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Paper:
Quantum Dot-Based Parametric Amplifiers

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Paper & Abstract

Quantum Dot-Based Parametric Amplifiers

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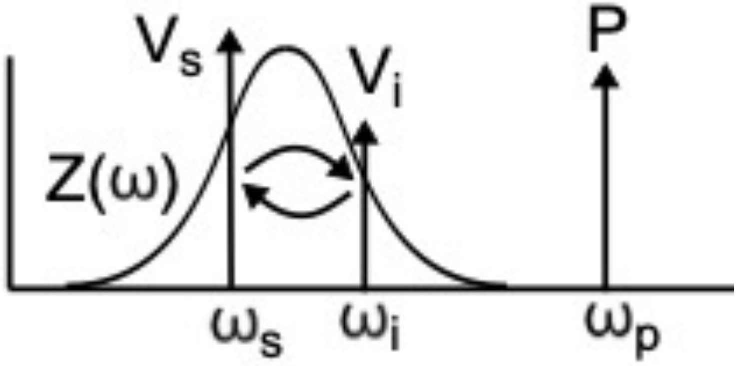
- JPAs/TWPAs instrumental in enabling high fidelity readout of sc qubits and QDs
- Proposal 1: Quantum Capacitance alternative dissipationless non-linear element (vs. Josephson Inductance)
- Demonstration: Parametric amplification with a CMOS device achieving gains of -3 to +3 dB
- Proposal 2: Optimised design which could achieve gains comparable to JPAs

Parametric amplification

- Energy conversion between 'signal' mode (f_s) and 'idler' mode (f_i)
- Conversion mediated by pumping a non-linear element (f_p)



- "Standard" JJ based devices are challenging to integrate with spin qubits due to the heavy magnetic shielding required.
- Alternative non-linearities, e.g. based on kinetic inductance studied [24-26]

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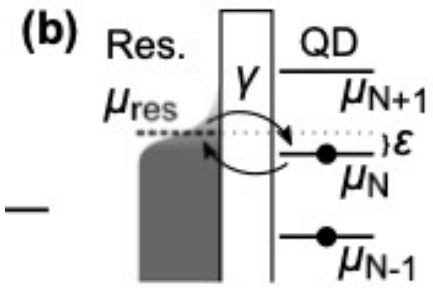
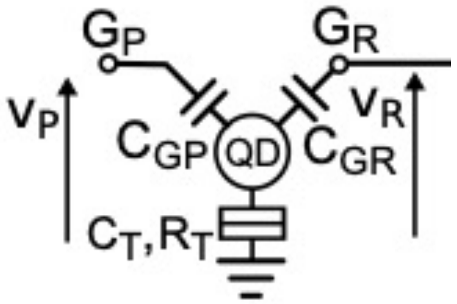
Quantum Capacitance as non-linear element

- Motivation: resilience against magentic fields, compact, tight integration with spin qubits
- Differential capacitance seen by gate of QD
- For f < γ and T > γ tunneling to reservoir occurs adiabatically -> dissipationless quantum capacitance



$$C_Q = (e\alpha_R)^2 \frac{\partial P}{\partial \varepsilon} = \frac{(e\alpha_R)^2}{4k_B T} \frac{1}{\cosh^2(\varepsilon/2k_B T)}$$

