DRDC project: Dielectric detection using an active SRR sensor

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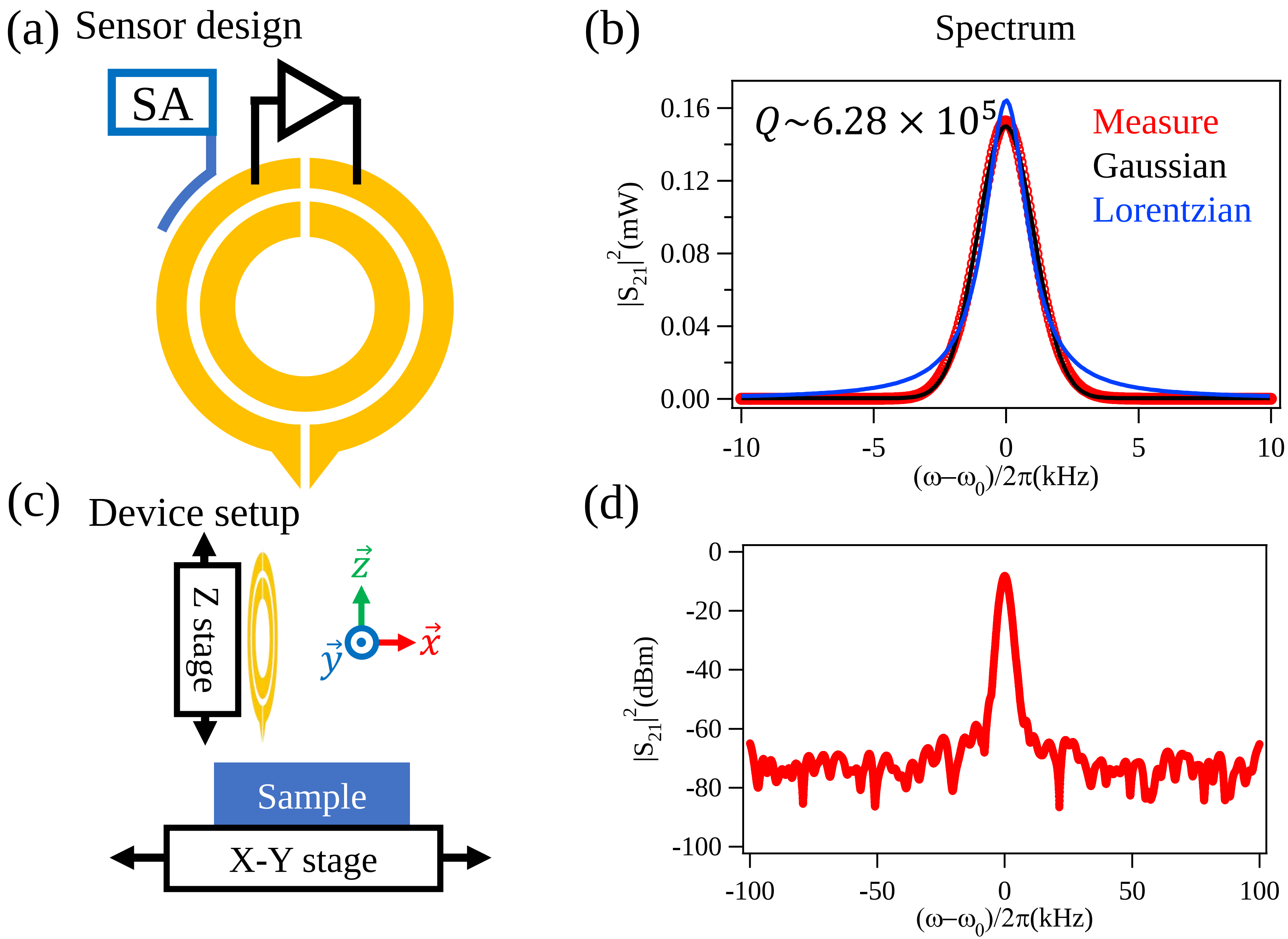
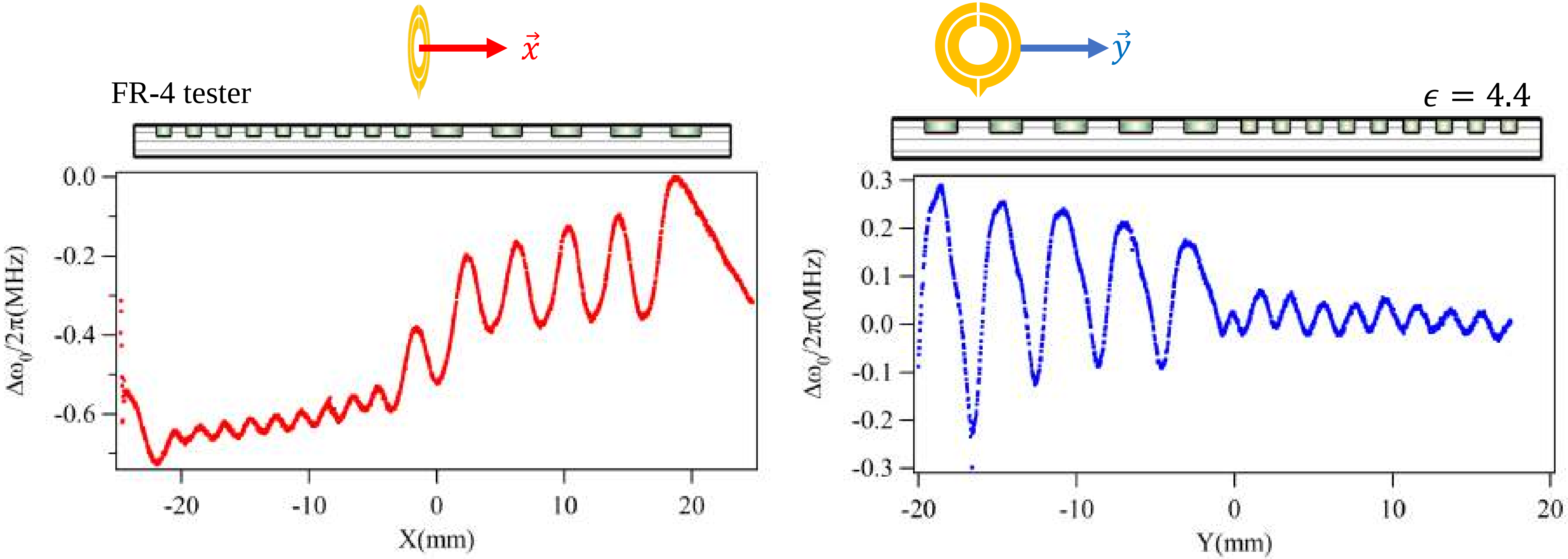
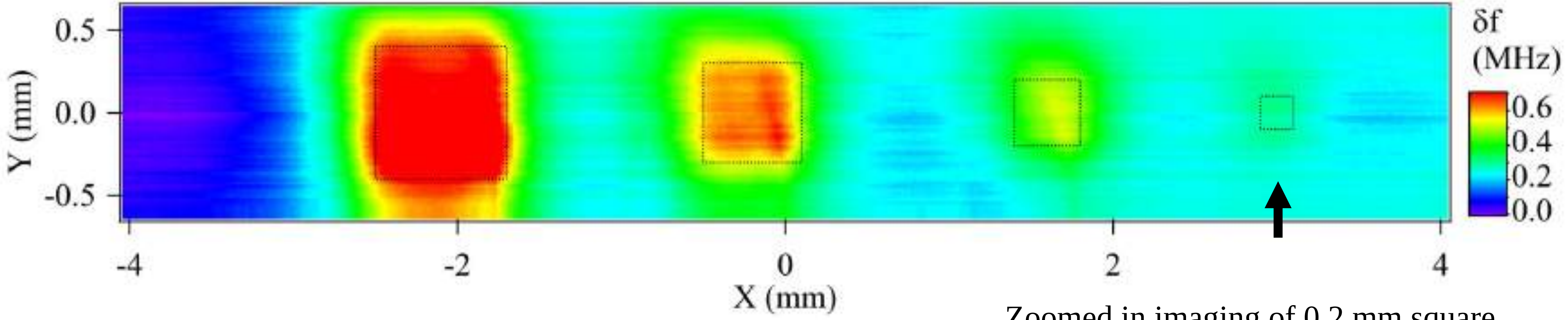

