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Superconducting Integrated Submm Wave Receivers for Earth Atmosphere Monitoring and Laboratory Applications

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A Superconducting Integrated Receiver (SIR) [1] comprises on one chip 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. The concept of the SIR looks very attractive for many practical applications due to its compactness and the wide tuning range of the FFO. Presently, the frequency range of most practical heterodyne receivers is limited by the tunability of the local oscillator, typically 10-15% for a solid-state multiplier chain. In the SIR the bandwidth is determined by the SIS mixer tuning structure and the matching circuitry between the SIS and the FFO. A bandwidth up to 35% has been achieved with a twin-junction SIS mixer design. All components of the SIR microcircuits are fabricated in a high quality Nb based tri-layer on a Si substrate. The receiver chip is placed on the flat back surface of the silicon lens, forming an integrated lens-antenna.

The Nb-AlN-NbN circuits exhibiting an extended operation frequency range compare to traditional fully Nb SIRs have been developed and studied. Continuous tuning of the phase-locked local oscillator has been realized at any frequency in the range 300-750 GHz. The output power of the FFO is sufficient to pump the matched SIS mixer in a wide frequency range and can be electronically adjusted. The FFO free-running linewidth has been measured between 0.3 and 5 MHz; resulting in the spectral ratio of the phase-locked FFO above 70% over the range. As a result of receiver's optimization the DSB noise temperature was measured below 100 K that is about 4 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 atmospheric-research instrument TELIS (TErahertz and submillimeter LImb Sounder) [2] - the balloon-borne instrument 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 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. Diurnal cycle of ClO has been observed; the BrO line with a level of only 0.3 K was isolated and clearly detected. The system performed nominally during the flights and after the parachute landing and recovery, allowing the post-flight 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.

Recently the SIR was successfully implemented for the first spectral measurements of THz radiation emitted from intrinsic Josephson junction stacks (BSCCO mesa) in the frequency range 585 – 735 GHz; linewidth as low as 7 MHz has been recorded in the high bias regime. The phase-locked SIR has been used not only for detection of the BSCCO oscillator emission, but also for the locking of the oscillator under the test. The IF signal down-converted by the SIR is actually a convolution of the BSCCO oscillator signal and stable phase-locked SIR LO. This signal is applied to the PLL, where phase of the signal is compared with phase of the stable reference. The error signal is returned back to the BSCCO oscillator to control it phase; the first results of the BSCCO oscillator phase locking will be demonstrated. That is the first, but very important step towards development of fully HTc phase-locked local oscillator.

A novel superconducting element, High-Harmonic Phase Detector (HPD) with regulation bandwidth (BW) as high as 70 MHz, that is intended for phase-locking of a FFO, has been proposed and experimentally realized. The achieved regulation BW 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. In particular the SIR is very attractive for future airborne and space-borne missions as well as for analysis of the breathed out air at medical survey and for security monitoring.

[1] B V. P. Koshelets and S. V. Shitov, "Integrated Superconducting Receivers," *Supercond. Sci. Technol.* vol. 13, pp. R53-R69 (2000).

[2] Gert de Lange, et al, "Development and Characterization of the SIR Channel of the TELIS Atmospheric Sounder", *Supercond. Sci. Technol.* vol. 23, 045016 (2010).

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