Noise in Josephson Effect Mixers and the RSJ Model

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Josephson effect mixers have previously been observed to display "excess" noise both in experiments with point contacts and in numerical simulations using the resistively shunted junction (RSJ) model. This excess noise causes the mixer noise temperature to be a factor of typically 20-100 times[1] the physical temperature of the device. Previously, this excess was ascribed to conversion from unwanted sidebands of the local oscillator and Josephson frequencies and their harmonics[2]. Our numerical modeling of the RSJ equations has led to a new understanding of the excess noise, which is simply due to the intrinsic Josephson oscillations of the device. In addition, we have extended the modeling to include the previously ignored case of finite device capacitance (i.e. RSJ capacitance parameter $\beta_c \neq 0$), which is more realistic for lithographically defined Josephson such as shunted tunnel junctions or SNS bridges. For some cases, this yields an improvement of a factor of two in noise temperature from the zero capacitance models. We will discuss the device parameters which optimize the mixer performance for frequencies approaching the characteristic frequency of the device, which is given by the Josephson frequency at the I_cR_n voltage ($\nu = 2eI_cR_n/h$). These modeling results predict good conversion efficiency and a noise temperature within a factor of a few of the physical temperature. Experiments are in progress to determine the accuracy of this modeling using a waveguide mixer at 100 GHz with optimized, resistively shunted Nb tunnel junctions. If the modeling results are valid, they are particularly encouraging for mixers in the submillimeter regime, given the possibility of obtaining non-hysteretic Josephson devices with I_cR_n products in excess of a millivolt, using, for instance, high-T_c SNS bridges. We discuss the modifications to the classical RSJ model which are necessary in the quantum regime ($h\nu > kT$), and conclude the Josephson mixers may attain noise temperatures less than ten times the quantum limit at high frequencies.

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[1]Y. Taur, *IEEE Transactions on Electron Devices*, ED-27, p. 1921, 1980.

[2]K.K. Likharev, *Dynamics of Josephson Junctions and Circuits*, New York: Gordon and Breach, p. 423, 1986.