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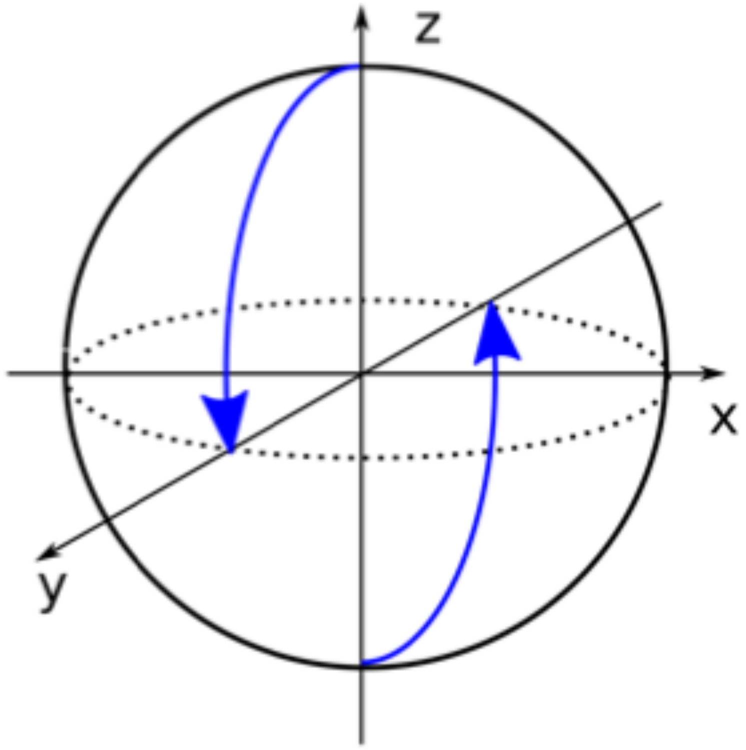
Operations in superconducting qubits: Single-qubit gates

Single-qubit gates

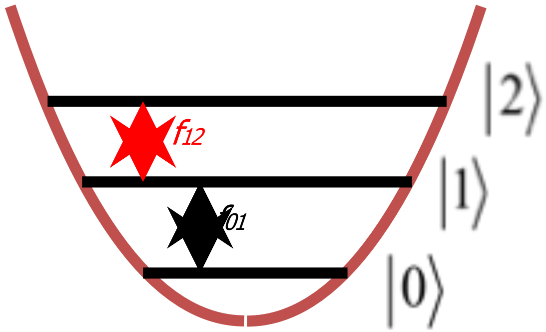


The X90 gate on
the Bloch sphere

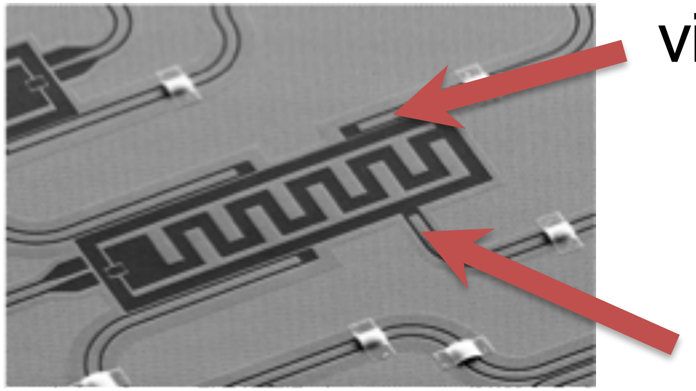
- Qubit states is visualized on the Bloch sphere
- Ground and first excited state on poles
- Single-qubit gates: Uniform rotations of the Bloch sphere

Applying a microwave electric field

- Rabi oscillation
- Apply an external electric field with the transition frequency f_{01}
- 3 to 10 GHz: Microwave frequency



