1. A transmon qubit involves creating an island of superconducting material connected to a larger superconductor via one or two Josephson junctions and shunting it with a large capacitor. The state of this circuit can be described by 2 variables: (a) number of excess Cooper pairs (N) that have tunneled onto the island and (b) the phase difference (φ) of the quantum wavefunction across the junction. Now the question is what happens in a transmon and charge island when it is in state |0> or |1> from physical perspective?

ChatGPT: In the **∣0⟩** state, the qubit is in its lowest possible energy configuration. This does *not* mean there are zero Cooper pairs on the island and zero phase difference. Instead, it's a state of **minimal quantum fluctuations**. The number of excess Cooper pairs on the island fluctuates slightly **around an average of zero**. In the|1> state, the single quantum of added energy manifests as larger quantum fluctuations. It is a common misconception that the ∣1⟩ state simply means "one extra Cooper pair has been added to the island." Instead, the wave function describing the system is now more spread out.

1. How to control operations (Entanglement, Single Qubit/Multi Qubit Gate operations) in a multi qubit chip?

**Flux Bias Entanglement (Tuning into Resonance):** using the flux bias line to temporarily make two qubits interact. The process physically changes the frequency of one qubit to match another. **Physically:** The state of "energy in Qubit A" and the state of "energy in Qubit B" become coupled. The quantum fluctuations of charge and phase in Qubit A become correlated with the fluctuations in Qubit B. For a specific duration, this interaction evolves the two-qubit system into an entangled state.

**Microwave Pulse Entanglement (Cross-Resonance):** A microwave pulse is sent down the charge drive line of Qubit A. However, the frequency of this pulse is set to the frequency of Qubit B. Since the drive frequency is off-resonance for Qubit A, it doesn't simply absorb the energy and flip its state. Instead, it's "forced" to oscillate at Qubit B's frequency. This forced oscillation of Qubit A's electric field then influences Qubit B. **Physically:** The electric field fluctuations of Qubit A, driven at Qubit B's frequency, start to resonantly interact with Qubit B. The key is that the nature of this interaction depends on the initial state of Qubit A. If Qubit A is in the ∣0⟩ state, its forced oscillation has a small effect on Qubit B. If Qubit A is in the ∣1⟩ state, its forced oscillation is stronger and has a much larger effect on Qubit B, causing Qubit B's state to rotate.

1. Can we apply single qubit gate, multi qubit gate and entanglement using only charge/drive line?

Yes, in certain architectures, you can perform single-qubit gates, multi-qubit gates, and create entanglement using only the charge/drive lines. This approach simplifies the chip design by removing the need for individual flux bias lines for each qubit, which can be a significant advantage in scaling up to more qubits.

1. But can we apply single qubit gate, multi qubit gate and entanglement using only flux bias line?

Yes, it's possible to perform all necessary quantum operations—single-qubit gates, multi-qubit gates, and entanglement—using only flux bias lines, but it's a **less common approach for single-qubit gates**. This "all-flux" control method relies on using carefully shaped magnetic field pulses to manipulate the qubits' energy levels and states. **Multi-Qubit Gates & Entanglement is the most natural and standard use for flux lines**. You apply a relatively slow DC flux pulse to one qubit to tune its resonant frequency until it matches a neighbor's. This brings them into resonance, allowing them to interact and become entangled. Turning the flux off separates them again, locking in the entangled state. **Performing single-qubit gates with only a flux line** is more complex and relies on a different physical principle. Instead of a slow DC pulse, you apply a very fast AC magnetic pulse via the flux line.

Single Qubit Operation using Flux Bias Line only:

* Rapidly Deforming the Energy Levels: A standard DC flux bias sets the qubit at an "idle" point where it's insensitive to noise. The fast AC pulse then rapidly changes the magnetic field, which in turn rapidly changes the energy gap between the qubit's ∣0⟩ and ∣1⟩ states.
* Non-Adiabatic Transition: **If this change happens quickly enough (a "non-adiabatic" change)**, the qubit doesn't have time to gracefully adapt to the new energy landscape. Instead, the rapid deformation can "shake" the qubit from the ground state (∣0⟩) into an excited state (∣1⟩) or a superposition.
* Pulse Area Determines Rotation: **The final state of the qubit depends on the total "area" of the flux pulse** (its amplitude integrated over its very short duration). A pulse with a specific area acts as a π-pulse, flipping the state from ∣0⟩ to ∣1⟩. A pulse with half that area acts as a π/2-pulse, creating an equal superposition.