- 'variable' capacitor with a quantum dot with 2 gates



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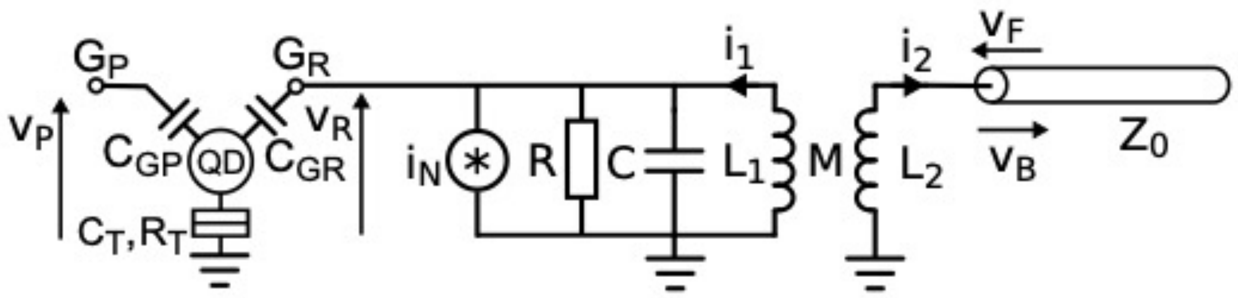
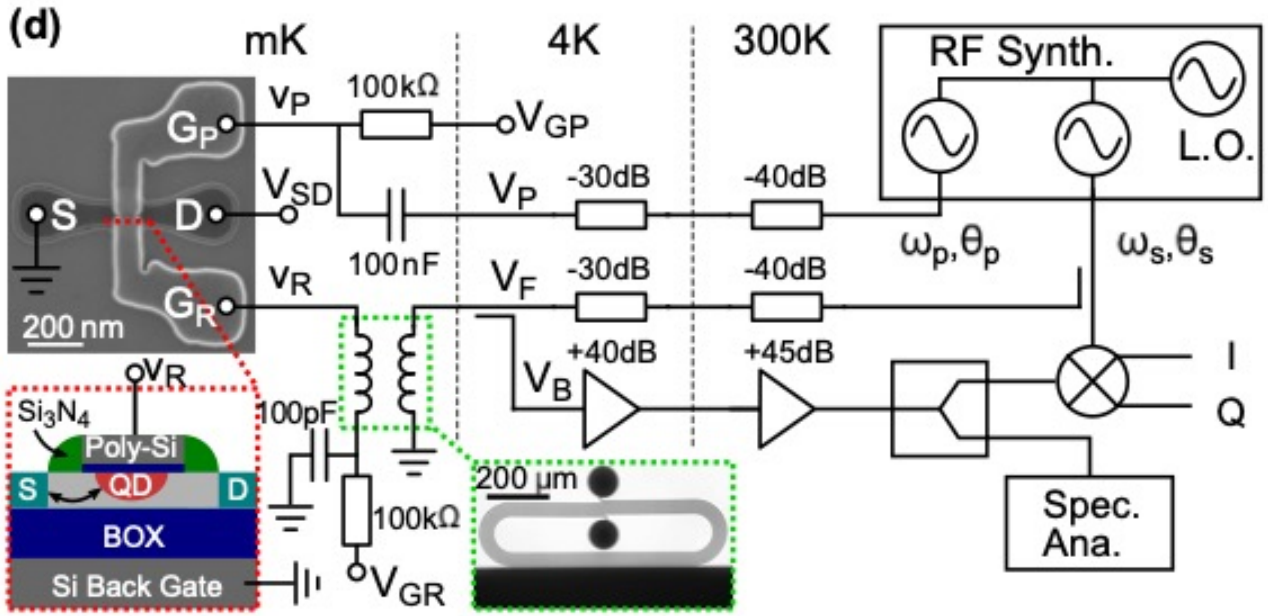
QDPA – the device



- Resonator attached to G_R
- Pump excitation applied to G_P

QDPA



- Leti SOI device: 7 nm Si, 145 nm BOX
- Barrier: 34 nm
- Channel width: 70 nm
- Gate length: 60 nm
- Gate separation 40 nm