(a) Sensor design
SA
(b)
Spectrum
$Q \sim 6.28 \times 10^5$
Measure
Gaussian
Lorentzian
$|S_{21}|^2$(mW)
0.16
0.12
0.08
0.04
0.00
-10
-5
0
5
10
$(\omega-\omega_0)/2\pi$(kHz)
(c) Device setup
Z stage
$\vec{z}$
$\vec{y}$
$\vec{x}$
Sample
X-Y stage
(d)
$|S_{21}|^2$(dBm)
0
-20
-40
-60
-80
-100
-100
-50
0
50
100
$(\omega-\omega_0)/2\pi$(kHz)

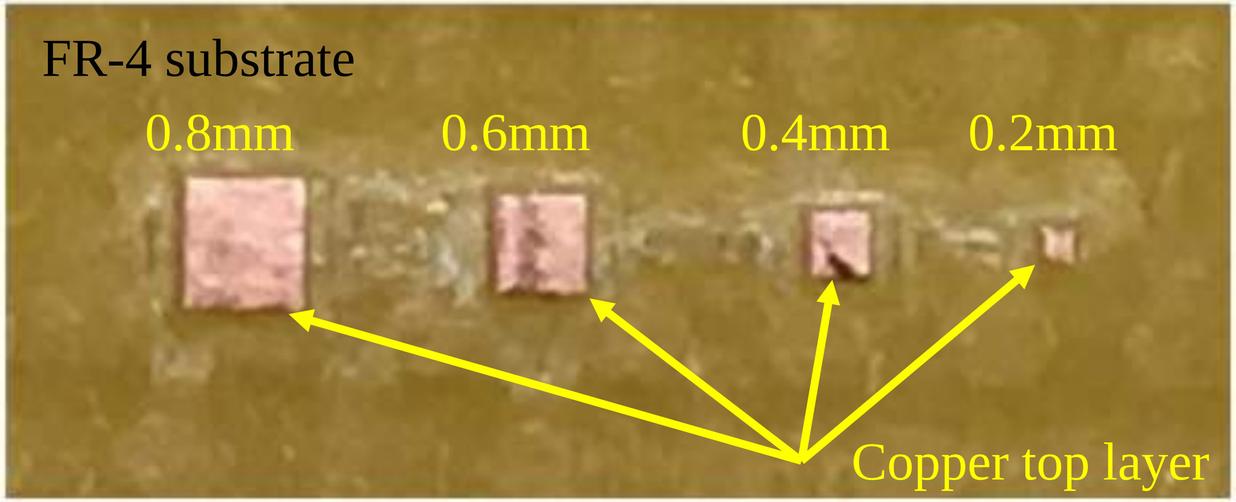


$\vec{x}$
FR-4 tester
0.0
-0.2
-0.4
-0.6
$\Delta\omega_0/2\pi$(MHz)
-20
-10
0
10
20
X(mm)
$\vec{y}$
$\epsilon = 4.4$
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
$\Delta\omega_0/2\pi$(MHz)
-20
-10
0
10
20
Y(mm)

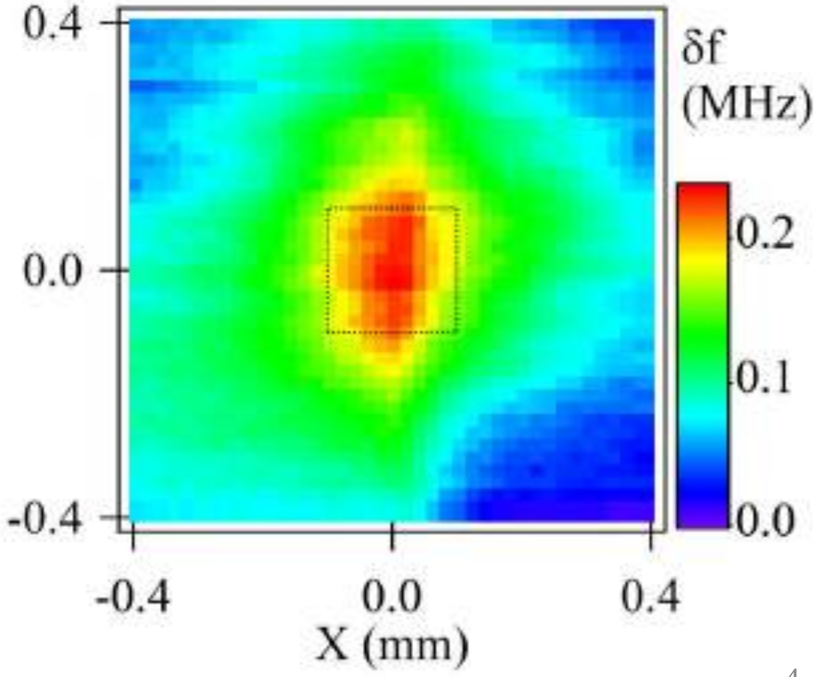
Dielectric imaging of metal (copper)



