Superconducting Integrated Submillimeter Receiver for TELIS

Valery Koshelets, Andrey Ermakov, Lyudmila Filippenko, Andrey Khudchenko, Oleg Kiselev, Alexander Sobolev, Mikhail Torgashin,

Institute of Radio Engineering and Electronics (IREE), Moscow, Russia

Pavel Yagoubov, Ruud Hoogeveen, and Wolfgang Wild

SRON Netherlands Institute for Space Research, the Netherlands

August 29, 2006
ASC-2006, Seattle - SIR for TELIS
Superconducting Integrated Receiver (SIR) for TELIS

Outline

• TELIS project; SIR channel
• SIR chip design and performance:
  – Chip Layout; FFO Optimization,
  – Noise Temperature,
  – Beam Pattern,
  – IF Performance,
  – Spectral Resolution,
  – Remote Control
• Nb-AlN-NbN SIR – first implementation
• Conclusion
**TELIS - TErahertz LIimb Sounder**

**TELIS Objectives:**
- Measure many species for atmospheric science (ClO, BrO, O₃, 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

**HCl spectrum, 2 km intervals, total atmosphere to 60 km**

- **Signal power (K)**
- **frequency (GHz)**

- 15 km
- 25 km
- 35 km
- 37 km
- 39 km
- 40 km
- 45 dgrs up
# TELIS-SIR Main Parameters

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

Integrated lens-antenna (L6)  
Magnetic shield

Parabola (L5)  
Hyperbola (L4)

Ellipse (L3)  
Wire grid

Window (L2)  
Parabola (L1)

Cryostat

SSB  
Flat  
Termination load
Photo of the SIR-TELIS channel
SIR Mixer Block with Shields
Schematics of PLL SIR

4 K dewar

SIR chip

SIS mixer

Harmonic mixer

FFO as LO
550-650 GHz

HEMT
4-8 GHz

IF Processor & DAC

Computer controlled data acquisition system

Electronics
FFO, SIS, HM control

PLL

LSU

Optical input
50-650 GHz

4 GHz

20 GHz reference

400 MHz reference

August 29, 2006
ASC-2006, Seattle - SIR for TELIS
Photo of the T4m SIR chip
**SIR Microcircuit for TELIS**

**Double-slot twin SIS** – 0.8 µm²

**HM** – 1.0 µm²

**FFO**

400*16 µm²

4 x 4 x 0.5 mm³ (Si); Nb-AlOx-Nb; Jc = 5 - 8 kA/cm²

Optionally: SIS – Jc = 8 kA/cm²; FFO + HM = 4 kA/cm²
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

(a) No pump, integral magnetic field applied
(b) & (c) SIS pumped by FFO
Power is controlled by FFO bias current

\[ f_{\text{FFO}} = 470 \, \text{GHz} \]
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)
\[ \Delta f := \left( \frac{2e}{h} \right)^2 \cdot (R_d + K \cdot R_{dCL})^2 \cdot \left[ \frac{e \cdot (lqp)}{2 \cdot \pi} \cdot \coth \left( \frac{e \cdot V}{2 \cdot k_B \cdot T} \right) + \frac{2 \cdot e \cdot (ls)}{2 \cdot \pi} \cdot \coth \left( \frac{e \cdot V}{k_B \cdot T} \right) \right] + \frac{1}{\pi} \cdot \left( \frac{2e}{h} \right) \cdot (R_d + R_{dCL}) \cdot I_{lf} \]
Averaged SIS (blue) and HM (red) pump for different T3 SIRs
Comparison of the FTS data, Y factor and SIS pump for T3 SIRs

D2C1; T3-031#01 (S=0.83 µm², d1=200)

S2C3; T3-032#08 (S=0.81 µm², d1=200)
Y-factor of the SIR,
$T = 2.1$ K, $V_{SIS} = 2.2$ mV, IF = 4.3 GHz
Tn (DSB) for different T3 designs (T bath = 4.2 K)

![Graph showing Tn (DSB) for different T3 designs](image)

- T3-031#06 (S2C1),
- T3-031#07 (S2C2),
- T3-032#08 (S2C3),
- T3-031#09 (S2C4),
- T3-032#21 (S2C5),
- T3-031#01 (D2C1)

