Solid-Sate Qubits with Current-Controlled Coupling

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Motivation：single qubit and multiple qubit operations can be realised in the same system

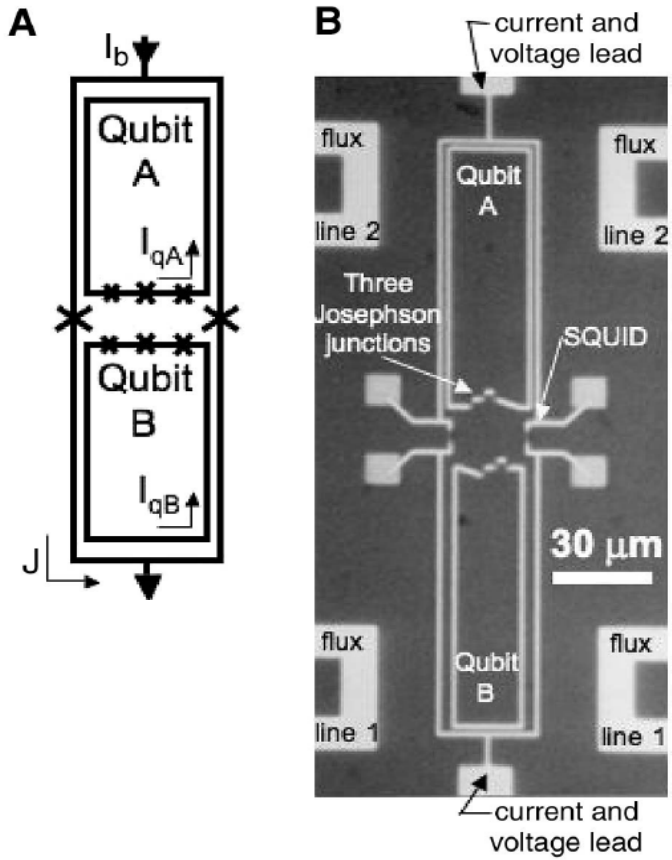
Single qubit operations

Rabi oscillations, Ramsey fringes, spin echoes

Multiple qubit operations

Entanglement, quantum gates

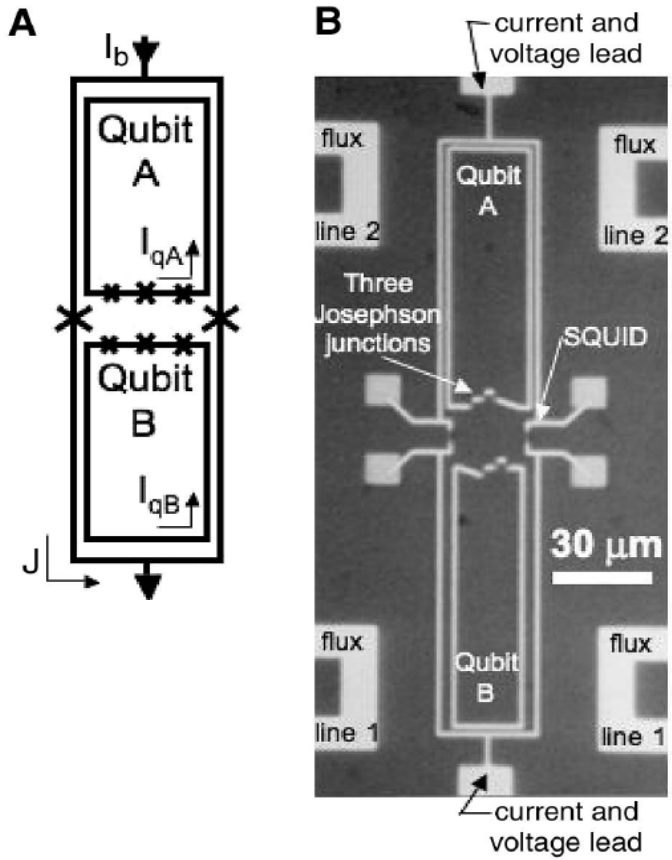
Structure: flux qubit



flux qubits

- Superconducting loop + 3 Josephson junctions
- External flux lines control flux Φ_A, Φ_B
- Two screening currents built up
  → states $|\uparrow\rangle, |\downarrow\rangle$
- Splitting between ground and excited state
  $\upsilon = \sqrt{\Delta^2 + \varepsilon^2}$ with $\varepsilon = 2I_q\left(\Phi_q - \left(n + 1/2\right)\Phi_0\right)$

