# Quantum limited superconducting integrated sub-THz receivers


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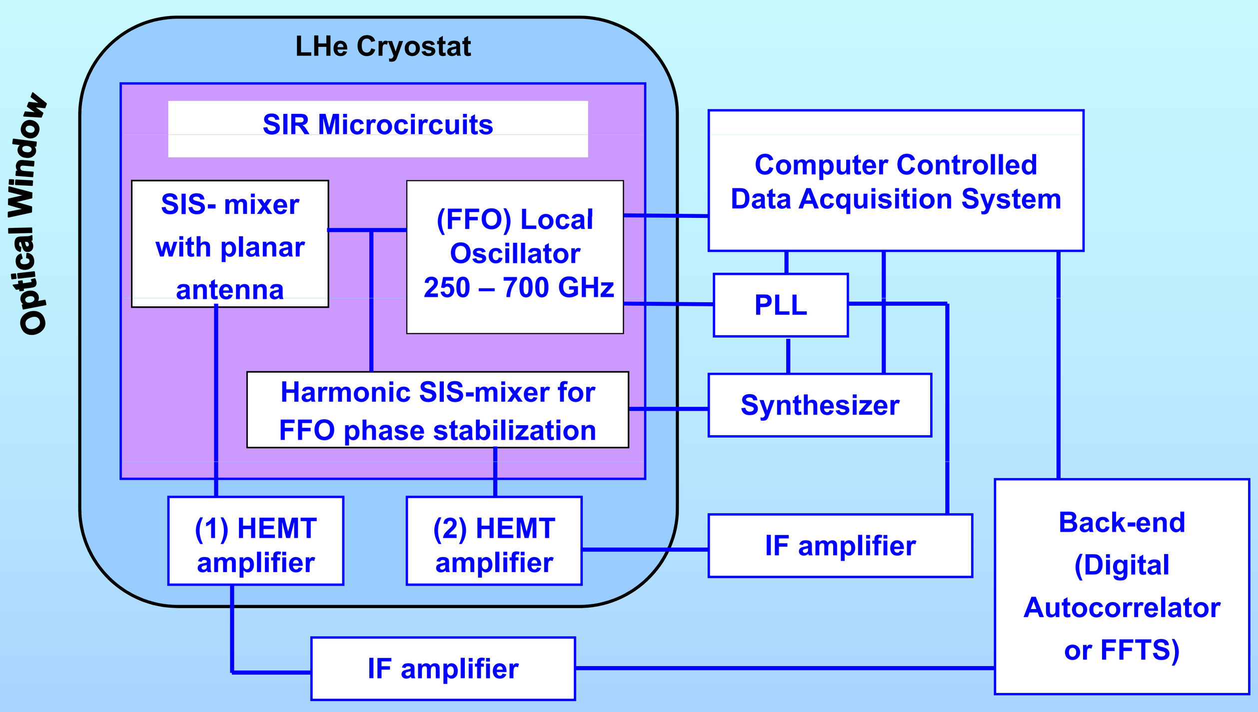
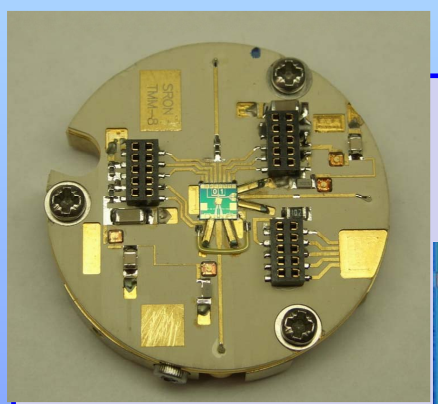
## Abstract

