Reports on senior projects in experimental/theoretical physics

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Contents

- Review of Senior Projects in Experimental/Theoretical Physics

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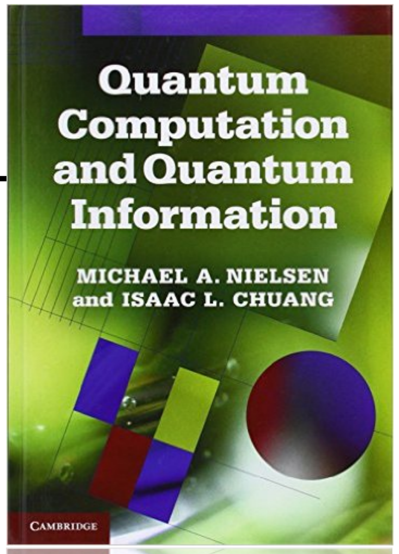
Experimental @Ando Lab.

☑ I did an experiment of testing coil-coil actuator with Arai-kun.

Report on this experiment

Theoretical @Murao Lab.

☑ 8 weeks: reading “Quantum Computation and Quantum Information” Michael A. Nielsen & Isaac L. Chuang



☑ 4 weeks: writing a review paper about *concentrating entanglement*

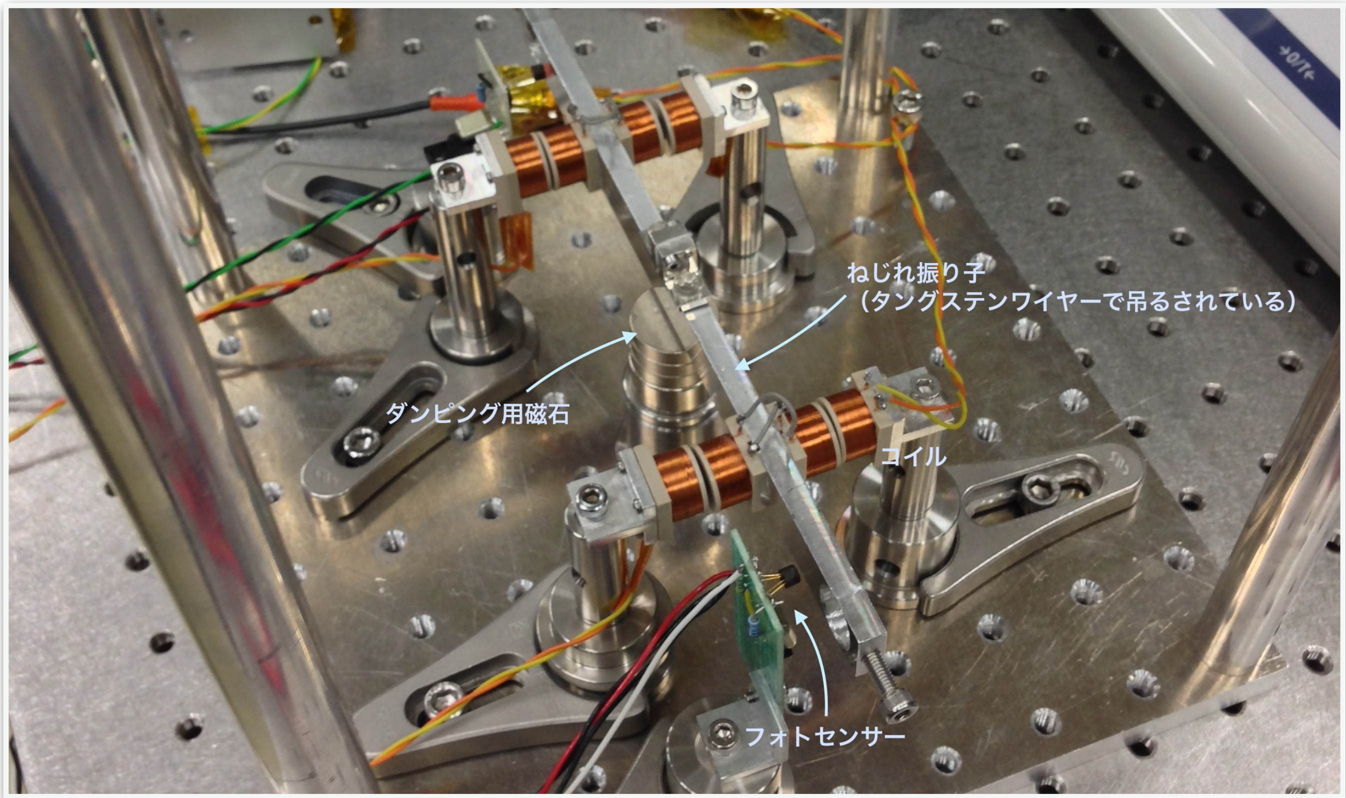
Introduction of concentrating entanglement