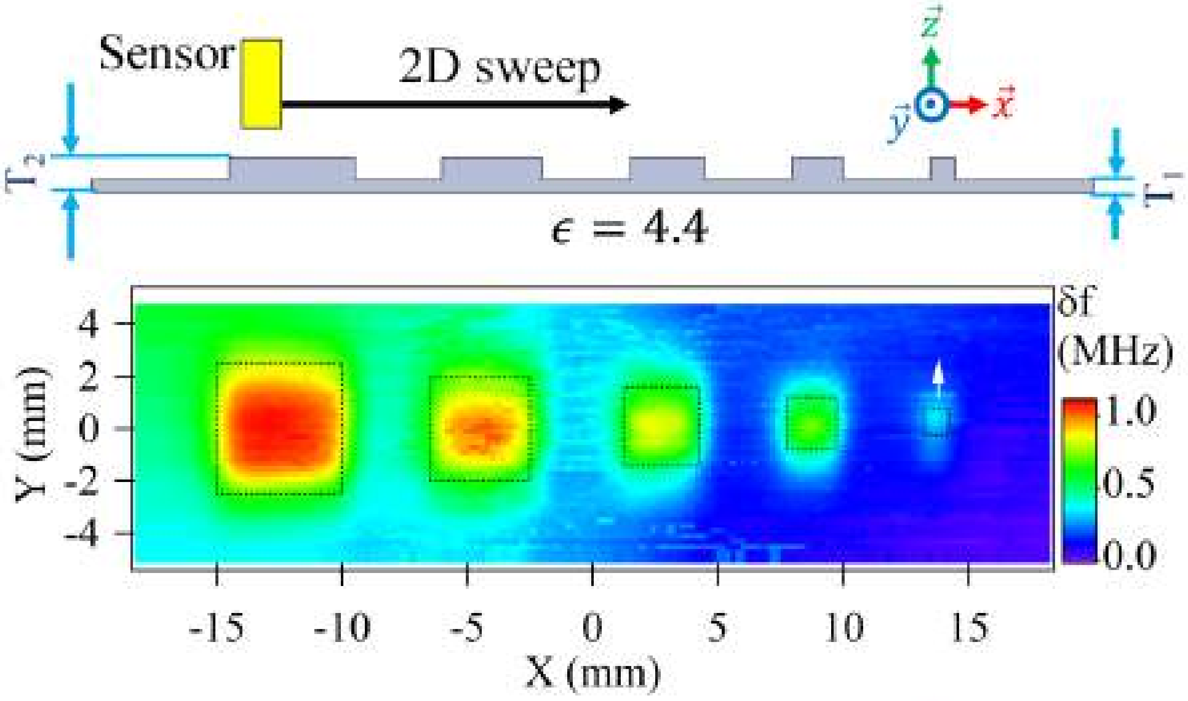
Optical image



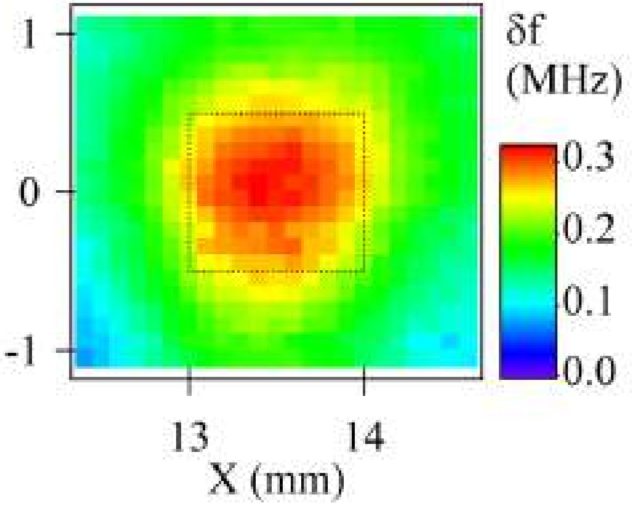
Zoomed in imaging of 0.2 mm square



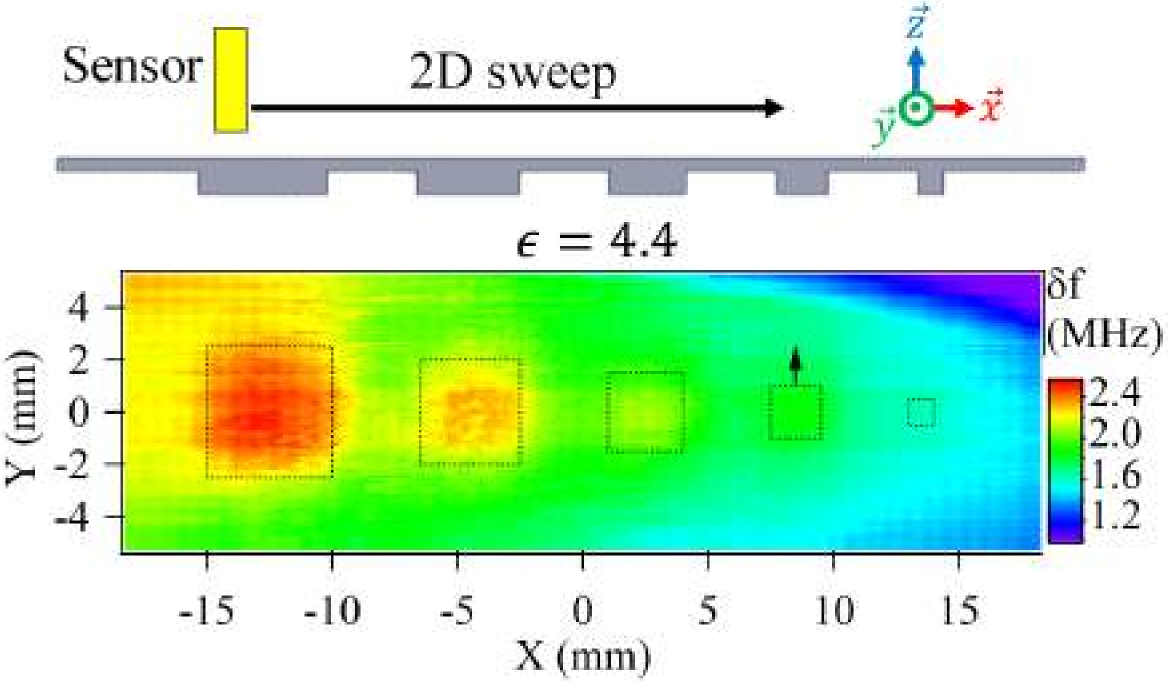
Touchless imaging



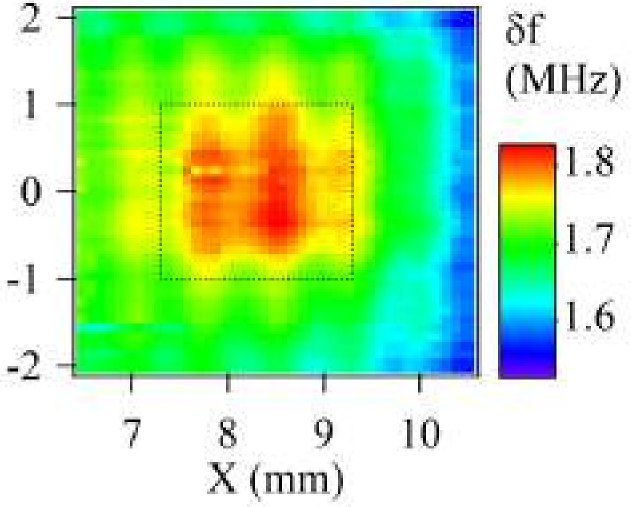
1mm×1mm
Dielectric square



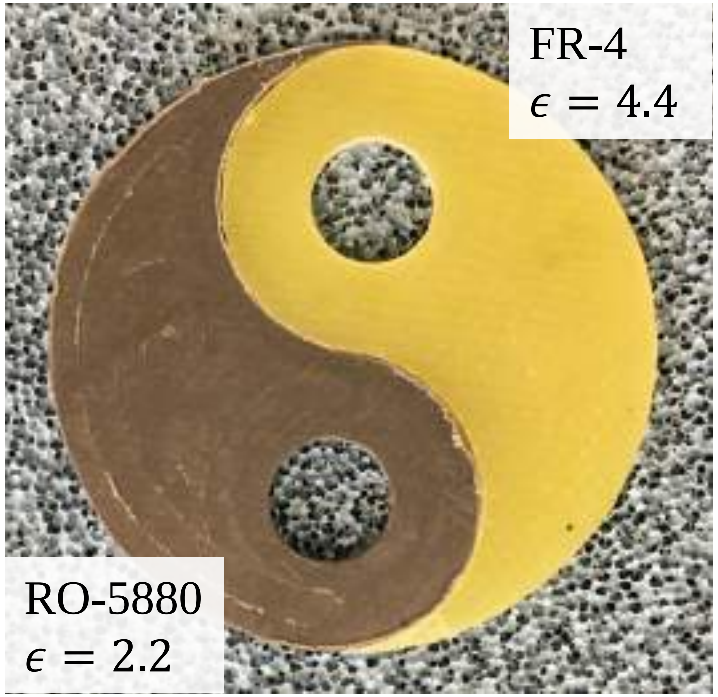
Penetration imaging



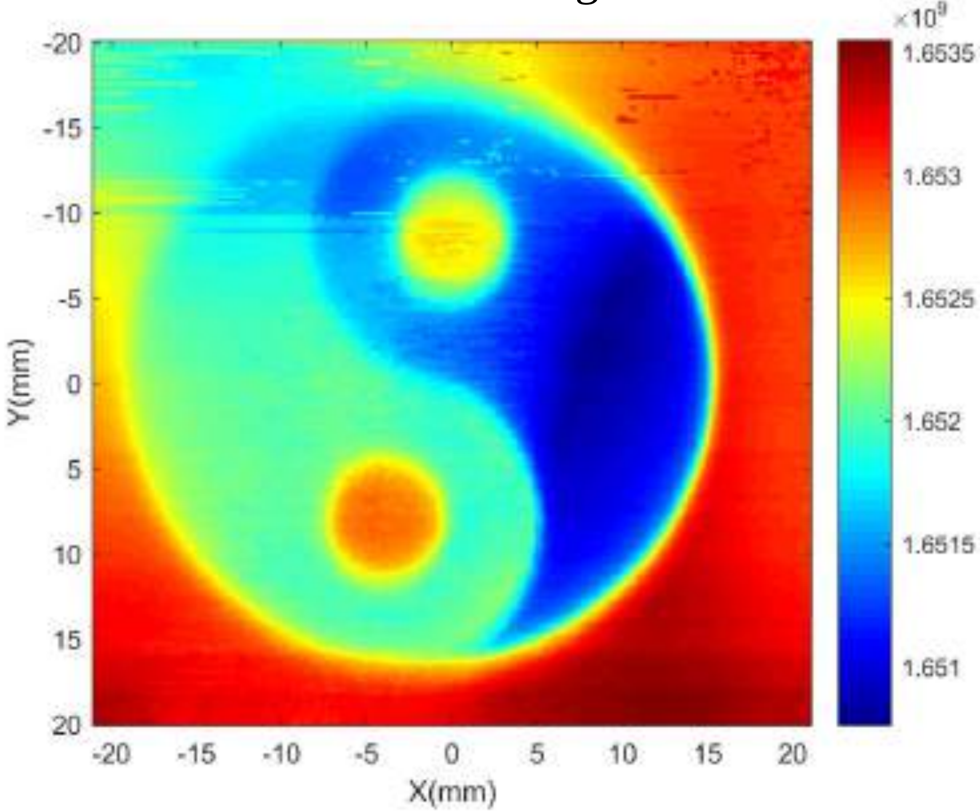
2mm×2mm