- Z_r = 540 Ohm

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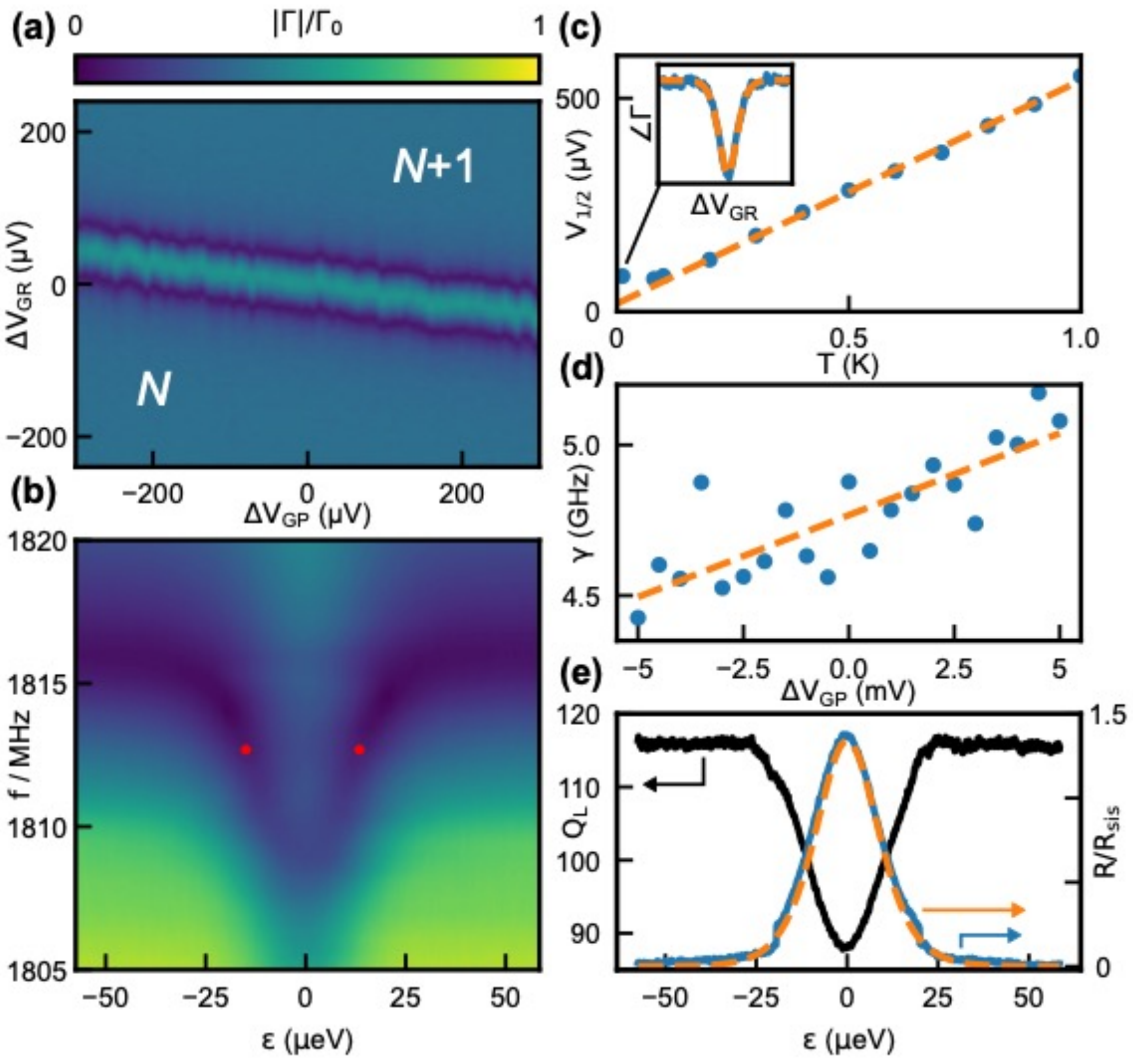
Resonator Characterisation near dot-to-reservoir transition



- No pumping
- C = 163 fF
- C_Q = 0.93 fF
- Q_i = 283
- At 12 mK transition is lifetime broadened
- Tunnel rate ~4.77 GHz