Coil-Coil Actuator

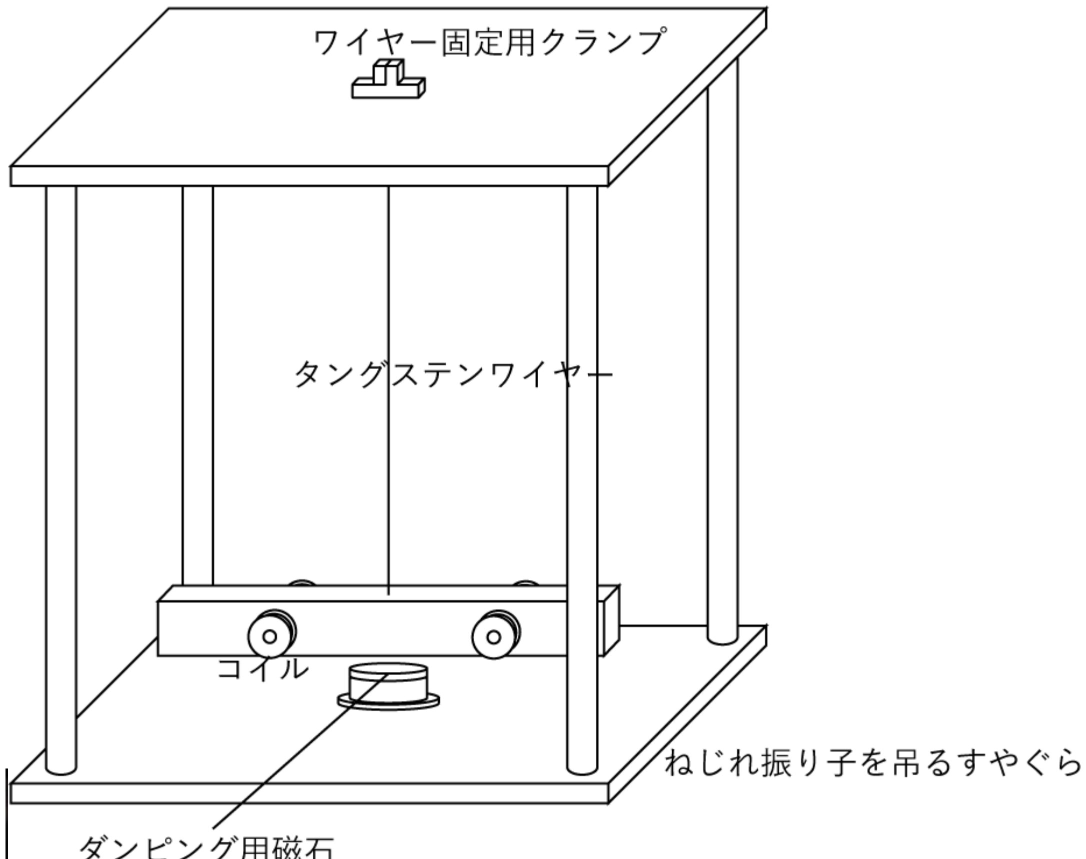
coil-coil actuator

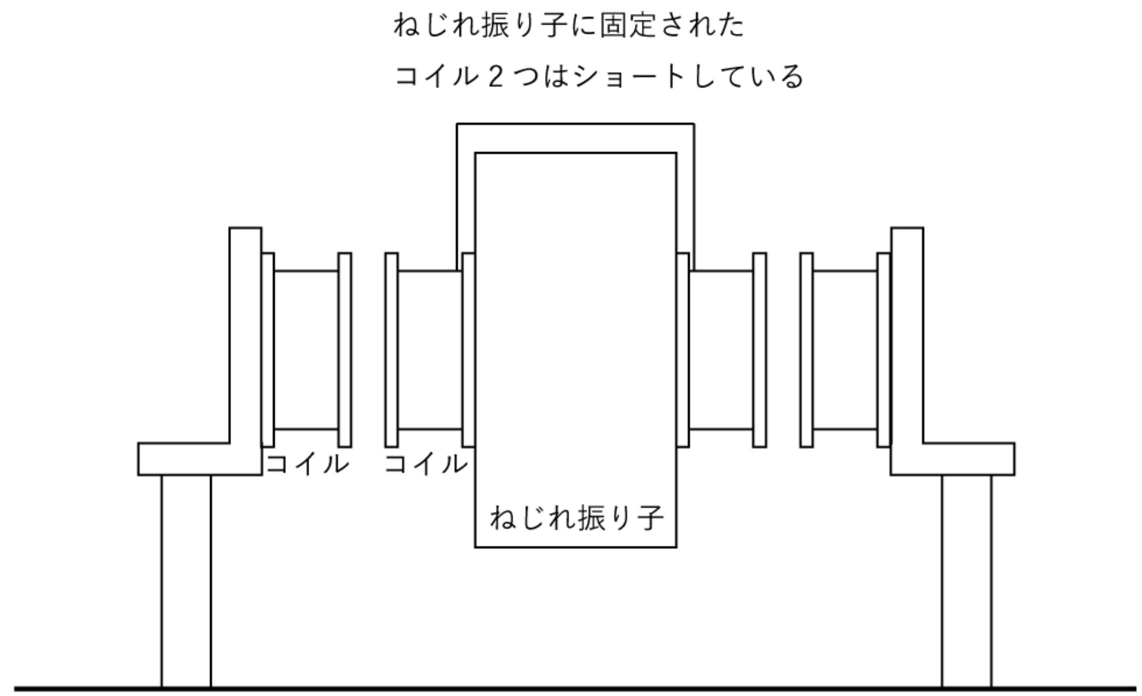
- coil-coil actuator was developed to control a torsion pendulum.

- **Advantage**: less coupling with magnetic field noise than coil-magnet actuator