Dielectric square



Optical image



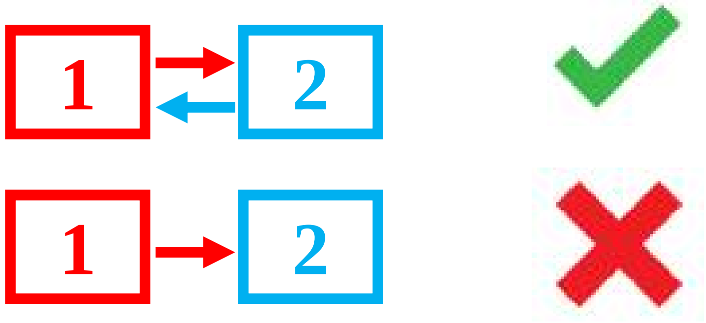
Dielectric image



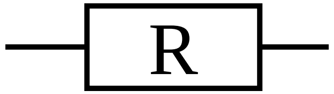
Long distance coupling between 2 SRRs

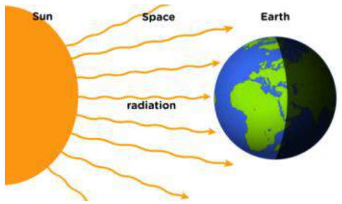
What is coupling?

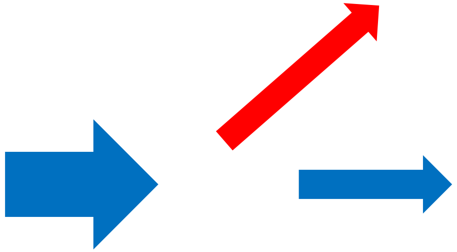
- Energy exchange between two systems:



Cooperativity: $C = \frac{g^2}{\Delta_1 \Delta_2}$

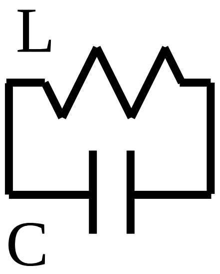


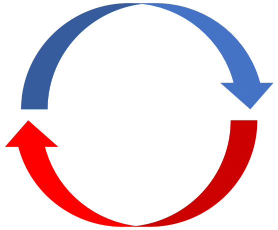




$g \to 0$, and $C = 0$

therefore, this is not coupling





$g > 0$, and $C > 0$

therefore, this is coupling

$0 < C < 1$

Non-coherent coupling

$C > 1$

Coherent coupling

Why there is no Rabi-splitting?

$$S_{21} = 1 - \frac{A}{\omega - \omega_c + i\beta\omega_c + \frac{g^2}{\omega - \omega_m + i\alpha\omega_m}}$$

