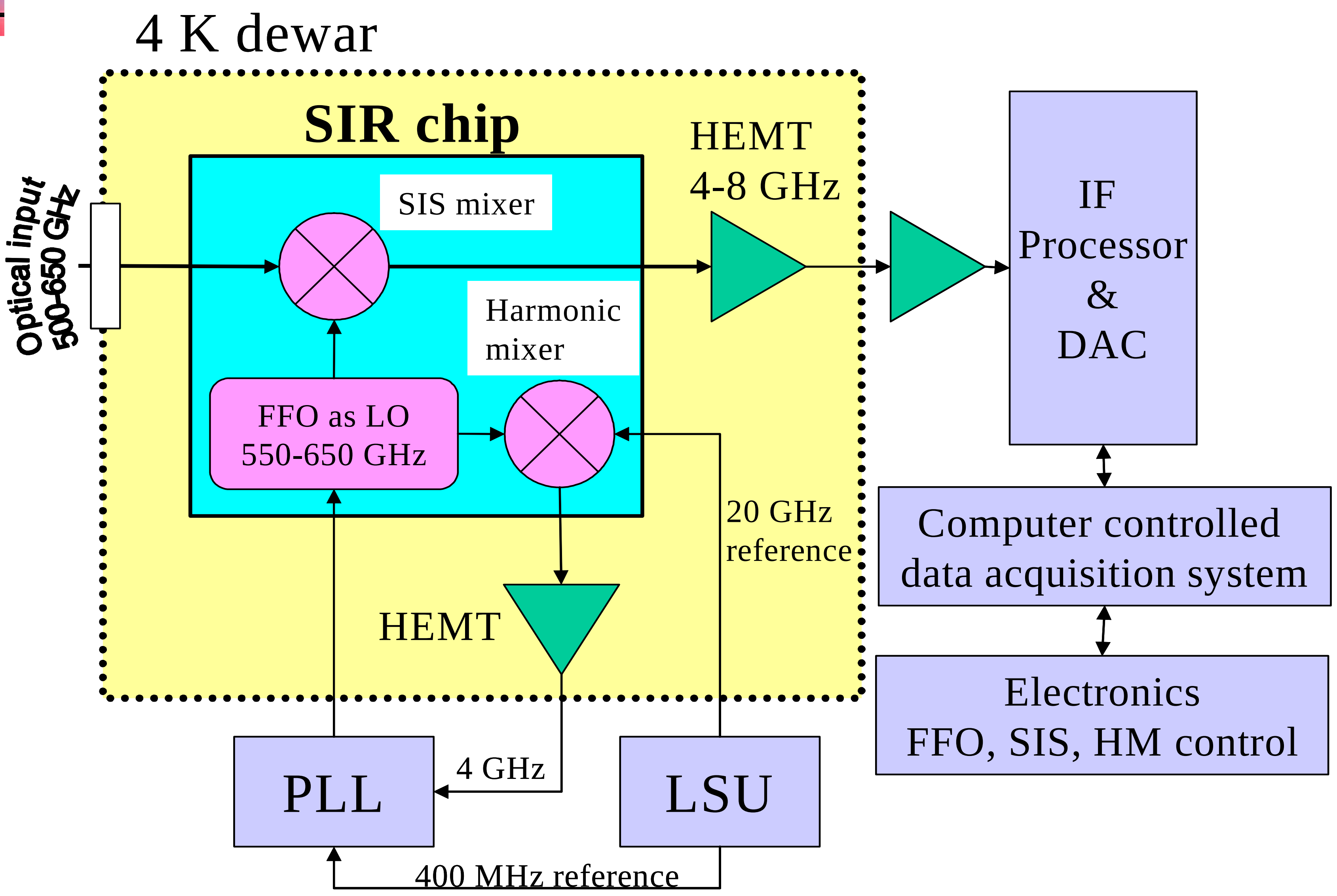
- Airborne Receiver for Atmospheric Research and Environmental Monitoring; Radio Astronomy
- Large Imaging Array Receiver
- Laboratory MM & subMM Spectrometer



STATE OF THE ART

- Single chip Nb-AlOx-Nb SIS receivers with superconducting FFO has 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
- Phase Locking (PLL) up to 700 GHz

Schematics of PLL SIR



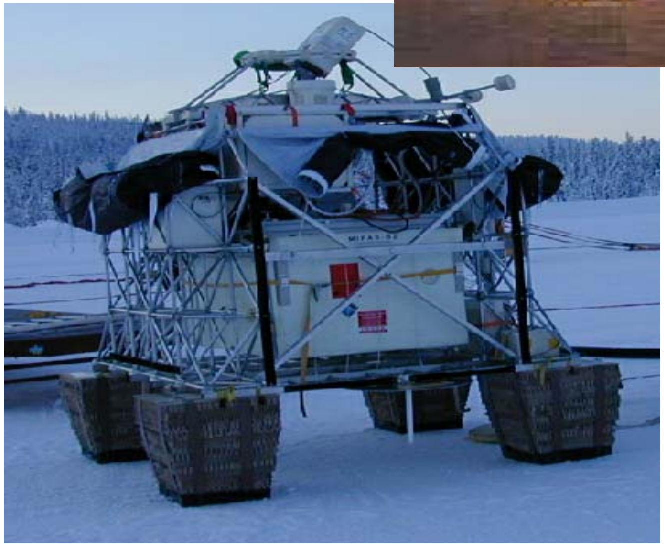
TELIS - TErahertz LImb Sounder

TELIS Objectives:

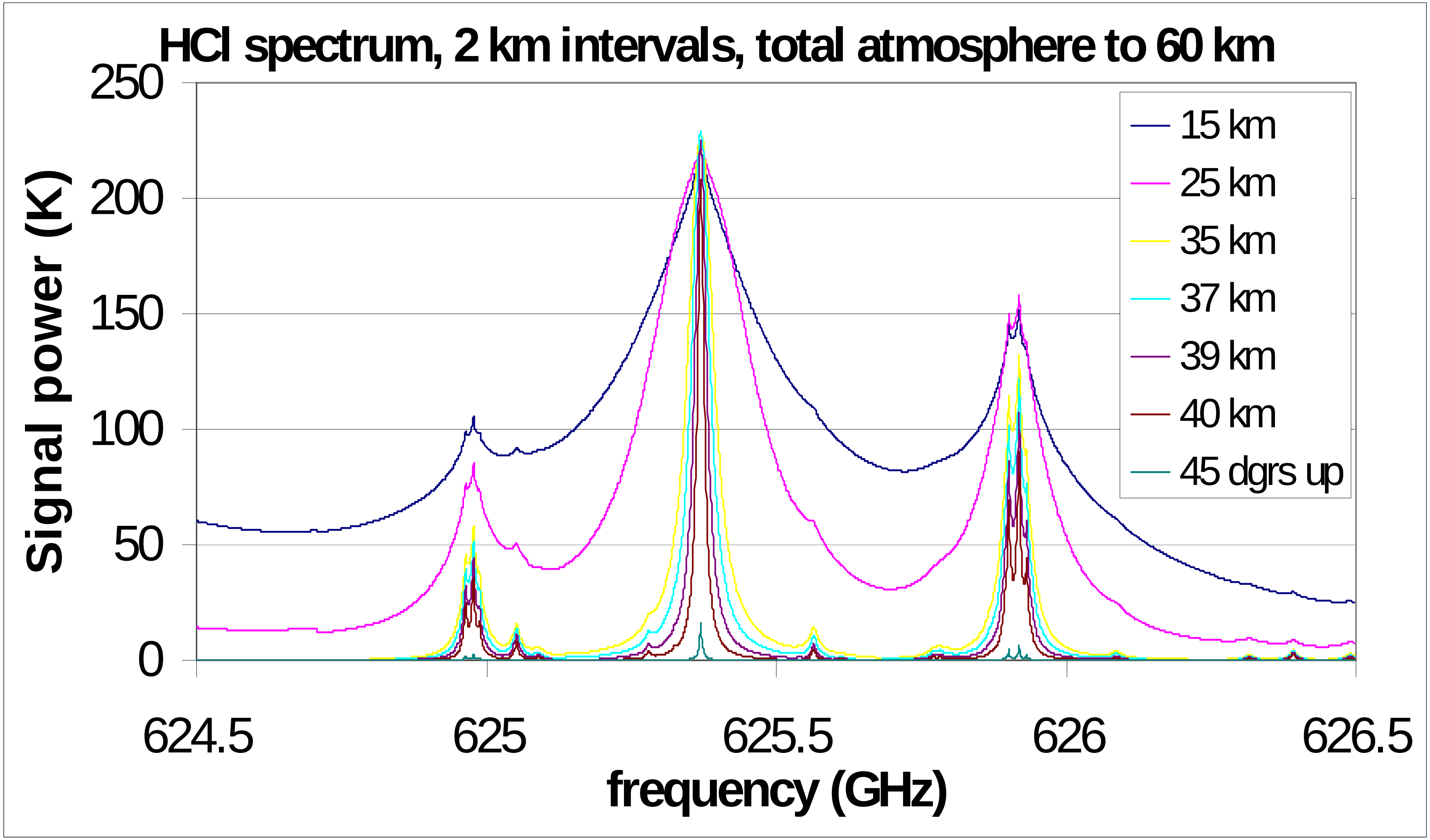
- Measure many species for atmospheric science
- Serve as a test platform for new sensors
- Serve as validation tool for future satellite missions

Three independent frequency channels, cryogenic heterodyne receivers:

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



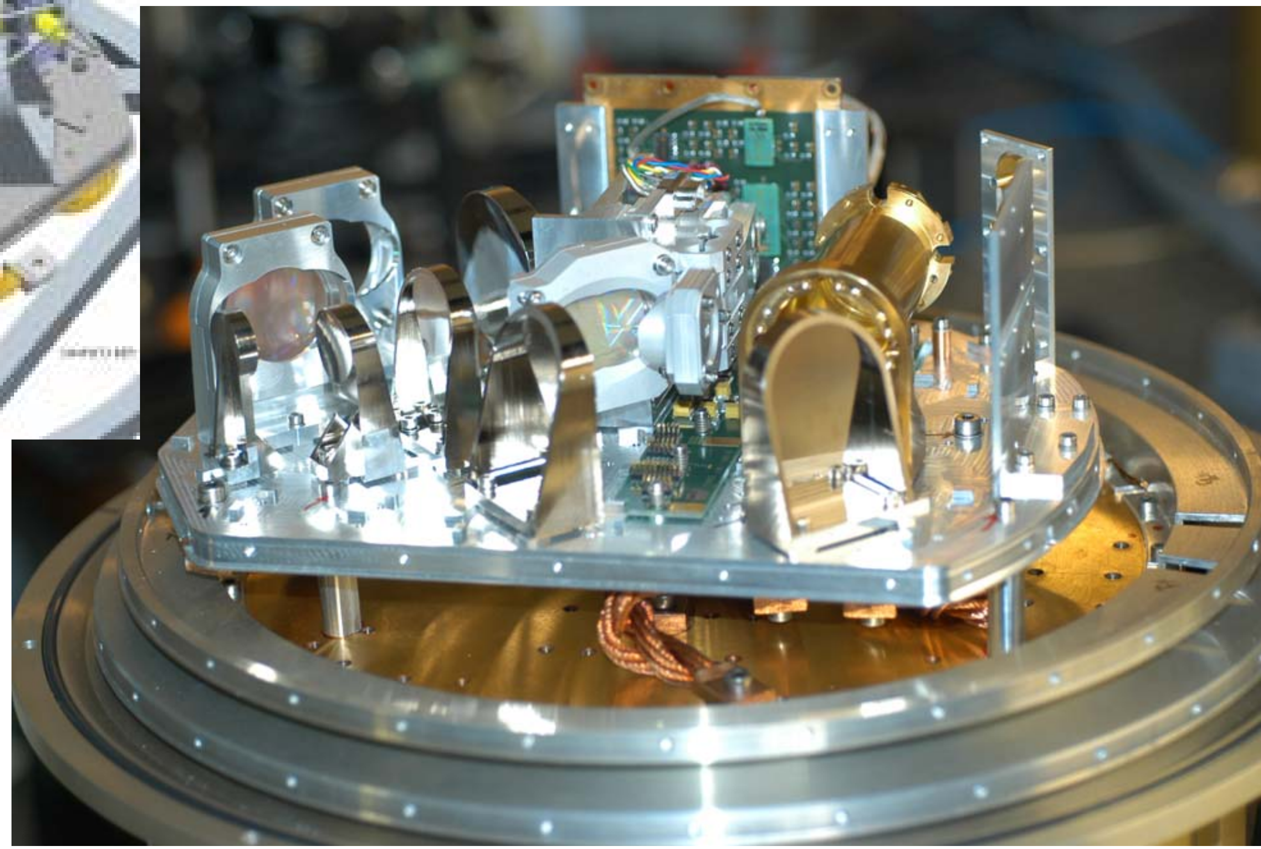
Example spectrum of HCl



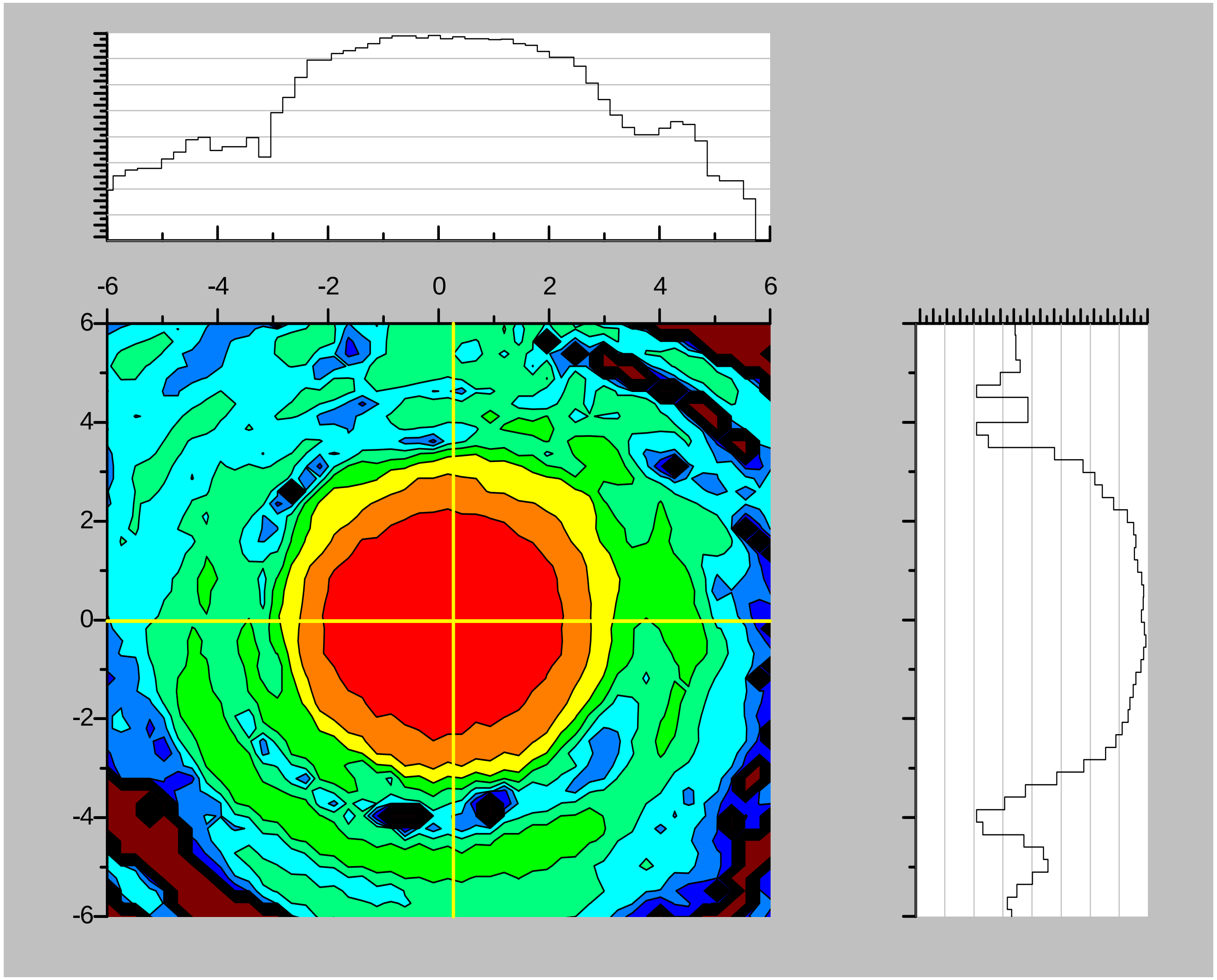
TELIS-SIR Main Parameters

##	Description	Value
1	**Input frequency range, GHz (Base line)**	**600 – 650**
2	**Input frequency range, GHz (Goal)**	**550 – 650**
3	**Minimum noise temperature in the range (DSB), K**	**250**
4	**Output IF range, GHz**	**4 - 8**
5	**Spectral resolution (width of the spectral channel), MHz**	**1**
6	**Contribution to the nearest spectral channel by phased locked FFO (dynamic range of the spectrometer), dB**	**-20**
7	**Contribution to a spectral channel by phased locked FFO at 4-6 GHz offset from the carrier, K**	**20**
8	**LO frequency net (distance between nearest settings of the PL FFO frequency), MHz**	**< 300**
9	**Dissipated power at 4.2 K stage (including IF amplifiers chain), mW**	**100**
10	**Operation temperature, K**	**< 4.5**

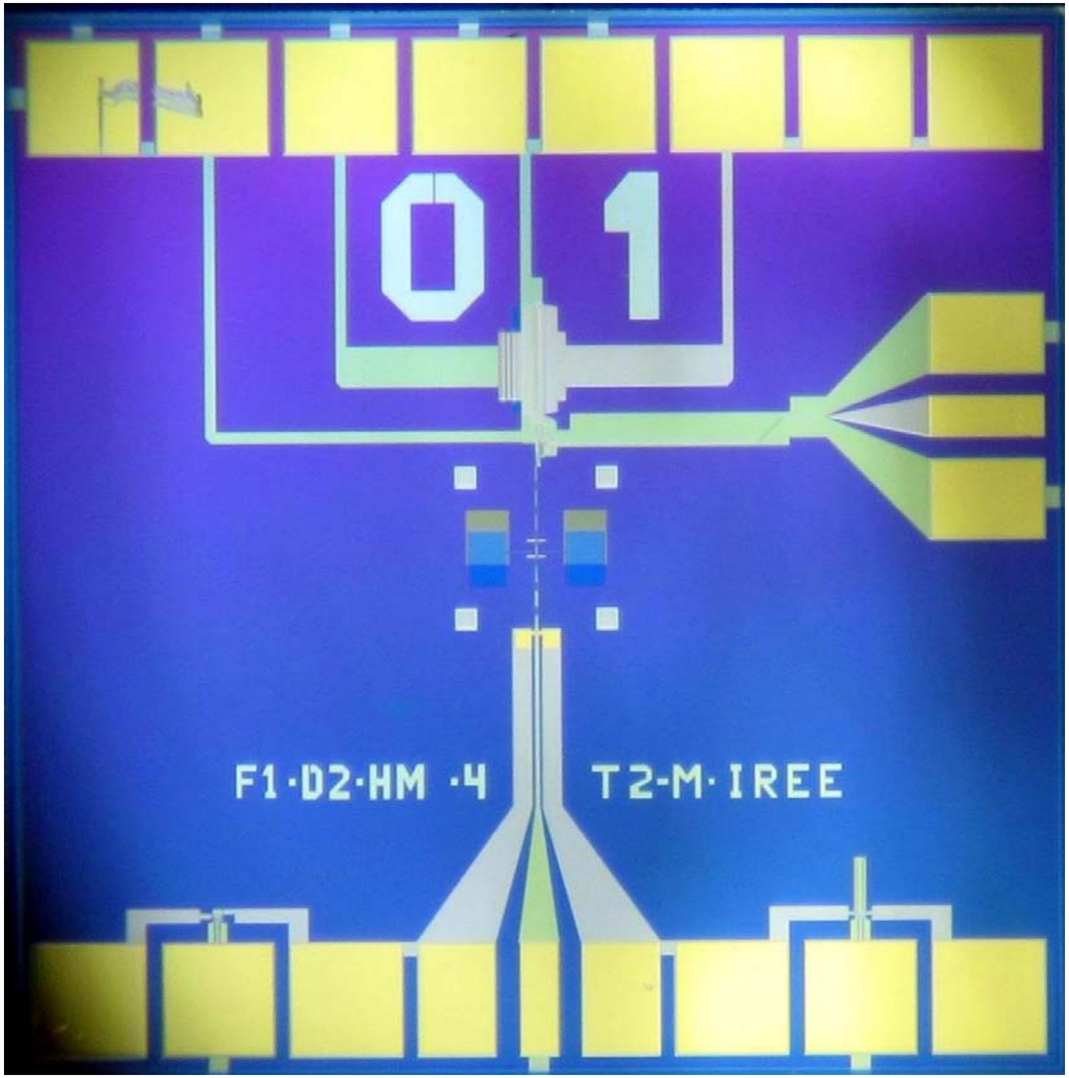
Photo of the SIR-TELIS channel



Beam Pattern of the SIR for TELIS



SIR Microcircuit for TELIS



4 x 4 x 0.5 mm^3 (Si)

Nb-AlOx-Nb

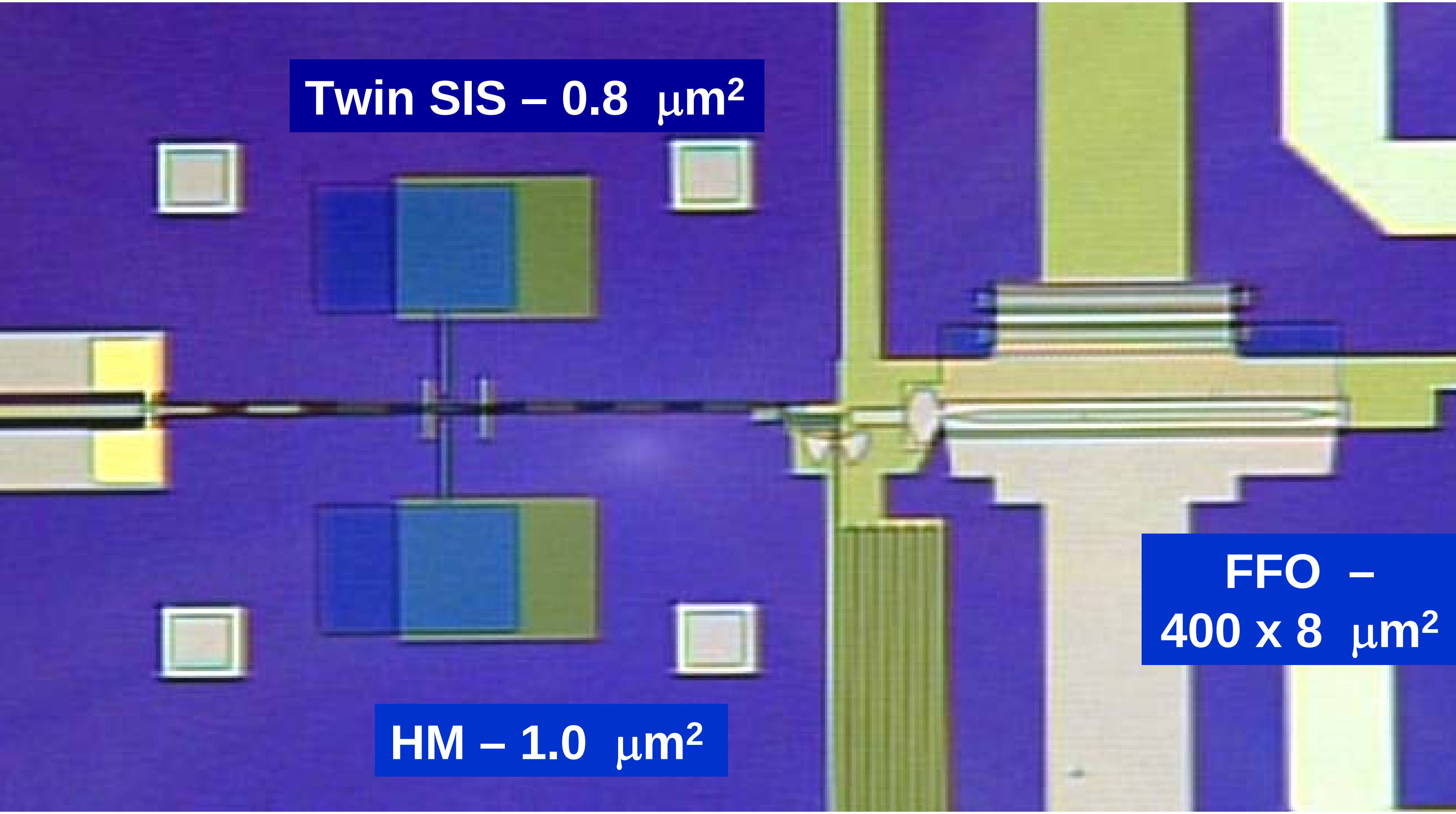
Jc = 5 - 8 kA/cm^2

Optionally:

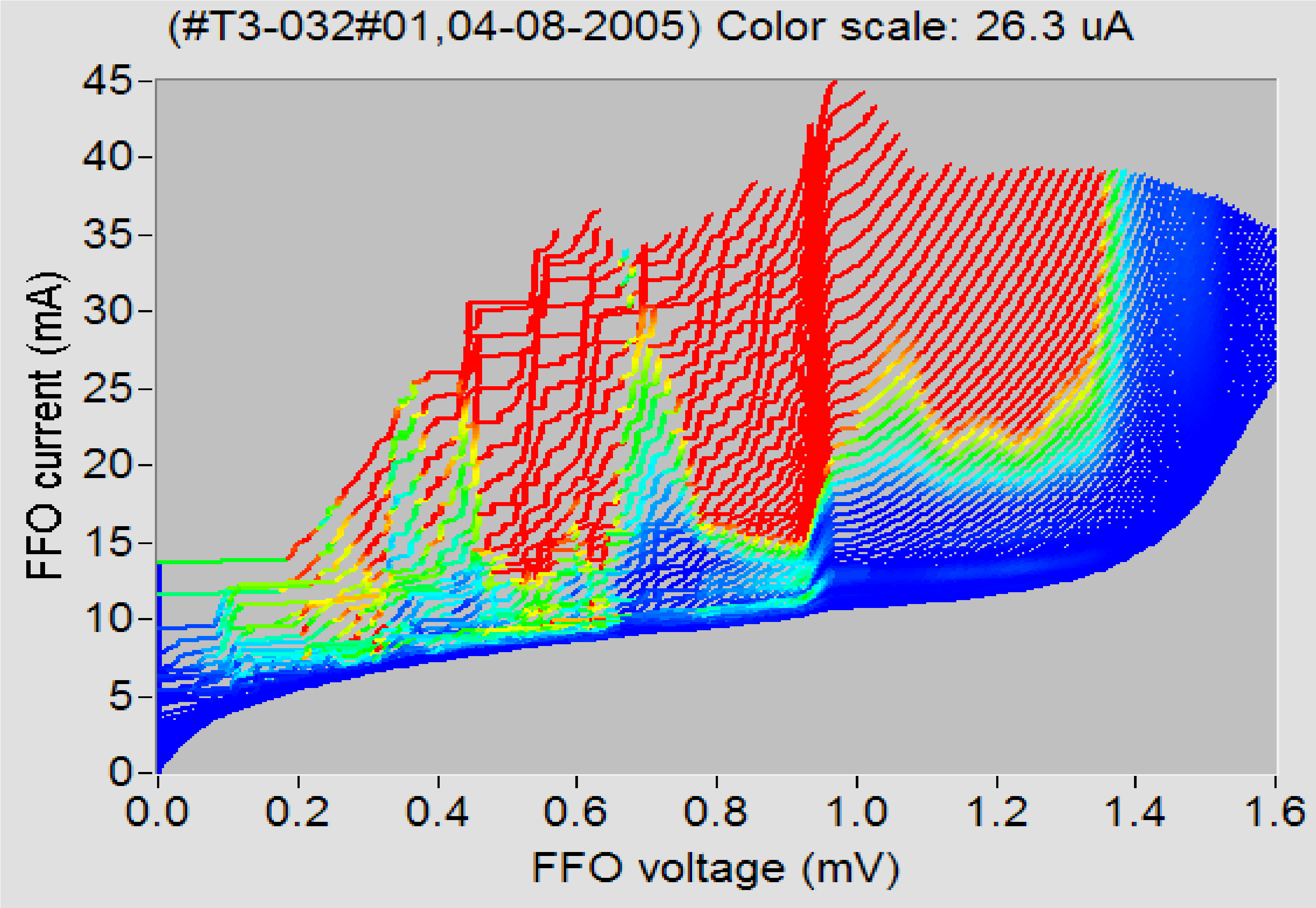
SIS – Jc = 8 kA/cm^2

FFO + HM = 4 kA/cm^2

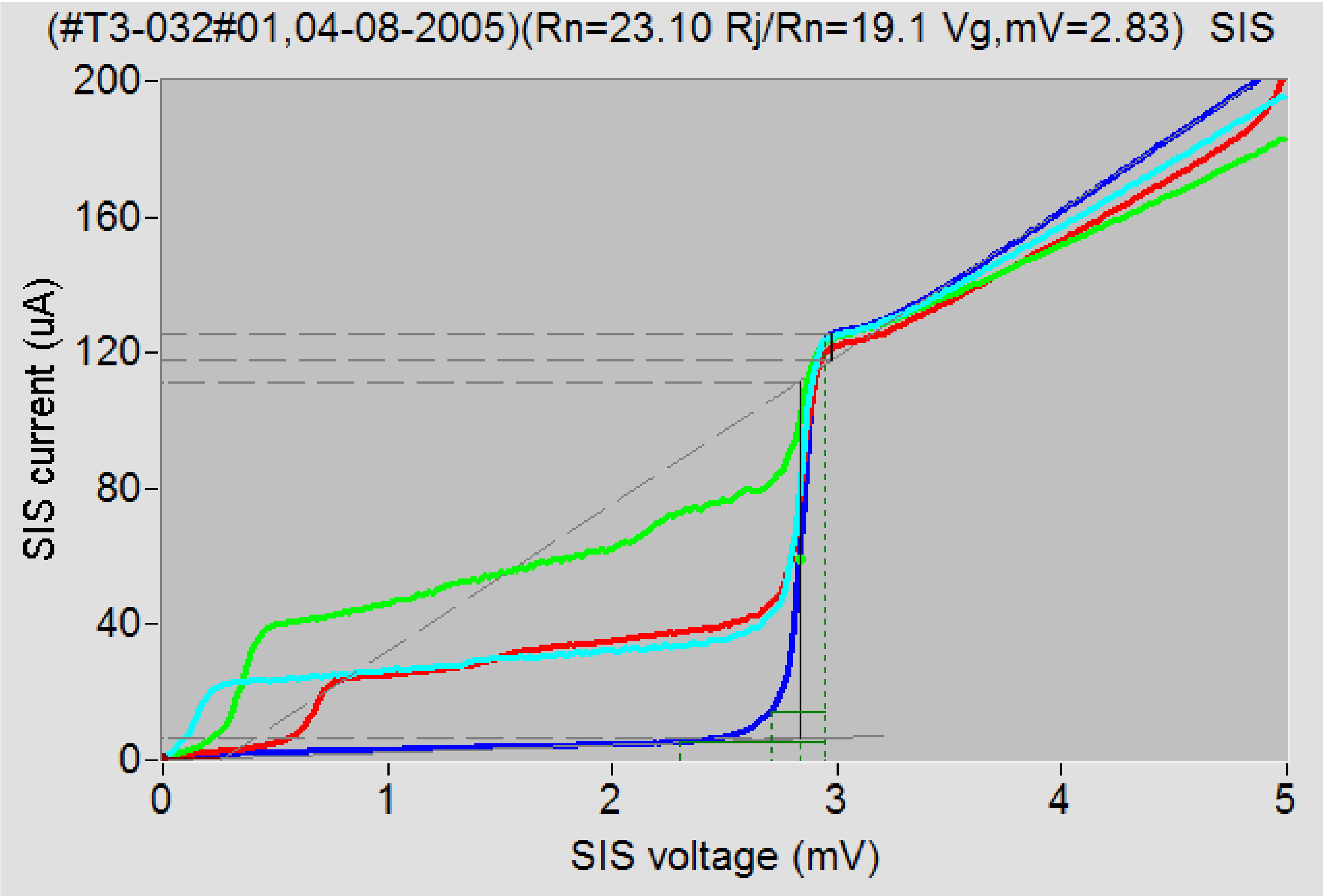
SIR Microcircuit for TELIS



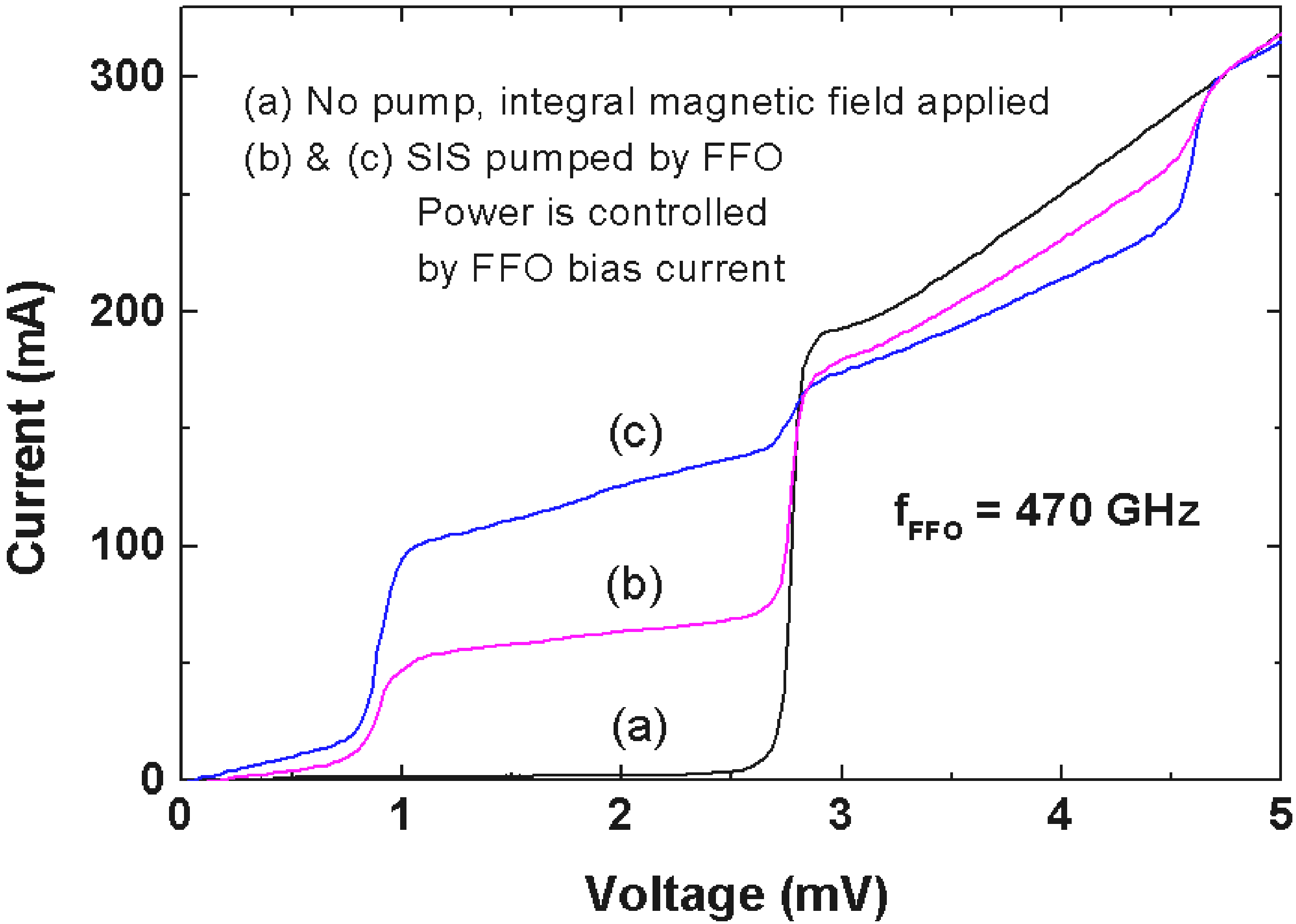
IVCs of the FFO of T3 design measured at different CL currents (red = > 25% of SIS Ig)



