20251021 mini colloquium

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Passive Superconducting Circulator on a Chip

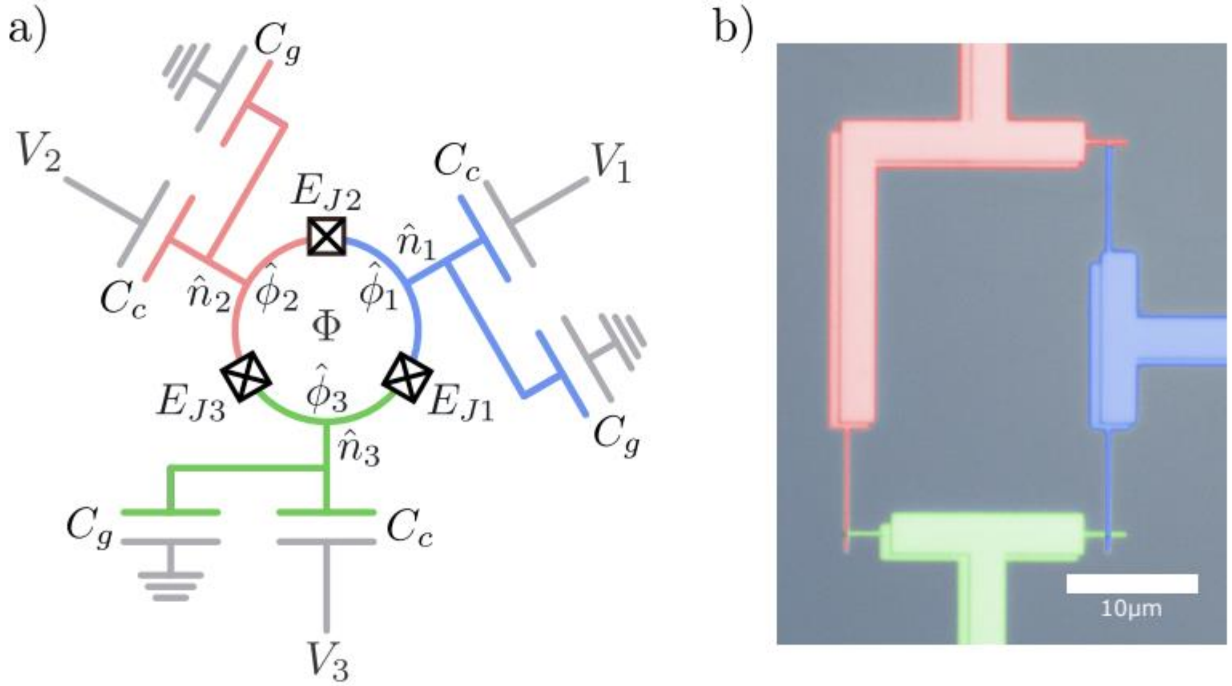
Background and Purpose

- Microwave circulator utilizing ferrite components
  - A strong magnetic field
  - Too large to be integrated
  - External drive

→passive, on-chip circulator without using ferrite

Devise design

- DC bias voltage Vi
- An external flux Φ



- Hamiltonian

$$\hat{H} = (2e)^2(\hat{\boldsymbol{n}} - \boldsymbol{n}_g)\mathbb{C}^{-1}(\hat{\boldsymbol{n}} - \boldsymbol{n}_g) - \sum_{i=1}^{3} E_{Ji}\cos(\widehat{\phi_i} - \widehat{\phi_{i+1}} - \frac{1}{3}\phi)$$

Theoretical model

- Hamiltonian

$$\hat{H} = (2e)^2(\hat{\boldsymbol{n}} - \boldsymbol{n}_g)\mathbb{C}^{-1}(\hat{\boldsymbol{n}} - \boldsymbol{n}_g) - \sum_{i=1}^{3} E_{Ji}\cos\left(\widehat{\phi_i} - \widehat{\phi_{i+1}} - \frac{1}{3}\phi\right)$$

