A hybrid ferromagnetic transmon qubit: a platform for probing interface phenomena and magnetic fluctuations

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Hybrid superconducting–ferromagnetic (S/F) platforms offer new opportunities for both the investigation of phenomena at the S/F interface and the development of quantum-computing-based sensing protocols. In this context, the ferrotransmon qubit layout proposes to employ a tunnel magnetic Josephson junction (MJJ) in a transmon architecture, enabling digital frequency control and offering a route to probe magnetic fluctuations through qubit spectroscopy protocols [1] (Fig. 1). Within this framework, we investigated Nb-based Superconductor–Insulator–thin superconductor–Ferromagnet–Superconductor (SIsFS) Josephson junctions as a playground for both coherent quantum circuits and the study of emergent phenomena at S/F interface. Our results show that SIsFS junctions are uniquely suited to distinguish inverse proximity effect (IPE) from other screening mechanisms, providing access to spin-screening phenomena at the nanometre scale [2] (Fig. 2). The investigation of the IPE plays a relevant role not only for understanding fundamental physics, but also for device optimization. Interface engineering and submicrometric scaling appear to be the most promising strategies to mitigate the IPE and achieve qubit operation [3].

In conclusion, this kind of architecture offers novel experimental tools to probe the rich phenomenology of superconductor/ferromagnet interfaces and to develop a set of quantum hardware components [4], ranging from amplifiers to couplers in a superconducting quantum processor, thus providing a relevant example of how unconventional materials can be used to realize functional and sensing devices.

References

[1] H. G. Ahmad *et al.*, Phys. Rev. B, 105 (2022) 214522
[2] R. Satariano *et al.*, Commun. Mater., 5 (2024) 67
[3] R. Satariano et al., *Appl. Phys. Lett.* 127, 252601 (2025)
[4] Italian patent application no. 102025000020416 (2025)

Figures

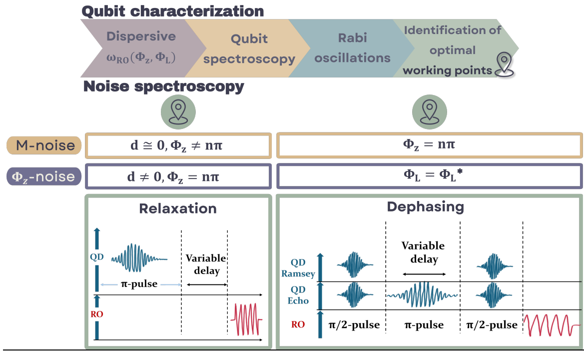

Figure 1: Measurement protocol for ferrotransmon qubit noise spectroscopy at selected working points, used to identify magnetization and flux noise sources. Adapted from [1].

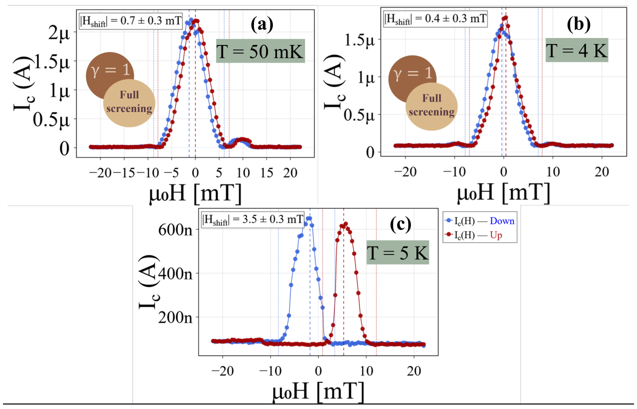

Figure 2: Temperature evolution of the magnetic interference pattern in a Nb-based SIsFS junction, showing a broadened, nearly centered lobe at low temperature (a) and the onset of hysteretic shift as the temperature increases (b-c), consistent with inverse proximity screening.