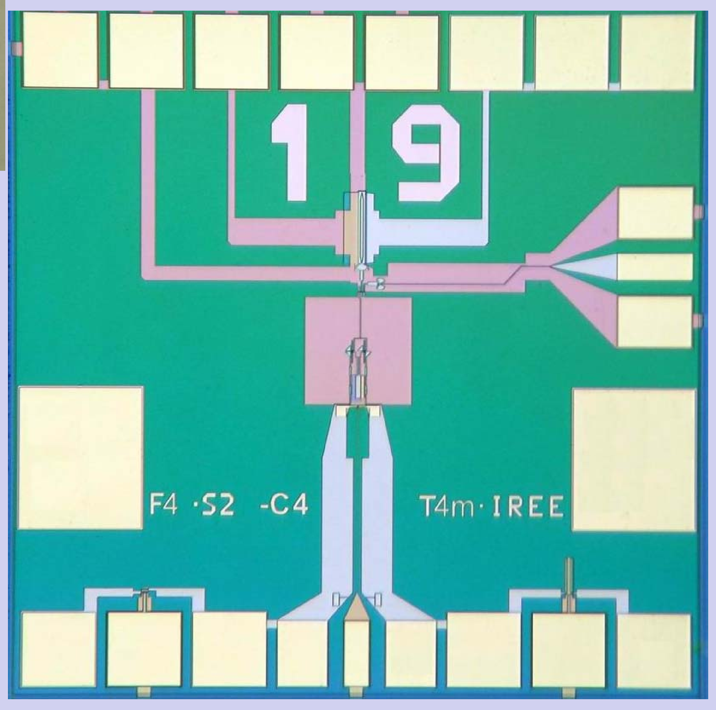
A Superconducting Integrated Receiver (SIR) was proposed more than 10 years ago and has since then been developed for practical applications. A SIR comprises on one chip (size of 4 mm*4 mm*0.5 mm) all elements needed for heterodyne detection: a low-noise SIS mixer with quasioptical antenna, an Flux-Flow Oscillator (FFO) acting as a Local Oscillator (LO) and a second SIS harmonic mixer (HM) for the FFO phase locking. The concept of the SIR looks very attractive for many practical applications due to its compactness and the wide tuning range of the FFO. Presently, the frequency range of most practical heterodyne receivers is limited by the tunability of the local oscillator, typically 10-15% for a solid-state multiplier chain. In the SIR the bandwidth is determined by the SIS mixer tuning structure and the matching circuitry between the SIS and the FFO. A bandwidth up to 30 – 40% can be achieved with a twin-junction SIS mixer design. All components of the SIR microcircuits are fabricated in a high quality Nb-AlN/NbN-Nb tri-layer on a Si substrate. The receiver chip is placed on the flat back surface of the silicon lens, forming an integrated lens-antenna. Light weight and low power consumption combined with nearly quantum limited sensitivity and a wide tuning range of the FFO make SIR a perfect candidate for many practical applications.


### Block Diagram of the Superconducting Integrated Receiver



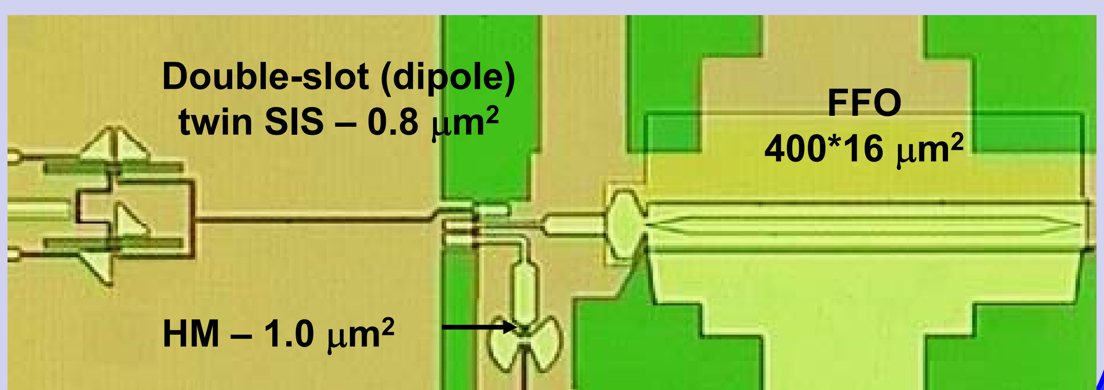

## SIR Chip Design






Silicon (Si);
4 x 4 x 0.5 $mm^3$
Nb-$AlO_X$-Nb or
Nb-AlN-NbN;
$J_C$ = 5 - 10 kA/$cm^2$