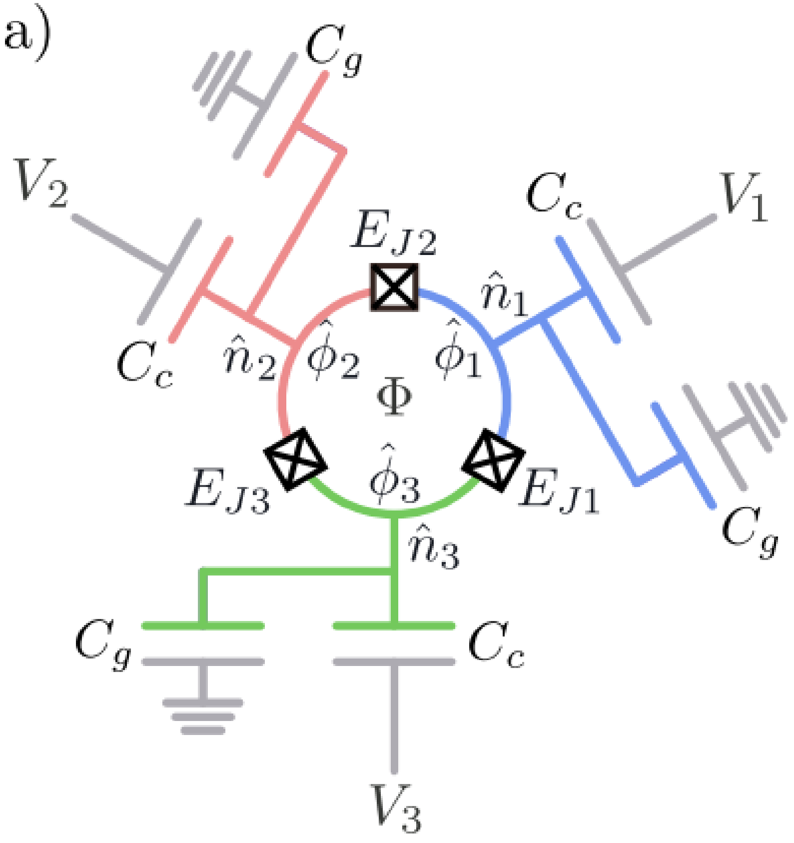
$\hat{n}$:the charge operator

n_g:the bias charge

$\widehat{\phi_i}$:the superconductive phase

$$\phi = \frac{2\pi\Phi}{\Phi_0}$$

a)



Theoretical model

- The scattering matrix Sij

$$S_{ij} = \delta_{ij} - \sum_{k=1,2,\ldots} \frac{\Gamma \langle k|\hat{n}_j|0\rangle\langle 0|\hat{n}_i|k\rangle}{i\Delta\omega_k + \Gamma_k/2},$$

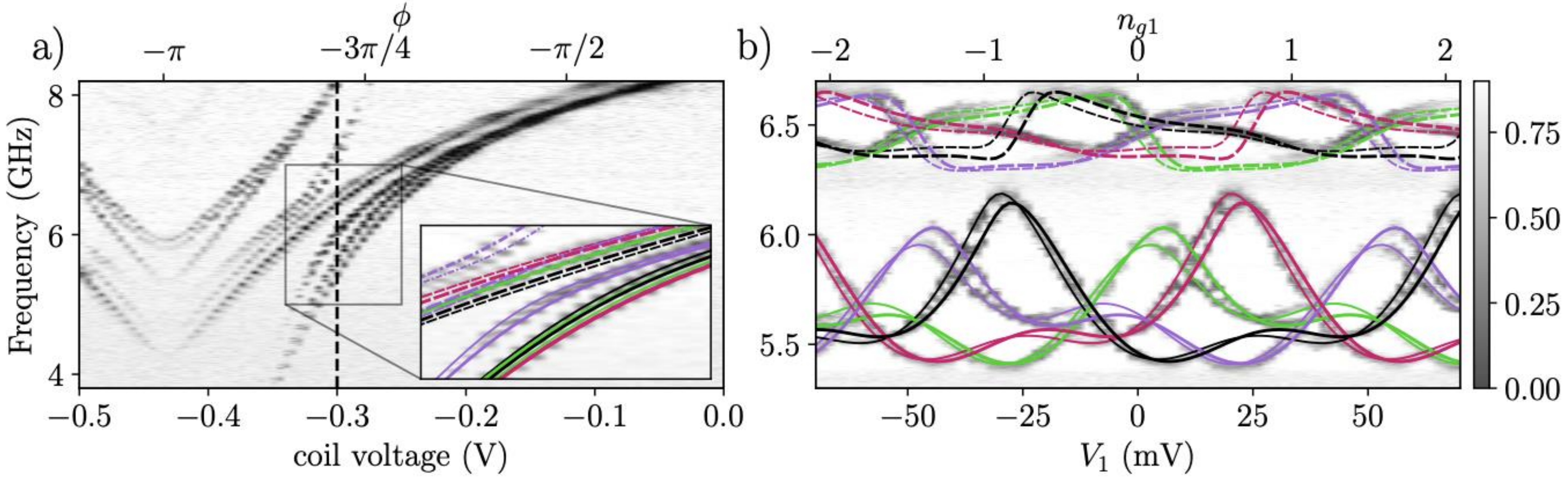
|k>:excited states

$\Delta\omega_k$:the detuning of the excited eigenenergy

Γ: the coupling strength

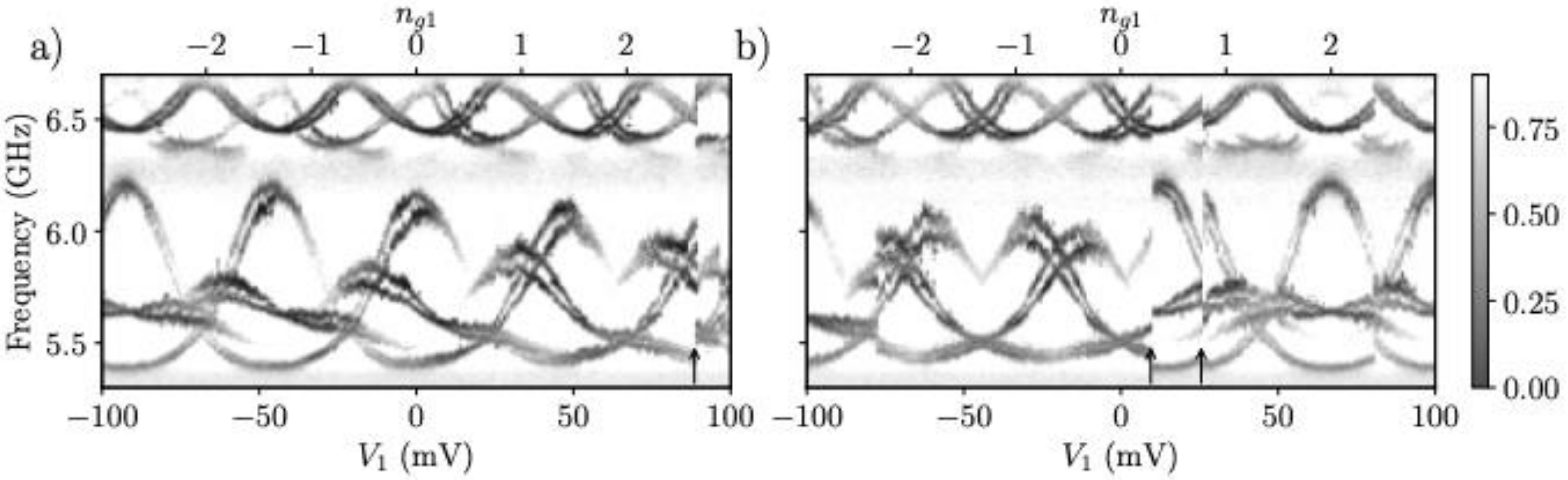
Γ_k: the decay rate

Simulations and result (fig.2)