Structure: flux qubit



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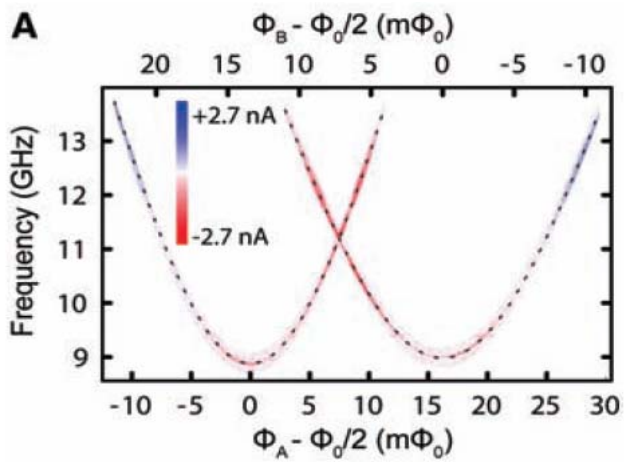
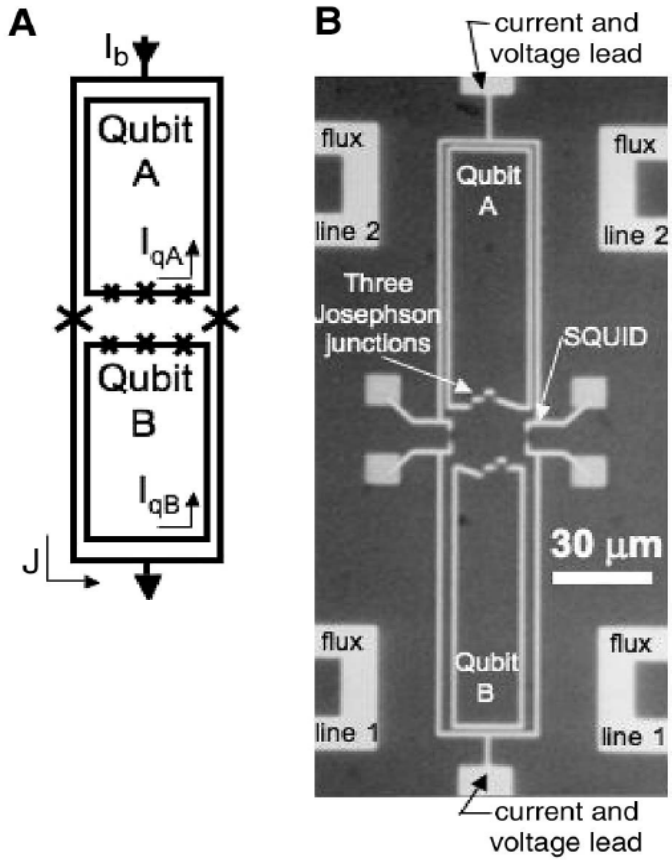


