# Tunable Coupling between Two Oscillators via Open Channel

Jiongjie Wang[1] and Jiang Xiao[1,2,3]

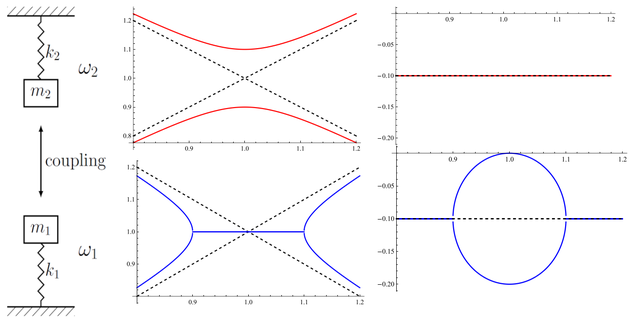
1 Department of Physics, Fudan University, Shanghai, China

2 Institute for Nanoelectronics Devices and Quantum Computing, Fudan University, Shanghai 200433, China

3 Shanghai Research Center for Quantum Sciences, Shanghai 201315, China

## Introduction

- Two types of coupling: level attractive coupling[1] and level attractive coupling. The latter one, accompanying with exceptional point (EP), often occurs at non-Hermitian system[2]-[4].
- $\begin{pmatrix} \omega_1 + i\gamma_1 & \kappa_{12} \\ \kappa_{21} & \omega_2 + i\gamma_2 \end{pmatrix}$
- Hermitian
- $\kappa_{21} = \kappa_{12}^*, \gamma_1 = \gamma_2 = 0$

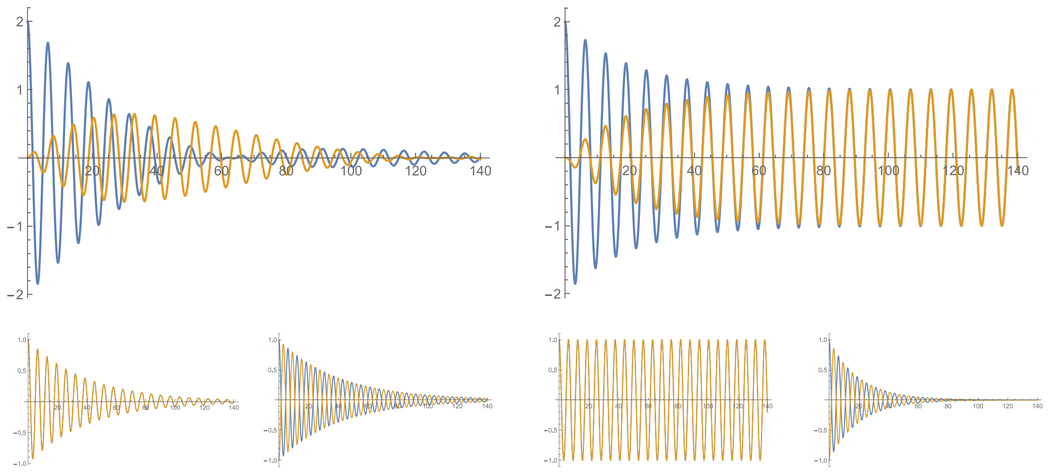



Level repulsive coupling and level attraction coupling

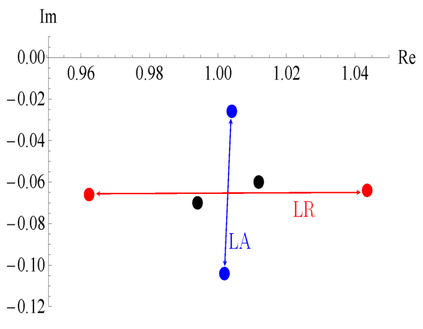
## $\pi/2$ Phase Delay

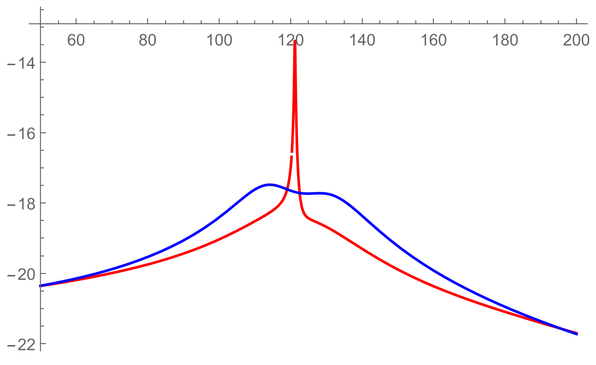
- $\begin{pmatrix} k_1 - m_1\omega^2 + \frac{F_{1\to1}}{y_1} & \frac{F_{2\to1}}{y_2} \\ \frac{F_{1\to2}}{y_1} & k_2 - m_2\omega^2 + \frac{F_{2\to2}}{y_2} \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}$
- $\begin{pmatrix} \omega_1^2 - \omega^2 & \kappa_{12} \\ \kappa_{21} & \omega_2^2 - \omega^2 \end{pmatrix}$
- $\begin{pmatrix} \omega_1 - \omega & \kappa_{12} \\ \kappa_{21} & \omega_2 - \omega \end{pmatrix}$

$$\kappa_{12} \propto \frac{F_{2\to1}}{y_2}$$



- Inject energy into high quality mode
- Consume energy with a high speed

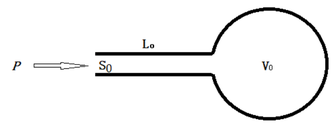


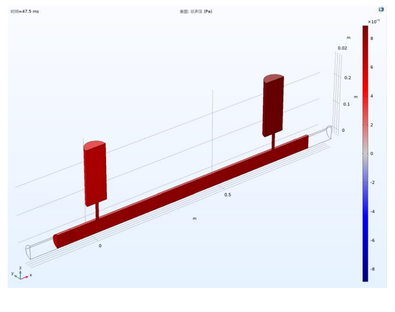



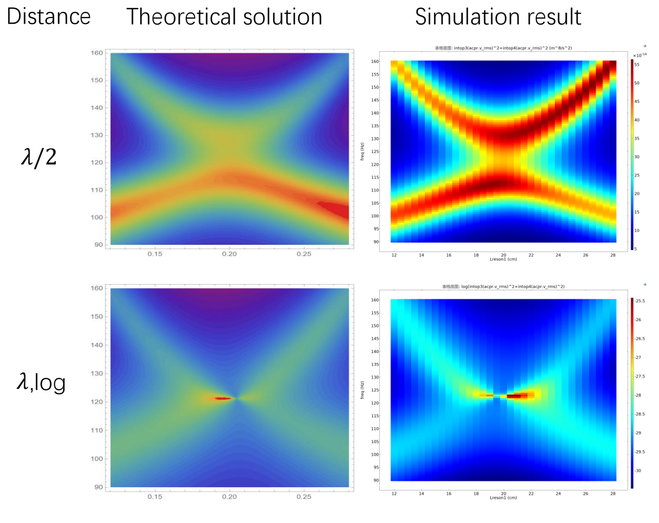

## Calculation and Simulation

- Acoustical system
- Helmholtz oscillator
- $\omega = c_0\sqrt{\frac{S_0}{L_1 V_1}}$

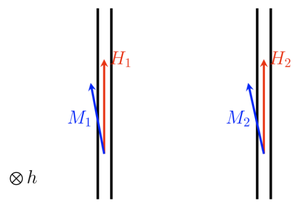
$$\begin{pmatrix} \omega_1^2 - \omega^2 - \frac{S_1\omega^2}{2ikS_mL_1} & -\frac{S_2\omega^2}{2ikS_mL_1}e^{ikl} \\ -\frac{S_1\omega^2}{2ikS_mL_1}e^{ikl} & \omega_2^2 - \omega^2 - \frac{S_2\omega^2}{2ikS_mL_1} \end{pmatrix}$$

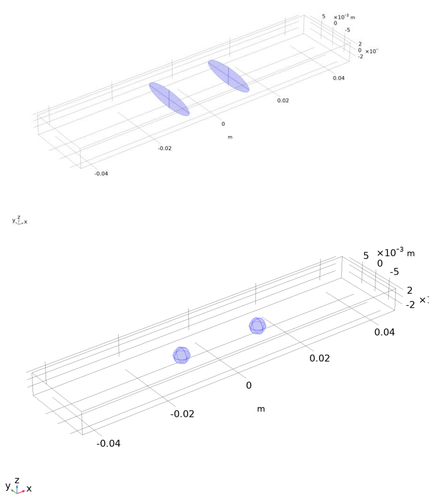


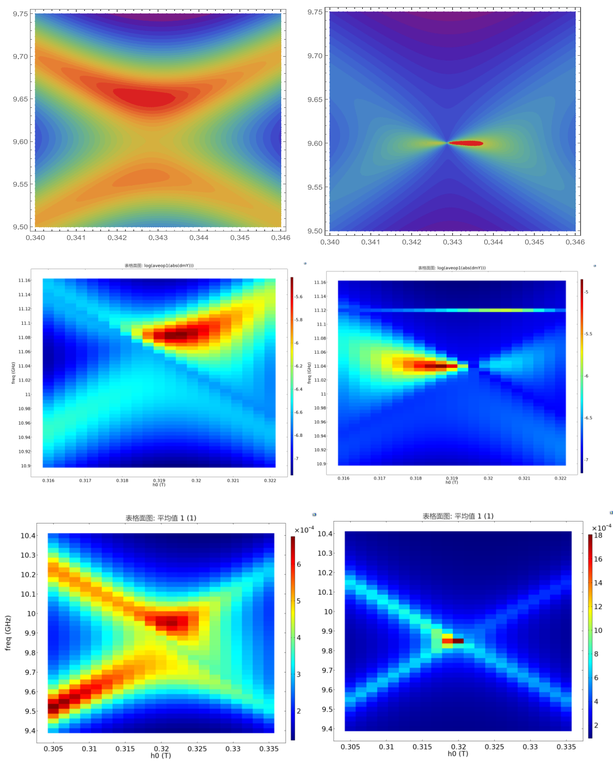






- Magnetic system





## Conclusion and Outlook

- Different phase delay leads to different coupling.
- Tunable coupling can be achieved via an open channel in acoustical and magnetic system.
- We can “open” or “close” system by changing the coupling type of oscillators.

## Reference

[1] M. Harder, Y. Yang, B. M. Yao, C.H. Yu, J.W. Rao, Y.S. Gui, R.L. Stamps, and C. M. Hu, Phys. Rev. Lett.121.137203 (2018)
[2] Y. P. Wang, J. W. Rao, Y. Yang, P. C. Xu, Y. S. Gui, B. M. Yao, J. Q. You, and C. M. Hu, Phys. Rev. Lett.123.127202 (2019)
[3] W. C. Yu, J. J. Wang, H. Y. Yuan, and J. Xiao, Phys. Rev. Lett.123.227201 (2019)
[4] Y. Yang, Y. P. Wang, J. W. Rao, Y. S. Gui, B. M. Yao, W. Lu, and C. M. Hu, Phys. Rev. Lett.125.147202 (2020)