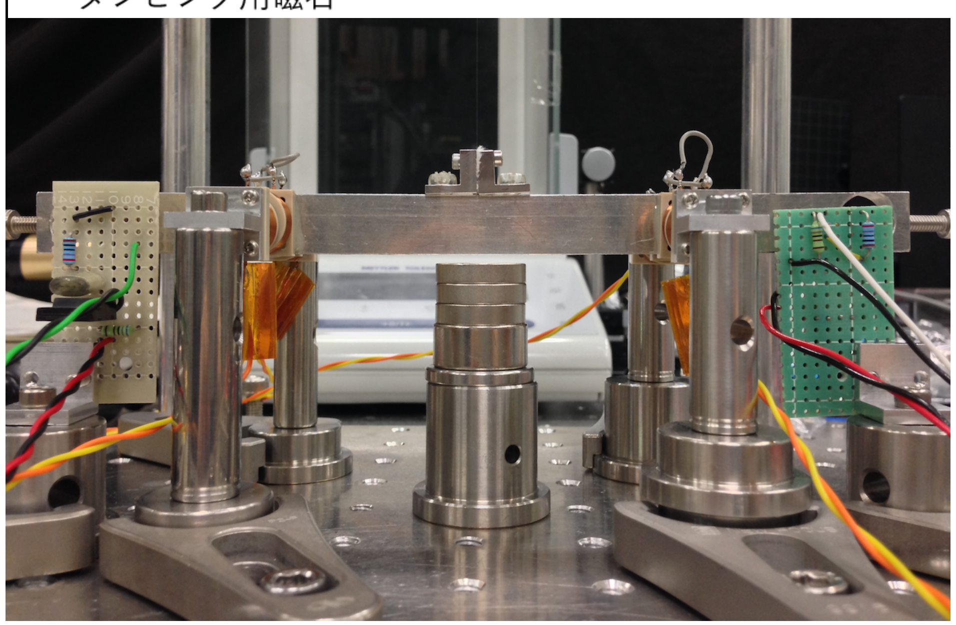


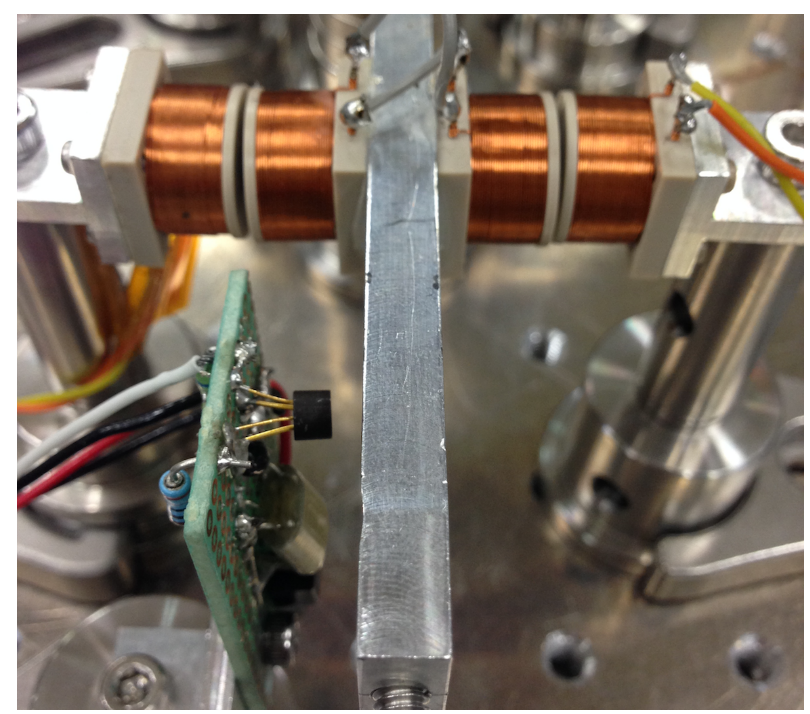
Instruments



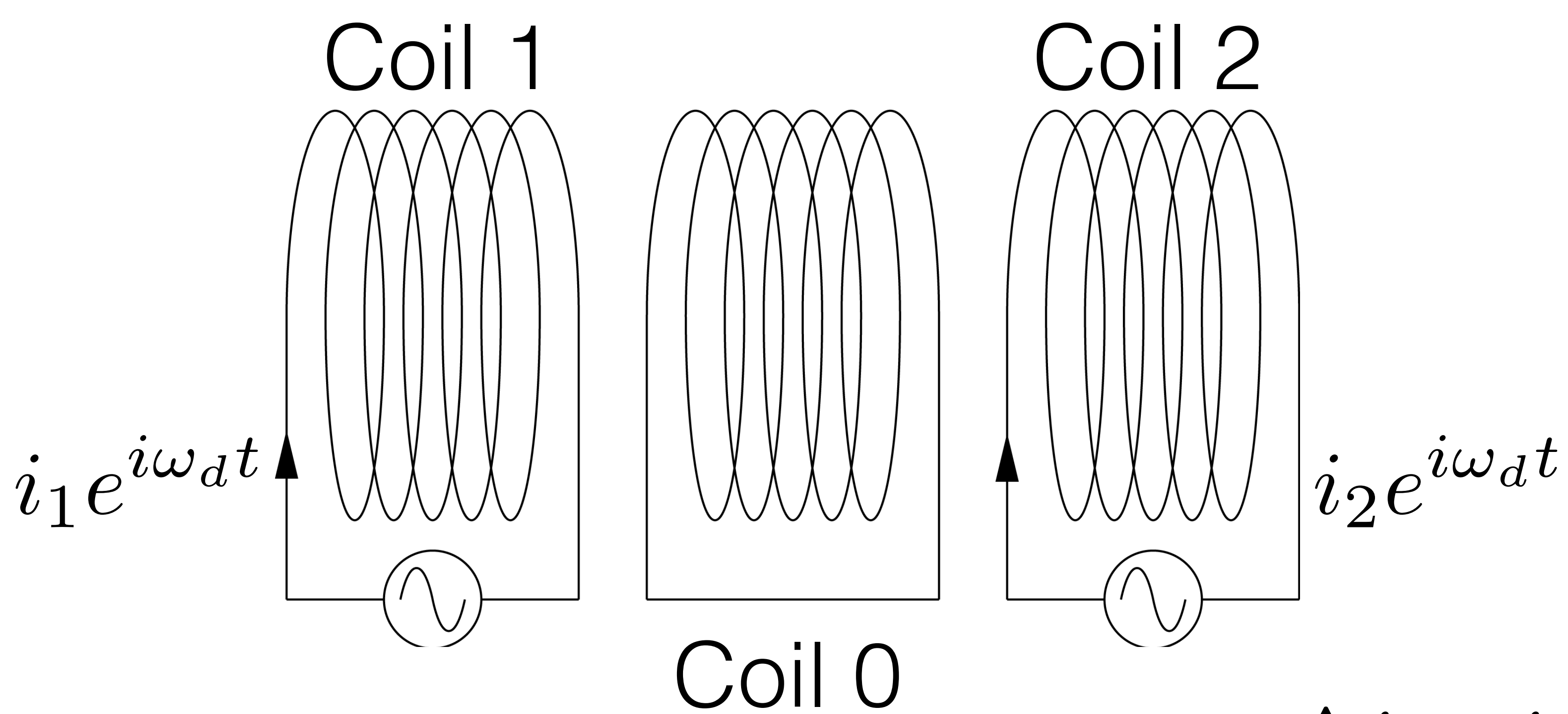


ねじれ振り子を横から見た図





