# Investigation of the mixing regimes in a superconducting tunnel junction

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*Abstract*— **We experimentally investigated different mixing regimes in the tunnel SIS-junction based on three-layer Nb/AlOx/Nb and Nb/AlOx/NbN structures. The SIS mixers were studied in quite unusual modes of operation: in the extremely low frequency range (0.1 – 20 GHz), and as high-harmonic mixers (for the frequencies of about 600 GHz and local oscillator of 20 GHz). The quasiparticle and Josephson mixing regimes have been compared. We demonstrated, that in some applications, such as cryogenic harmonic phase detector, Josephson regime can be more preferable than quasiparticle one due to the possibility to realize larger output signal and better signal-to-noise ratio. This might be caused by partial synchronization of the Josephson current components by powerful local oscillator. Also, we demonstrated the prospects of Josephson mixing regime for up- and down-conversion for the cryogenic multiplexing systems.**

## INTRODUCTION

Superconducting mixers based on tunnel junctions are widely used in terahertz receiving systems. In such systems the Josephson effect is usually considered as parasitic, leading to extra noise appearance. That is why critical current is usually suppressed by the external magnetic current. In this work the probability and advantages of Josephson mixing regime in some applications are shown.

## CRYOGENIC HARMONIC PHASE DETECTOR

One of the novel applications of the tunnel SIS-junction is cryogenic harmonic phase detector (CHPD) for the broadband phase-locking systems for the cryogenic terahertz generators. Earlier it was demonstrated that functional integration of the harmonic mixer and phase detector in one element allows to significantly increase the synchronization bandwidth of the phase-lock system and improve spectral quality of the radiation [1]. As the spectral quality depends on the amplitude of the CHPD output signal, the optimization of working regimes and mixing regimes investigation is needed. The investigation of the output signal power was conducted in the harmonic mixer regime (HM). Two signals – from flux-flow oscillator(FFO), frequency of about 600 GHz and local oscillator (LO), ~ 20 GHz – were mixed on a tunnel SIS-junction Nb/AlOx/Nb. The intermediate frequency (IF) band was determined by 4-8 GHz amplifiers chain. IF signal was recorded by the spectrum analyzer or power meter. The spectra of the down-converted FFO signal for different mixing regimes are presented in Fig. 1: dotted line is for the fully suppressed by the external magnetic field critical current, dashed line is for the optimal mixing regime without critical current suppression, solid line is for the signal without phase-locking.

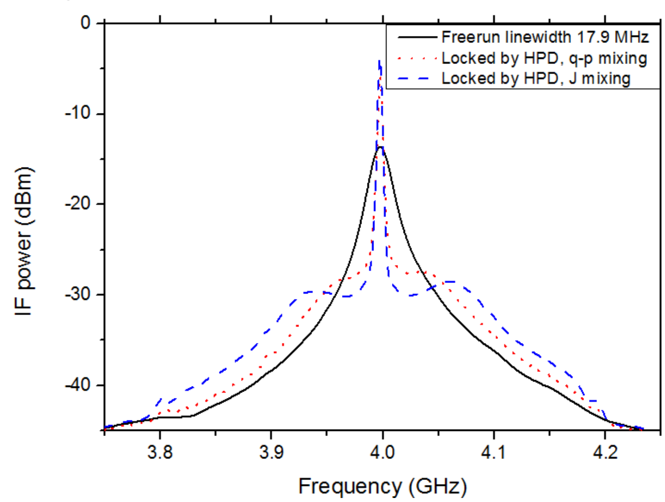


Fig. 1Spectra of FFO radiation at two CHPD mixing regimes:quasiparticle (dotted line) and Josephson (dashed line); and without phase locking (solid)

It is seen from the graphs that using Josephson non-linearity (dashed line) allows to increase the output signal in comparison with only quasiparticle regime (dotted line)due to higher gain; furthermore the signal-to-noise ratio is also better at the first case. Our results demonstrated thatthe CHPD-based phase-lock system is able to phase-lock theFFO with output signal linewidth as wide as 17.9MHz.High effectivity of the Josephson mixing regime in CHPD allows to synchronize up to 83% of the FFO power, while pure quasiparticle regime (atJosephson effect suppression) decreases this value to 70%. So, the Josephson mixing regime is preferable for the effective functioning of the SIS-junction as CHPD..