1. In a 16-qubit chip, to perform two qubit and single qubit operations, do we need to add charge/drive line and flux bias line to each of the qubits? Or is it okay if we add them only to some of them?

For a universal quantum computer, every qubit must be controllable. This leads to two primary design choices:

* Hybrid Control: All 16 qubits get a charge/drive line AND a flux bias line.
* All-Microwave Control: All 16 qubits get a charge/drive line, and flux lines are either absent or used only for slow adjustments.

1. How does a SQUID help to obtain frequency tunability of a Transmon?

This arrangement creates two parallel paths for Cooper pairs to travel around the loop, and it's the interference between these two paths that makes the device work. When the magnetic field is applied perpendicular to the plane of the ring, the current is induced at the two Josephson junctions. The induced current produces the interference pattern and it flows around the ring so that the magnetic flux in the ring can have the quantum value of magnetic field applied. A **DC current** is sent through the nearby flux bias line. This creates a stable magnetic field (constant valued) that passes through the center of the SQUID loop. The **magnetic flux changes the quantum phase of the Cooper pairs** as they travel around the loop. It **advances the phase on one path and retards it on the other**. This causes the wavefunctions of the Cooper pairs tunneling through the left and right junctions to interfere with each other.

1. Anharmonicity in flux qubit

Unlike a transmon qubit, whose anharmonicity comes from the cosine nature of a single Josephson junction, the **anharmonicity in a flux qubit arises naturally** from its **double-well potential energy landscape**. This potential is created by the superconducting loop with its three Josephson junctions. It has two distinct energy minima, corresponding to a persistent current flowing clockwise (∣0⟩ state) or counter-clockwise (∣1⟩ state). **A system with a double-well potential is inherently anharmonic**—its energy levels are not equally spaced.

1. Flux Qubit – Double Well Potential, Phase Qubit – Tilted Washboard Potential

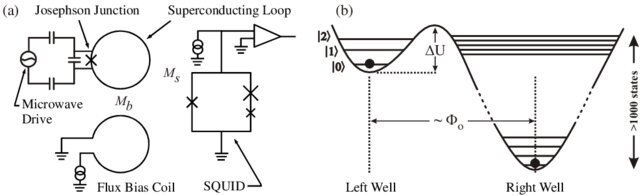
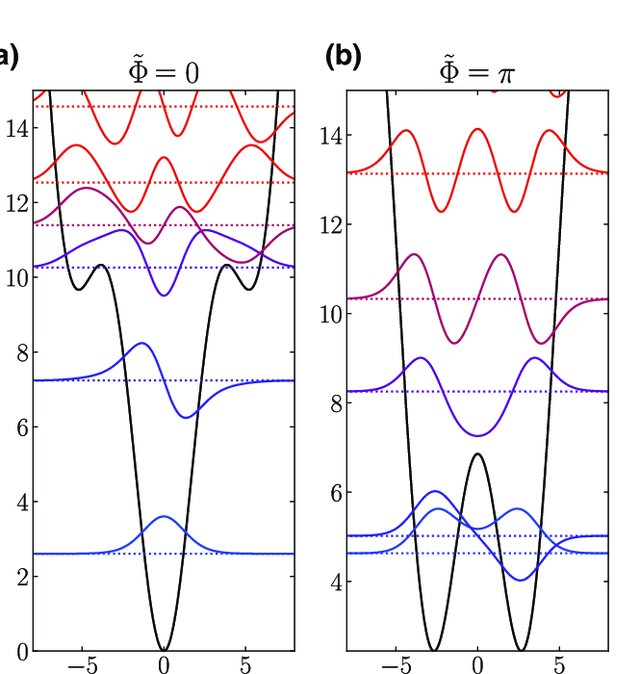


 Fig: (a) The phase qubit schematic circuit. (b) The potential U (δ) at a particular φ (**tilted washboard potential, not a double well potential like flux qubit**)

1. Potential Profile and Flux Biasing in Fluxonium

The potential is a deep parabola (due to the large inductor) with small, periodic "wiggles" or "scallops" superimposed on it (due to the small Josephson junction). An external magnetic flux can shift this potential landscape.



At zero flux, single potential well. At half flux sweet spot, the two lowest energy states of the system are now localized in these **two separate wells**. This is the regime where the fluxonium behaves most like a traditional flux qubit, with its states corresponding to quantum oscillations in the left and right wells.

**At a sweet spot, because the frequency curve is flat, small jitters in the magnetic flux have no effect (to a first-order approximation)** on the qubit's frequency.

1. Odd modes of propagation while CPW design:

