Superconducting Integrated Receiver
(Development and Implementation)

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in collaboration with
SRON Netherlands Institute for Space Research, the Netherlands
Superconducting Integrated Receiver (SIR) with phase-locked FFO

4 K dewar

SIR chip

SIS mixer

Harmonic mixer

FFO as LO 500-650 GHz

HEMT 4-8 GHz

Reference 20 GHz

IF Processor & Digital Auto Correlator

Computer controlled data acquisition system

Electronics FFO, SIS, HM control

PLL 4 GHz

LSU 400 MHz reference

Optical Input 50-650 GHz

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Internal part of the SIR Microcircuit

Double-slot (dipole) twin SIS – 0.8 μm²

HM – 1.0 μm²

Nb-AlOx-Nb, Nb-AlN-NbN; Jc = 5 - 10 kA/cm²

Optionally: SIS – Jc = 8 kA/cm²; FFO + HM = 4 kA/cm²
Nb-AlOx-Nb and Nb-AlN-NbN FFO for SIR

400 GHz

Frequency Tuning

700 GHz

JSC, $V_B = V_g/3$

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

HD13-09#26 (Vg=3.7mV, Rn=21 Ohm)

- FFO Frequency: 0 GHz
- FFO Frequency: 400 GHz
- FFO Frequency: 500 GHz
- FFO Frequency: 600 GHz
- FFO Frequency: 700 GHz
Nb-AlN-NbN SIS pumped by FFO; FFO power tuning (f = 500 GHz)
FL and PL spectra of the Nb-AlN-NbN FFO: frequency 605 GHz; LW = 1.7 MHz; SR = 92%
Phase Noise of the PL FFO

Absolute FFO phase noise, \( (n = 20); \) SR = 97.7%
- R&S Synthesizer at 22 GHz \( \times n^2 \) (\( n = 20 \))
- Phase locked FFO, \( f_{\text{FFO}} = 450 \text{ GHz} \) (\( \delta f_{\text{aut}} = 0.5 \text{ MHz}; \) SR = 97.7%)
- R&S Synthesizer at 22 GHz (Specification)

R&S Synthesizer at 22 GHz * \( n^2 \) (\( n = 20 \))

Phase locked FFO, \( f_{\text{FFO}} = 450 \text{ GHz} \) (\( \delta f_{\text{aut}} = 0.5 \text{ MHz}; \) SR = 97.7%)

R&S Synthesizer at 22 GHz (Specification)

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Development of the Integrated Spectrometer for TELIS

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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
  - 500-650 GHz by SRON-REE
  - 1.8 THz by DLR (PI)
SIR Mixer Block with Shields
Noise Temperature of the Flight SIR (DSB)

(T4m-093-05f, 17-Dec-2007)

Receiver Noise Temperature (K)

FFO frequency (GHz)

Water line
557 GHz

IF 4-8 GHz
IF = 8 GHz

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SIR Noise Temperature on Intermediate Frequency and SIS Bias

(T4m-093-05f, 14-Dec-2007)

Data

YIG-filter's frequency (GHz)

FFO Freq = 601 GHz
FFO Freq = 497 GHz

(T4m-093-05f, 30-Mar-2008)

Receiver Noise Temperature (K)

SIS Bias (mV)

FFO frequency 497 GHz
SIR Stability: Allan variance test

- IF amp
- Power meter
- BP filter
- SIS
- FFO

Graph showing Allan variance test results with different channels.

4K cryostat
- SIS
- RT
- FFO
- IF amp
- Power meter 1
- BP filters
- Power meter 2

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Deconvolved spectrum of the OCS emission lines at a gas pressure 2.6 mBar. LO frequency 601 GHz.

