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Analytical derivation of Low-Tc DC SQUID response

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The superconducting quantum interference device (SQUID) is a basic component of superconductor electronics having numerous applications. The DC SQUID, being basically a magnetic flux-to-voltage transformer is used e.g. in highly sensitive magnetometers, amplifiers, readout circuits and antennas. These devices are routinely designed for fabrication process utilizing low temperature superconductors (LTS) and tunnel Josephson junctions, which have become a workhorse of modern superconducting electronics.

Qualitative understanding of SQUID or SQUID-based structure response can be based on an analytical approach, assuming zero SQUID inductance. However, for quantitative estimation of designed LTS circuit characteristics, accounting for a certain real value of the inductance is inevitable.

Despite the fact that half a century is gone since the year of the first demonstration of quantum interference between two Josephson junctions connected in parallel by superconducting inductance [1], a shape of DC SQUID response still was not found analytically for practical parameters of the device at low temperature ($T \sim 4.2$ K). This statement is confirmed by the fact that practical circuit optimization is always performed in the context of numerical analysis, which slows down the design process.

We consider [2] voltage and current response formation in low-Tc DC superconducting quantum interference device (SQUID) with overdamped Josephson junctions in resistive and superconducting state in the context of a resistively shunted junction (RSJ) model. For simplicity we neglect the junction capacitance and the noise effect. Explicit expressions for the responses in resistive state were obtained for a SQUID which is symmetrical with respect to bias current injection point. Normalized SQUID inductance $l = 4\pi eL/L$ (where $I_c$ is the critical current of Josephson junction, $L$ is the SQUID inductance, $e$ is the electron charge and $h$ is the Planck constant) was assumed to be within the range $l < 1$, subsequently expanded up to $l \sim 7$ using two fitting parameters. SQUID current response in the superconducting state was considered for arbitrary value of the inductance. The impact of small technological spread of parameters relevant to low-temperature superconductor (LTS) technology was studied, using a generalization of the developed analytical approach, for the case of a small difference of critical currents and shunt resistances of the Josephson junctions, and inequality of SQUID inductive shoulders for both resistive and superconducting states. Comparison with numerical calculation results shows that developed analytical expressions can be used in practical LTS SQUIDs and SQUID-based circuits design, e.g. large serial SOI, drastically decreasing the time of simulation.

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