Theory of coil-coil actuator



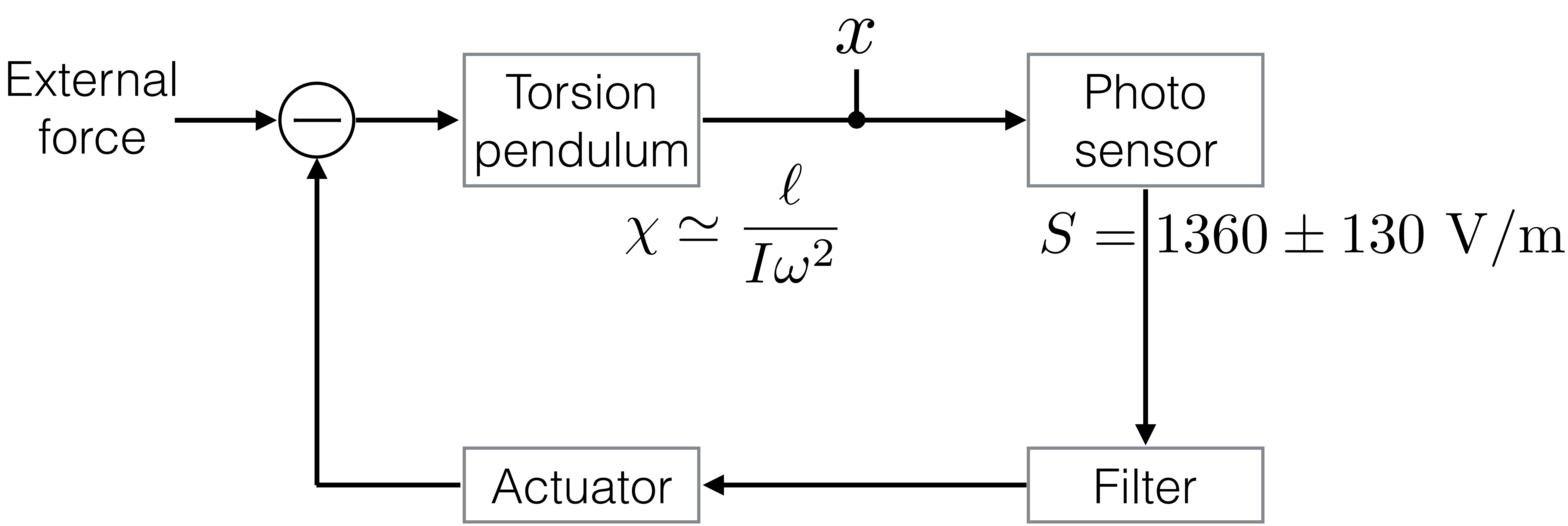
$$\Delta i = i_2 - i_1 \ll 1$$

$$K \simeq \mu M_0 \frac{\omega_d^2 L_0}{R_0^2 + \omega_d^2 L_0^2} i_1 \Delta i$$

fixed

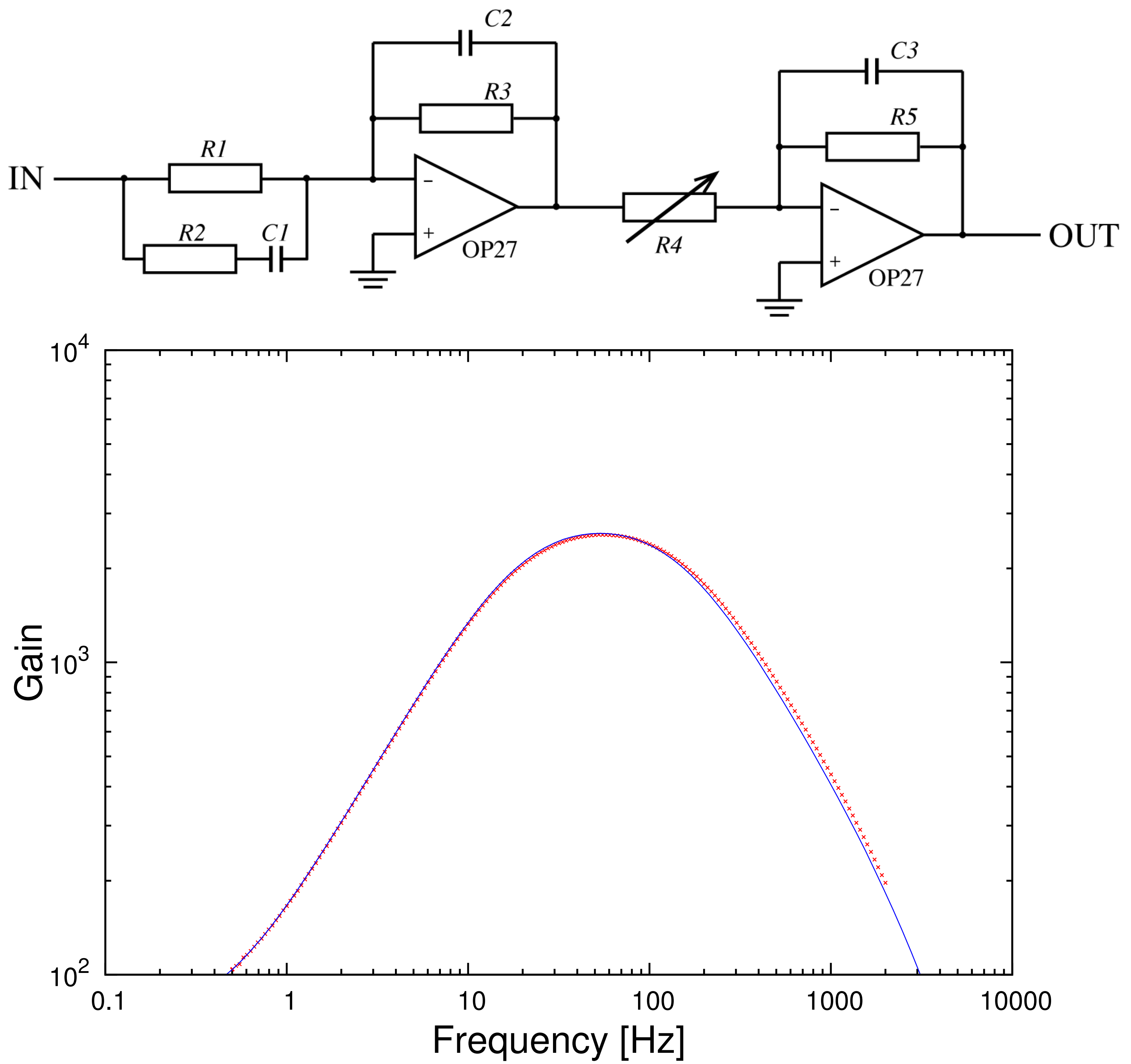
- Suppose linear response to Δi

Feedback control system

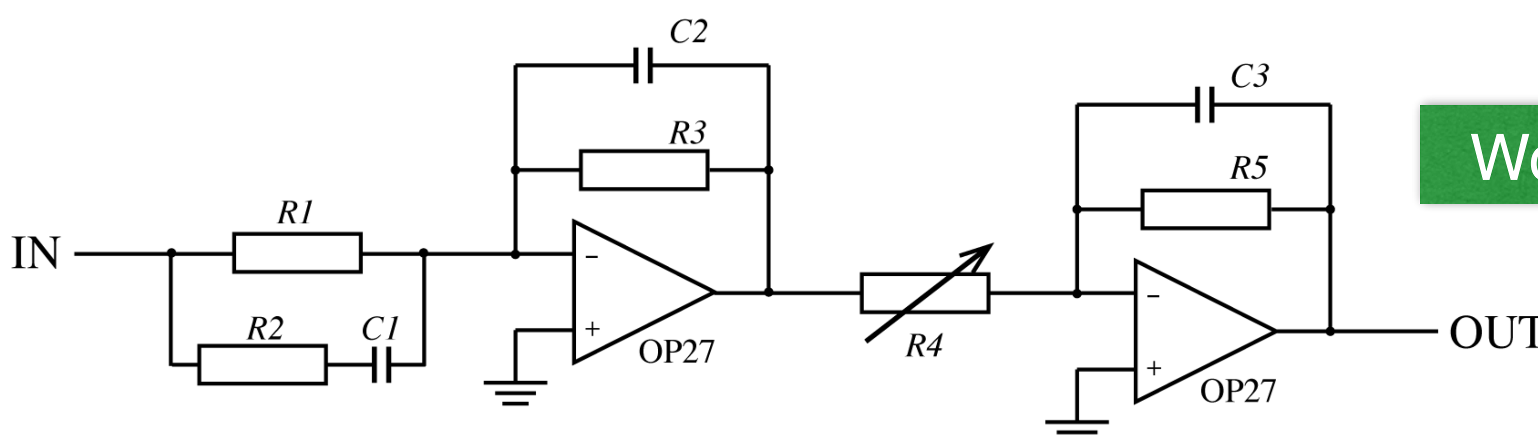


$$x = \frac{\chi F_{ext}}{1 + AFS\chi}$$

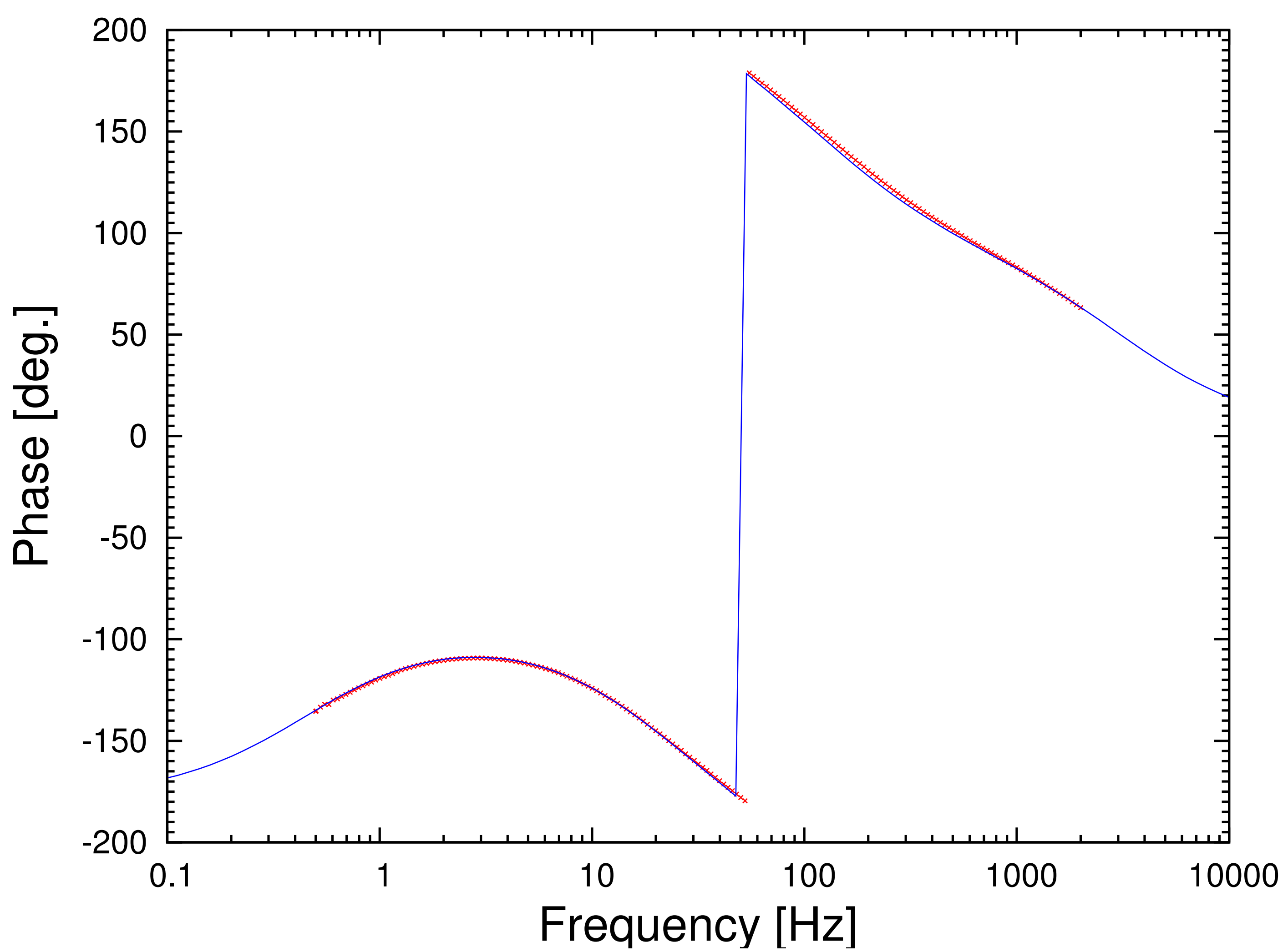
Transfer function of the filter circuit



Transfer function of the filter circuit



Working !



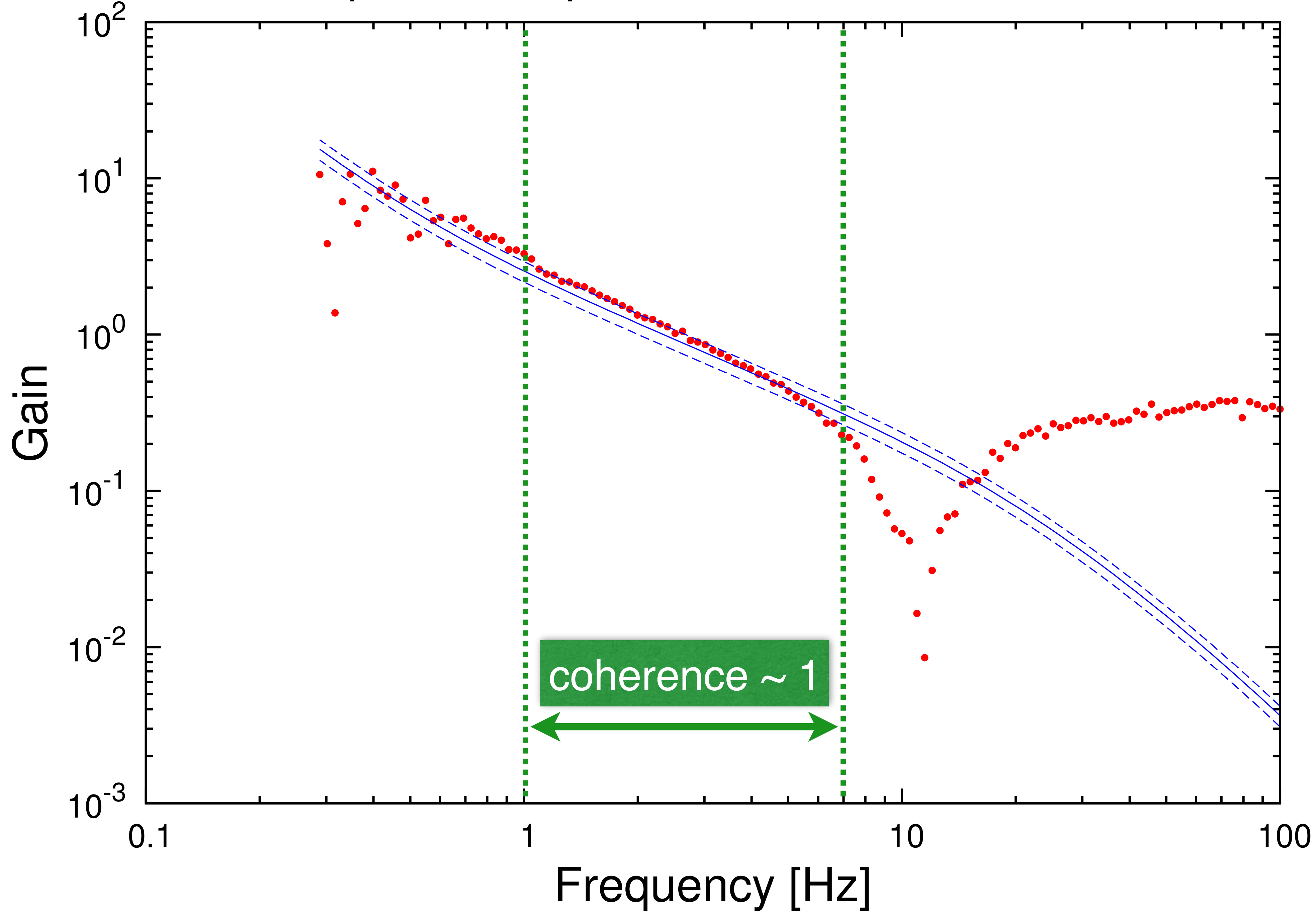
Difficulties

- It took a long time to lock the torsion pendulum.
  - adjusted the resistance of the filter circuit.
  - changed the jig that fixed the wire for good stability.
  - added one more set of coil-coil actuator to the other side of the pendulum to make the driving force twice stronger.

