



#### Superconducting sub-THz coherent receivers for space and ground-based radio astronomy – Russian experience and technologies

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### SIS THz receivers for space and ground-based radio astronomy Outline

- 211 275 GHz SIS Receiver for Millimetron
- Nb/AIN/NbN Tunnel Junctions
  780 950 GHz Array Receiver for APEX
- Balloon-borne Receiver 470 670 GHz TELIS (Terahertz Limb Sounder)
- Technological Facilities at Kotel'nikov IREE









Quantum-limited coherent SIS-mixers

Frequency range 0.1 – 1.4 THz; Noise temperature down to hf/k<sub>B</sub>

> Nb-AlOx-Nb Nb-AlN-Nb(N)  $J_c = 5-30 \text{ kA/cm}^2$

> > **Rj/Rn > 20**

 $\equiv c_J$ 

# SIS receivers for ground-based radio astronomy





Event Horizon Telescope (EHT)







#### "Millimetron" – Russian Space Agency 10 m cryogenic mirror (6 μm RMS) ; λ = 0,07- 10 mm http://millimetron.ru/en/ Provisional launch date 2029



Earth-Space VLBI receivers Band 3 (ALMA B6) : 211-275 GHz SSB Noise Temperature < 45 K



Earths-space interferometer



#### 3D CST model for 211-275 GHz mixer









Chip holder with IF PCB Waveguide is 1 x 0.5 mm Photo and IVCs of the Nb-AlOx-Nb SIS mixer;  $A = 1 \ \mu m^2$ 





#### Hot/Cold IF signal at 6.5 GHz; LO = 262 GHz



#### **Uncorrected DSB receiver noise temperature**



### Nb/AI-AIN/NbN SIS



(A = 0.5 μm<sup>2</sup> ; Jg ~ 30 кA/см<sup>2</sup>) inserted in the microstrip line: base electrode – NbTiN, top - Al

Rn = 9.7 Ohm; Rj/Rn = 30 Jg = 34 kA/cm<sup>2</sup>; Vg = 3.22 mV





#### **DSB Receiver Noise Temperature**



#### **Atacama Pathfinder EXperiment (APEX)**



#### CHAMP+

- 7 SIS mixers
  600 720 GHz
- 7 SIS mixers
  780 950 GHz
- IF: 4 8 GHz



#### Lens array at the top of the cartridge body; opened horns with the mixers & single pixel







#### DSB mixer noise temperature for the entire 4-12 GHz IF band vs LO frequency







#### **TELIS (Terahertz Limb Sounder)**





#### **Balloon-Borne TELIS Instrument**

#### **TELIS-SIR Main Parameters**

Input frequency range	470 – 670 GHz
Minimum DSB noise temperature	< 120 K
Output IF range	4 - 8 GHz
Spectral resolution	< 1 MHz
System stability (Allan variance)	20 s
Dissipated power (at 4.2 K stage)	< 30 mW
Operation temperature	< 4.5 K







#### **TELIS (Terahertz Limb Sounder)**



TELIS-MIPAS at Esrange, Sweden; Balloon size: 400 000 m3; Payload weight: 1 200 kg Altitude: 40 km (max); Duration: 12 hours Pressure: 5 mbar; Temperature as low as -105 C.









## **4 TELIS flights;** Esrange, Sweden; Canada (CIO level = $2.1 \pm 0.3$ ppbv; BrO - 0.3 K = a few pptv)

CIO diurnal cycle



#### **Technological Facilities at IREE**





High-vacuum plants for thin-film deposition Leybold L-560 UV and Mask aligners Karl Suss MA150

#### Kurt J. Lesker In-Line Sputter Deposition System



#### **Ultra-High Resolution E- Beam Lithography**





#### Cross-section of an Integrated Superconducting Microcircuit





#### **Nb-AIN-NbN; Nb-AlOx-Nb;** $J_c = 1 - 100 \text{ kA/cm}^2$ ; S = 0.1 – 1000 mkm<sup>2</sup> Vg as high as 3.7 mV for Nb-AIN-NbN



#### Conclusion

- SIS mixers for frequency range 211 275 GHz based on Nb tunnel junctions have been designed and tested.
   DSB noise temperature below 20 K has been realized.
- SIS mixers based on Nb/AIN/NbN twin tunnel junctions incorporated in a NbTiN/AI microstrip line have been developed. The best noise temperature as low as 120 K has been achieved at 725 GHz, that is of about 3 hf/k<sub>B</sub>.
   7-pixel 790 -950 GHz array receiver for APEX was upgraded.
- The SIS fabrication technology developed at Kotel'nikov IREE is mature enough for current radio-astronomy projects and future ground-based and space missions.

## Thank you for your attention !