## SIS FREQUENCY CONVERTER

One more promising application of the SIS-based mixers is cryogenic multiplexed readout system for the large arrays of transition edge sensors (TES) [2]. In this system the SIS-mixer works as frequency up- and down-converter for frequencies from hundredsof Megahertz to 1-10 GHz. For the experimental investigation of the SIS-junction as the up-converter we applied to the mixer two signals – 223 MHz and 5 GHz, the IF is 5.223 GHz. The dependencies of the conversion gain on SIS bias voltage at LO power -40 dBm with and without critical current suppression are presented in Fig 2. We also showed the up-conversion of three input signals on a same SIS-device, the IF spectra of the output signal is shown in the Fig. 3.

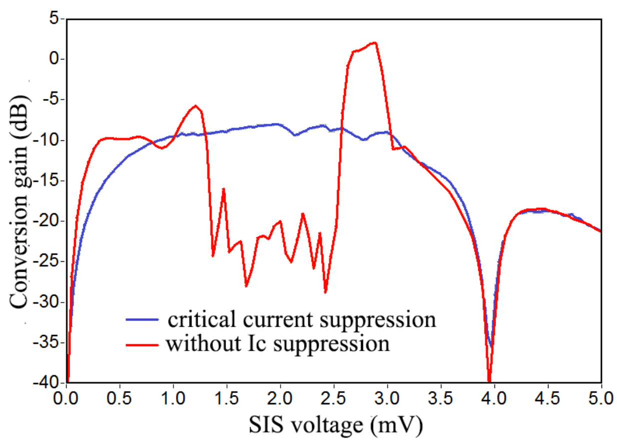


Fig. 2 Dependencies of the conversion gain on SIS bias voltage at LO power -40 dBm with and without critical current suppression.

As seen from the figures 2 and 3, both regimes have their advantages and disadvantages. The Josephson mixing regime provides higher conversion gain;in addition the signal-to-noise ratio at this regime is larger than at quasiparticle one. On the other hand the Josephson mixing has larger noise level, than quasiparticle one. Moreover, it can be realized in comparatively narrow SIS bias voltage and LO power range. Contrariwise, the Josephson regime doesn't require critical current suppression by external magnetic field that would be advantageous for many practical applications.

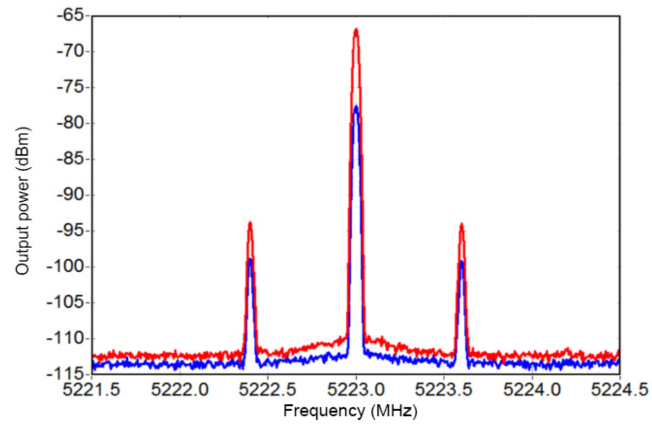


Fig. 3.Up-conversion IF signal spectra (from ~223 MHz to ~5223 MHz)

## CONCLUSIONS

So, in this work we have demonstrated that for some practical applications, such as cryogenic harmonic phase detector and cryogenic readout system, the Josephson regime can be more preferable than the quasiparticle one.The Josephson mixing regime of high-harmonic mixer provides 12 dB higher output signal power value, resulting in 4 dB better signal-to-noise ratio (compared to the quasiparticle regime).The Josephson regime allows to achieve larger gain value for low frequency (0.5 – 5 GHz) SIS-mixers.

## ACKNOWLEDGMENT

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