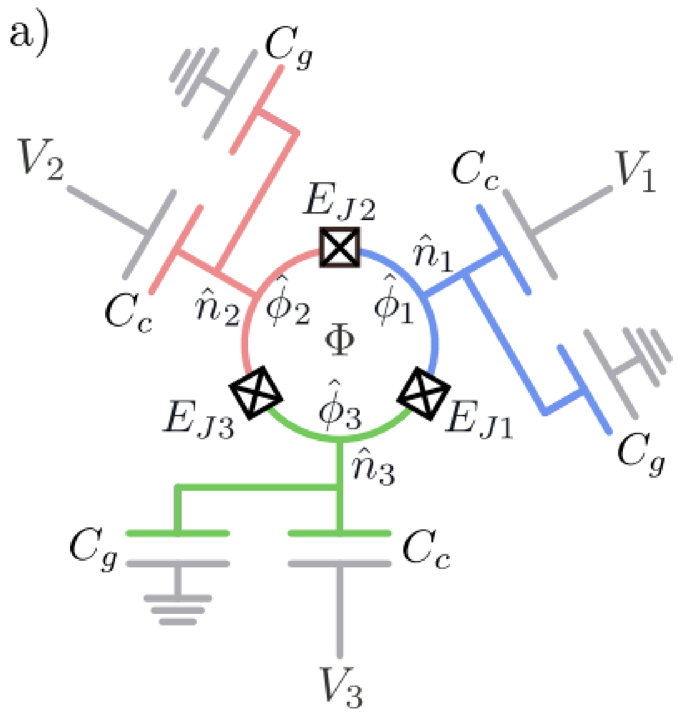
- Coler : quasiparticle configurations
- Line types : transition frequencies
- Line thickness : charge configurations

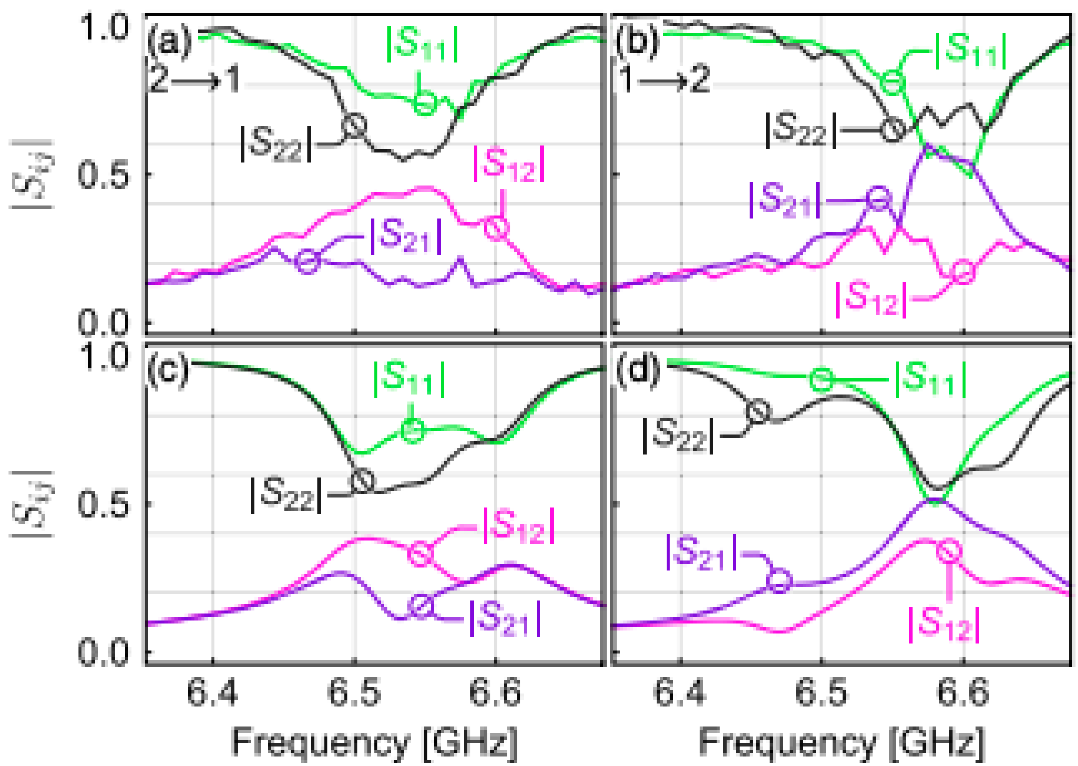
Periodic dependence on applied charge bias



S-matrix elements for two different charge-bias configurations. (fig.3)

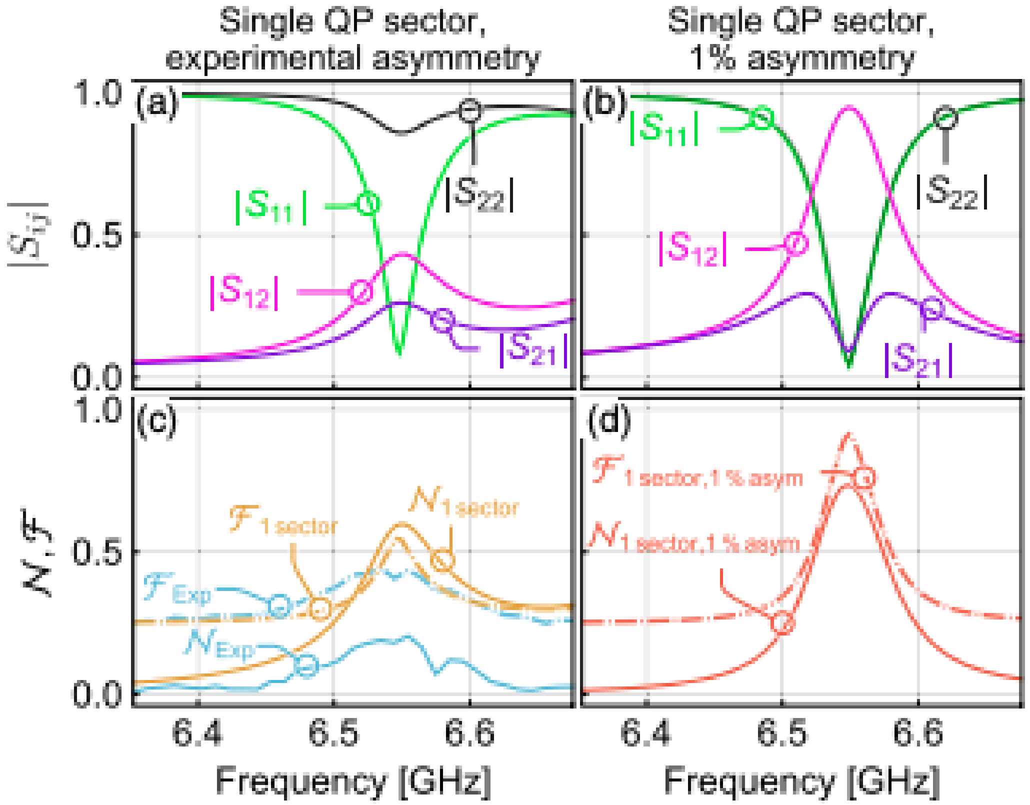
- The non-reciprocity can be changed by gate bias Vi.





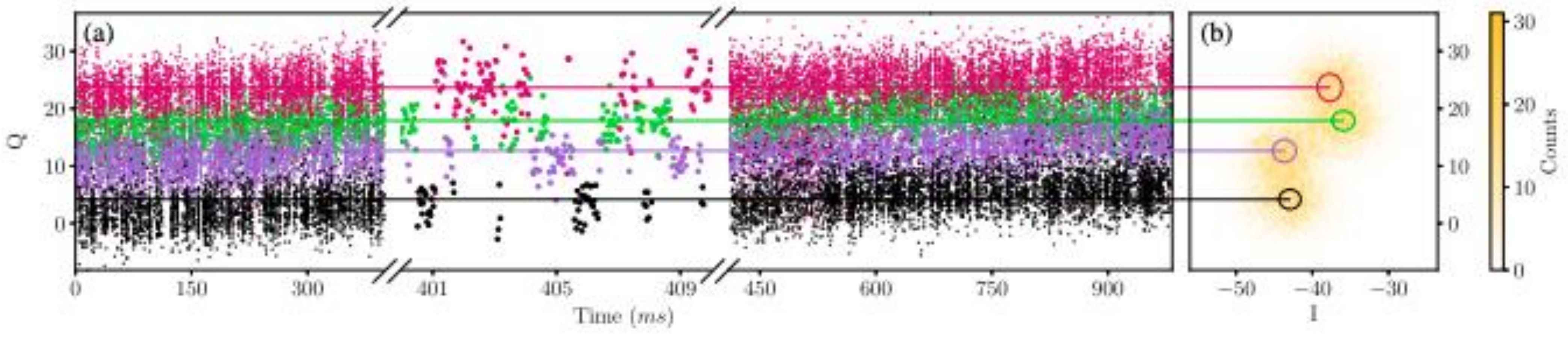
Simulation of Asymmetry(fig.4)

- (a) Asymmetry in this experiment
- (b) 1% asymmetry
- (c) non–reciprocity and fidelity in this experiment
- (d) 1% asymmetry



Detection of Quasiparticle Tunneling Using Hidden Markov Models(fig.5)

- Freq : 6.709GHz, ϕ=1.9
- identify the four quasi-particle states with HMM
- Time vs Re(S11), Im(S11) vs Re(S11)
- lifetime of the quasi-particle sector : ~200us.

