Observation of Frequency Up-conversion Gain in SIS Junctions at Millimeter Wavelengths

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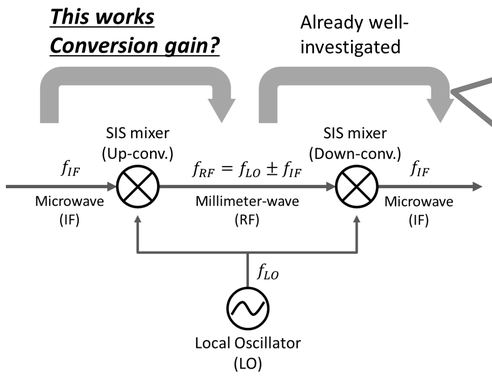
Why is up-converter necessary?

◆ **Proposing low-noise and low-power-consumption amplifier**

– Consisted of an SIS up-converter and an SIS down-converter



Conversion gain in mm-wave quasiparticle heterodyne mixers

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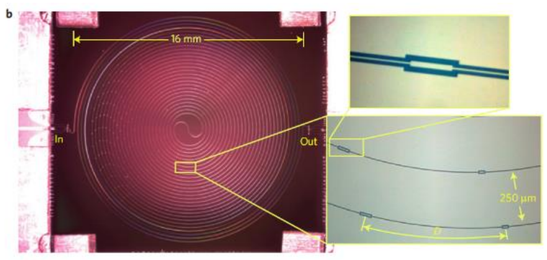
We report the observation of heterodyne mixing in superconductor-insulator-superconductor tunnel junctions with significant conversion gain and with a noise temperature comparable to the photon noise limit. (Double sideband $L^{-1} = 1.40 \pm 0.14$, $T_M \lesssim 1.5$ K at 36 GHz.) The mixing arises from the strong nonlinearity in the quasiparticle tunneling currents at voltages comparable to the full energy gap. Gain is observed when the onset of quasiparticle current is sufficiently sharp that quantum effects are important. The observed gain is in good quantitative agreement with calculations based on the work of Tucker. It should make possible the construction of photon-noise-limited microwave heterodyne receivers.

◆ **Possible application**

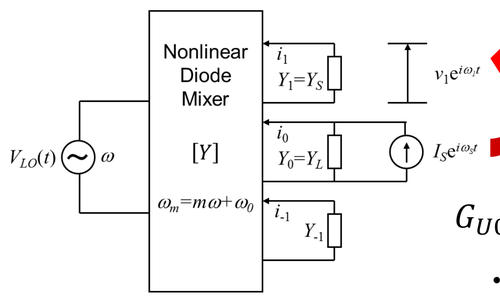
– Multi-beam receivers (I/O InP HEMT Amp.)
– Quantum computers (I/O Supercond. Para. Amp.)
– Others?

InP HEMT Amp.:
High power dissipation
A few mW

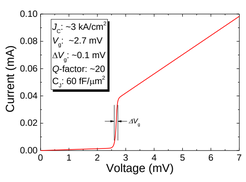


Supercond. Para. Amp.:
Very low operation temp. < 1 K

Simulation

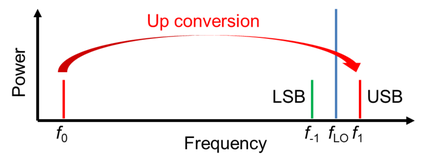


Up-conv. component (USB)

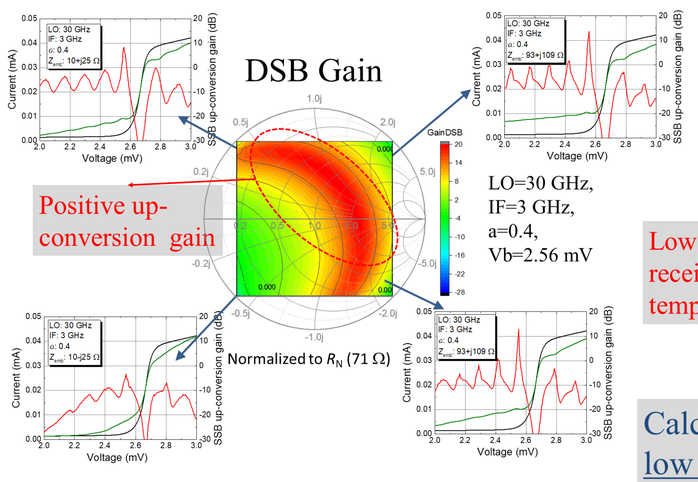


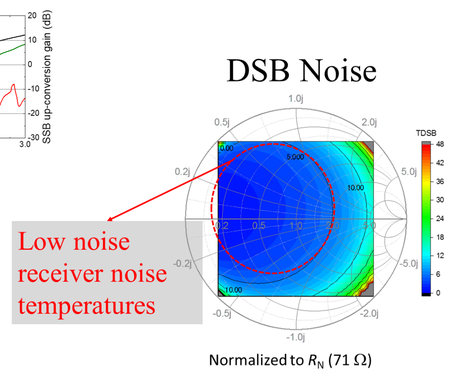
$$G_{U0\to1} = 4G_0G_1|Z_{10}|^2$$

$$\begin{bmatrix} Z_{11} & Z_{10} & Z_{1-1} \\ Z_{01} & Z_{00} & Z_{0-1} \\ Z_{-11} & Z_{-10} & Z_{-1-1} \end{bmatrix} = \left\{ [Y] + \begin{bmatrix} Y_1 & 0 & 0 \\ 0 & Y_0 & 0 \\ 0 & 0 & Y_{-1}^* \end{bmatrix} \right\}^{-1}$$



