Scanning Near-field Microwave microscopy

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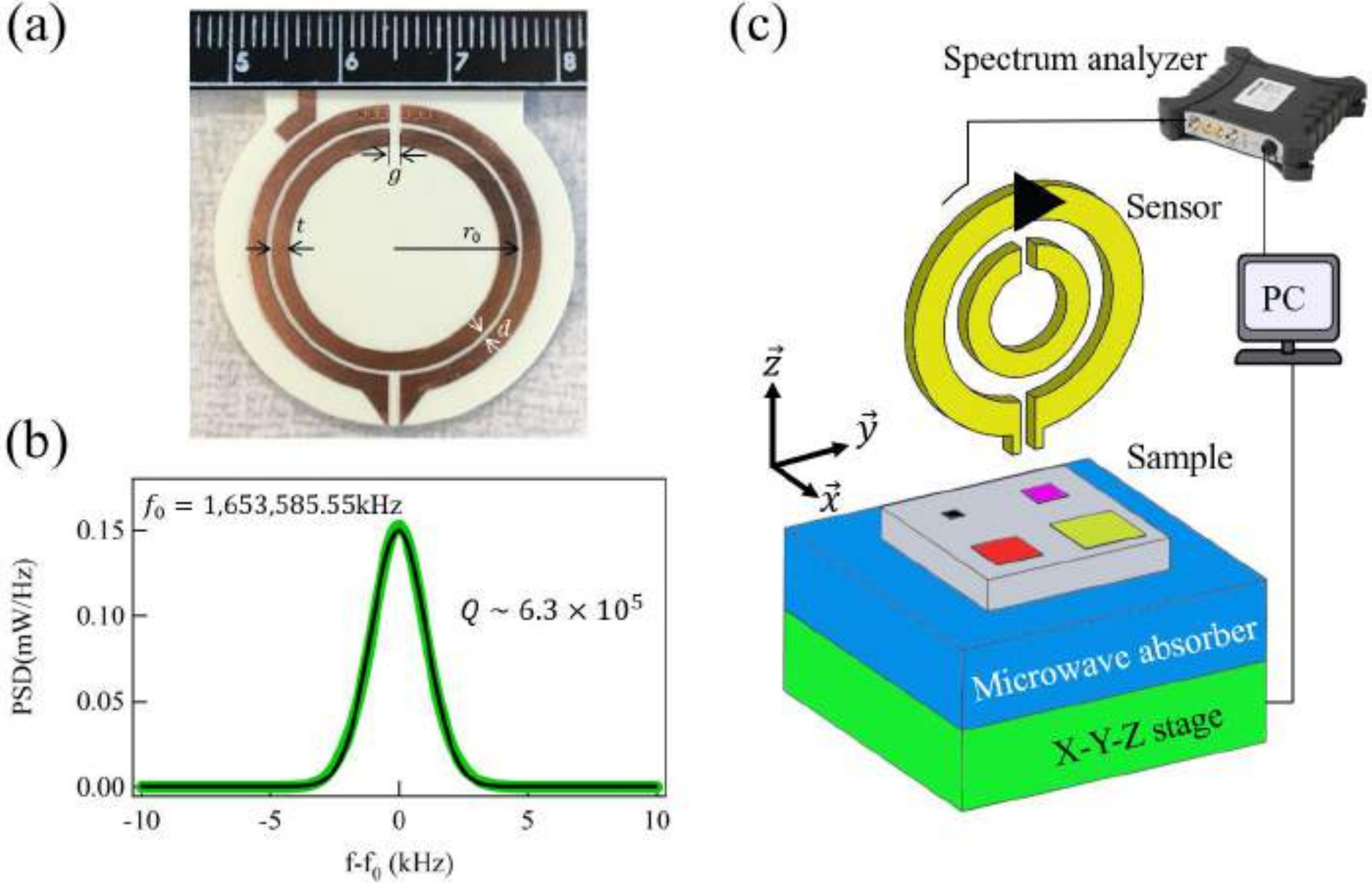
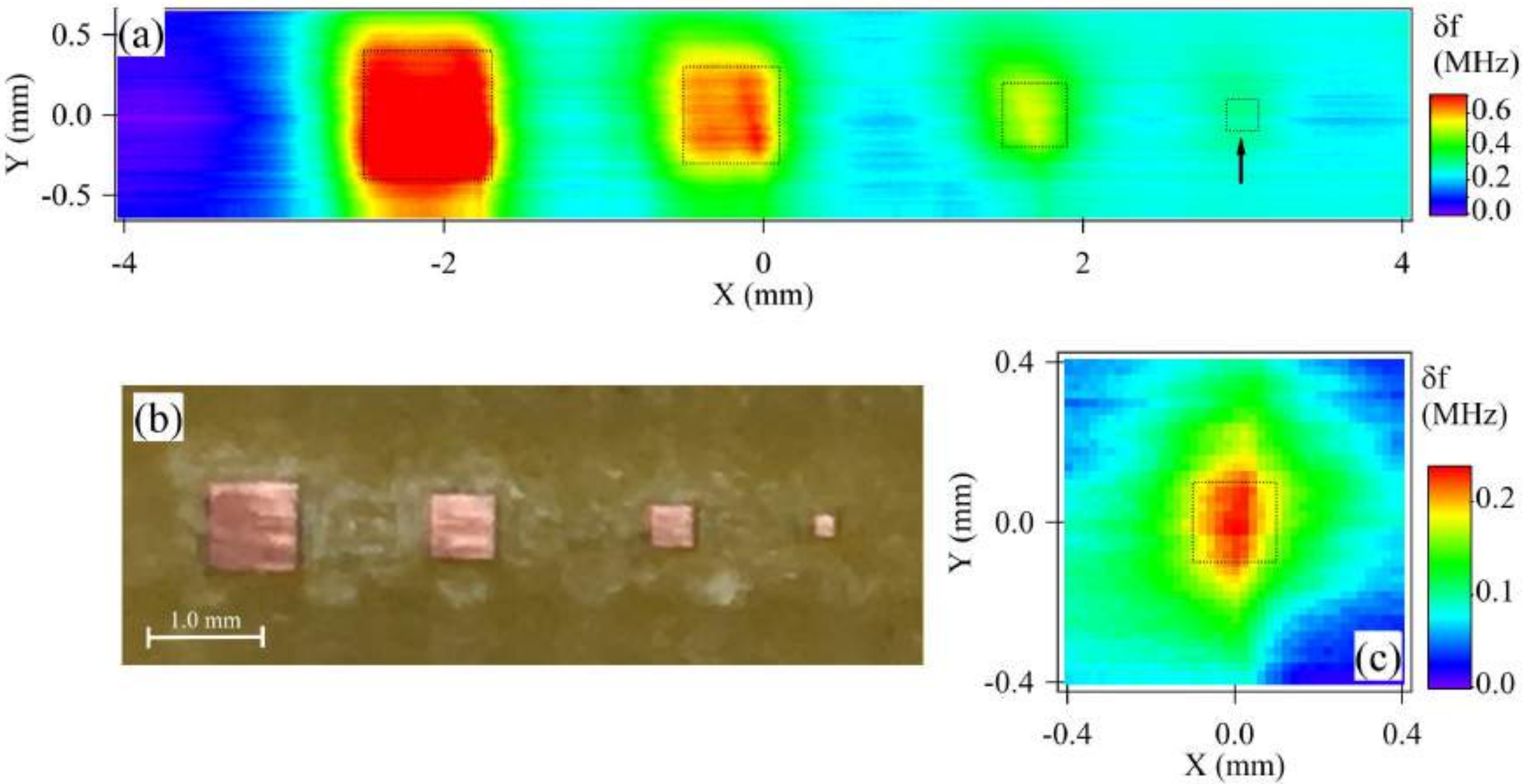
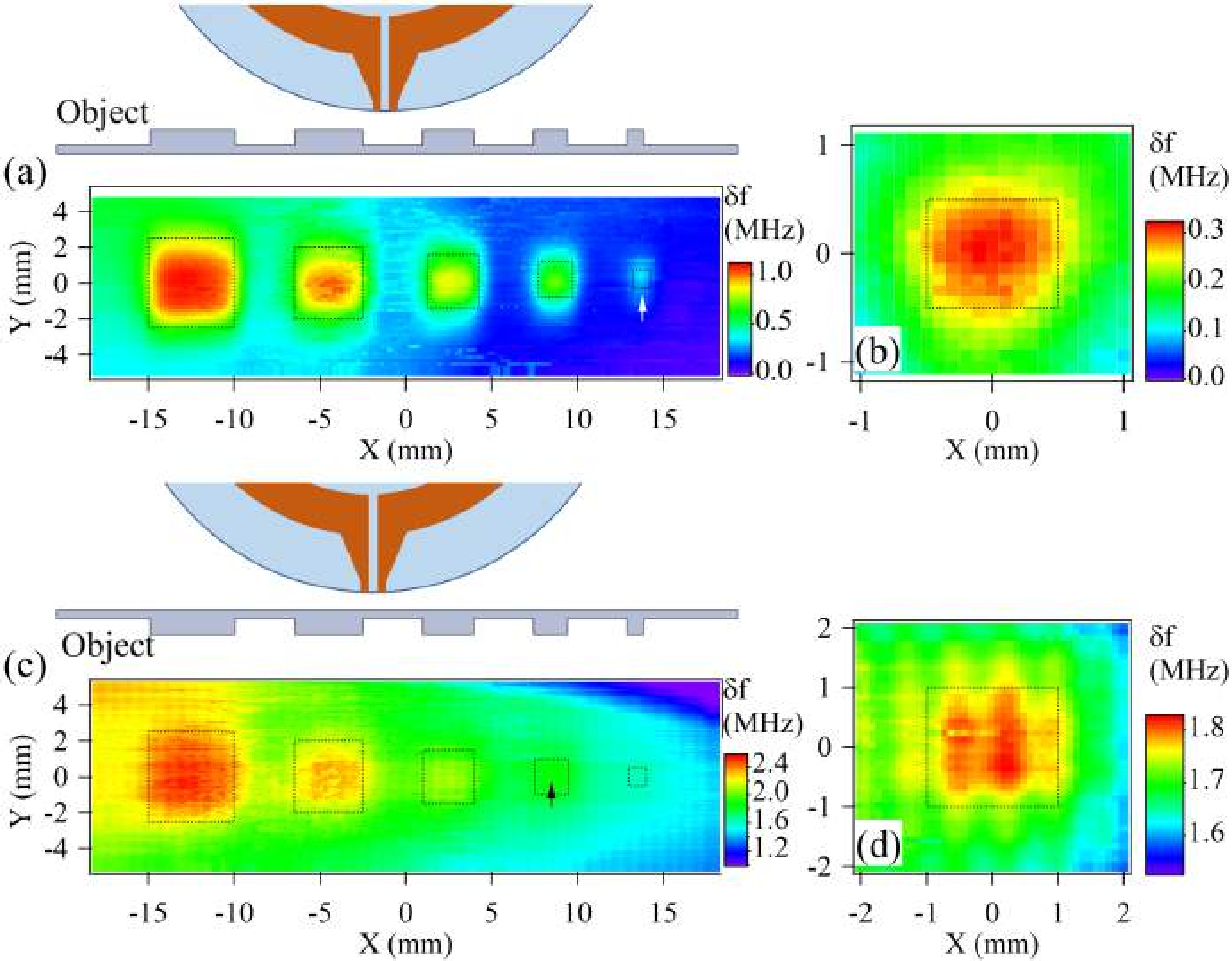
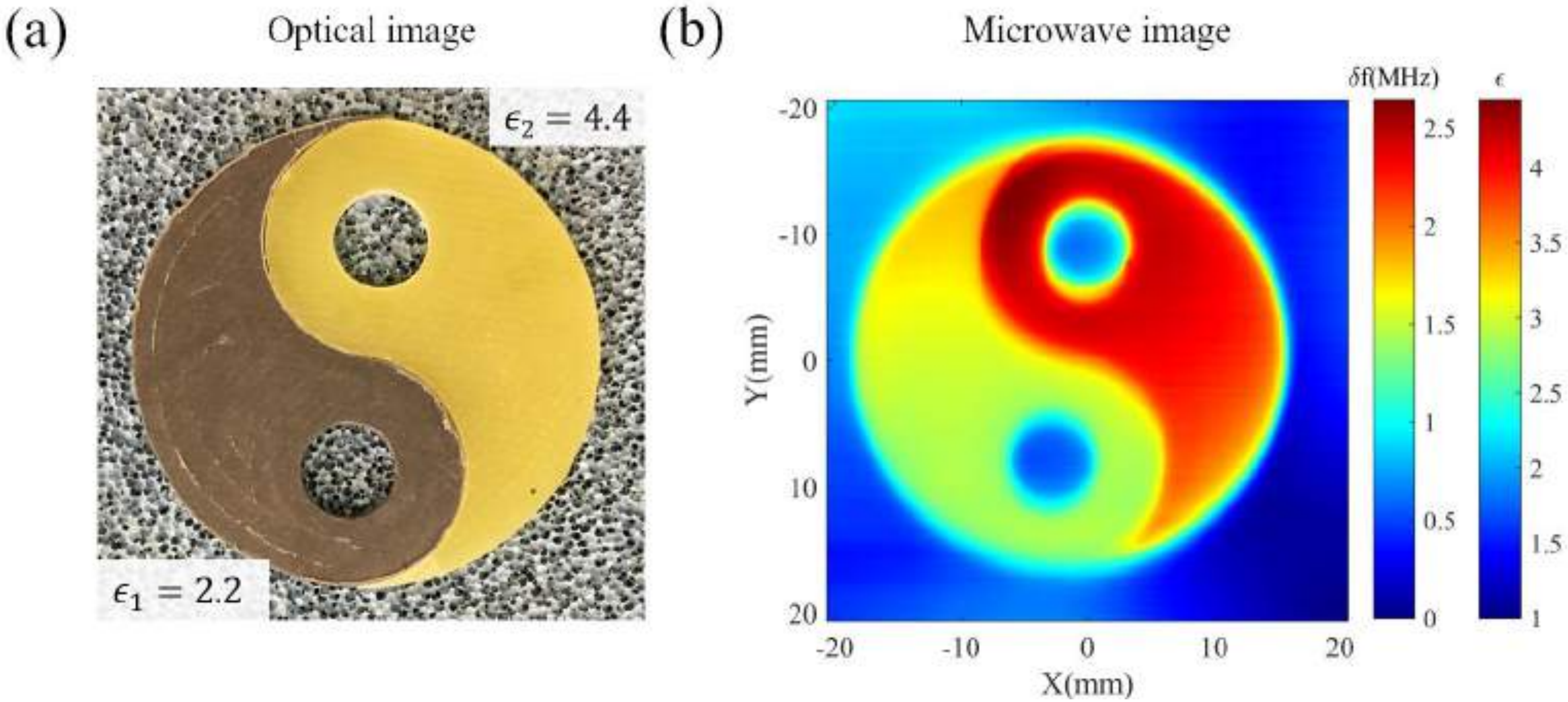
