Superconducting Integrated THz Receivers: Development and Applications

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Superconducting Integrated THz Receivers: Development and Applications

Outline

• Superconducting Integrated Receiver (SIR)
• Flux Flow Oscillator (FFO) for the SIR
• TErahertz Limb Sounder (TELIS) project
• Results of the TELIS flights
• Future SIR applications
• Conclusion
Superconducting Integrated Receiver (SIR) with phase-locked FFO
Internal part of the SIR Microcircuit

Double-slot (dipole) twin SIS – 0.8 μm²

HM – 1.0 μm²

Nb-AlOx-Nb, Nb-AlN-NbN; \( J_c = 5 - 10 \text{ kA/cm}^2 \)

Optionally: SIS – \( J_c = 8 \text{ kA/cm}^2 \); FFO + HM = 4 kA/cm²
Nb-AlOx-Nb and Nb-AlN-NbN FFO for SIR

**Graph:**
- **x-axis:** FFO voltage (mV)
- **y-axis:** FFO current (mA)
- **Labels:**
  - 400 GHz
  - 700 GHz
  - Frequency Tuning
  - JSC, $V_B = V_g/3$
FFO frequency and power tuning

FFO Frequency:
- 0 GHz
- 400 GHz
- 500 GHz
- 600 GHz
- 700 GHz

FFO frequency = 500 GHz

2011, September 22
FL and PL spectra of the FFO:
frequency 605 GHz; LW = 1.7 MHz; SR = 92 %

2011, September 22
Linewidth and Spectral Ratio on the FFO frequency

![Graph showing the linewidth and spectral ratio on the FFO frequency. The x-axis represents the FFO frequency (GHz), and the y-axis represents the spectral ratio of the PL FFO (%). There are four different curves representing different materials: SR Nb-AlN-NbN (solid blue line), $\delta f$ Nb-AlN-NbN (dashed blue line), SR Nb-AlOx-Nb (solid red line), and $\delta f$ Nb-AlOx-Nb (dashed red line).]
TELIS (Terahertz Limb 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
  - 490-630 GHz by SRON-IERE
  - 1.8 THz by DLR (PI)

**Balloon-Borne TELIS Instrument**
### TELIS-SIR Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input frequency range</td>
<td>470 – 670 GHz</td>
</tr>
<tr>
<td>Minimum DSB noise temperature in the range</td>
<td>&lt; 120 K</td>
</tr>
<tr>
<td>Output IF range</td>
<td>4 - 8 GHz</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>&lt; 1 MHz</td>
</tr>
<tr>
<td>System stability (Allan variance)</td>
<td>20 s</td>
</tr>
<tr>
<td>Dissipated power (at 4.2 K stage)</td>
<td>&lt; 30 mW</td>
</tr>
<tr>
<td>Operation temperature</td>
<td>&lt; 4.5 K</td>
</tr>
</tbody>
</table>
SIR for TELIS – remote operation

FFO frequency 500 GHz

FFO linewidth, Hz vs. FFO voltage, mV

SIS current (mA) vs. New CL (mA)

Power of HP83724 (dBm) vs. HM voltage (mV)
## 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>$\text{H}_2^{18}\text{O}$</td>
</tr>
<tr>
<td>2</td>
<td>496.88</td>
<td>HDO</td>
</tr>
<tr>
<td>3</td>
<td>505.6</td>
<td>BrO ($\Delta T = 0.3 \text{ K} !!$)</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 ($\Delta T = 0.3 \text{ K} !!$)</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>
TELIS (Terahertz Limb Sounder)

TELIS-MIPAS at Esrange, Sweden;
March 2009; January 2010; March 2011
Balloon size: 400,000 m³; Payload weight: 1,200 kg
Altitude: 40 km (max); Duration: 12 hours
Spectra measured at limb-sounding

FFO Freq = 495 GHz
Orbit – 30 km;
Increment – 1.5 km,
Tangent: 10.5 – 30 km

45 degrees up

\[ \text{O}_3 \]
Second TELIS flight
January 2010; Esrange, Sweden

ClO diurnal cycle

BrO
30 times averaged

26 km
28 km
30 km
32 km
Future SIR applications

New balloon missions

High-altitude airplanes

Space project “Millimetron”

Ground-space interferometer
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

PLL + mod. + sweep.

IF processor, Computer

Gunn
112-116 GHz

x5

gas cell

SIR

SIR control

NH₃ (p = 5*10⁻³ mbar)

Intensity (mV)

Frequency (GHz)

572,485 572,490 572,495 572,500 572,505 572,510
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:
  Frequency range 470 – 670 GHz; Noise temperature < 120 K;
  IF bandwidth 4 - 8 GHz; Spectral resolution better 1 MHz;
  System stability (spectroscopic Allan variance) 20 sec;
  Beam Pattern - FWHM = 3 deg, with sidelobes < -17 dB.

• Procedure for remote SIR operation has been developed and experimentally proven.

• 3 successful TELIS flights have been completed in March 2009, January 2010 and March 2011 at Esrange (Kiruna, Sweden).

• Future space and ground-base missions are under consideration.

• SIR Technology is mature enough for future space missions, non-invasive medical diagnostic, and security applications.