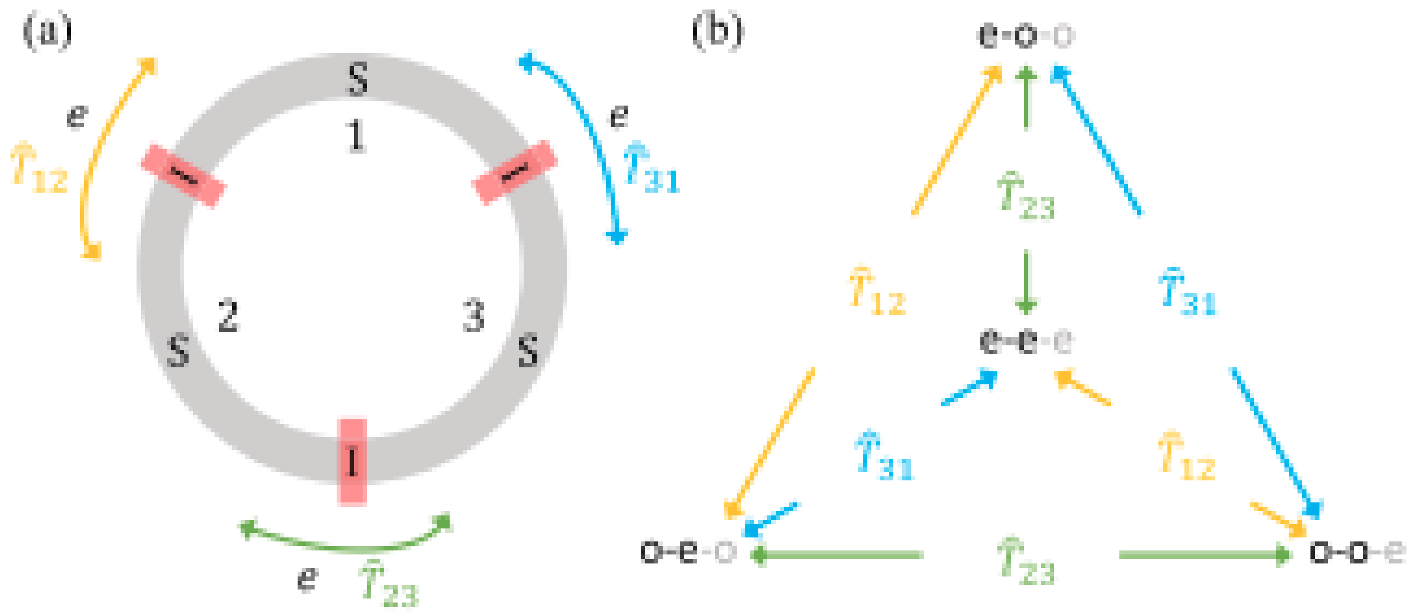


Summary

- First demonstration of passive superconducting circulator operation.
- Non-reciprocity is tunable by changing charge bias and magnetic flux.
- High-fidelity operation expected by reducing junction asymmetry and quasiparticle density.