- Tucker theory is applied
- Standard I-V curve of Nb junction (1 μm², 3 kA/cm²) is used
- Intermediate frequency (IF), f_0, is assumed to be 3 GHz
- IF embedding impedance is fixed to be 50 Ω
- RF amplifier noise is assumed to be 10 K
- RF embedding impedance is swept to see gain and noise



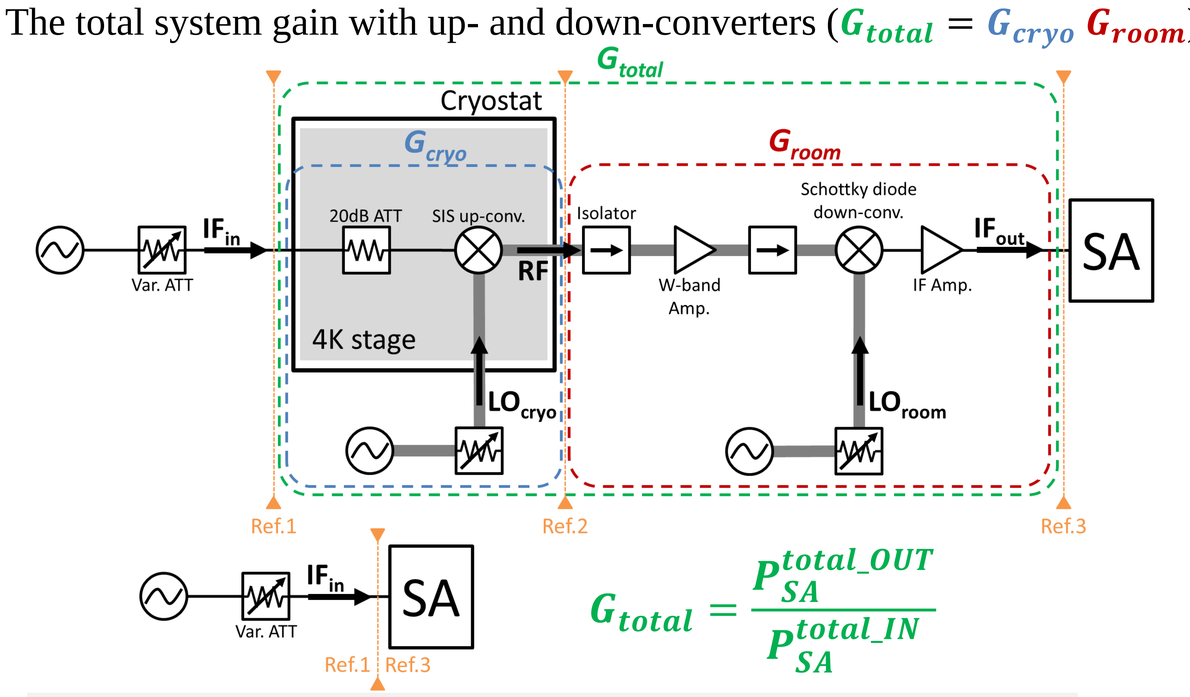


Calculation shows possible gain and low noise as well as down conversion!

Experiment

◆ **Measurement setup**

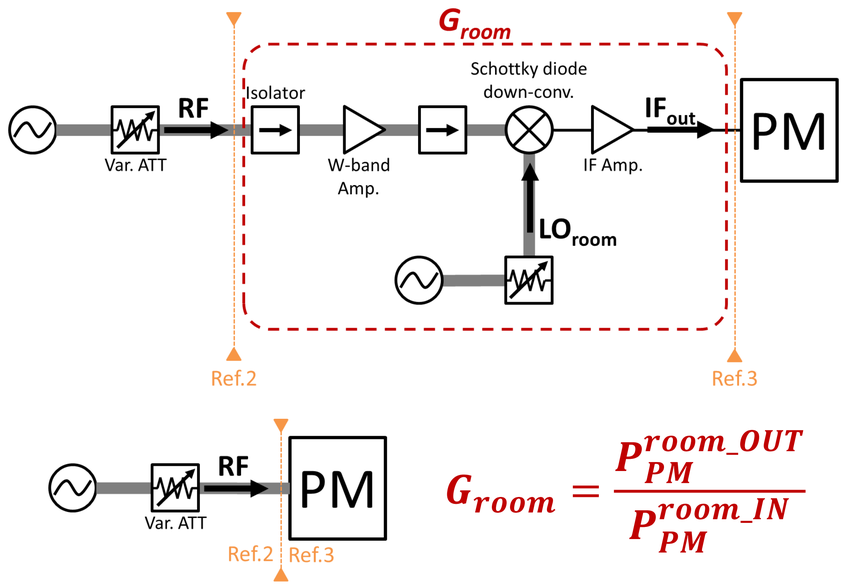
- The total system gain with up- and down-converters ($G_{total} = G_{cryo}\, G_{room}$)



