Title of the Semester Project at QuDev

Research Project II

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Abstract

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Introduction

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Chapter 1

Experimental Setup

In this chapter we introduce the experimental setup used for our experiments. We start by presenting the design of our implementation of a qubit: the Transmon. Then we will show how the qubit is driven for our purposes, in particular how to perform readout and 2-qubit gates.

Finally we put everything together and present the chip used for quantum entangling and photon emission.

1.1 The Qubit

The basic idea behind the implementation of a quantum device for quantum information is realizing a 2-level quantum system. In the Quantum Device Lab this is done through superconducting circuits. The qubits are star-shaped transmon qubits [1]. They are characterized by a large capacitor and a SQUID (see fig. 1.1). The latter is flux-tunable and it is made out of two Josephson junctions in parallel.

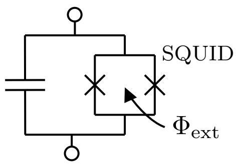


Figure 1.1: Circuit diagram of a transmon qubit

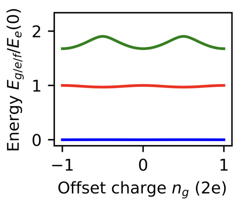
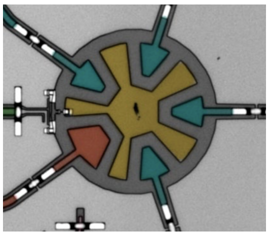


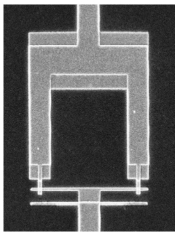
Figure 1.2: Energy spectrum relative to N_g

The Hamiltonian representing the dynamics of such a transmon is

$$\hat{H} = E_C(\hat{N} - N_g)^2 - E_{J_0,\max} \cos\left(\pi \frac{\Phi_{\text{ext}}}{\Phi_0}\right) \cos\hat{\delta} \tag{1.1}$$



(a) Star-shaped transmon



(b) Zoom-in of a SQUID loop

Figure 1.3: Images of the devices used in the lab

where $\hat{N}$ is the operator of number of Cooper pairs in the island and $\hat{\delta}$ is the phase operator of the transmon. This can be seen as a non-linear harmonic oscillator.

By changing the external magnetic flux through the SQUID Φ_{ext}, it's possible to change the energy splitting between the first two energy levels $|g\rangle$ and $|e\rangle$, and thus the frequency of the qubit. Furthermore, the anharmonicity allows us to access the first and second transition separately, since they have different energy gaps (see fig. 1.2). Nevertheless, it is important to mention that in our particular setup the qubits are not flux-tunable, because it is not useful for out purposes. We will present our setup in more detail in Section 1.4.

The qubits are star-shaped and made out of niobium(see fig. 1.3), fabricated on a silicon substrate.

1.2 Dispersive Readout

The readout mechanism allows us to measure the state of the qubit in a non-demolishing way [3]. In our experiments this is needed in order to characterize the device and for calibration purposes.

The transmon our capacitively coupled to a readout resonator, which is a waveguide on our device. By sending through this waveguide a signal far detuned from the qubit's frequency, its frequency will slightly change depending on the state of the qubit, without interfering with the state of the latter. This process ids described by the James-Cummins Hamiltonian

$$\hat{H} = \hbar\omega_r \hat{a}^\dagger \hat{a} + \frac{1}{2}\hbar\omega_{ge}\hat{\sigma}^z + \hbar g(\hat{a}^\dagger \hat{\sigma}^- + \hat{a}\hat{\sigma}^+), \tag{1.2}$$

which models the coupling between a 2-level system and a light mode in a cavity. Thus, by measuring the frequency shift of the readout resonator, we are able to infer the qubit's state.

In order to not let the qubit couple too strongly to the environment through the readout resonator, a Purcell filter is applied between the resonator and the qubit. This allows to keep the lifetimes fo the qubits long, by suppressing spontaneous emission due to the Purcell effect [2].

1.3 Tunable Couplers

1.4 Our Chip

Chapter 2

Protocols for 2 qubit gates

2.1 Storage-Storage

2.2 Storage-Emitter

2.2.1 SWAP

2.2.2 CNOT

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