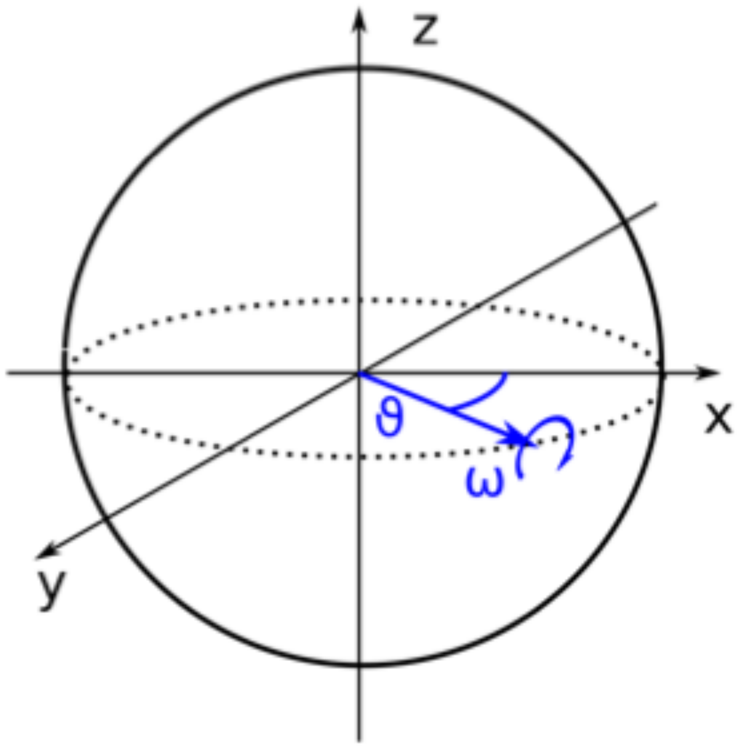
Microwave pulse is generated at room temperature,goes into the fridge, reaches the transmon...