$$G_{total} = \frac{P_{SA}^{total\_OUT}}{P_{SA}^{total\_IN}}$$

Peak powers, $P_{SA}^{total\_IN}$ and $P_{SA}^{total\_OUT}$, of signals, IF_{in} and IF_{out} , measured by a spectrum analyzer (SA) with same resolution bandwidth.

- Room temp. down conversion gain (G_{room})

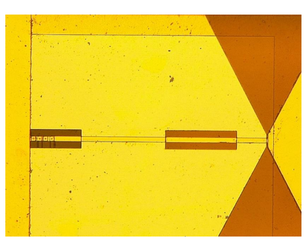


$$G_{room} = \frac{P_{PM}^{room\_OUT}}{P_{PM}^{room\_IN}}$$

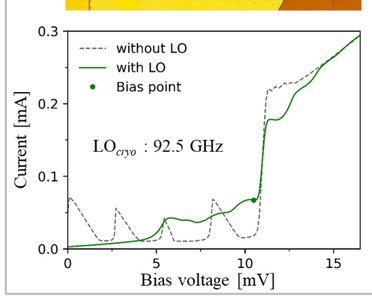
Total powers, $P_{PM}^{room\_IN}$ and $P_{PM}^{room\_OUT}$, of signals, RF and IF_{out} , measured by a microwave power meter (PM) with appropriate power sensors for RF- and IF-band, respectively.

◆ **SIS up-converter**

- Designed as down-converter for 100-GHz band, not optimized as up-converter.



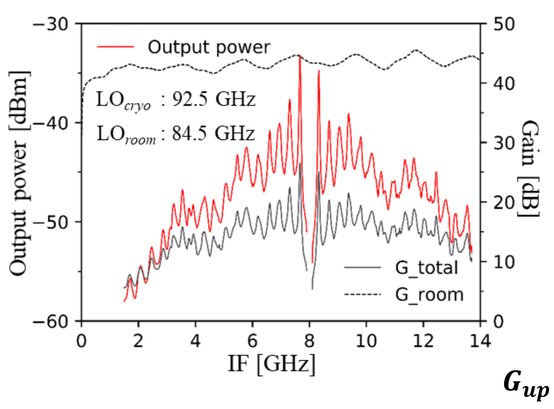
4 series junctions

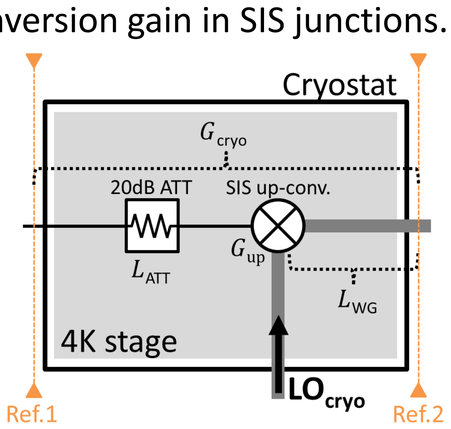


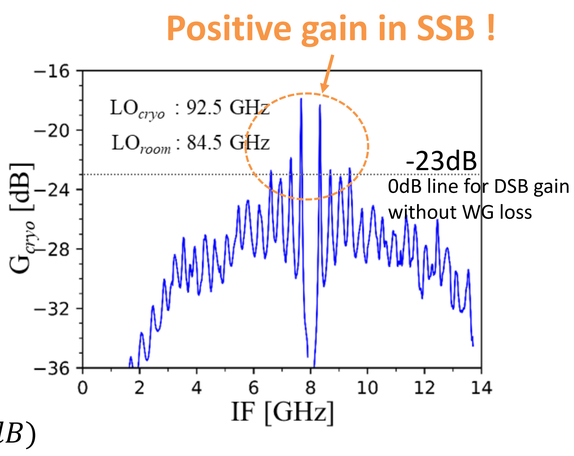
I-V characteristics

◆ **Results**

- Successful observation of up-conversion gain in SIS junctions.







$$G_{up} = G_{cryo} + L_{ATT}(20\ dB) + L_{WG}(\sim 3.6 dB)$$

Note: SUS WG loss at room temp. in L_{WG} was about 3.6 dB. Thus, SIS up-conversion gain would be more than 4.2 dB, if less temp. dependence of SUS WG loss.