Quantum limited superconducting integrated sub-THz receivers

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A Superconducting Integrated Receiver (SIR) comprises on one chip 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. Improving on the fully Nb-based SIR we have developed and studied Nb-AlN-NbN circuits which exhibit an extended operation frequency range. Continuous tuning of the phase-locked local oscillator has been experimentally demonstrated at any frequency in the range 300-750 GHz. The FFO free-running linewidth has been measured between 0.3 and 5 MHz, which allows to phase-lock up to 97 % of the emitted FFO power. The output power of the FFO is sufficient to pump the matched SIS mixer in a wide frequency range and can be electronically adjusted. As a result of receiver's optimization the DSB noise temperature was measured below 100 K that is about 3 hf/k_B; the spectral resolution is well below 1 MHz.

All these achievements enabled the development of a 450 - 650 GHz integrated receiver for the novel atmospheric-research instrument TELIS (TErahertz and submillimeter LImb Sounder). This balloon-borne instrument is a three-channel superconducting heterodyne spectrometer for the detection of spectral emission lines of stratospheric trace gases that have their rotational transitions at THz frequencies. We demonstrate for the first time the capabilities of the SIR technology for heterodyne spectroscopy in general, and atmospheric limb sounding in particular. We also show that the application of SIR technology is not limited to laboratory environments, but that it is well suited for remote operation under harsh environmental conditions; it was successfully proven by three TELIS high-altitude balloon flights from Kiruna, North Sweden in 2009 - 2011.

To ensure remote operation of the SIR under flight conditions several software procedures for automatic control have been developed. The science goals of the campaigns were threefold: investigation of the stratospheric hydrological cycle by measurements of isotopic water, catalytic ozone destruction by chlorine chemistry, and the bromine content of the stratosphere. After sunrise the diurnal cycle of various species was monitored; in total several hundred limb sequences have been recorded in each flight. Diurnal cycles of ClO and BrO has been observed with BrO line level of only about 0.3 K. The MIPAS-TELIS balloon system performed nominally during the flights and after the parachute landing and recovery, the instruments were found to be undamaged, allowing for post-flight checks and calibration measurements and future missions.

Capability of the SIR for high resolution spectroscopy has been successfully proven also in a laboratory environment by gas cell measurements. The possibility to use SIR devices for the medical analysis of exhaled air has been demonstrated. Many medically relevant gases have spectral lines in the sub-terahertz range and can be detected by a SIR-based spectrometer.

A novel superconducting element, High-Harmonic Phase Detector (HPD), intended for phase-locking of a FFO has been proposed and experimentally tested. Regulation bandwidth (BW) of the phase-locking loop (PLL) system based on the HPD as high as 70 MHz has been experimentally achieved; that value several times exceeds BW of any other regular PLL systems used for cryogenic oscillators. The HPD PLL concept is very promising for future applications, especially for building of the multi-pixel SIR array, long-base interferometry and for phase-locking of the THz range FFO.

Nowadays the SIR is probably the most functionally complex fully superconducting device that was already successfully implemented for practical applications. 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 variety of practical applications, in particular for future airborne and space-borne missions as well as for analysis of the breathed out air at medical survey and for security monitoring.

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