A $Q_\phi=25000$ SUPERCONDUCTING CHARGE QUBIT

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Stony Brook, May 2003
THE JOSEPHSON TUNNEL JUNCTION: AN ATOM-LIKE SYSTEM TO WHICH YOU CAN ATTACH WIRES ...
.... IN 3 DIFFERENT WAYS

“CURRENT-BIASED JUNCTION”

“RF-SQUID”

“COOPER-PAIR BOX”

\[ Z(\omega) \]

\[ \delta \]

\[ Z(\omega) \]

\[ \phi \]

\[ \Phi_b \]

\[ N_g = C_g U/2e \]

\[ Z(\omega) \sim Z_{vac} = 377\Omega \]
ENERGY LEVELS OF THE COOPER PAIR BOX IN THE CHARGE REGIME

\[ E_j/E_c = 0.25 \]

\[ E_c = \frac{e^2}{2(C_g + C_j)} \]

Zorin, Averin & Likharev '85
# Experimental Implementations of Squubits

<table>
<thead>
<tr>
<th>CONTROL</th>
<th>CHARGE</th>
<th>FLUX</th>
<th>PHASE</th>
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<tbody>
<tr>
<td>MEASURE</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CHARGE</td>
<td>Saclay, SUNY Stony Brook, NEC, Yale, Chalmers, LPS, JPL, …</td>
<td>______</td>
<td>______</td>
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<tr>
<td>FLUX</td>
<td>______</td>
<td>SUNY Stony Brook, TU-Delft, UC Berkeley, NTT, Rome …</td>
<td>NIST</td>
</tr>
<tr>
<td>PHASE</td>
<td>Saclay Yale/Saclay</td>
<td>IBM TU-Delft …</td>
<td>NIST U. Kansas U. Maryland …</td>
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</tbody>
</table>
BOX AS SPIN 1/2

OFFSET CHARGE!
ENERGY LEVELS IN THE INTERMEDIATE REGIME

\[ E_J/E_C = 4 \]

\[ E/EC \]

\[ N_g = C_g U / 2e \]

optimum work. pt.
KEY IDEA: WRITE WITH CHARGE, READ WITH PHASE

readout measures current response to applied phase $\delta$ instead of island charge $N$

$N_g = \frac{C_g U}{2e}$

Cottet et al. 2002
Friedman & Averin, Zorin, Buisson et al.
ELECTRON MICROGRAPH OF SAMPLE

EXPERIMENTAL SETUP

Vion et al., Science 296 (2002), 286
**CW ABSORPTION LINESHAPe AT OPTIMAL POINT**

- $N_g = 0.5$
- $\delta = 0$
- $\tau = 4 \mu s$

Lorentzian fit:
- $\nu_{01} = 16463.64 \text{ MHz}$
- $Q_{\text{app}} \sim 20000$
RELAXATION TIME AT OPTIMAL POINT

Exponential fit:
$T_1 = 1.84 \mu s$

$Q_1 \sim 90,000$
RABI OSCILLATIONS

\[ U_{w} = 22 \text{ } \mu\text{V} \]

\[ \tau \]

\[ \nu_{RF} = 16430.05 \text{ } \text{MHz} \]

\[ \text{RF pulse duration } \tau (\mu\text{s}) \]

\[ \text{Rabi frequency } \nu (\text{MHz}) \]

\[ \text{switching probability } (%) \]

\[ \text{nominal } U_{w} = \mu\text{V} \]
MEASURING QUANTUM COHERENCE LIFETIME (1)

preparation

90° pulse

free evolution

90° pulse

measurement

Ramsey fringe experiment, principle of atomic clocks
MEASURING QUANTUM COHERENCE LIFETIME (2)

preparation | 90° pulse | free evolution | 90° pulse | measurement

Ramsey fringe experiment, principle of atomic clocks
RAMSEY FRINGES MEASUREMENT

\( f - f_{01} = 20.6\, \text{MHz} \)

\( Q_\phi \sim 25000 \)
TRANSITION FREQUENCY vs BIAS

FIT:

\[ E_J = 0.68 \text{ k}_B\text{K} \]
\[ E_{CP} = 0.86 \text{ k}_B\text{K} \]
junction asymmetry = 0
LINEWIDTH CLOSE TO THE OPTIMAL POINT

\[ 2 \times 10^{-3} \frac{\partial \nu_{01}}{\partial \phi} \]

\[ 4 \times 10^{-3} \frac{\partial \nu_{01}}{\partial N_g} \]
2-QUBIT GATE

qubit # 1

qubit # 2

will prepare

$$\frac{|01\rangle - |10\rangle}{\sqrt{2}}$$
### QUANTUM vs CLASSICAL SPIN-SPIN CORRELATIONS FOR 2 QUBITS

<table>
<thead>
<tr>
<th></th>
<th>Qubit1</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
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<tbody>
<tr>
<td>Qubit2</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>X</td>
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<td>-1</td>
<td>0.5 (&lt;0.33)</td>
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</tr>
<tr>
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RF PULSE READOUT PRINCIPLE

write qubit

μW pulses
f~15GHz

excite readout junction

RF pulse
f’~1GHz

amplify & mix reflected pulse

S\textsubscript{out}\ast\sin(2\pi f''t)

IF pulse
f’-f''=20MHz

state 1

state 0
PRELIMINARY RESULTS ON QUBIT READOUT PERFORMANCE

- Measurement time is <15 ns! (<< T₁)
- Single-shot qubit state readout recorded in < 100 ns
- Discriminating power = 76% for 1% change in I₀ @ T=380 mK
CONCLUSIONS AND PERSPECTIVES

- EXISTENCE PROOF OF COHERENCE QUALITY FACTORS OF $Q_\phi \sim 25\,000$ FOR CHARGE-PHASE QUBITS

- GATES BASED ON SIMPLE CAPACITORS

- RF-PULSE READOUT SHOULD BE QUASIPARTICLE-FREE; SHOULD IMPROVE CONTRAST, EFFICIENCY AND REPETITION RATE

- PROTECTION FROM $1/f$ CHARGE NOISE AND FLUX NOISE CAN BE IMPROVED FURTHER WITHIN PRESENT TECHNOLOGY