And then
the torsion pendulum
was locked…

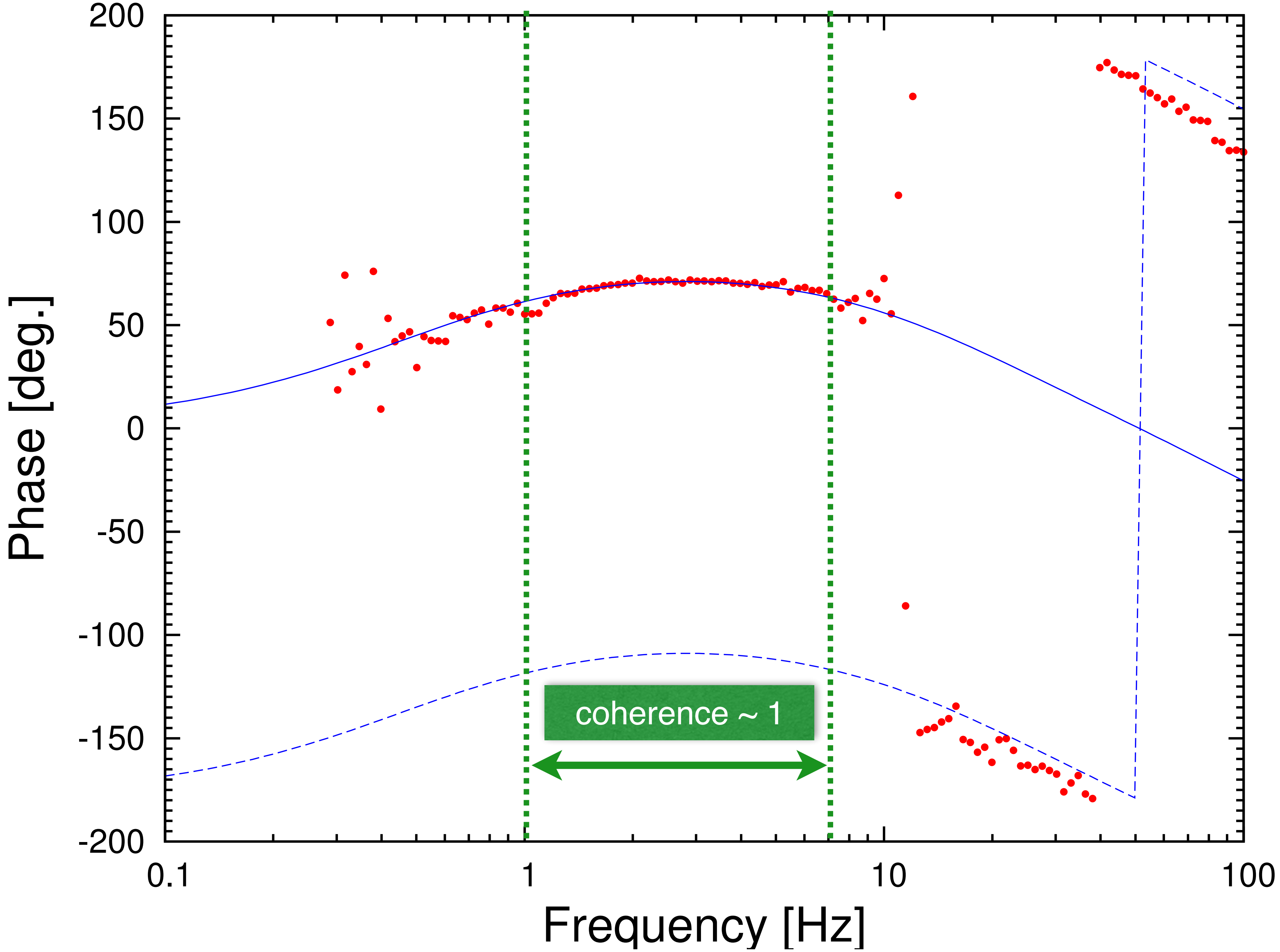
Result

Open-loop transfer function



Result

Open-loop transfer function



Result & Discussion

- We confirmed the theory of coil-coil actuator experimentally (in the range coherence~1).
- The behavior over 7 Hz is mysterious.
    - Why did the gain go up again?
    - Why did the phase flip?

Future experiment

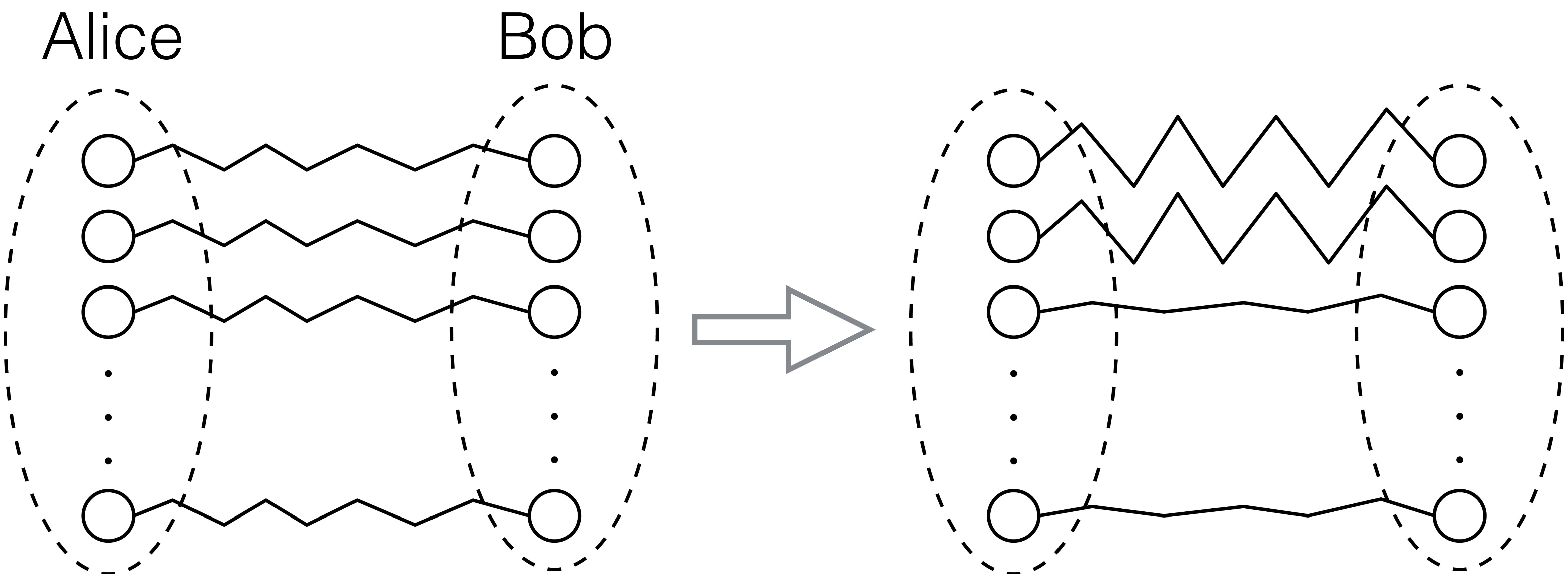
- High drive frequency (1000 Hz -> 100 kHz)
  - Magnetic field noise is down-converted by drive frequency.

    1001 Hz (noise) - 1000 Hz (drive freq.) = 1 Hz (observed sig.)
  - Less noise in high frequency
- Making circuits for high frequency
  - RLC resonance can avoid inductance of a coil.

$$Z(i\omega) = R + i\left(\omega L - \frac{1}{\omega C}\right)$$

Entanglement Concentration

Concentrating Entanglement



Many partially entangled pairs

-> A few of maximally entangled pairs

Why concentrating is important

- Entanglement can be used for information transmission.
- Quantum teleportation, superdense coding, … require that entanglement must be supplied in the maximally entangled form.
- Concentrating entanglement is important!