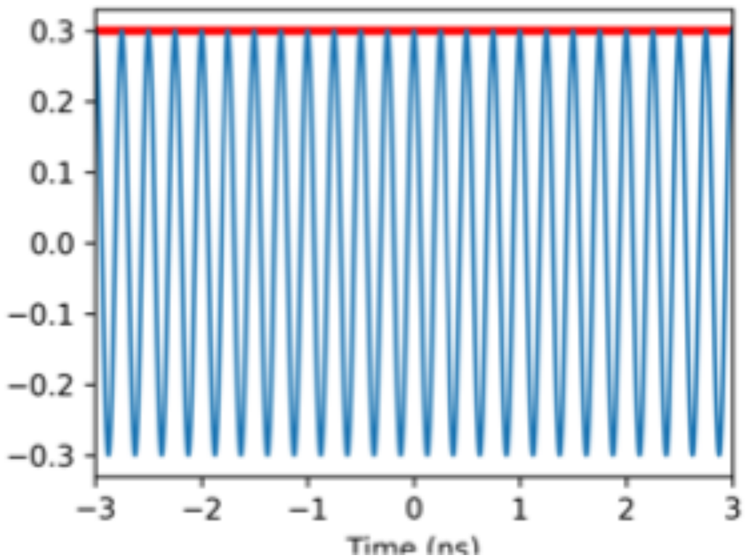
via readout resonator

via a separate microwave drive line

Rabi oscillations

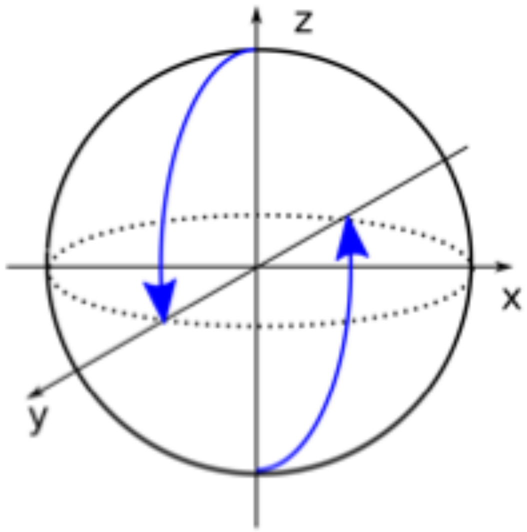


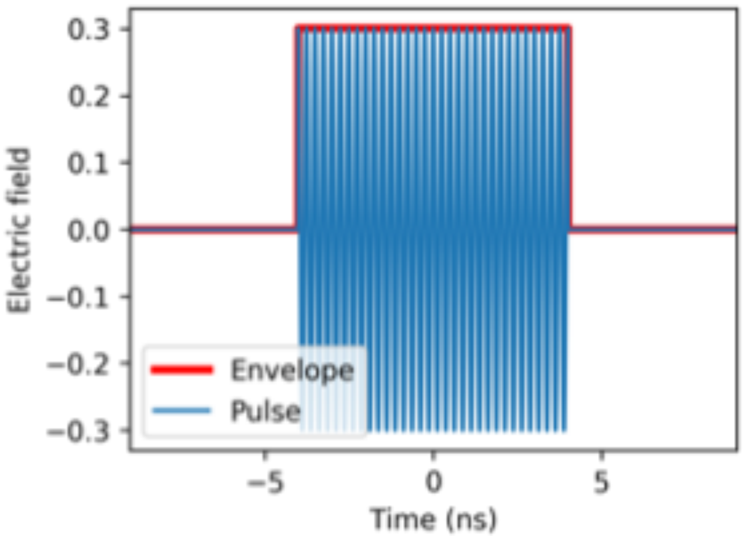
$$E(t) = E_0 \sin(2\pi f_{01} t + \theta)$$



- Rotation around axis in x-y plane
- Axis ↔ phase θ
- Rotation speed ↔ amplitude E_0