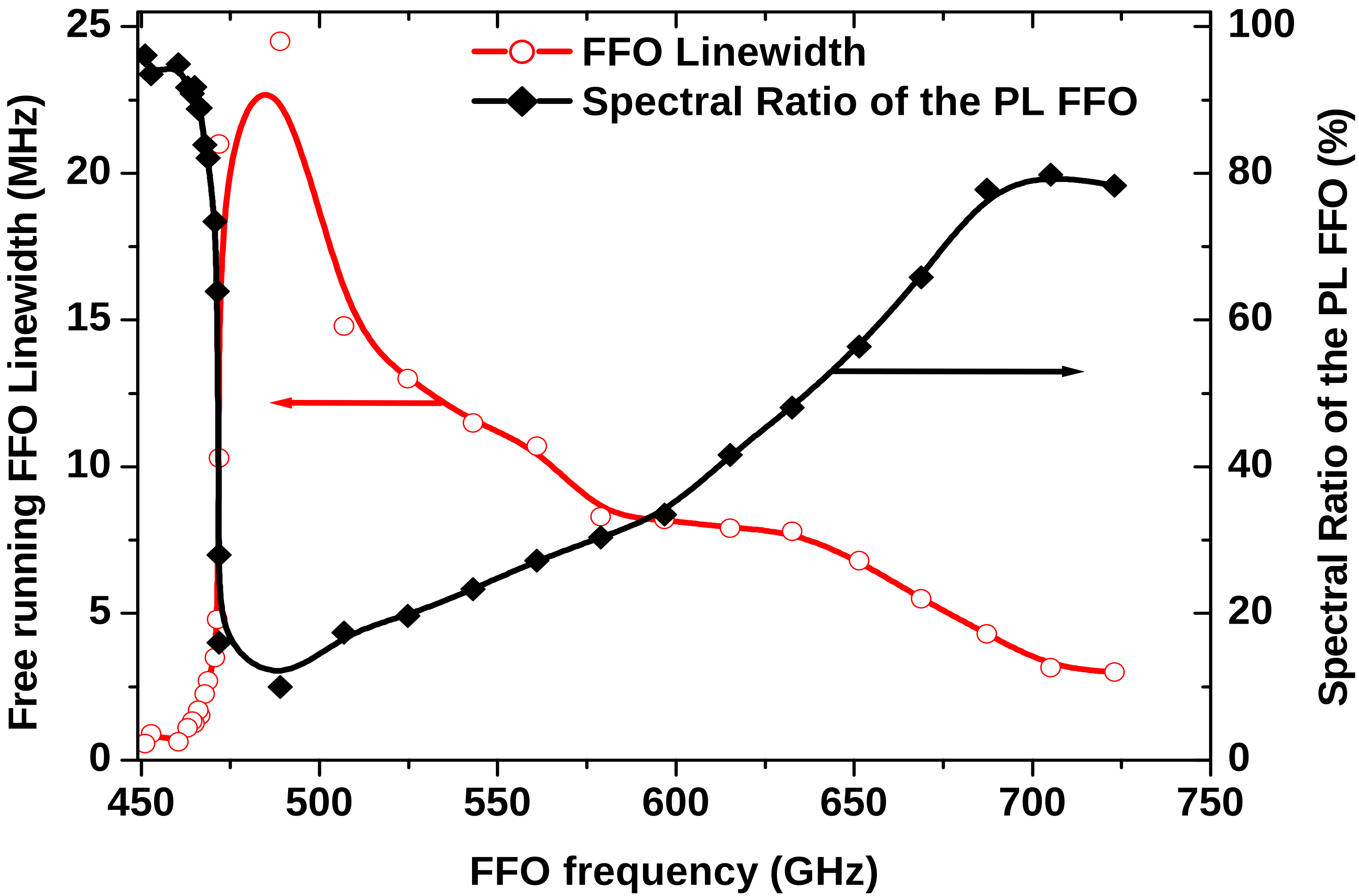
IVCs of the SIS-mixer of T3 design; f FFO = 522, 600 and 650 GHz



FFO + SIS; Power Control

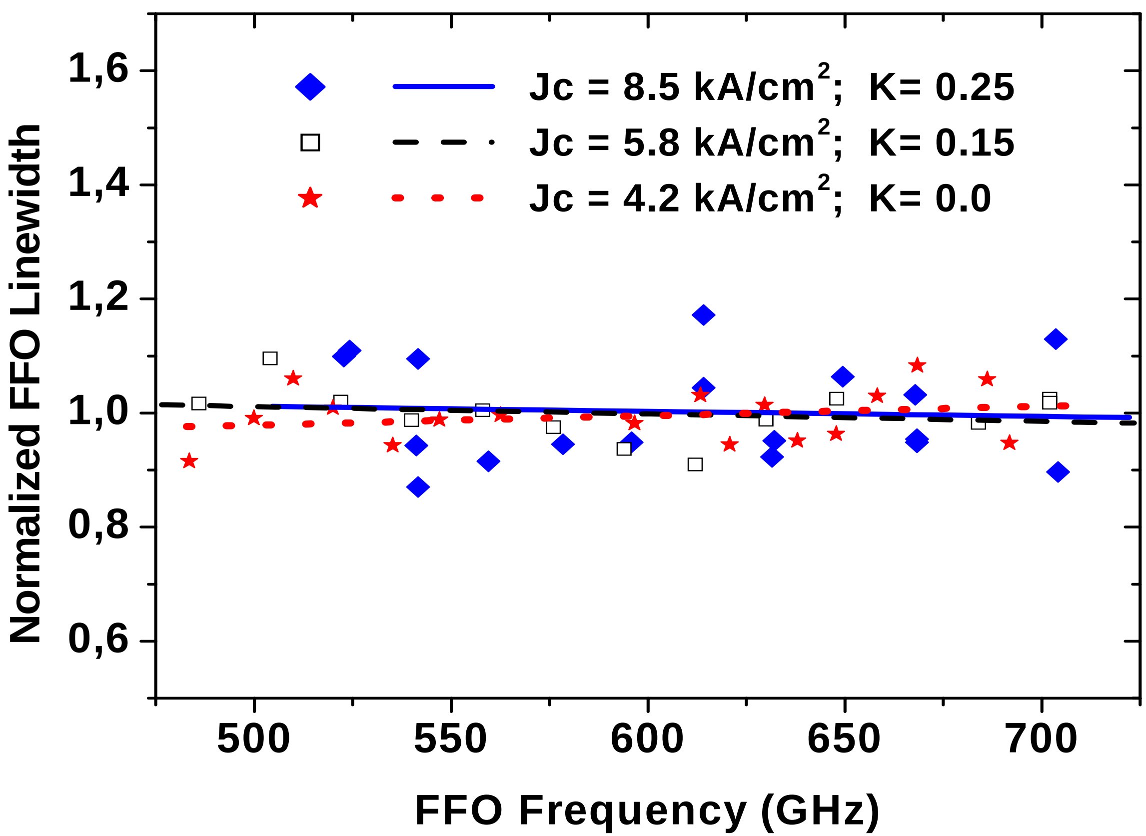


FFO linewidth and Spectral Ratio PL FFO on its oscillation frequency.

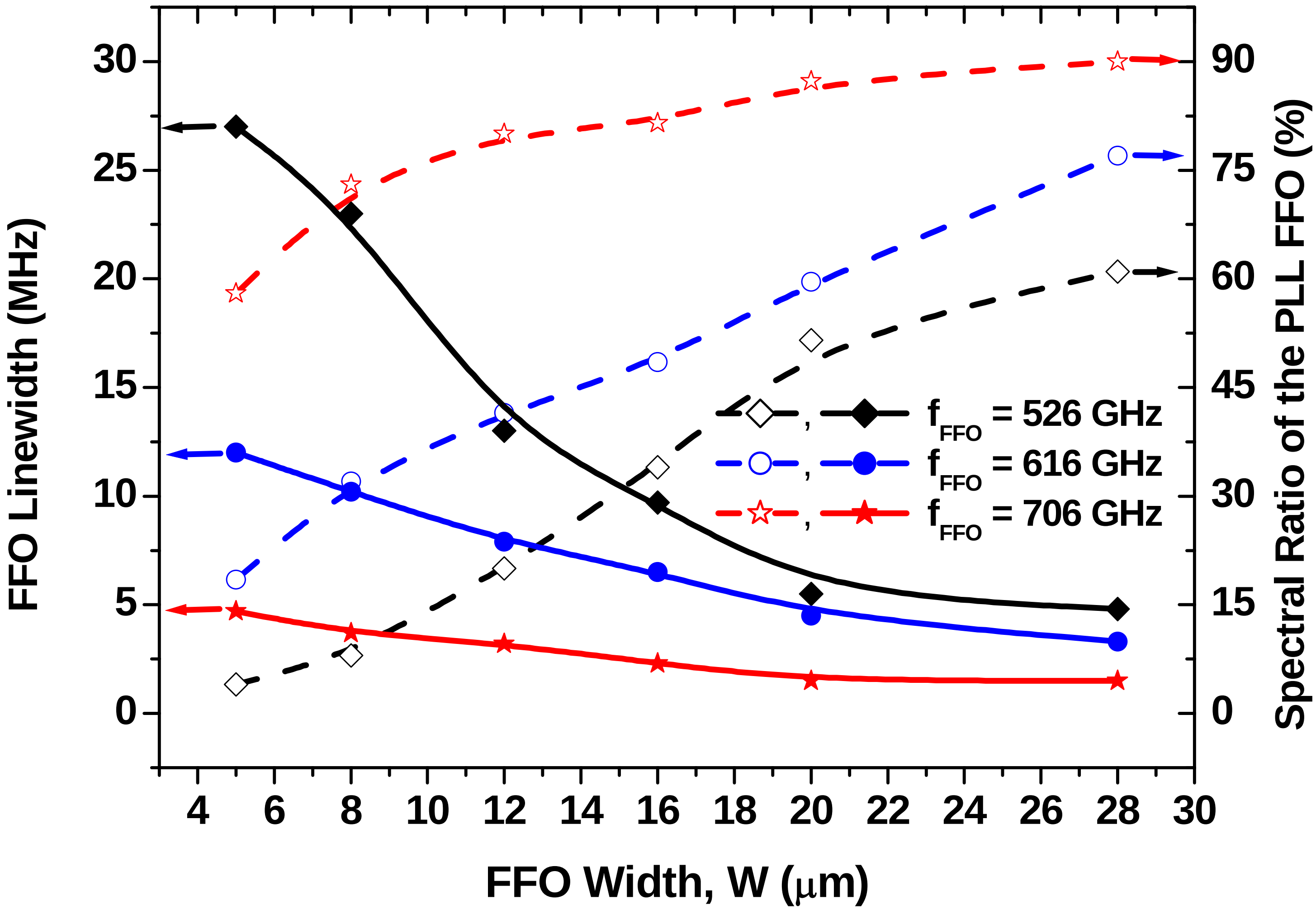


Normalized FFO Linewidth

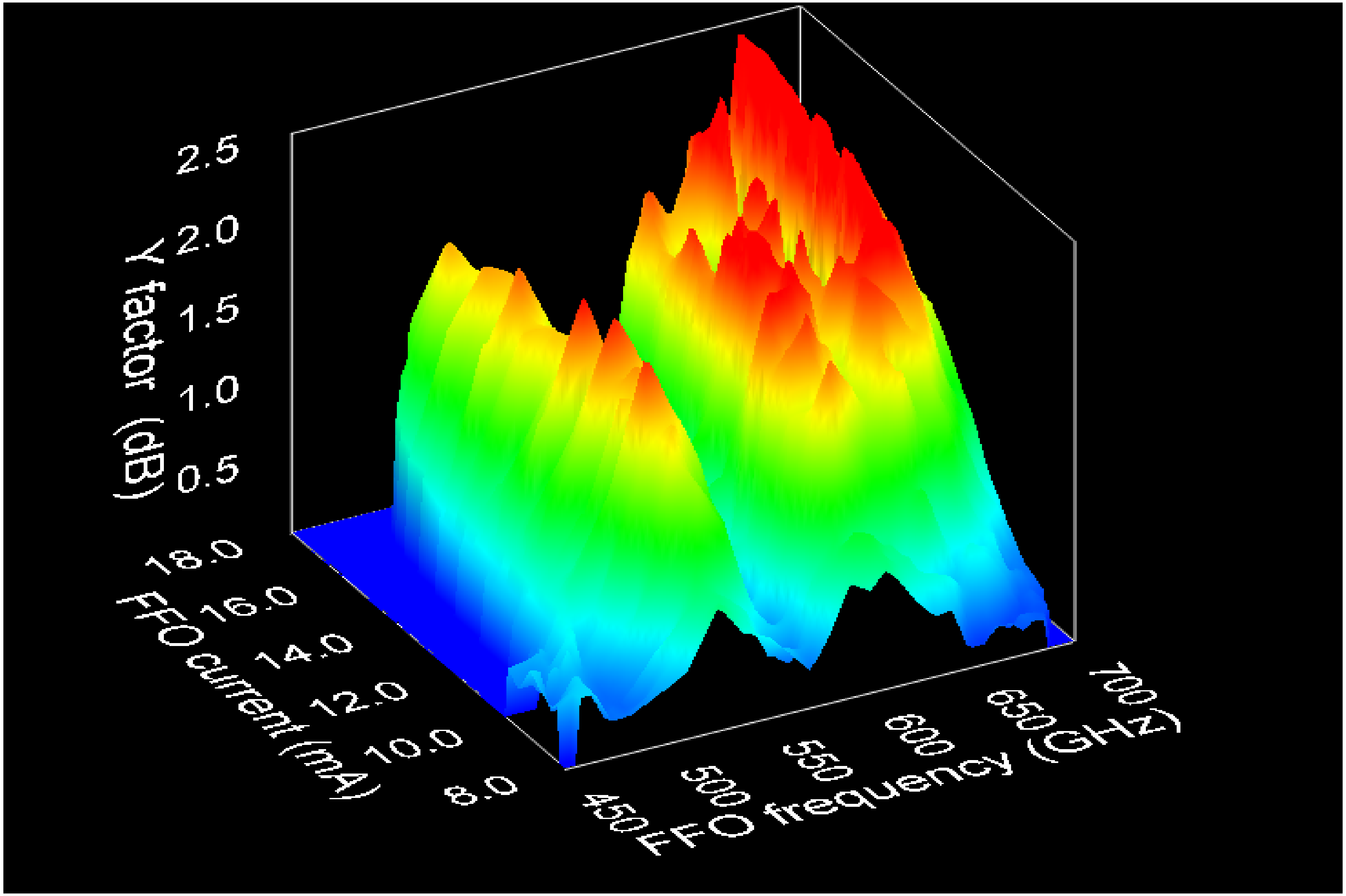
$$\Delta f := \left(\frac{2\cdot e}{h}\right)^2 \cdot \left(R_d + K\cdot R_{dCL}\right)^2 \cdot \left[\frac{e\cdot(Iqp)}{2\cdot\pi}\cdot\coth\left(\frac{e\cdot V}{2\cdot k_b\cdot T}\right) + \frac{2\cdot e\cdot(Is)}{2\cdot\pi}\cdot\coth\left(\frac{e\cdot V}{k_b\cdot T}\right)\right] + \frac{1}{\pi}\cdot\left(\frac{2\cdot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