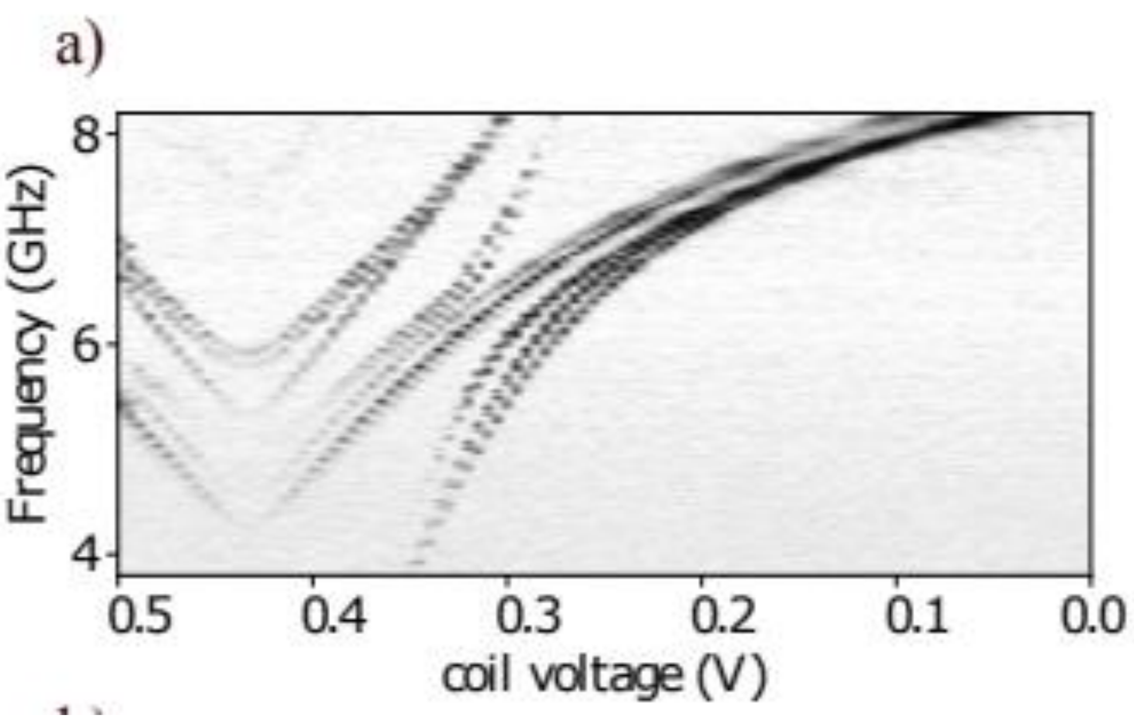
Back up

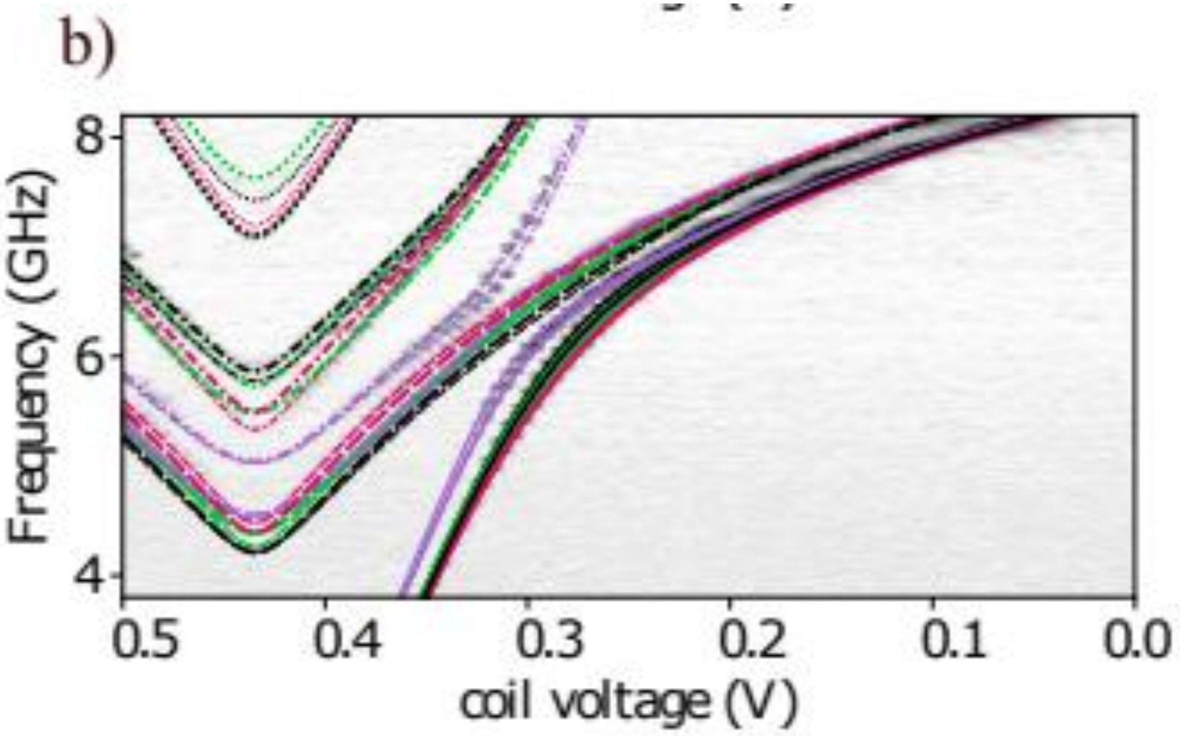
Charge parity



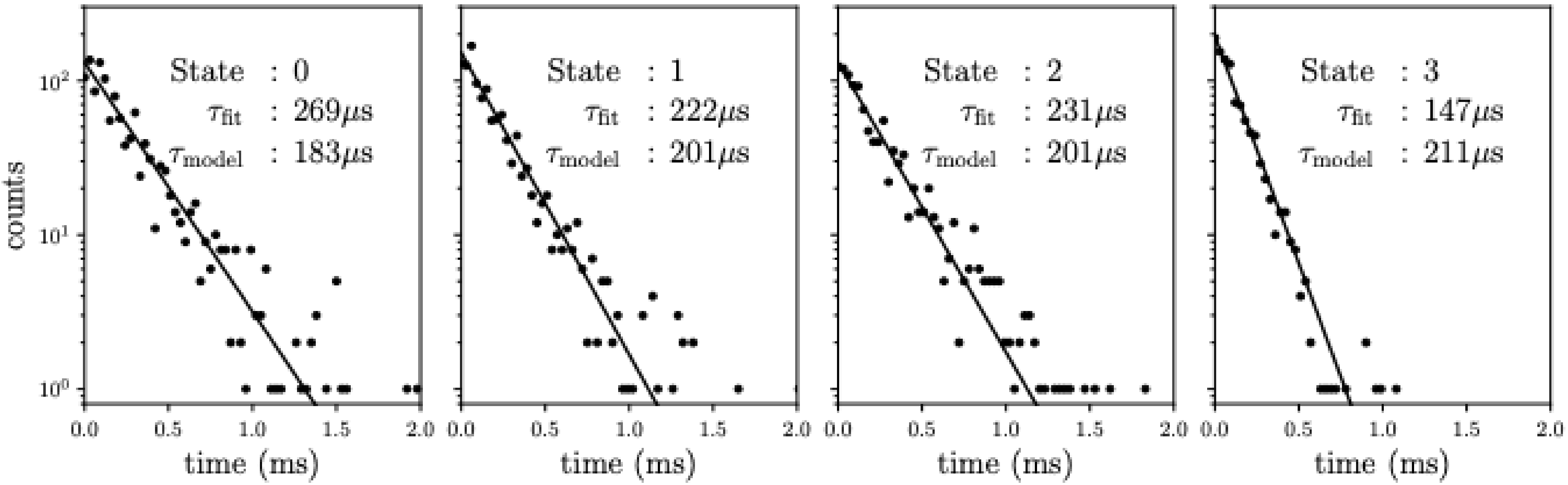
D. T. Le, C. Müller, R. Navarathna, A. Fedorov, and T. M. Stace, Operating a passive on-chip superconducting circulator: Device control and quasiparticle effects, Phys. Rev. Res. 3, 043211 (2021).

Full fits of fig.2





HMM fitting



State : 0
τ_{fit} : 269μs
τ_{model} : 183μs
State : 1
τ_{fit} : 222μs
τ_{model} : 201μs
State : 2
τ_{fit} : 231μs
τ_{model} : 201μs
State : 3
τ_{fit} : 147μs
τ_{model} : 211μs
counts
10^0
10^1
10^2
0.0
0.5
1.0
1.5
2.0
time (ms)

Nonreciprocity and fidelity

$$\mathcal{N} = ||\mathbf{S} - \mathbf{S}^{\intercal}||/\sqrt{8},$$
$$\mathcal{F} = 1 - \sum\nolimits_{i,j} ||S_{ij}| - |S_{ij}^{\mathrm{ideal}}||/8,$$

ideal circulator : N=$\sqrt{3/4}$, F=1

$$S^{ideal} = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} or \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$$