1,498 citations!

Preliminary

qubit: any two-state quantum system $|0\rangle \quad |1\rangle$

Schmidt decomposition: For a state of a bipartite system

$$\Psi(A,B) = \sum_{i=1}^{d} c_i \, |\alpha_i\rangle \otimes |\beta_i\rangle$$

where $|\alpha_i\rangle$s and $|\beta_i\rangle$s are orthonormal.

Applying Schmidt decomposition to a pair of qubits

$$\Psi(A,B) = \cos\theta \, |\alpha_1\rangle \otimes |\beta_1\rangle + \sin\theta \, |\alpha_2\rangle \otimes |\beta_2\rangle$$

What is entanglement?

- Measurements are (usually) projectors.

$$|0\rangle \otimes |1\rangle + |1\rangle \otimes |0\rangle \longrightarrow |0\rangle \otimes |1\rangle$$

Alice measures the state.

- Then, Bob can only get the outcome “1”.
- Although two systems are isolated, they have a kind of correlation. -> *Entanglement*

What is entanglement?

- Definition

$|\alpha\rangle \otimes |\beta\rangle$ -> Not entangled

otherwise -> Entangled

- Quantification

$$\rho_A = \mathrm{Tr}_B \left|\Psi(A,B)\right\rangle \left\langle\Psi(A,B)\right|$$

$$\rho_B = \mathrm{Tr}_A \left|\Psi(A,B)\right\rangle \left\langle\Psi(A,B)\right|$$

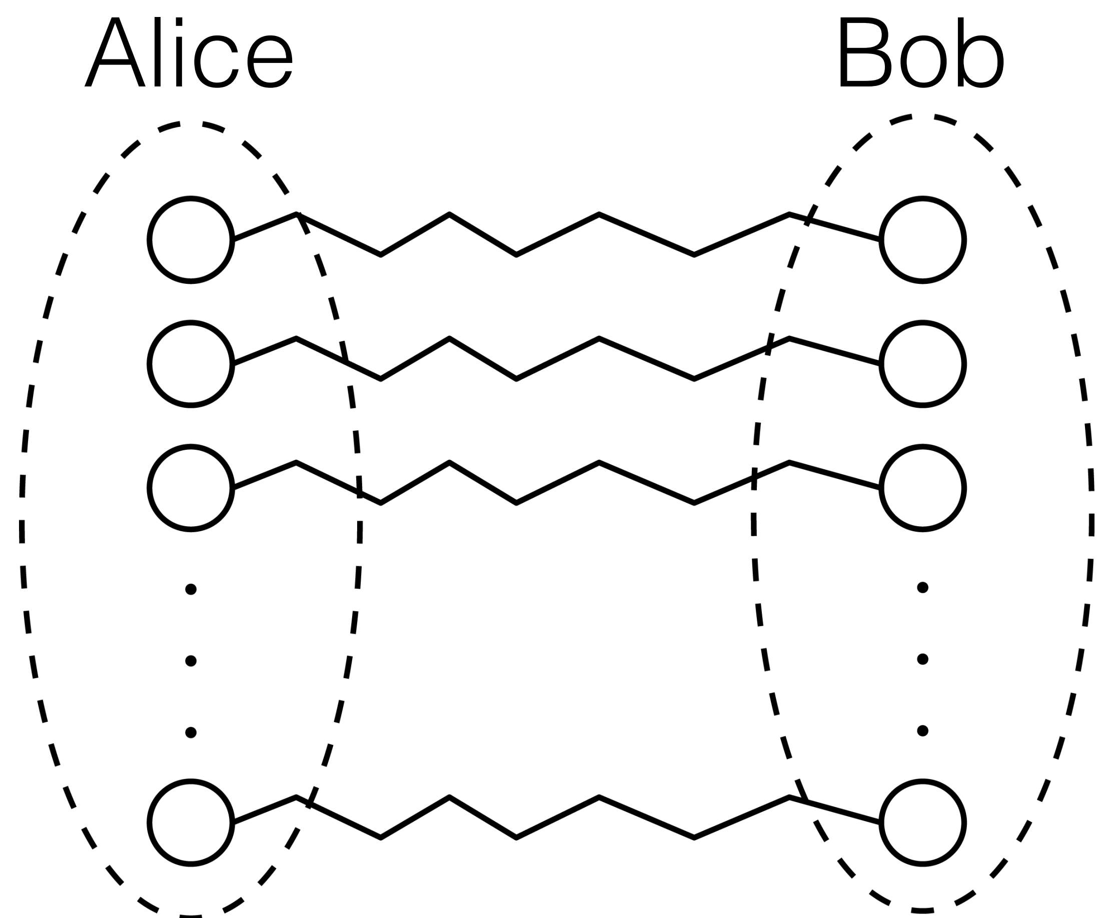
$$E \equiv -\mathrm{Tr}(\rho_A \log_2 \rho_A) = -\mathrm{Tr}(\rho_B \log_2 \rho_B)$$

easy calculation shows…

If coefficients are the same in Schmidt decomposition
-> maximally entangled

Situation

- Alice and Bob have n pairs of qubits.
- n pairs are identically entangled.
- Operations are local.



Method

(i) The state we are supposing

$$\Psi(A,B) = \prod_{i=1}^{n} \left[\cos\theta \,|\alpha_1(i)\beta_1(i)\rangle + \sin\theta \,|\alpha_2(i)\beta_2(i)\rangle\right]$$

(ii) Expand

Coefficients: $(\cos\theta)^{n-k}(\sin\theta)^k$

(iii) Projective measurement by Alice

Leaving only terms with the coefficient, $(\cos\theta)^{n-k}(\sin\theta)^k$ for a particular k.

(iv) Let Bob know the outcome of Alice’s measurement.

The residual system is maximally entangled!

Summary

Experimental part

- We confirmed the theory of coil-coil actuator.
- High drive frequency is a future plan.

Theoretical part

- Entanglement can be concentrated by projective measurement and classical communication.