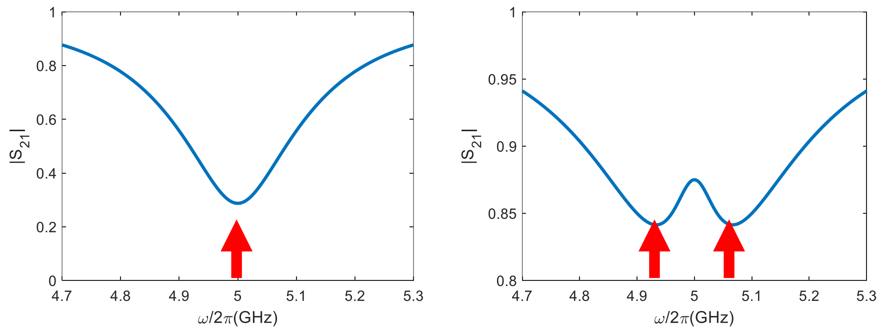
Magnons coupling with cavity photons

$$S_{21} = i\left(1 - \frac{2i\Delta\omega_e}{\omega - \omega_c + i\Delta\omega + \frac{\Delta\omega_e^2}{\omega - \omega_c + i\Delta\omega}}\right)$$

Two identical SRR coupled through transmission line

$$\Delta\omega = \Delta\omega_e + \Delta\omega_i \qquad \Delta\omega_e \rightarrow g$$

$$|S_{21}|^2 = S_{21} \cdot S_{21}^{\star} = \frac{\left(\Delta\omega_i^2 + (\omega - \omega_c)^2\right)^2}{\left(g^2 + \left(\Delta\omega - i(\omega - \omega_c)\right)^2\right)\left(g^2 + \left(\Delta\omega + i(\omega - \omega_c)\right)^2\right)}$$



Solve this problem: $\frac{d|S_{21}|^2}{d\omega} = 0$

→ We can get the eigenvalue of ω

Why there is not Rabi-splitting? (2)

Five solutions:

$$\omega_1 = \omega_c$$

$$\omega_{2,3} = \omega_c \pm \sqrt{-(\Delta\omega - g)^2}$$

$$\omega_{4,5} = \omega_c \pm \frac{\sqrt{g^4 - 2g^3\Delta\omega + 2g^2\Delta\omega^2 - \Delta\omega^4}}{\Delta\omega - g}$$

(1). $-(\Delta\omega - g)^2$ always smaller than zero → $\omega_{2,3}$ have no physical meaning

(2). $(g^4 - 2g^3\Delta\omega + 2g^2\Delta\omega^2 - \Delta\omega^4) < 0$ one solution → no splitting

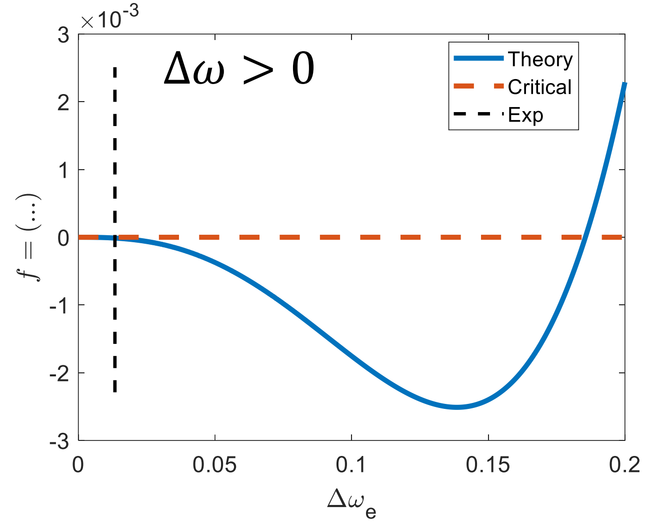
$(g^4 - 2g^3\Delta\omega + 2g^2\Delta\omega^2 - \Delta\omega^4) > 0$ three solutions → Rabi splitting

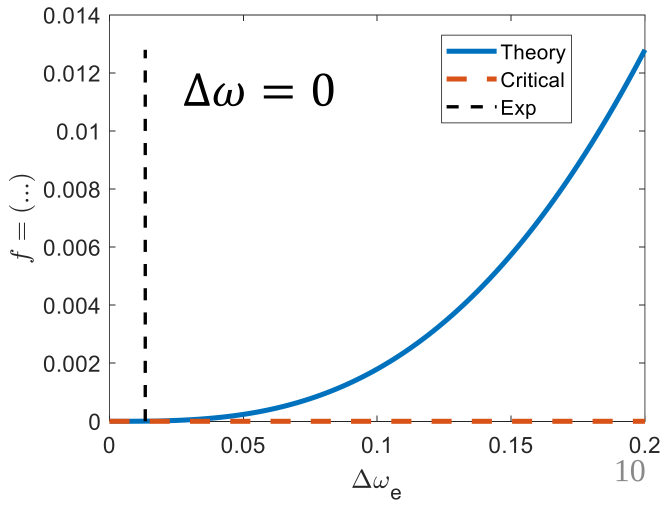
(3). Consider the approximation $\Delta\omega \to 0$ (ignore dampings)

