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Modeling Coupled Serial Non-Uniform bi-SQUIDs

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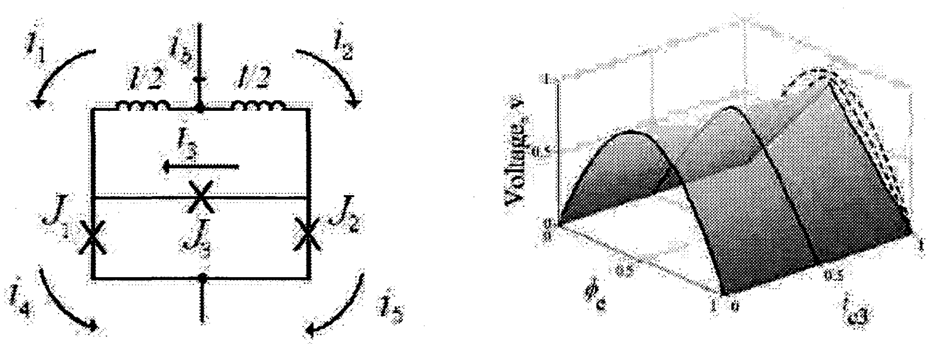
In this work we study, analytically and computationally, the behaviour of a non-uniform array of Superconducting Quantum Interference loops with three Josephson Junctions or bi-SQUID [1]. We show that the average voltage response of the coupled system to an external magnetic field is greatly increased compared to that of a single element. The non-uniformity is related to the distribution of loops sizes of each bi-SQUID, which is similar to the SQIF (Superconducting Quantum Interference Filter) design [2]. However, the single bi-SQUID has the ability to improve linearity by tuning t e current across an additional shunting junction. In addition, it has been reported that the SQIF is at least one order of magnitude greater than the values reported for the known SQUIDs [3]. The focus of this work is to investigate in great detail a serially connected bi-SQUID array. Computer simulations confirm that a voltage response with an `anti-peak' profile can be obtained with high linearity arou d zero flux. Applications of this device include: geological equipment, biomedical equipment such as MRI machines, and applications to homeland defence such as mine detection.

Background

A basic SQUID is made of two Josephson junctions symme ically connected in a closed loop. A Josephson junction is made by sandwiching a thin layer of a nonsuperconducting material between two layers of superconducting material. The construction of a single bi-SQUID differs from a conventional two-junction dc SQUID (junctions J_1, J_2) by adding a third Josephson junction (J_3) as is shown in Figure 1(a). Figure 1(b) demonstrates that the additional junction (J_3) can improve the linearity of the V-B response by choosing an optimal i_{c3}, where i_{c3} is related to the critical current for junctions J_1 and J_2. When operating below the critical temperature the material changes from the normal state, where it has electrical resistance, to the superconducting state, where there is essentially no resistance to the flow of direct electrical current. Detecting and measuring the change from one state to the other is the basic application of Josephson junctions. Readout electronics have used many approaches such as the commonly used flux-locked loop (FLL) and other alternate readouts that seek to improve dynamic range.

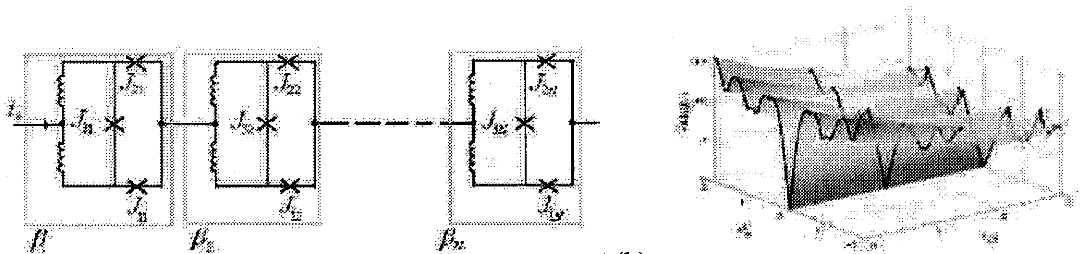


(a) (b)

Figure 1: Single bi-SQUID (a) Schematic diagram of a single bi-SQUID. (b) Average voltage response vs. the external magnetic flux (F_e) and varying the current across the third junction (J_3) by the parameter i_{c3}.

Serial Array of bi-SQUIDs

In this research work we demonstrate, through numerical simulations, that there is a significant increase the dynamic range and linearity of the voltage response by using a non-uniform serial bi-SQUID design (shown in Figure 1(a)). The main difference from the single bi-SQUID is the mutual inductances between elements. Also, each bi-SQUID element is design with a different loop size (b_k) for $k = 1,\dots, N$, where N is the number of elements connected in series. Interestin ly, there exists an optimized value of i_{c3} (i.e., relation to the current across the third junction J_{3k}, for $k = 1,\dots, N$) where the serial bi-SQUID achieves its greatest linearity. Generally, a serial array of N SQUIDs is believed to deliver a significant power increase, such that the dynamic range increase as $N^{1/2}$. Similarly, serial arrays of bi-SQUIDs can be implemented to not only increase the dynamic range but also to improve the linearity around the anti-peak voltage profile. This 'anti-peak' is useful for readout mechanisms and the device can be used as an absolute magnetometer, i.e., it has the ability to measure the intensity of a magnetic field without reference to other magnetic instruments.



(a) (b)

Figure 2: Serial bi-SQUID (a) Schematic diagram of a serial bi-SQUID. (b) Average voltage response vs. the external magnetic flux (F_e) and varying the current across the third junction (J_3) by the parameter i_{c3}.

Conclusions

We demonstrate numerically the existence of a unique 'anti-peak' at zero magnetic flux by constructing a non-uniform serially connected bi-SQUID array. Essentially, with an optimal distribution of loops sizes and critical current i_{c3} we can improve the dynamics range and linearity of the device. The array n lead to future improvements for low noise amplifiers (LNA) and electrically small antennas that can provide acceptable gain.

Acknowledgements

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