Two strong lines are saturated; weaker lines are not saturated isotopes. The lines are detected, one in the LSB, the other one in the USB.
Amplitude and phase APB of the SIR with cold optics

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SIR for TELIS – remote operation
**TELISTELIS-SIR Main Parameters**  
(parameters determined by digital correlator are in parentheses)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input frequency range, GHz</td>
<td>500 – 650 ГГц</td>
</tr>
<tr>
<td>Minimum noise temperature in the range (DSB), K</td>
<td>120 К</td>
</tr>
<tr>
<td>Output IF range, GHz</td>
<td>4-8 (5-7) ГГц</td>
</tr>
<tr>
<td>Spectral resolution, MHz</td>
<td>&lt; 1 (2) МГц</td>
</tr>
<tr>
<td>LO frequency net, MHz</td>
<td>&lt; 300 МГц</td>
</tr>
<tr>
<td>Dissipated power at 4.2 K stage, mW</td>
<td>&lt; 30 мВт</td>
</tr>
<tr>
<td>Operation temperature, К</td>
<td>&lt; 4.5 К</td>
</tr>
</tbody>
</table>

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TELIS (Terahertz Limb Sounder)

TELIS-MIPAS at Esrange, Sweden; March 2009
Balloon size: 400 000 m3; Payload weight: 1 200 kg

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Flight trajectory (predicted)

Flight profile (actual)

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## Frequencies and substances selected for the first TELIS flight

<table>
<thead>
<tr>
<th>##</th>
<th>FFO Frequency, GHz</th>
<th>Substances (High priority)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>495.04</td>
<td>H$_2$$^{-18}$O</td>
</tr>
<tr>
<td>2</td>
<td>496.88</td>
<td>HDO</td>
</tr>
<tr>
<td>3</td>
<td>505.6</td>
<td>BrO ($\Delta T = 0.3$ K !!)</td>
</tr>
<tr>
<td>4</td>
<td>507.28</td>
<td>ClO</td>
</tr>
<tr>
<td>5</td>
<td>515.25</td>
<td>O$_2$ /pointing /pressure</td>
</tr>
<tr>
<td>6</td>
<td>519.25</td>
<td>BrO ($\Delta T = 0.3$ K !!)</td>
</tr>
<tr>
<td>7</td>
<td>607.78</td>
<td>O$_3$ isotopes</td>
</tr>
<tr>
<td>8</td>
<td>619.1</td>
<td>HCl (HOCl, ClO)</td>
</tr>
</tbody>
</table>
Spectra measured at limb-sounding

FFO Freq = 495 GHz

Orbit – 30 km;
Increment – 1.5 km,
Tangent: 10.5 – 30 km
45 degrees up
ClO line over time (FFO = 495 GHz)

Sunrise 5h08

O$_3$, ClO, O$_3$

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Back to the Earth…
30-cm POrtable Submillimeter Telescope (POST)
Purple Mountain Observatory; Nanjing.
Site: Delingha of Qinghai province (altitude ~3200 m)

Frequency - 345 GHz
Tr (DSB) < 100 K
Spectral resolution < 1 MHz

2-stage GM type;
cooling capacity – 0.1 W;
compressor – 42 kg;
power consumption - 1.2 kW
ESPRIT – Exploratory Submm Space Radio-Interferometric Telescope

- Telescope sizes $\sim 3.5$ 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; \( \lambda = 0.01-20 \text{ mm} \).
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
- **NH₃** Diseases of gastro-enteric tract, liver, kidney
- **CH₄** Malabsorption of hydrocarbons
- **CS₂** Markers of coronary arteries diseases, schizophrenia
- **H₂O₂** Radiation injury, asthma
Gas Spectra Detection by FFTS

\[ \text{NH}_3 \quad - \quad 572.498 \text{ GHz} \]

Transmission

Frequency (GHz)


P = 1 mBar
0.4 mBar
0.1 mBar
0.02 mBar
0.002 mBar

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Gas Spectra Detection - 2

PLL + mod. + sweep. → IF processor, Computer

Gunn 112-116 GHz → x5 → gas cell

SIR → SIR control

Intensity (mV)

Frequency (GHz)

-1500 -1000 -500 0 500 1000 1500

572,485 572,490 572,495 572,500 572,505 572,510

NH₃ (p= 5*10⁻³ mbar)

Intensity (mV)

Frequency (GHz)

-150 -100 -50 0 50 100 150

571,110 571,115 571,120 571,125 571,130

OSC (p= 2*10⁻³ mbar)

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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 500 – 650 GHz; Noise temperature < 150 K; IF bandwidth 4 - 8 GHz; Spectral resolution better 1 MHz; Beam Pattern - FWHM = 3 deg, with sidelobes < - 17 dB.
• Procedure for remote SIR operation has been developed and experimentally proven.
• TELIS flight has been completed in March 2009 (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.