August 29, 2006
ASC-2006, Seattle - SIR for TELIS
Noise Temperature (DSB), T3 - D2C1:
Red - T bath = 4.2 K; Blue – T bath = 2 K

Water line 557 GHz
Beam Pattern of the SIR for TELIS
Antenna-lens beam pattern

Scan angle, deg

Co-polar, dBi

- vertical scan
- horizontal scan
- PILRAP simulation

August 29, 2006
ASC-2006, Seattle - SIR for TELIS
IF Performance of the T3 SIRs

Y factor (300/77 K), dB

Intermediate Frequency, GHz

August 29, 2006

ASC-2006, Seattle - SIR for TELIS
SIR schematic diagram at IF

C\textsubscript{F} – parasitic SIS-mixer and matching elements capacitance
L\textsubscript{T} – tuning on-chip inductance (CPW line),
C\textsubscript{T} – tuning on-chip capacitor
L\textsubscript{B}, R\textsubscript{B} – bond wires inductance and resistance
L\textsubscript{TMM}, C\textsubscript{TMM} – parameters for the microstrip line on the base (TMM) plate
Results of Sonnet simulations

Signal transmission by amplitude (S12 parameter) for the new wideband (soled lines) and the old narrowband (dash-dot lines) IF networks at the two values of SIS Rp
Experimental check of T4m IF performance

Noise measurements of the SIR with a slot-antenna. SIS-mixer IF output at the hot (red curve) and the cold (blue curve) optical loads. The green curve is the difference between them.

Noise breakdown: possible increase of the SIR Tn < 50 K
Photo of the gas-cell measurement setup at DLR
Deconvolved spectrum of two OCS emission lines
(gas pressure 1.2 mBar; FFO frequency 625.24 GHz)
Gas cell measurements; resolution determined by DAC

OCS gas, P=2mB

IF frequency, MHz

T, K

August 29, 2006
ASC-2006, Seattle - SIR for TELIS
Phase locked FFO; spectral resolution < 1 MHz

Synthesizer Frequency = 644.8 GHz

Intermediate Frequency of the PL SIR (GHz)

IF Output Power (dBm)
Remote optimization of the PLL SIR operation (3-D)
Remote optimization of the PLL SIR operation (2-D and 1-D)

August 29, 2006 ASC-2006, Seattle - SIR for TELIS
Ic (H) for twin SIS mixer - remote suppression of the SIS critical current by computer tuning
Nb-AlN-NbN SIR – new features

Wednesday, August 30, 2:00pm - 4:00pm; Report 3EG08

August 29, 2006

ASC-2006, Seattle - SIR for TELIS
Nb-AlN-NbN circuits: LW on frequency

- NbN, Ib=47mA
- NbN, Various Ib
- Nb, Ib=30mA
- Nb, Ib=42mA

Wednesday, August 30, 2:00pm - 4:00pm; Report 3EG08

August 29, 2006 ASC-2006, Seattle - SIR for TELIS
Nb-AIN-NbN SIR: Tₙ on FFO frequency

Wednesday, August 30, 2:00pm - 4:00pm; Report 3EG08
TELIS requirements can be realized for already developed designs and existing technology:

- Uncorrected receiver DSB noise temperature is of about 250 K at 600 GHz for SIR with phase-locked FFO;
- IF bandwidth 4 - 8 GHz was proven, Tn increase < 50 K
- Beam pattern: FWHM = 3 deg, Sidelobes – 17 dB
- Improved design of the FFO for TELIS: free-running linewidth from 9 to 2 MHz (500 – 710 GHz) that allows to phase lock from 35 up to 90 % of FFO power.
- Spectral resolution < 1 MHz ( < 3 MHz in flight due to DAC)
- Procedure for remote optimization of the PL SIR operation has been developed and experimentally proven

- New Nb-AlN-NbN SIRs (ready for first TELIS flight):
  - Frequency range 350- 700 GHz; Tn < 250 K;
  - LW < 3 MHz (350-600 GHz), below 10 MHz (600-700 GHz)

- First qualification TELIS flight is foreseen in 2007