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

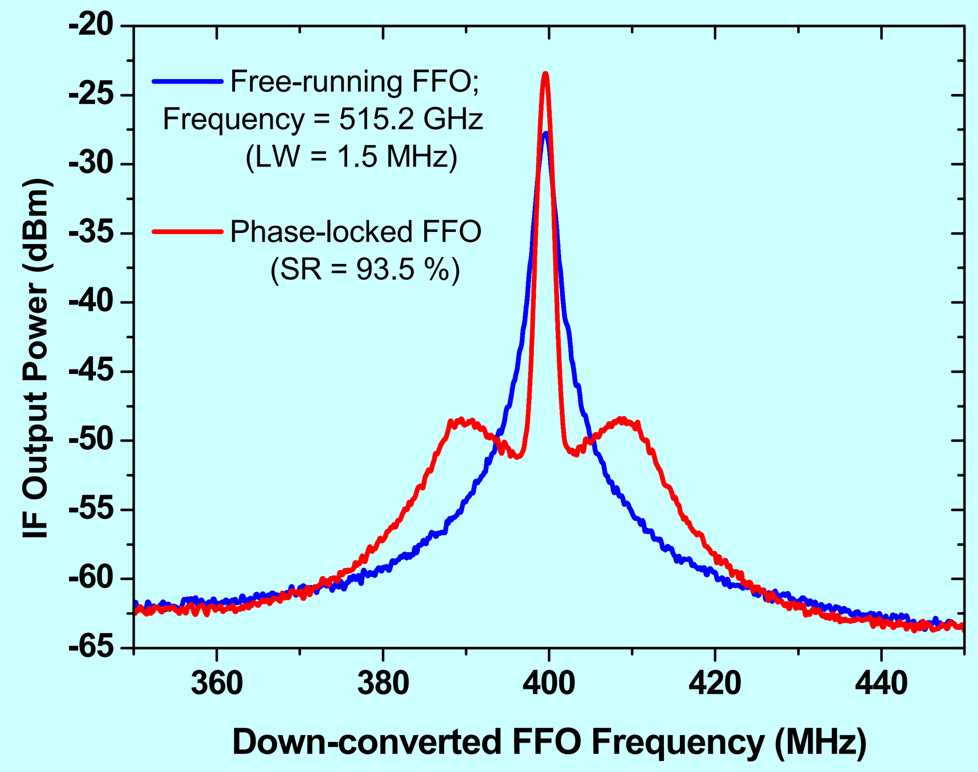



## TELIS-SIR Main Parameters

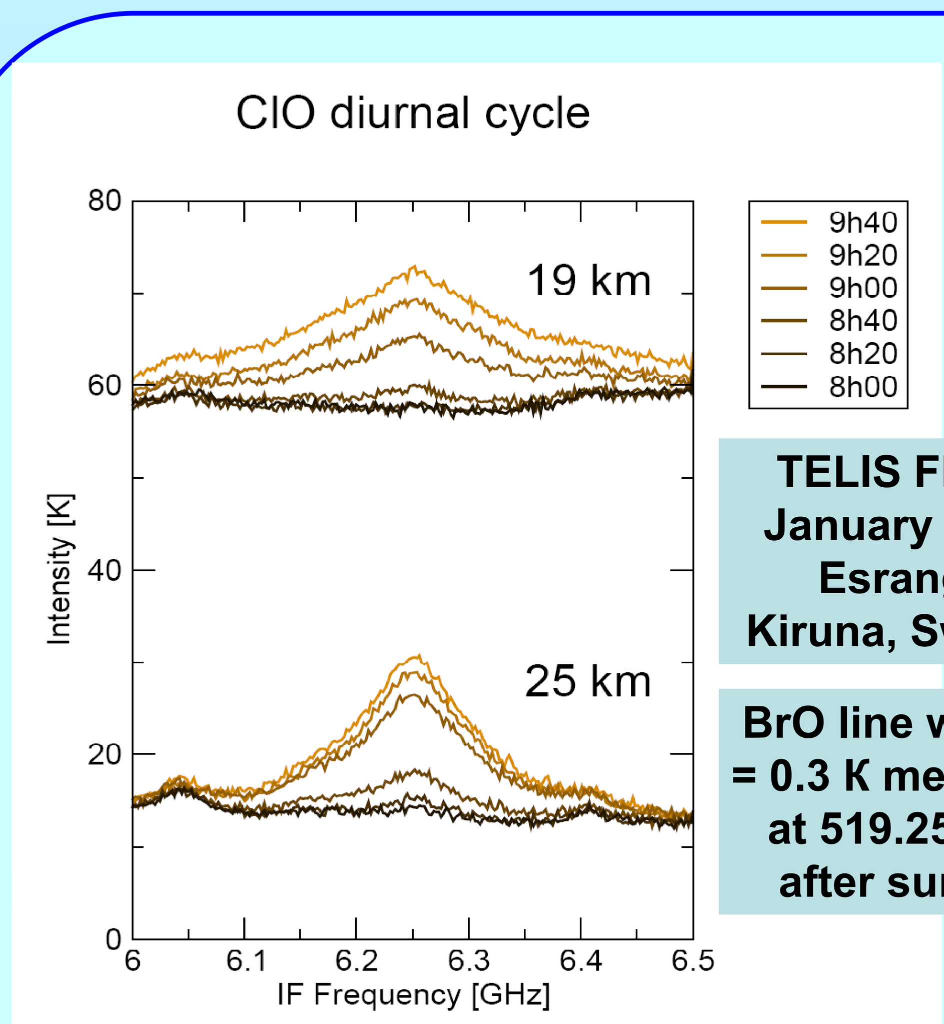
**(see report P3.1 by Gert de Lange, et al. )**

| # | Description | Value |
|---|---|---|
| 1 | Input frequency range | 450 – 650 GHz |
| 2 | Minimum noise temperature (DSB) | 120 K |
| 3 | Output IF range | 4 – 8 GHz |
| 4 | Spectral resolution | < 1 MHz |
| 5 | LO frequency net | < 300 MHz |
| 6 | Dissipated power at 4.2 K stage (including IF amplifiers chain | < 30 mW |
| 7 | Operation temperature | < 4.5 K |

## SIR Spectral Resolution




Spectra of the FFO operating at 515.2 GHz (red curve – frequency locked; blue curve – phase-locked). Linewidth (LW) = 1.5 MHz; Signal to Noise Ratio (SNR) = 36 dB; Spectral Ratio (SR) = 93.5 %. Spectra measured with RBW = 1 MHz.



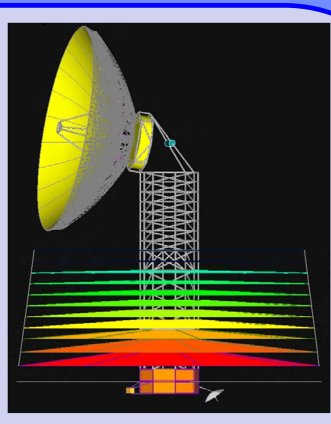

**TELIS Flight, January 2010; Esrange, Kiruna, Sweden**

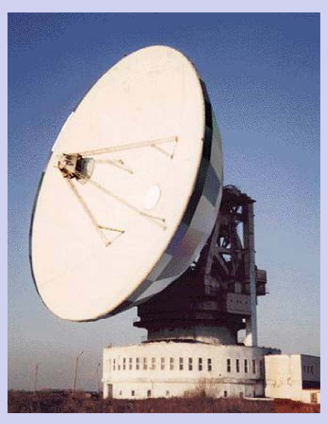
**BrO line with ΔT = 0.3 K measured at 519.25 GHz after sunrise**

**"Millimetron"** – Russian Space Agency mission ( after 2017)

12 m cryogenic mirror;

Frequency range : 15 GHz – 3 THz; Cryogenic detectors and mixers





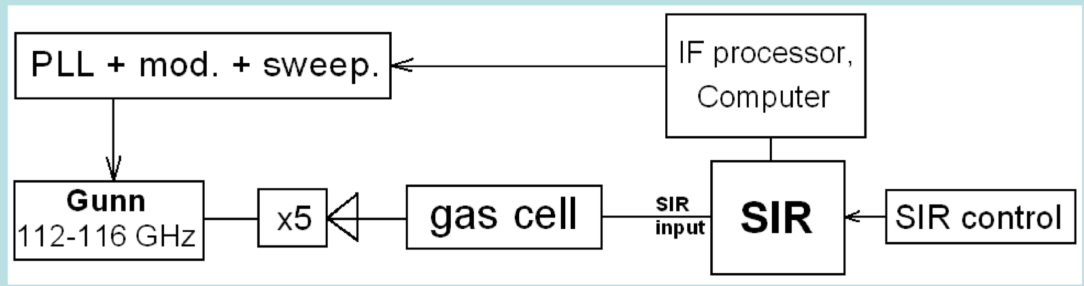
**Ground-space interferometer**

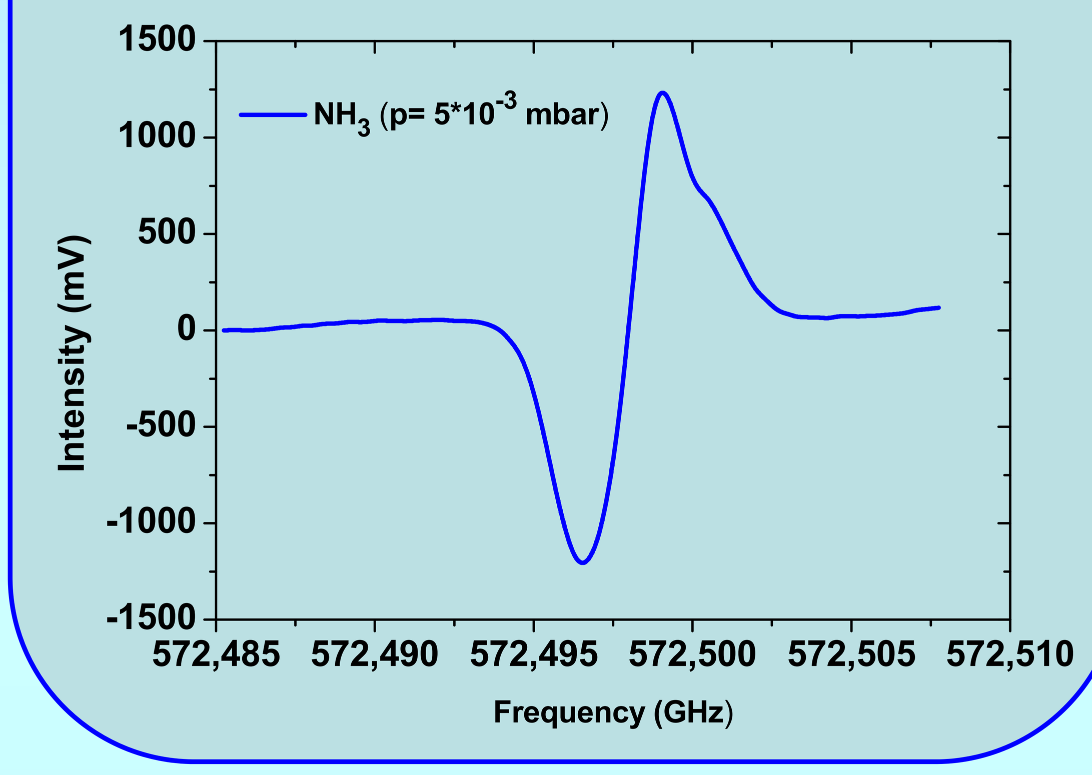
## Gas Spectra Detection for Medical Applications