Rabi pulses

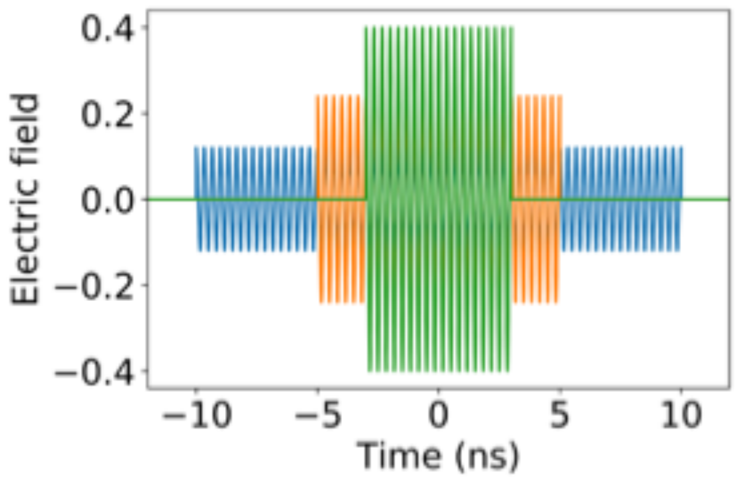


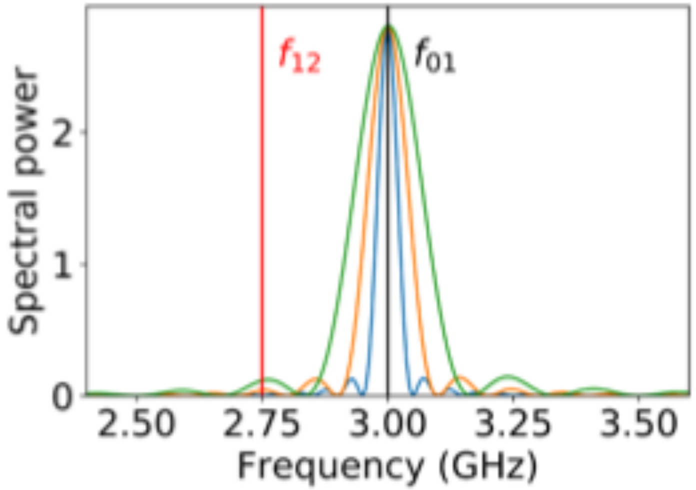


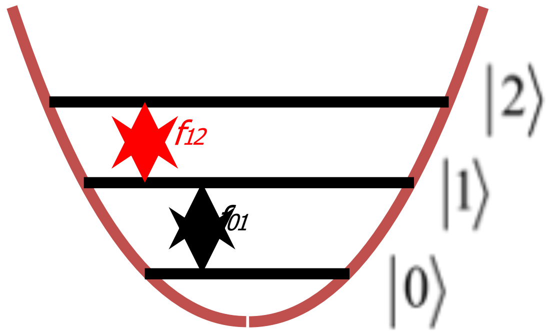
- Angle = speed x duration = area of pulse envelope
- Can do any rotation around an axis in x-y plane
- Other rotation must be decomposed in such rotations (this is always possible)

Fast pulses: the second excited state

- We want fast gates, short pulses
- But shorter pulses have a broader frequency spectrum and can excite to state 2!
- This must be avoided if we want a qubit



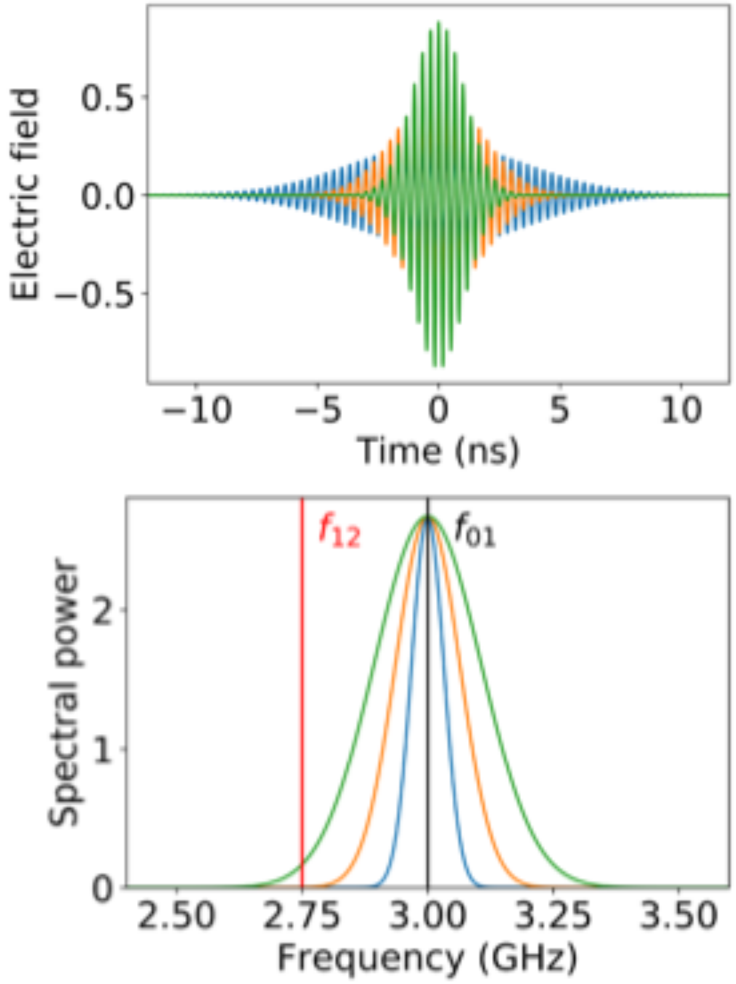




Faster pulses: Gaussian envelope

- Pulses with a Gaussian envelope have a more concentrated frequency spectrum

- These pulses can be made shorter before they drive the 1-2 transition



Even faster pulses: DRAG pulses

- "Derivative removal by adiabatic gate" (DRAG) pulses push the limit further
- Add a fine-tuned component:
  - shape the pulse so that 1-2 transitions are suppressed
  - No change of pulse area
- Gates with <10 ns duration and >0.999 fidelity are possible