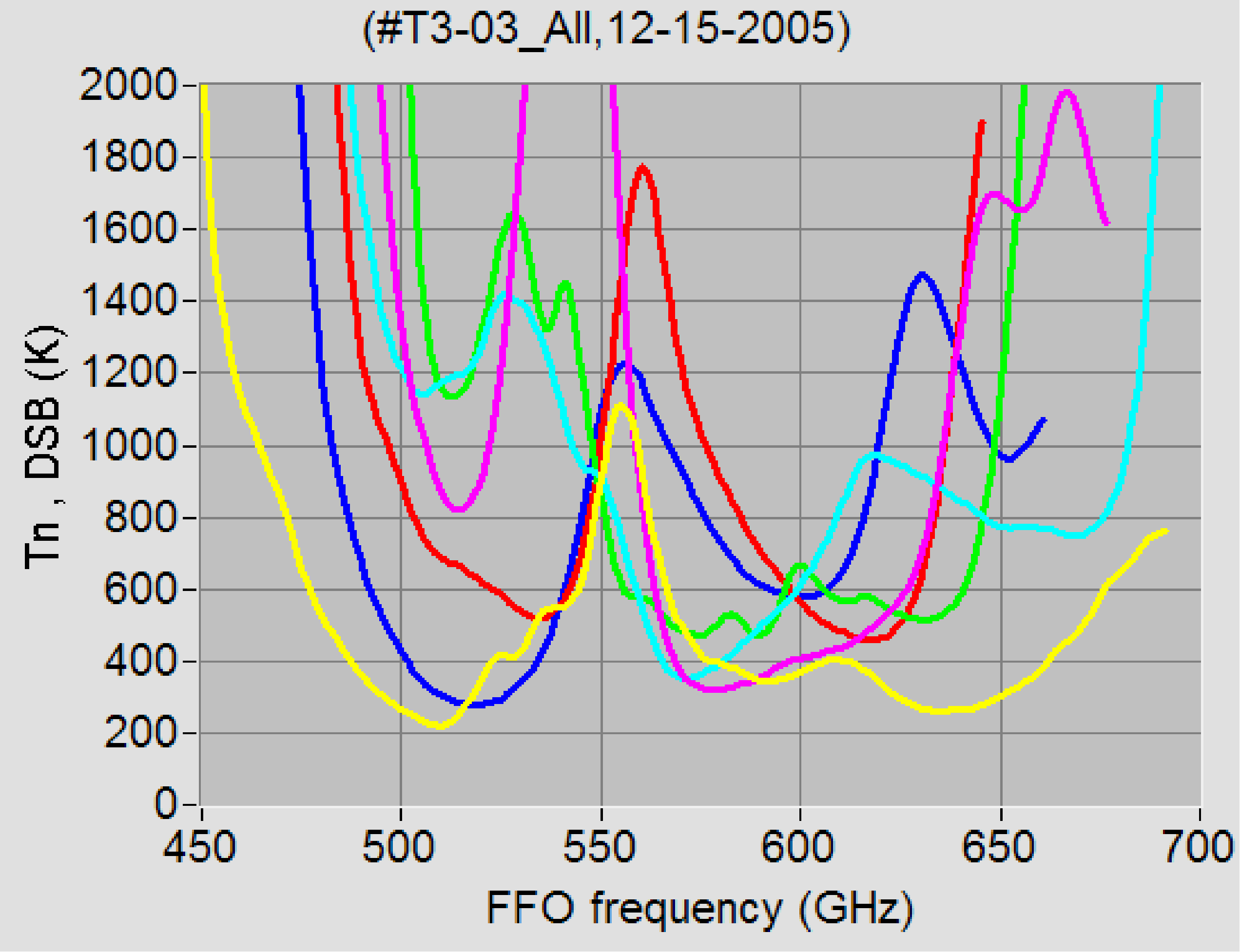
Linewidth of free-running FFOs and SR for the PL FFO as a function of FFO width (RnS =30 Ω*μm²)



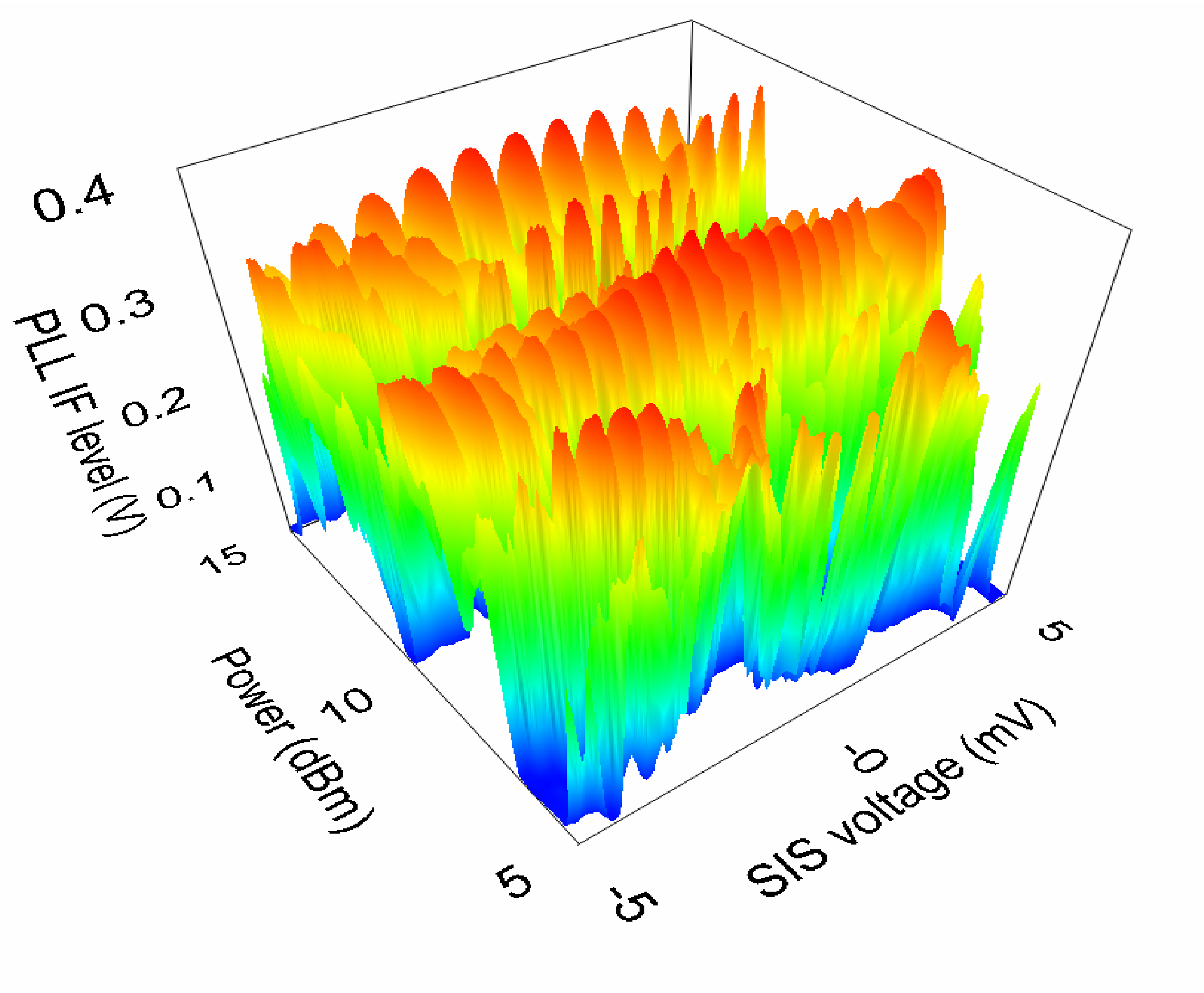
Y-factor of the SIR,
T= 2.1 K, V_{SIS} = 2.2 mV, IF = 4.3 GHz



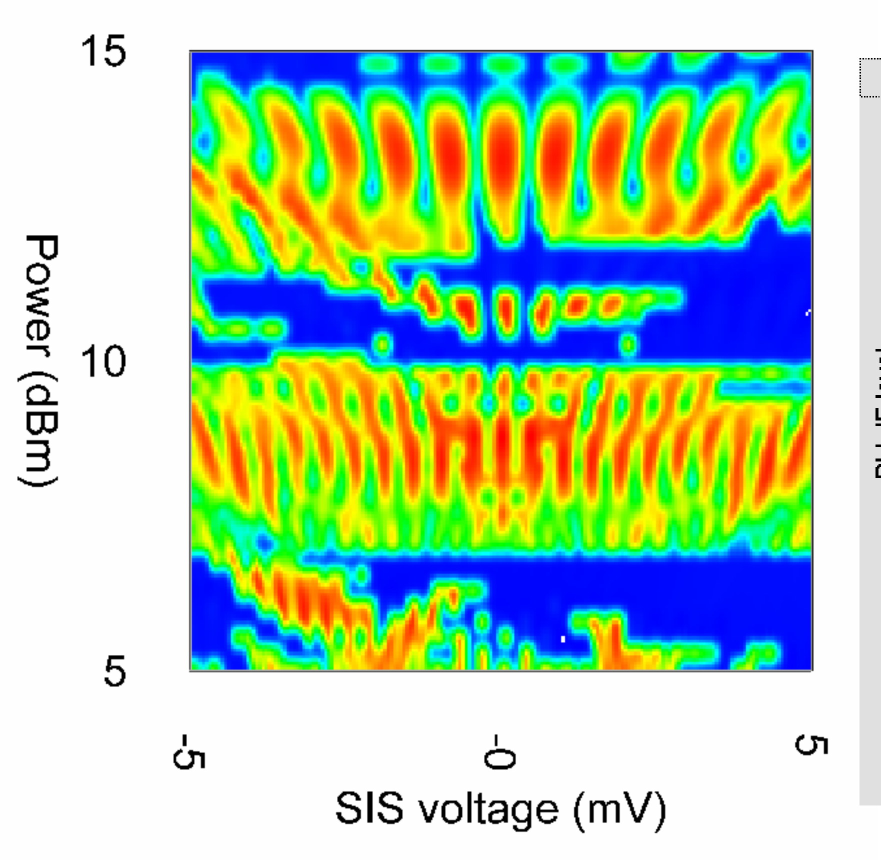
Uncorrected Tn (DSB) , T=4.2 K, for different TELIS-SIR designs;
peak at 557 GHz is due to water line

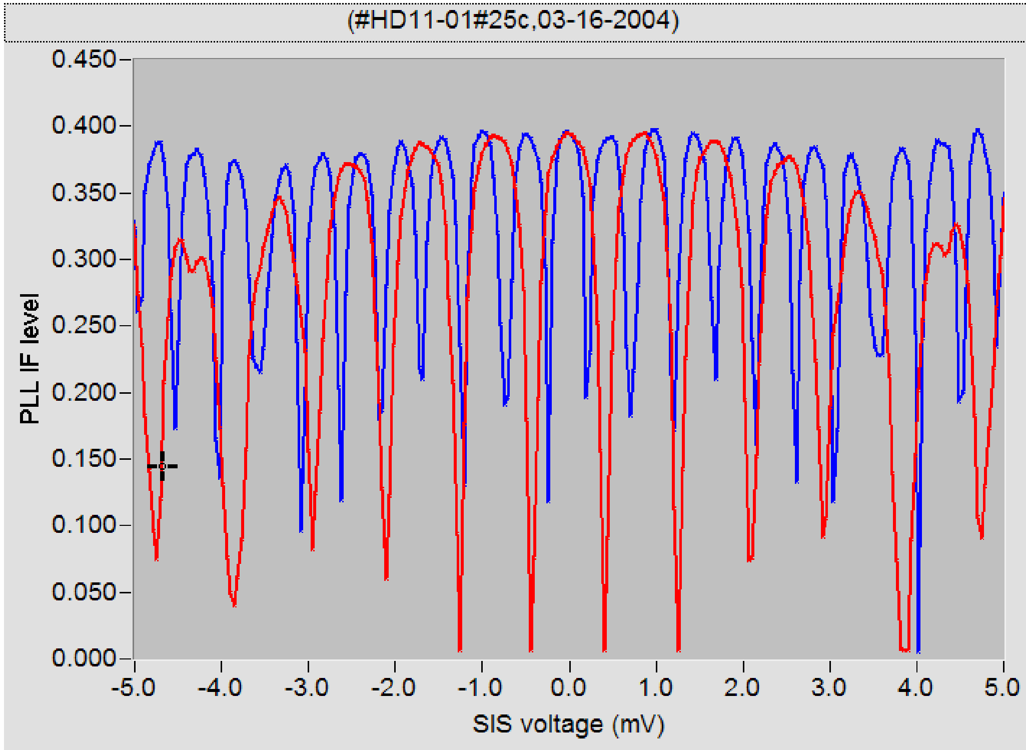


Remote optimization of the PLL SIR operation (3-D)



