Circuit Quantum Electrodynamics

Wentao Jiang

Contents

1 Introduction

Requirements of a quantum computer:

1. isolated from sources of noise
2. strongly coupled to each other
3. refer to [1] for more and detailed requirements

Cavity QED system: an atom modeled as a two-level system coupled to a harmonic osccillator, whose excitations are photons.

cQED-like systems:

- alkali atoms above an optical cavity formed by two mirrors, readout by transmission of a laser through the cavity
- Rydberg atoms with 3-D microwave cavities, require cooling to ∼1K, use atoms to probe the cavity photons by selective ionization

1.1 Quantum Circuits

the only known dissipationless non-linear circuit element

High frequencies (GHz) LC circuit at low temperatures (<100mK) will have resolvable energy levels corresponding to microwave photons. However, its harmonicity makes it impossible to observe the discrete nature of these photons.

Josephson junction, cooper pair box (CPB): enhance nonlinearity

Atoms: quantum purity for 10^{14} periods, hard to tune

Artificial atoms (quantum dots, CPB): more tunable, more decoherence

1.2 Circuit Quantum Electrodynamics

Superconductive circuits $\Longleftrightarrow$ artificial atoms

Key to cQED readout: use 1-D coplanar waveguide (CPW) resonator as a cavity

Benefits:

- travel length of MW photon in CPW: 10km
- stronger coupling (10000 times larger than ordinary alkali atom, 10 times larger than Rydberg atom)
- 1-D transmission line cavity increasing the energy density by 10^6 over 3-D MW cavities, further increase dipole coupling by 1000

2 Cavity Quantum Electrodynamics

Jaynes-Cummings Hamiltonian:

$$H_{\mathrm{JC}} = \hbar\omega_r(a^\dagger a + 1/2) + \hbar\frac{\omega_a}{2}\sigma_z + \hbar g(a^\dagger\sigma^- + a\sigma^+) \tag{2.1}$$

κ: photon decay rate
$Q = \omega_r/\kappa$: quality factor
$\gamma_\perp$: atom decay rate
T_{transit}: atom transit time before leaving cavity

References

[1] David P DiVincenzo. The physical implementation of quantum computation. *arXiv preprint quant-ph/0002077*, 2000.