SFQ circuits with ground plane hole-assisted inductive coupling designed with InductEx

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Introduction

- Inductance is a key element of SFQ circuit design, yet its layout is often complex and requires numerical calculation.
- The 2D inductance solver Lmeter [1] is fast and sufficiently accurate for normal SFQ circuits.
- Where 3D extraction is necessary, an accurate tool that integrates easily into the design flow is required. For this we developed InductEx [2].
- InductEx was first tested for accuracy on standard circuit layouts [2]; then on lines crossing ground plane holes [3].
- The next step is to demonstrate InductEx on advanced circuit layouts, such as mutual coupling over ground plane holes.
- We demonstrate the design of an inductive pulse transfer (TX) cell and a DC-resettable latch (DCRL) with InductEx, and show the accuracy of the layouts.

Cells with mutual inductance

- Power dissipation in SFQ circuits is important in large-scale systems. Static power dissipation can be reduced [4] or eliminated [5].
- However, even low power gates use ~1 mA of current, so that magnetic fields from total bias currents degrade performance in large circuits [6].
- Current recycling [7-9] reduces total bias current, and is made possible with inductive coupling between cells (instead of electrical contacts).
- We designed an inductive transfer cell (TX) cell with InductEx for the IPHT RSFQ niobium process [10].
- We also designed a DC resettable latch (DCRL) [11] with InductEx to use ground plane hole-assisted coupling.

Inductance design and layout

- Several coupling layouts (Fig. 3) for the TX cell were analyzed with InductEx and compared to reports by Igarashi et al. [9].
- The divided ground plane limits coupling efficiency (Table 1).
- To reduce $L_4$ and improve $M_{13}$, we used a ground plane tongue and isolated hole, as suggested by Igarashi et al. [9].
- Optimal layout requires careful design due to differences in $L_1$ and $L_2$, $M_{12}$, and $M_{23}$.
- The optimal layout is shown in Fig. 4, and the circuit micrograph in Fig. 5.
- The circuits were fabricated by the FLUXONICS foundry.

InductEx was used to model all circuits. The DC cell model is shown in Fig. 7.

InductEx gives excellent results, and TX cell coupling design is very good ($M_{12} / L_1 = 0.75$).

Conclusions

- We can now reliably design circuits with hole-assisted coupling for the IPHT RSFQ niobium process with the aid of InductEx, as demonstrated for the TX cell.
- We showed that the TX cell layout identified by Igarashi et al. [9] as optimal is indeed so.
- However, using InductEx, we obtain better agreement between calculated and measured results (1% to 5%) and a significantly higher ratio of mutual to self inductance on the receiver side (0.75, compared to 0.63).

References