- f_0 comparable to tunnel rate -> non-adiabatic tunneling contributions

- Engineer tunnel rate to be >>f_0

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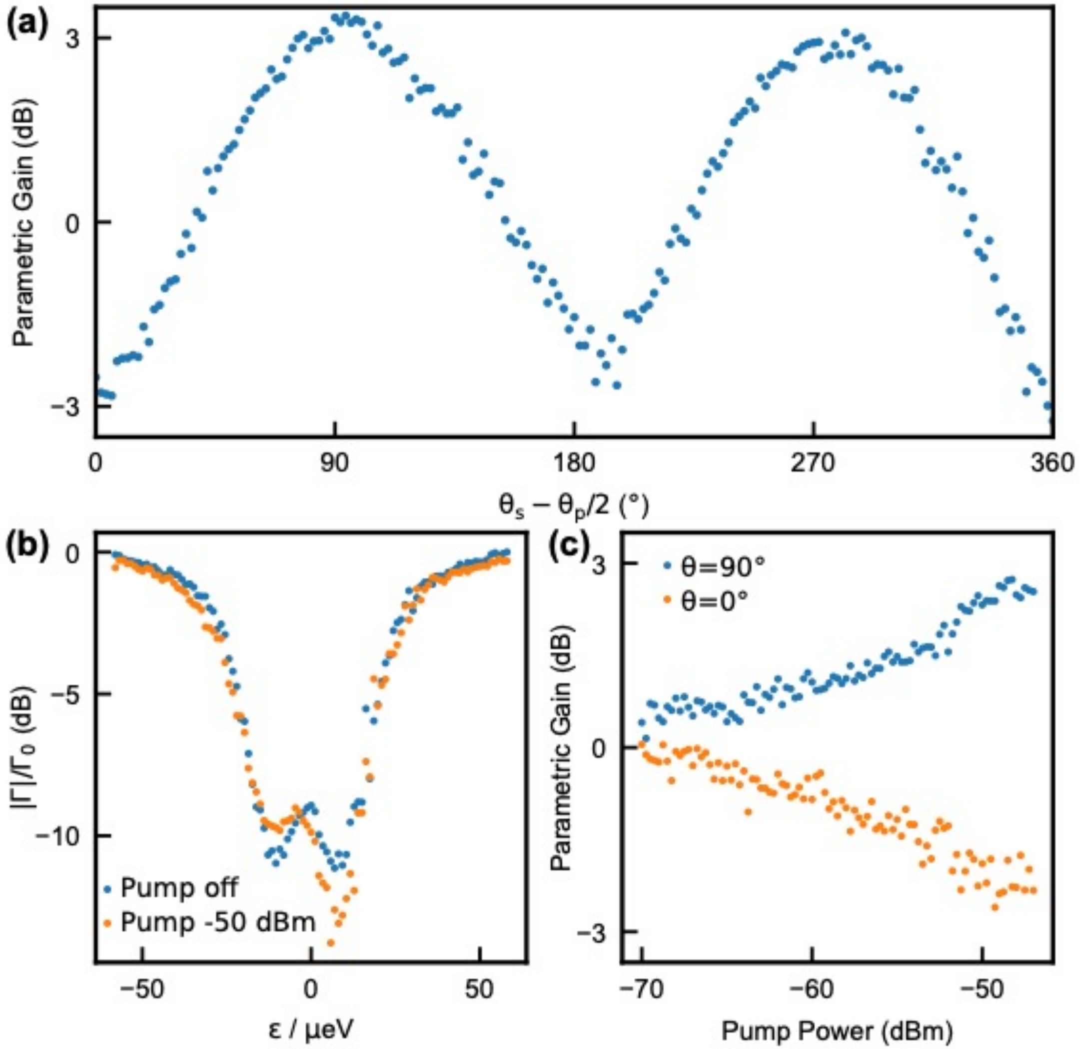
Parametric amplifier



