Dynamical Decoupling for Measuring and Suppressing Crosstalk

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1. Crosstalk and decoherence: hurdles toward high-fidelity quantum gates and circuits

- Dynamical decoupling (DD) is a noise-mitigating strategy that has been extensively studied and demonstrated for suppressing single-qubit decoherence.
- We present an important adaptation of DD where crosstalk between qubits are probed and suppressed.
- ZZ is the dominating crosstalk form between qubits on superconducting transmon-based quantum devices.
- We designed a family of syncopated DD sequences that effectively suppress ZZ coupling between qubit pairs, which is the dominating crosstalk form on the device.
- Syncopated DD sequences yield significant improvement on the performance of algorithms on the hardware.
- Experiments were performed on Rigetti Aspen-M-3 chip.

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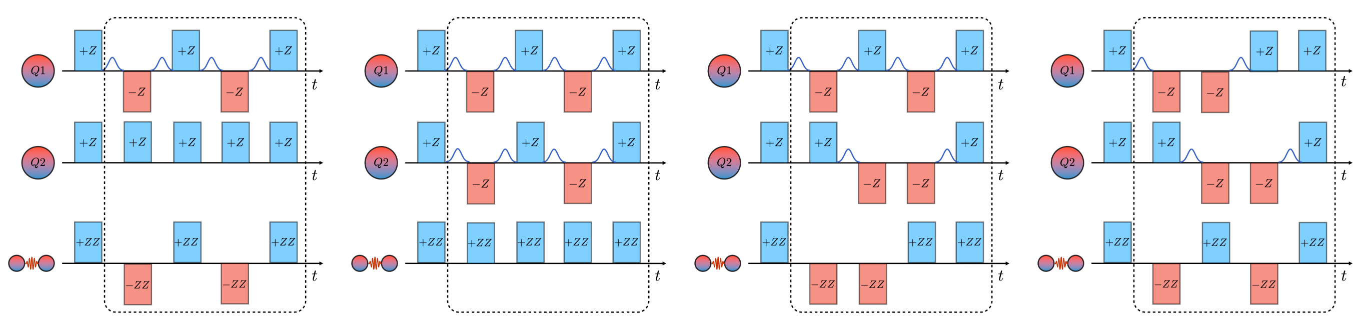
2. Effect of different DD design on **decoherence** and **crosstalk**

How DD cancels phase accumulation due to static Z or ZZ noise

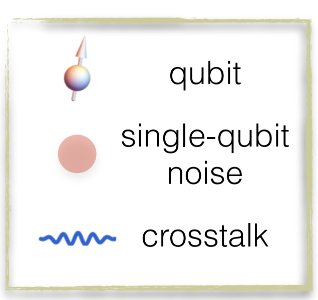


(a) DD on Q1 only: crosstalk suppressed

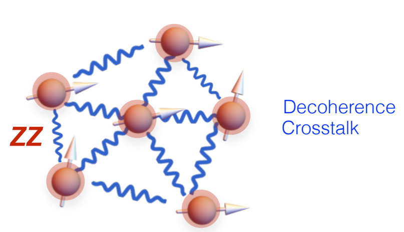
(b) DD on both qubits: crosstalk remains!

(c) Syncopated DD: crosstalk suppressed Broader-range protection

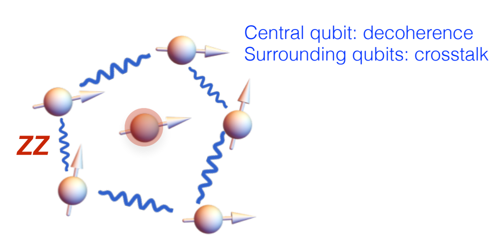
(d) Syncopated DD: a short-sequence variant



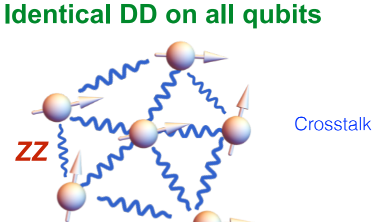
No DD, qubits exposed to decoherence and crosstalk



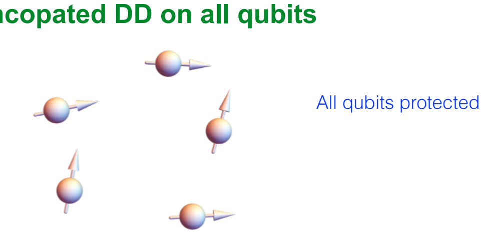
Identical DD on neighboring qubits



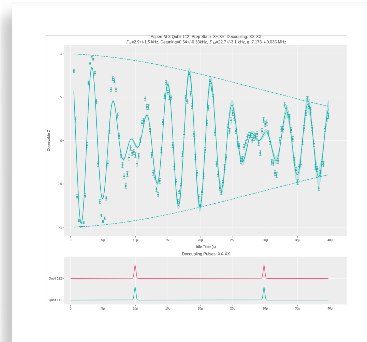
Identical DD on all qubits

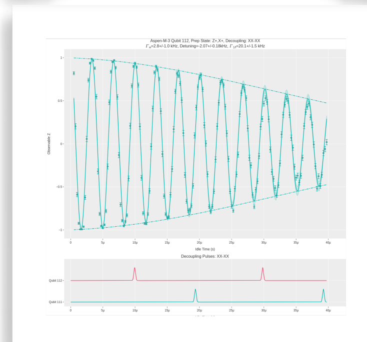


Syncopated DD on all qubits



3. Dynamical decoupling for **measuring** crosstalk





$$Fid = \underbrace{e^{-\Gamma_w t} e^{-\Gamma_{1/f}^2 t^2}}_{\text{Decoherence}} \underbrace{\cos(\delta\omega t)}_{\text{Detuning}} \underbrace{\cos(J' t)}_{\text{Crosstalk}}$$

- Identical DD on both qubits singles out the effect of crosstalk by suppressing single qubit decoherence
- From the beating frequency, we extracted an effective coupling g ~ 7 MHz
- Independent method based on low-level qubit physics: g ~ 9 MHz

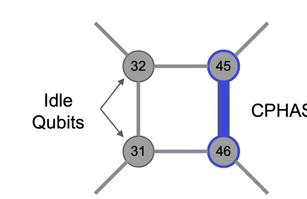
DD provides a complementary techniques to measure the magnitude of crosstalk.

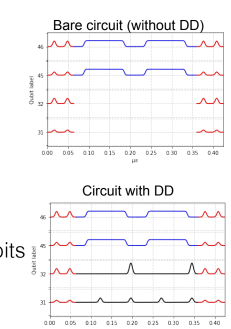
Extended fidelity decay also facilitates detailed noise characterization.

4. Dynamical decoupling for **suppressing** crosstalk

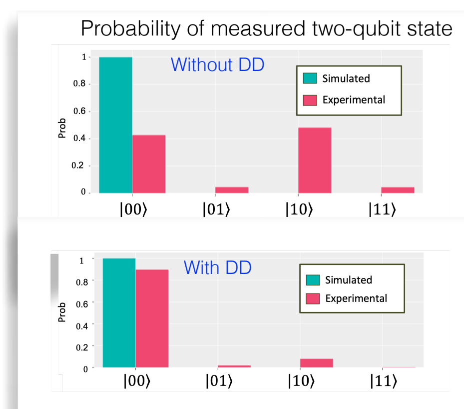
- Beating disappeared after applying syncopated DD. The envelope shows boosted fidelity.
- Short-sequence version provides more versatility: more pulses might not always be desired due to finite pulse duration and pulse error accumulation.

4. Syncopated DD **applied** to quantum circuits





In a compiled circuit, Often when a pair of qubits undergo a two-qubit gate, to avoid degrading of gate fidelity the neighboring qubits are idle. This provides a natural time slot to apply DD without adding to the circuit length.



Circuit for a layer of level-1 QAOA algorithm on four qubits; DD is sequentially applied to each pair of qubits while the neighboring pair undergoes a CPHASE gate

QAOA cost layer: 4 cycles, 2 idle qubits in each cycle