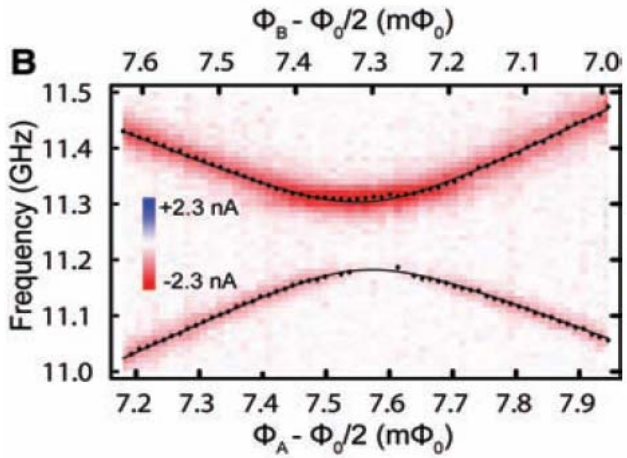
Structure: coupled flux qubits



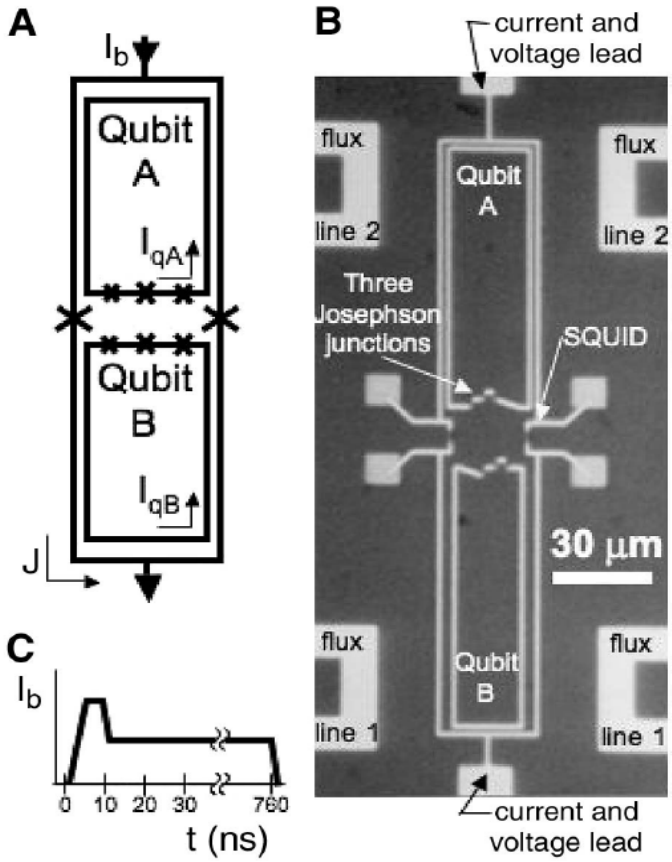
coupled qubits

- coupled via mutual inductuctance M_{qq} and inductances M_{qAS}, M_{qBS} to SQUID
- 4 new states, superpositions of

$$|\downarrow\downarrow>, |\uparrow\uparrow>, \frac{1}{\sqrt{2}}\left(|\uparrow\downarrow> + |\downarrow\uparrow>\right), \frac{1}{\sqrt{2}}\left(|\uparrow\downarrow> - |\downarrow\uparrow>\right)$$