- $f_p = 2f_s$
- Small variation of C_Q and dissipation limits gain

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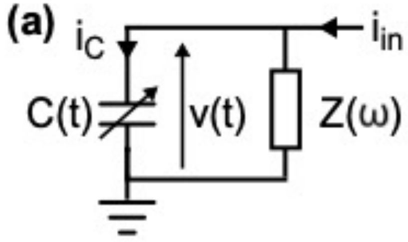
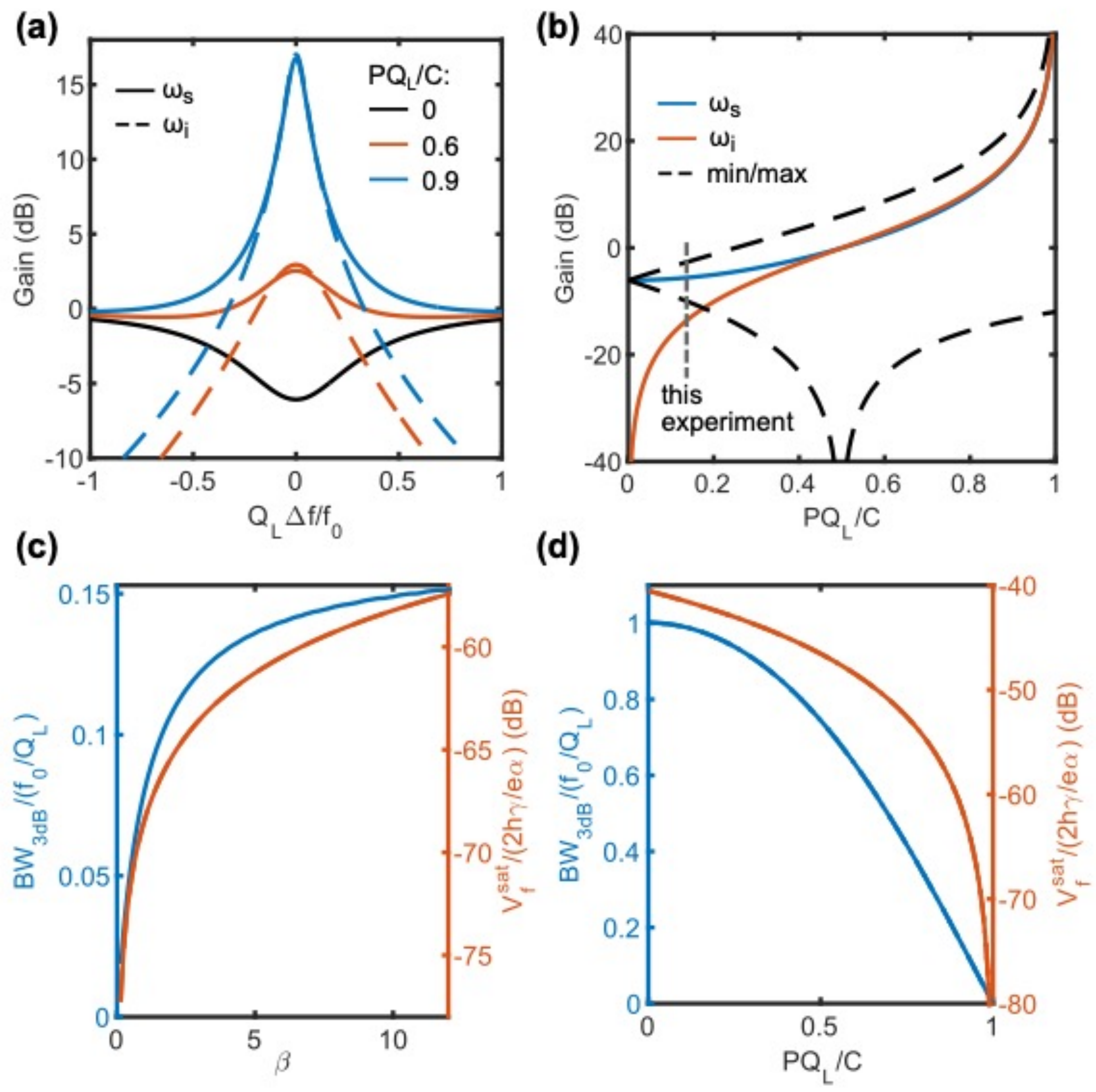
Model for better design





$$V_s = \frac{I_{in} Z(\omega_s)}{1 - \omega_s \omega_i \left|P\right|^2 Z(\omega_s) Z^*(\omega_i)}$$

$$V_i^* = \frac{j\omega_i P^* I_{in} Z(\omega_s) Z^*(\omega_i)}{1 - \omega_s \omega_i \left|P\right|^2 Z(\omega_s) Z^*(\omega_i)}$$

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