Remote optimization of the PLL SIR operation (2-D and 1-D)





ESPRIT – Exploratory Submm Space Radio-Interferometric Telescope

The six elements of ESPRIT in an Ariane 5

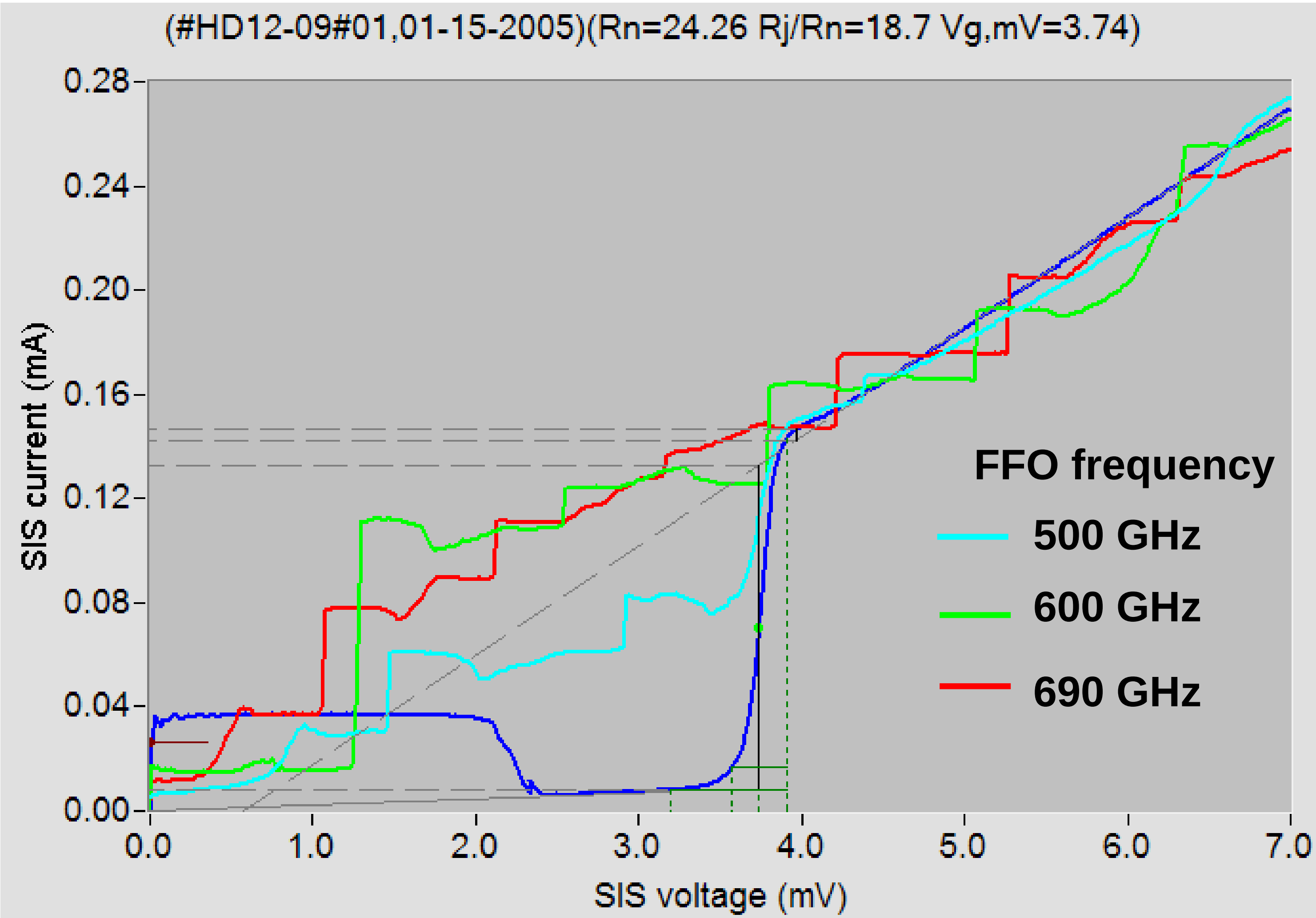
- Telescope sizes ~ 3.5 meter ; off-axis
- Number of elements N = 6 (15 baselines)
- Frequencies:

  Spots in the range 0.5 – 6 THz
- Projected baselines 200 - 1000 meter
- Front Ends -

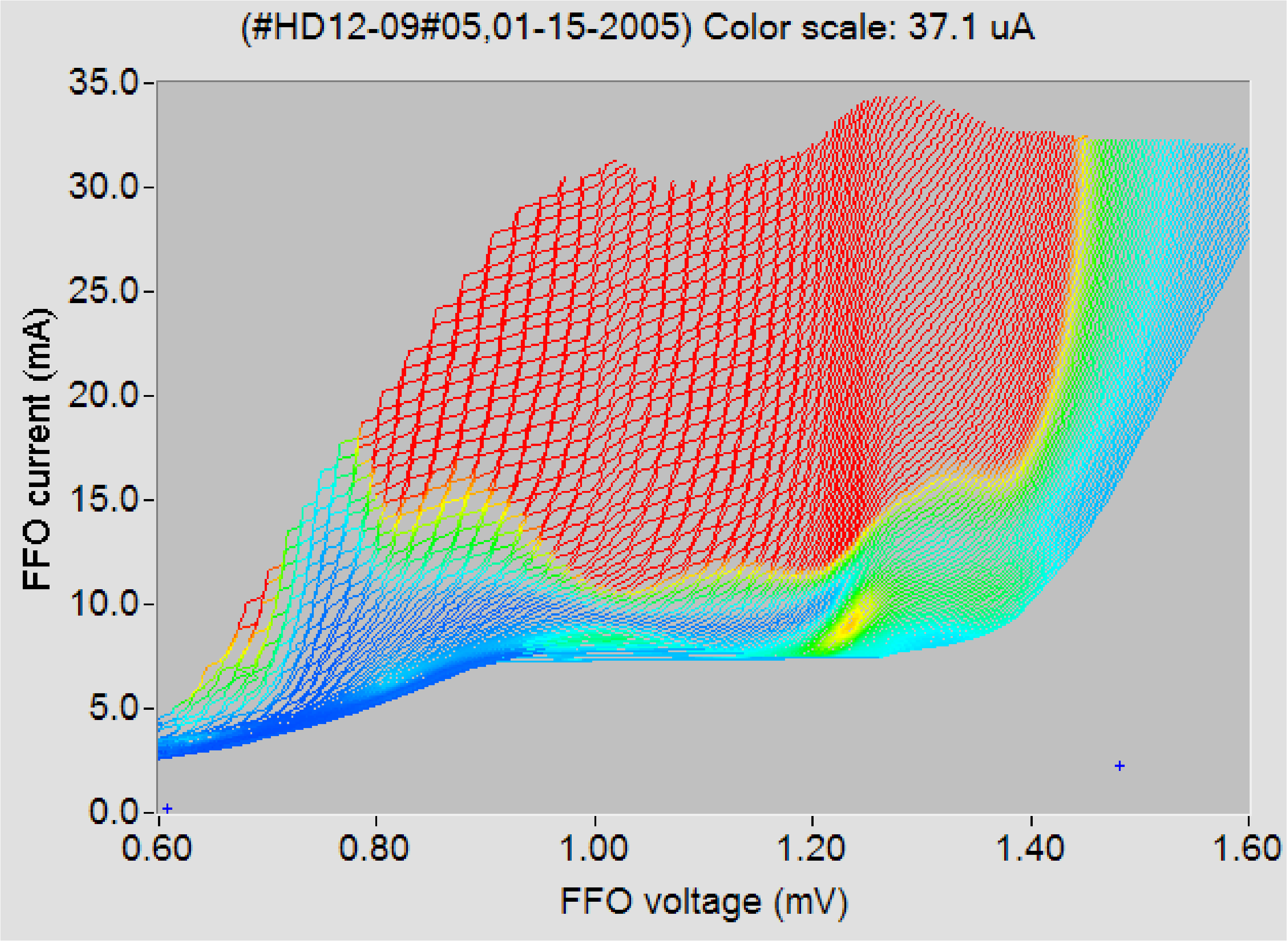
  (0.5 – 1.5 THz) SIS mixers, multiplier LO/FFO

  (1.5 – 6 THz) HEB mixers, QCL as LO
- System temperature 1000 K
- IF bandwidth > 4 GHz (goal 8 GHz)