We have: $\omega_1 = \omega_c$, $\omega_{2,3} = \omega_c \pm \sqrt{-g^2}$; $\omega_{4,5} = \omega_c \pm g$

Corresponding to a frequency split of $2g$

Plot: $f = \sqrt{(\ldots)}$; $\Delta\omega_e \to g, \Delta\omega_i \to 0.01$

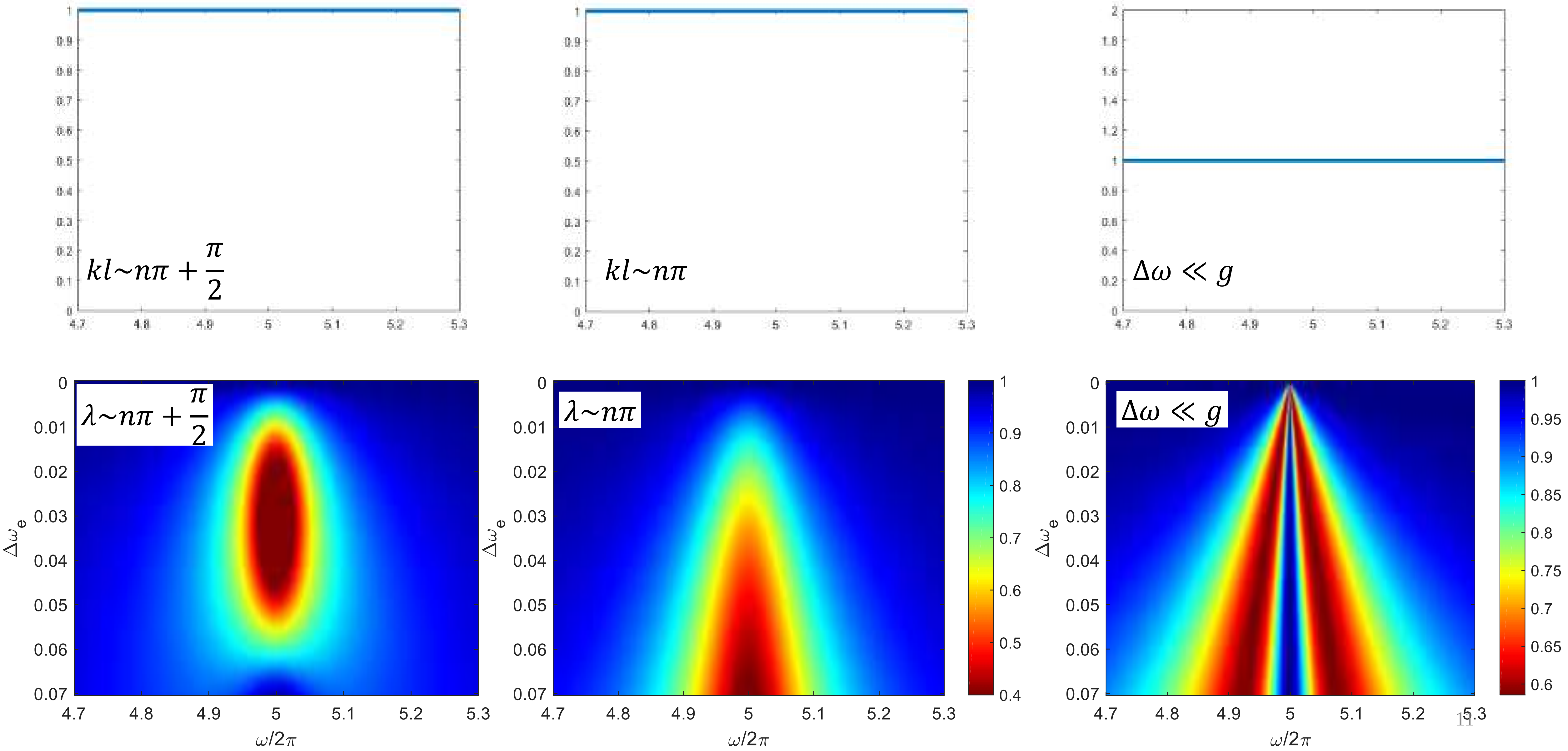




Calculations $g \uparrow$

$$S_{21} = i\left(1 - \frac{2i\Delta\omega_e}{\omega - \omega_c + i\Delta\omega + \frac{\Delta\omega_e^2}{\omega - \omega_c + i\Delta\omega}}\right)$$

$$S_{21} = \left(1 - \frac{i\Delta\omega_e}{\omega - \omega_c + \mathrm{i}(\Delta\omega_i + \Delta\omega_e)}\right)$$



Next step:

- Using two YIG spheres to realize the long distance coupling between magnons.