Structure: SQUID



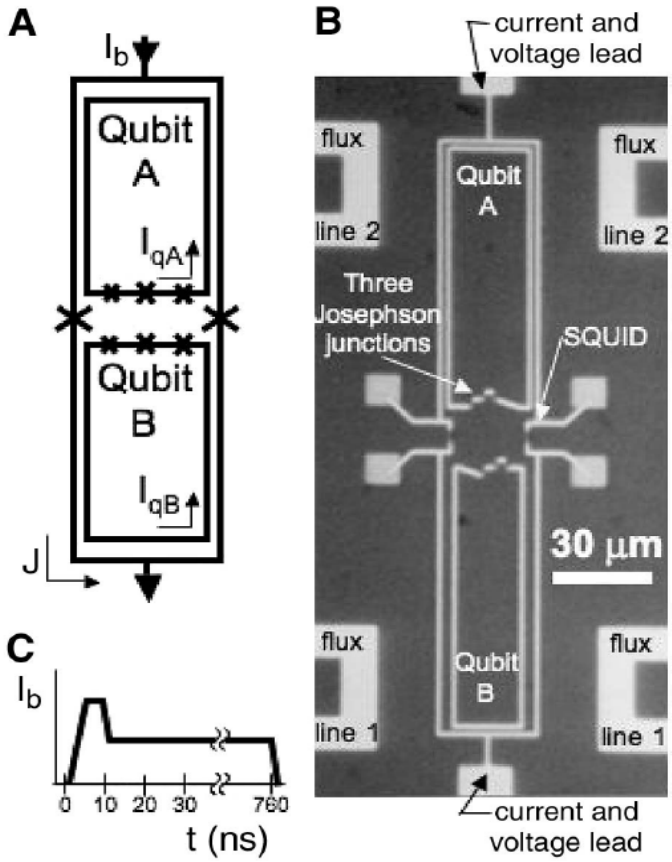
SQUID

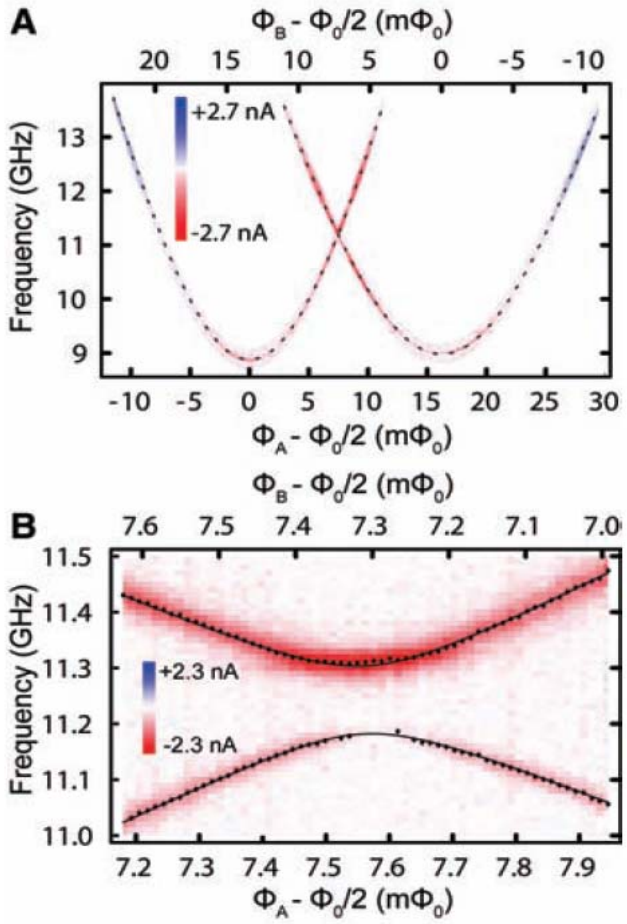
- Superconducting loop + 2 Josephson junctions
- Φ_S is determined by Φ_A, Φ_B
- Current biased with I_b

Measurement

- Determine critical current I_0 via voltage pulses
- Work in zero voltage regime
- Adjust I_b, that SQUID switches out of zero voltage regime with 50% probability

Measurement





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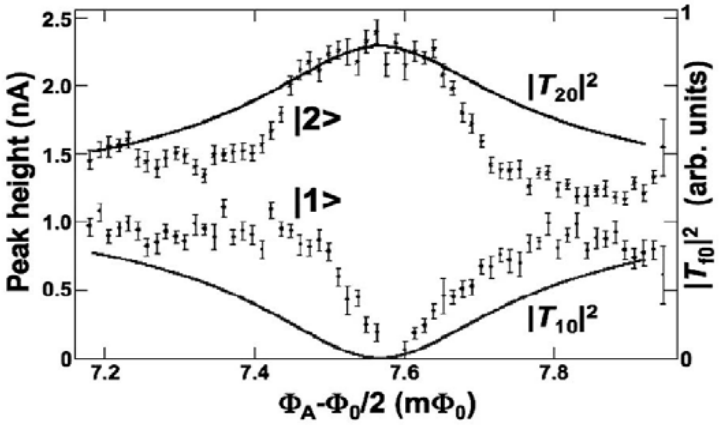
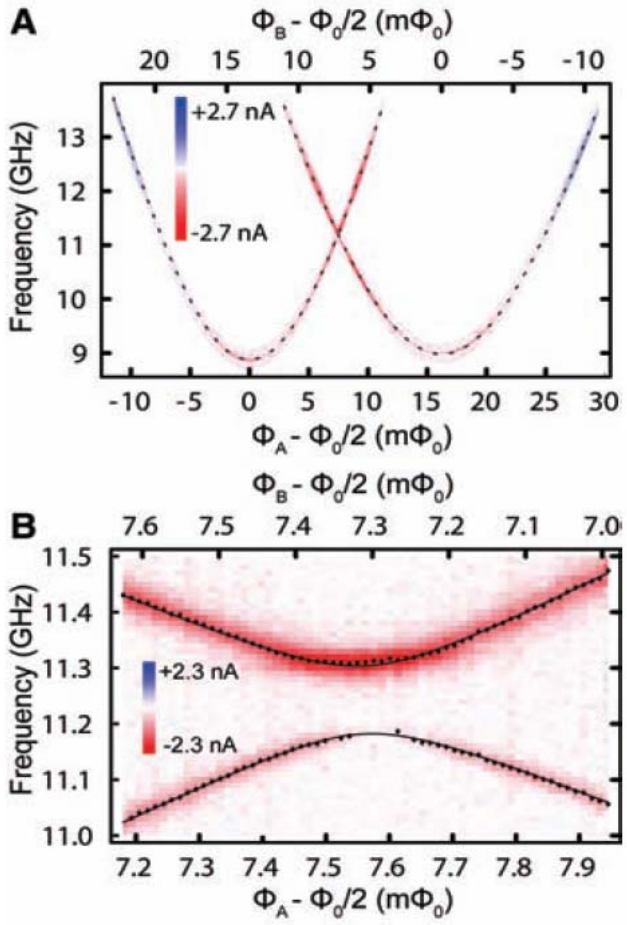


