

# Superconducting Integrated THz Receivers: Development and Applications

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**Abstract**— A Superconducting Integrated Receiver (SIR) comprises on one chip all elements needed for heterodyne detection. Light weight and low power consumption combined with nearly quantum limited sensitivity and a wide tuning range of the superconducting local oscillator make SIR a perfect candidate for many practical applications.

## I. INTRODUCTION AND BACKGROUND

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.

## II. RESULTS AND APPLICATIONS

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 FFO free-running linewidth has been measured between 0.3 and 5 MHz; spectral ratio of the phase-locked FFO above 70% has been demonstrated over the range. 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 atmospheric-research instrument TELIS (TERahertz and submillimeter LIMb Sounder) [2]. 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. Diurnal cycles of ClO and BrO has been observed with BrO line level of only about 0.3 K. The system performed nominally during the flights and after the parachute landing and recovery, allowing for 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 25 MHz has been recorded in the high bias regime.

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; the SIR is very 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.

## REFERENCES

- [1] V. P. Koshelets and S. V. Shitov, "Integrated Superconducting Receivers," *Superconductor Science and Technology*, vol. 13, pp. R53-R69 (2000).
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