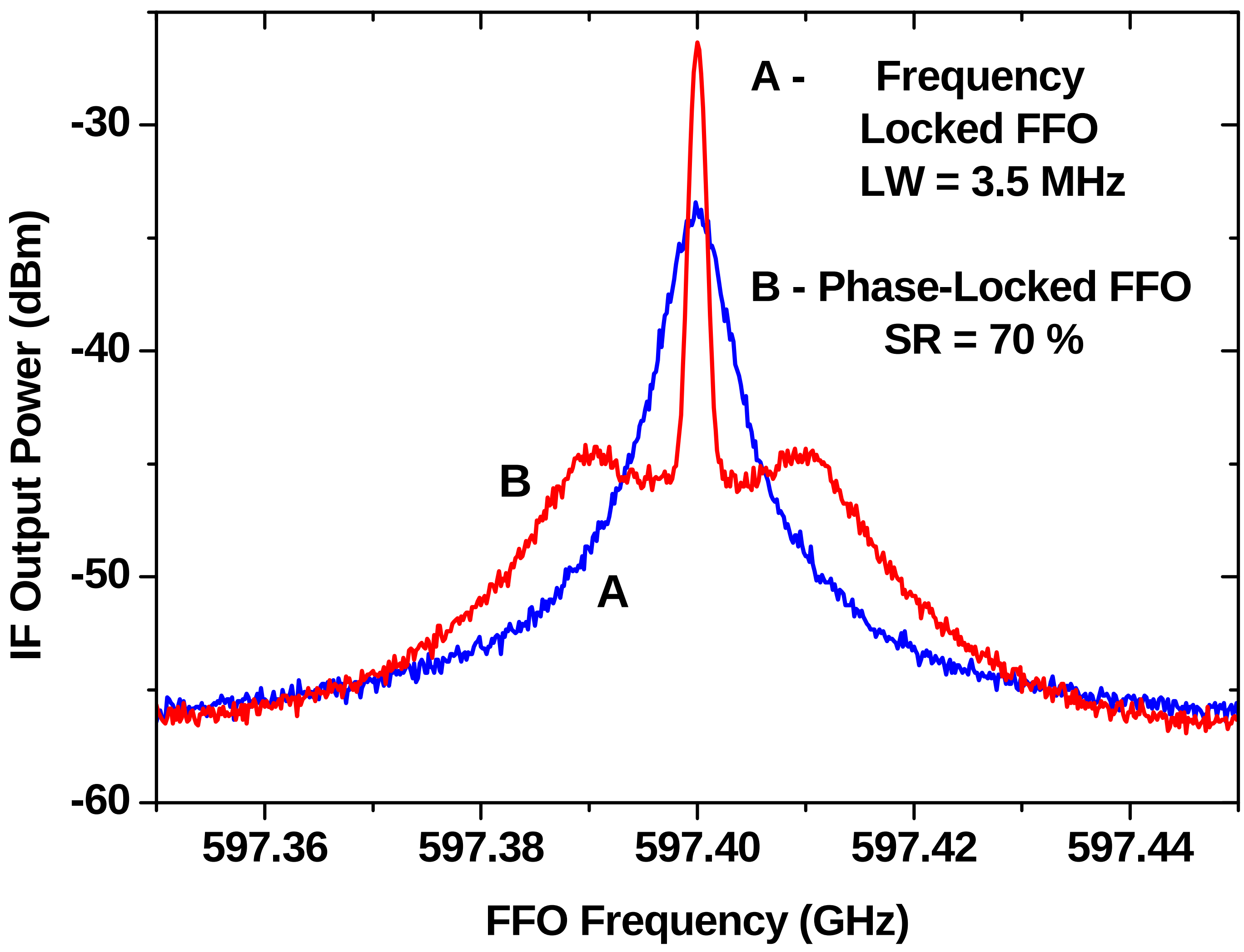
Nb-AlN-NbN SIR – first implementation



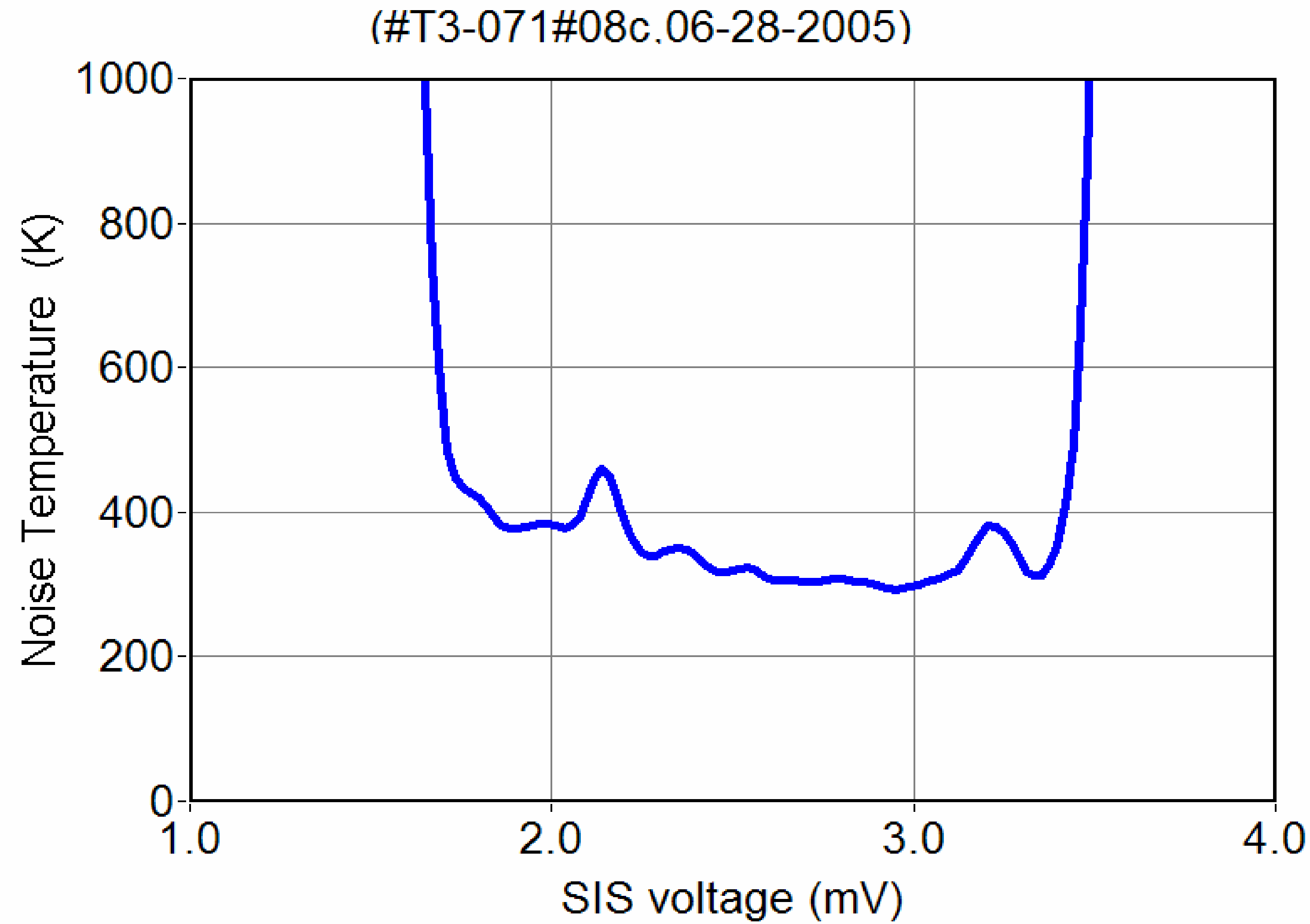
Nb-AlN-NbN FFO – new features



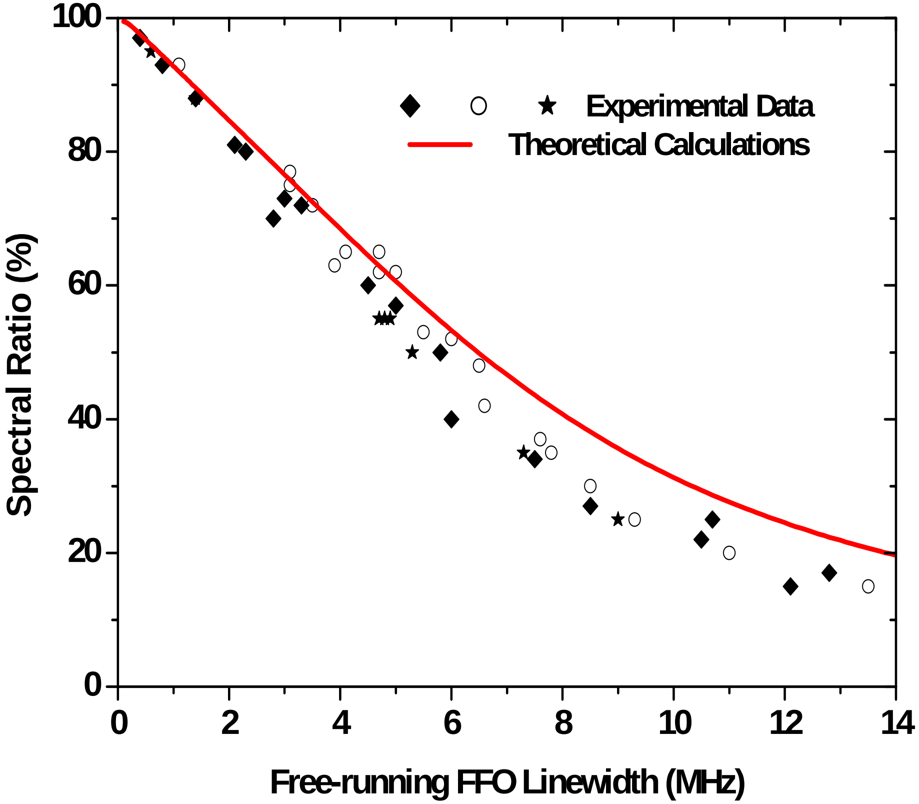
Nb-AlN-NbN FFO – phase-locking

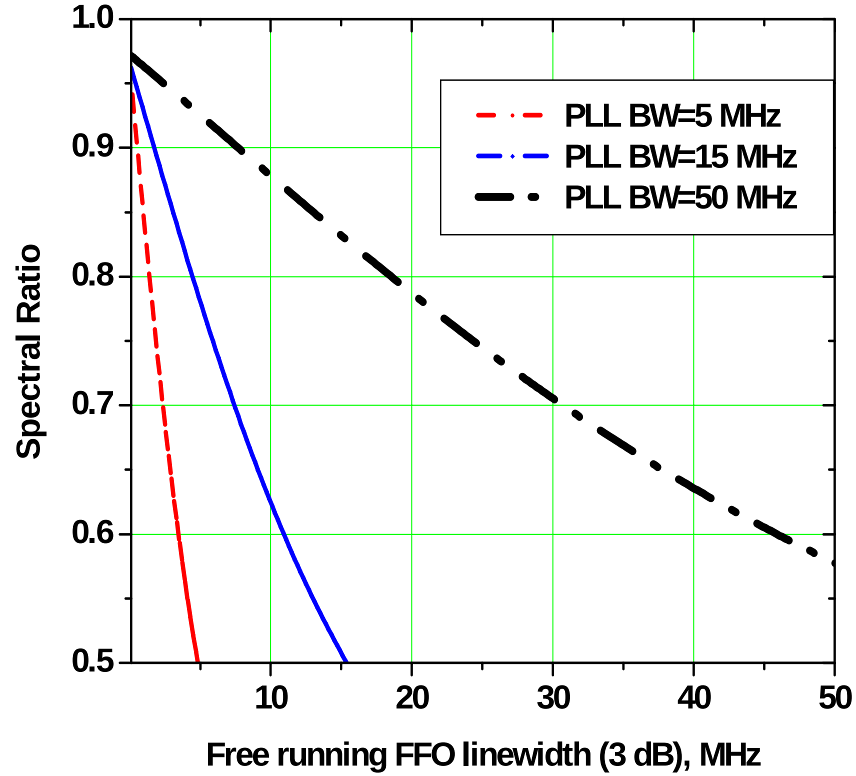


Nb-AlN-NbN SIR (FFO frequency 510 GHz)