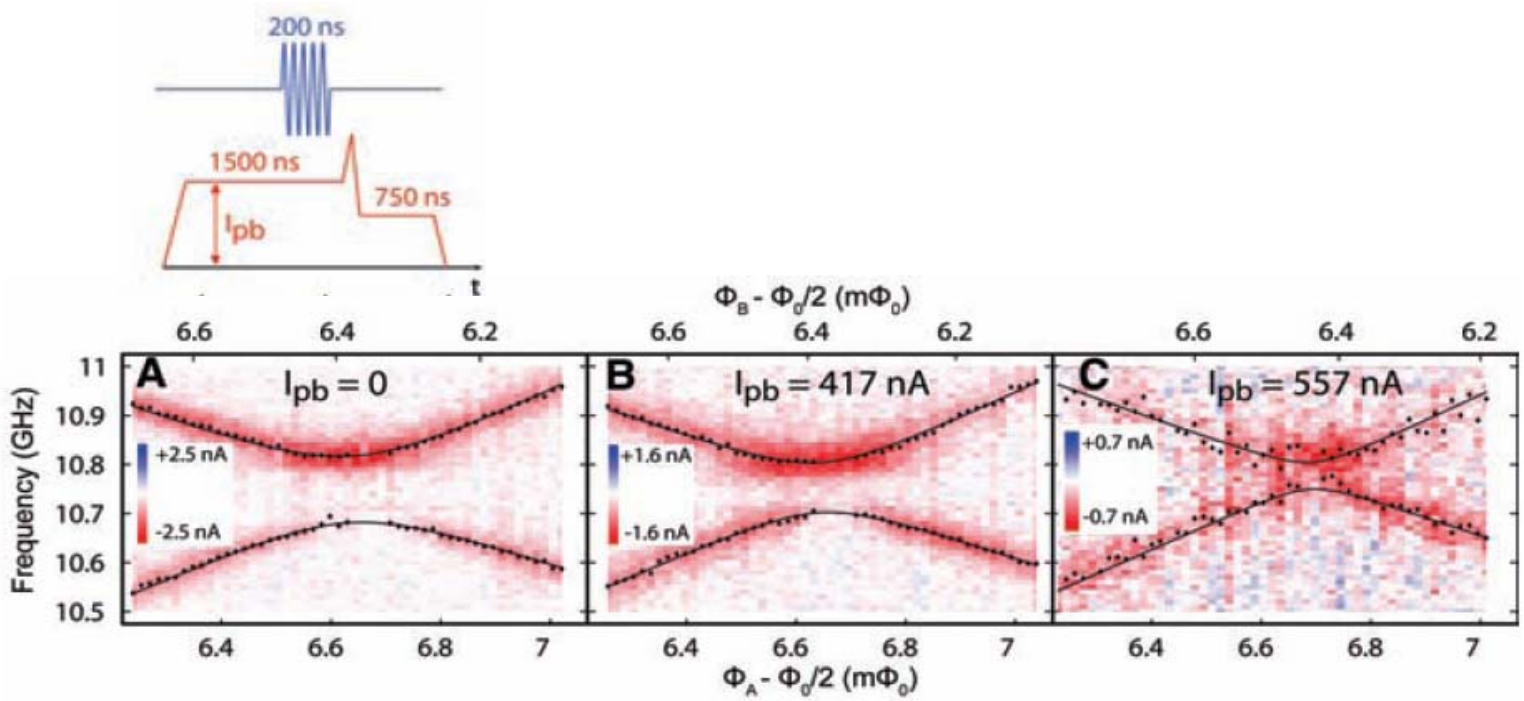


Controlled Coupling

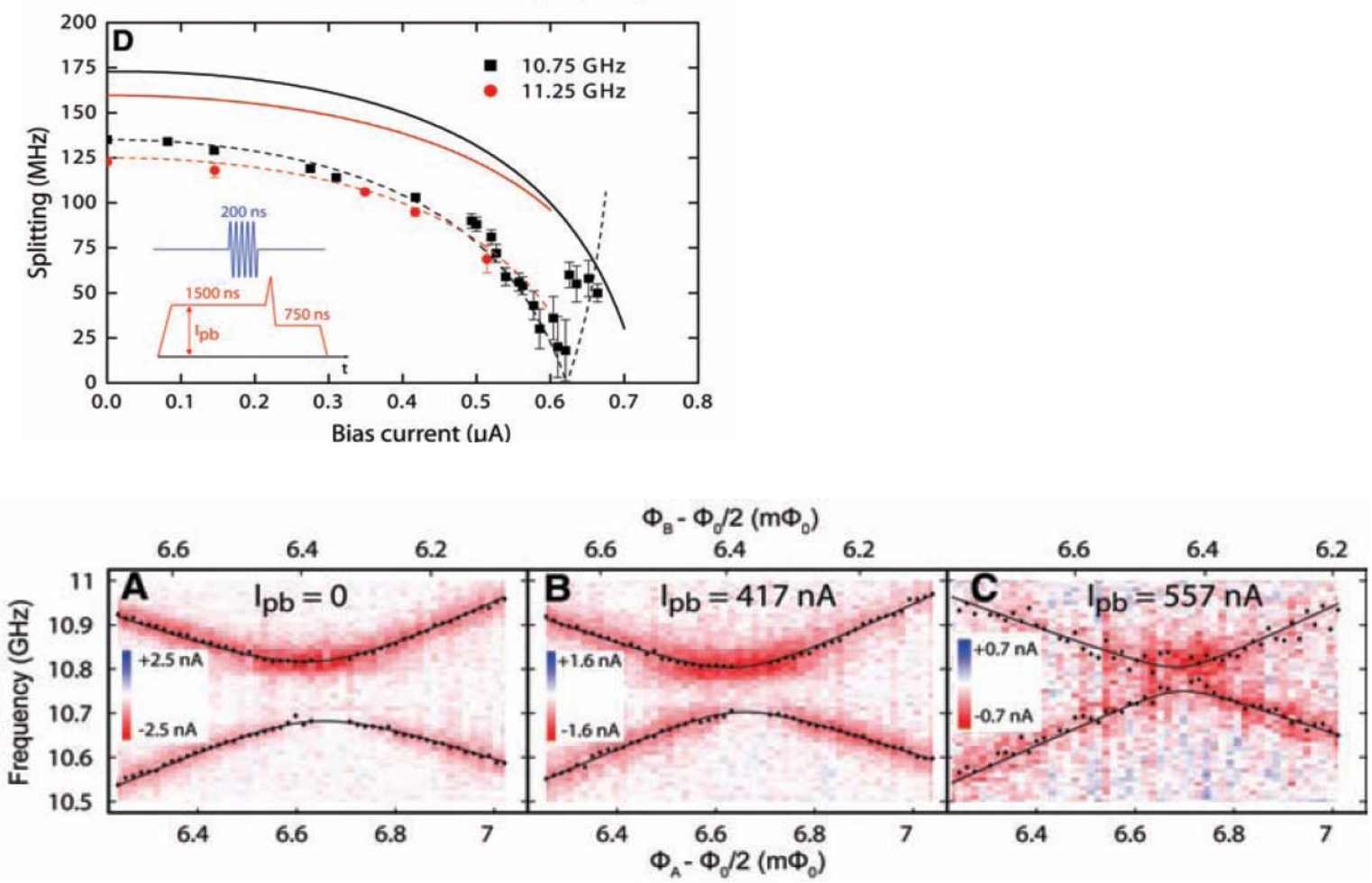
Coupling energy $K = K_0 + K_S = 2I_{qA}I_{qA}\left(-M_{qq} - M_{qAS}M_{qAS}\ell\right)$

Dynamic inductance $\ell^{-1} = \mathrm{Re}\left(\partial J / \partial \Phi_S\right)_{I_b}$ depends on I_b and Φ_S

→ keep Φ_S constant and vary I_b



Controlled Coupling



Coupled states