**Non-invasive medical diagnostics based on analysis of exhaled air**

- human exhalation contains up to 600 volatile compounds
- some of them can be used as **markers of diseases**

| | |
|---|---|
| CO | Blood disease, asthma, oxidative stress |
| NO | Diseases of respiratory tract, oncology |
| $NH_3$ | Diseases of gastro-enteric tract, liver, kidney |
| $CH_4$ | Malabsorption of hydrocarbons |
| $CS_2$ | Markers of coronary arteries diseases, schizophrenia |
| $H_2O_2$ | Radiation injury, asthma |

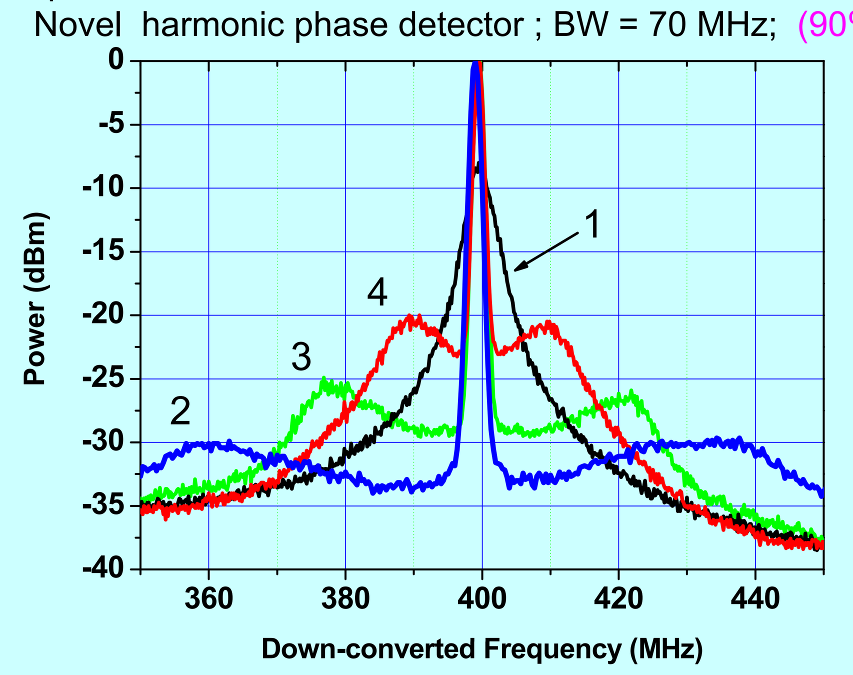



## Cryogenic Phase Detector

Down-converted spectra of the FFO operating at 600 GHz:

Curve "1" – Free running, linewidth 2 MHz (11 MHz)
"2" – phase-locked with CPLL, BW = 40 MHz; SR = 94% (63%);
"3" – phase-locked with CPLL, BW = 25 MHz; SR = 91% (45%);
"4" – phase-locked with RT PLL, BW = 12 MHz; SR = 82% (20%).
Novel harmonic phase detector ; BW = 70 MHz; (90%).




## Conclusion

- Concept of the phase-locked SIR is developed and proven.
- Nb-AlN-NbN FFOs and SIRs have been successfully implemented.
- New generation of the SIR with PL FFO for TELIS has been developed showing a possibility to achieve all TELIS requirements:
  Frequency range 450 – 650 GHz;
  Noise temperature < 120 K;
  IF bandwidth 4 - 8 GHz;
  Spectral resolution better 1 MHz;
  Beam pattern - FWHM = 3 deg, sidelobes < -17 dB
- Procedure for remote SIR operation has been developed and experimentally proven.
- 3 successful high-altitude balloon TELIS flights in 2009, 2010 and 2011 (Kiruna, Sweden).
- Future space and ground-base missions are under consideration.
- SIR Technology is mature enough for both future space missions and non-invasive medical diagnostic.