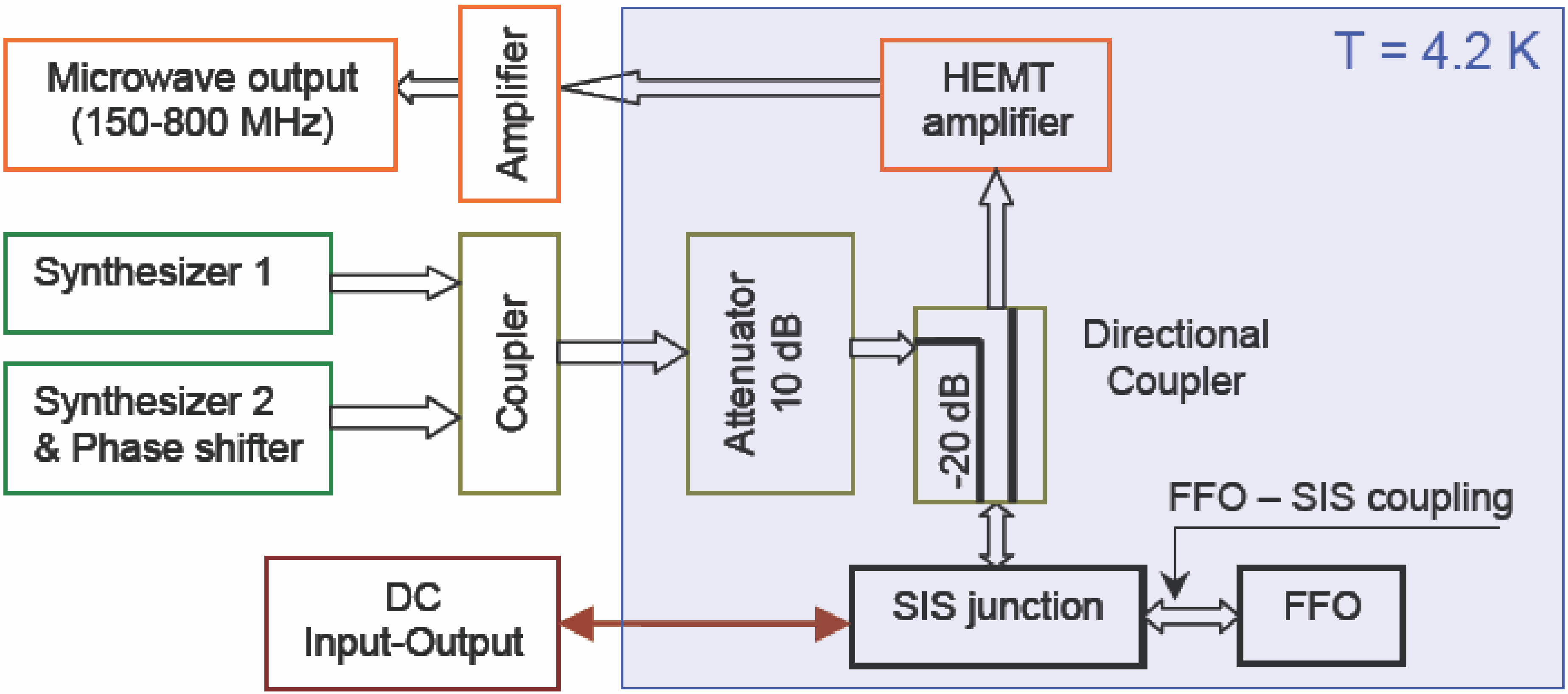


Spectral Ratio of the PL FFO vs free running FFO linewidth

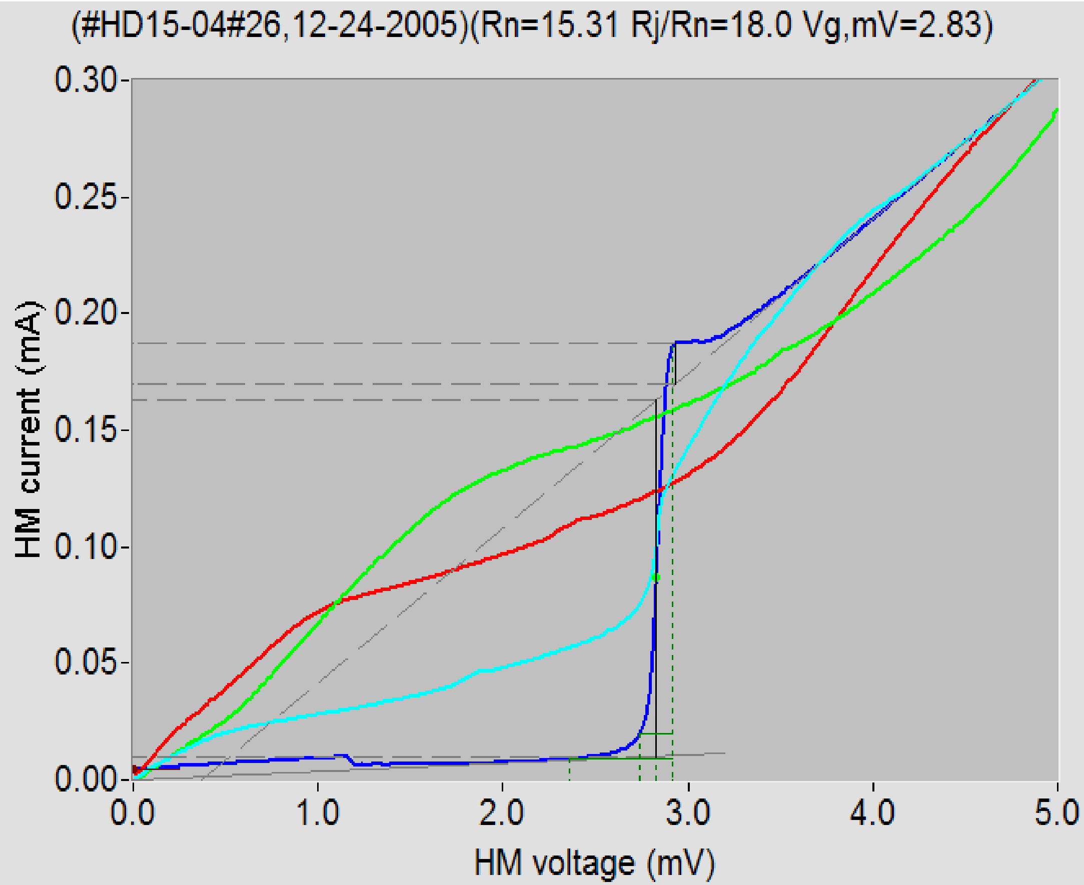


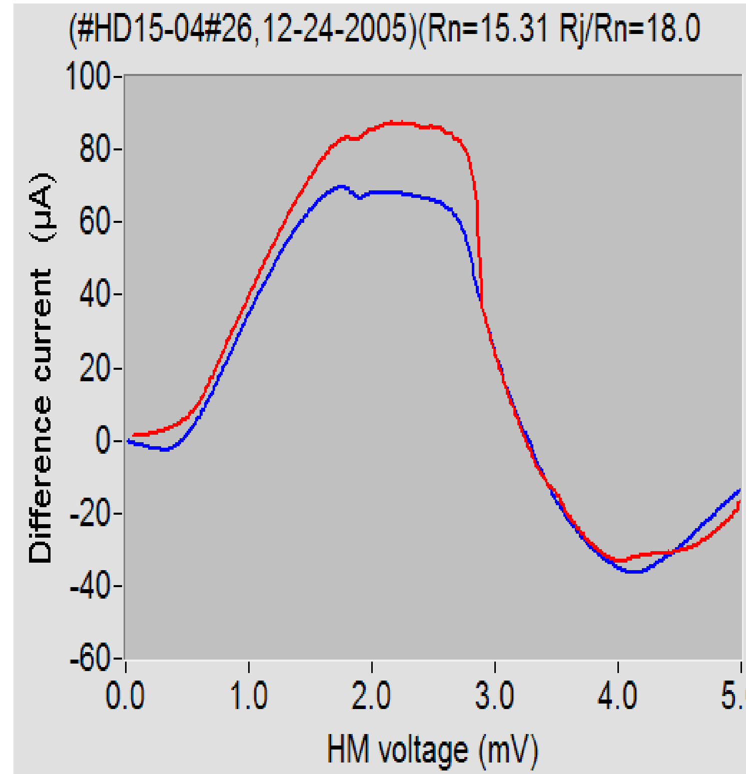


Block-diagram
for the Cryogenic Phase Detector Tests

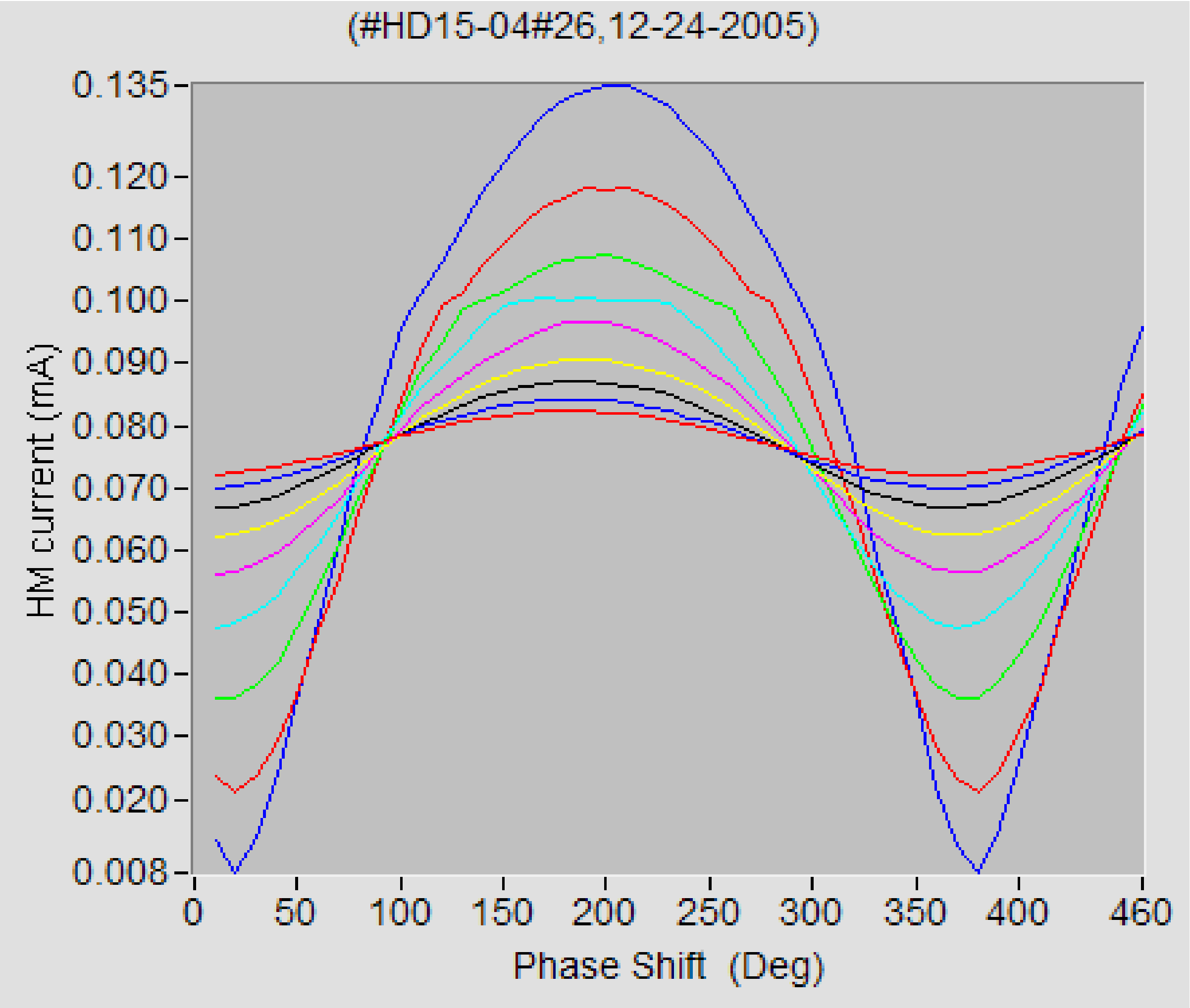


SIS IVCs at 5 GHz and the difference current corresponding to phase shift on 180°

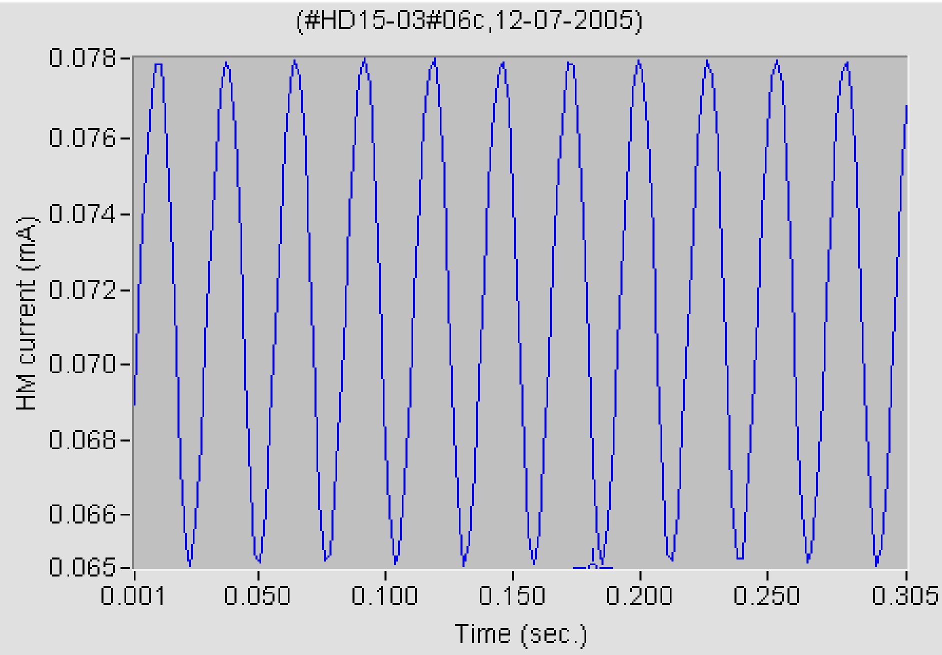


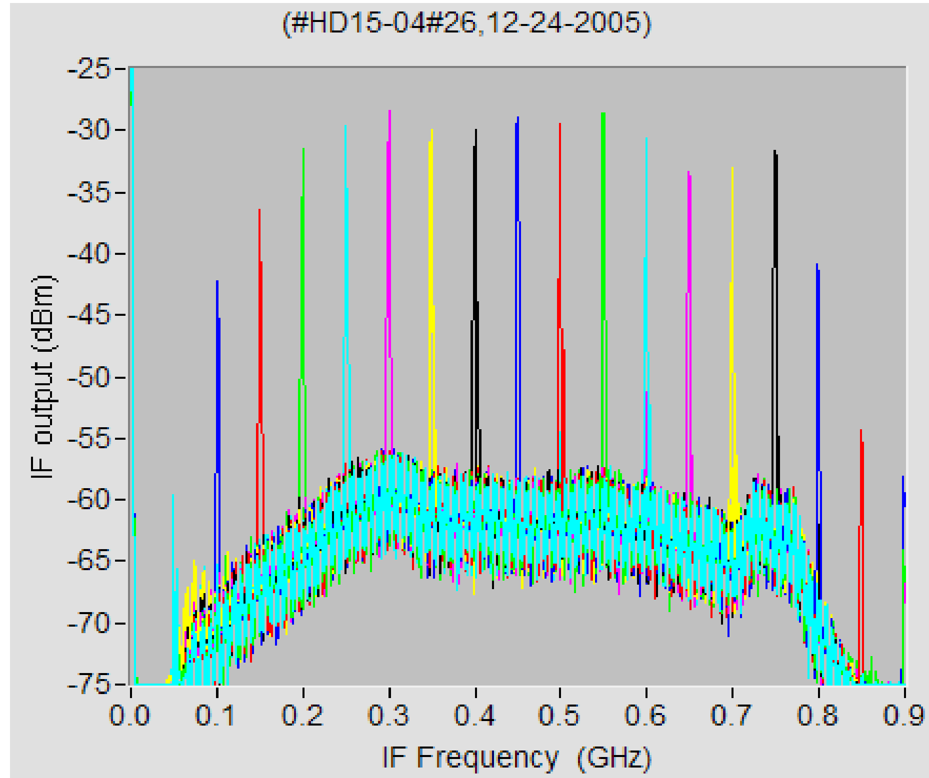


Dependence of SIS current on the phase between two 5 GHz signals



SIS Phase Detector output at DC and IF; two different frequencies applied





Snow peak as high as 2 m …

… has been successfully integrated to the igloo

Conclusion

- Concept of PL SIR is developed and tested.
- Improved design of the FFO for TELIS has been developed and optimized; free-running linewidth from 9 to 2 MHz recorded in the frequency range 500 – 710 GHz that allows to phase lock from 35 up to 90 % of FFO power.
- Third generation of the PL SIR IC for TELIS has been developed showing a possibility to realize TELIS requirements (Tn below 250 K from 550 up to 650 GHz).
- Procedure for remote optimization of the PL SIR operation has been developed and experimentally proven.
- NbN based FFO and SIR have been successfully tested.
- Possibility to use SIS mixer as a core element for the ultra-wideband cryogenic PLL system has been demonstrated.