Nov 19th 2018


(a)
5
6
7
8
g
t
r_0
d
(b)
f_0 = 1,653,585.55kHz
$Q \sim 6.3 \times 10^5$
PSD(mW/Hz)
0.15
0.10
0.05
0.00
-10
-5
0
5
10
f-f_0 (kHz)
(c)
Spectrum analyzer
Sensor
PC
$\vec{z}$
$\vec{y}$
$\vec{x}$
Sample
Microwave absorber
X-Y-Z stage


(a)
0.5
0.0
-0.5
Y (mm)
-4
-2
0
2
4
X (mm)
δf
(MHz)
0.6
0.4
0.2
0.0
(b)
1.0 mm
0.4
0.0
-0.4
Y (mm)
-0.4
0.0
0.4
X (mm)
(c)
δf
(MHz)
0.2
0.1
0.0



Object
(a)
δf (MHz)
1.0
0.5
0.0
Y (mm)
4
2
0
-2
-4
-15
-10
-5
0
5
10
15
X (mm)
(b)
δf (MHz)
0.3
0.2
0.1
0.0
1
0
-1
X (mm)
Object
(c)
δf (MHz)
2.4
2.0
1.6
1.2
(d)
δf (MHz)
1.8
1.7
1.6
2
-2


(a)
Optical image
$\epsilon_2 = 4.4$
$\epsilon_1 = 2.2$
(b)
Microwave image
δf(MHz)
ϵ
Y(mm)
X(mm)
-20
-10
0
10
20
0
0.5
1
1.5
2
2.5
1
1.5
2
2.5
3
3.5
4

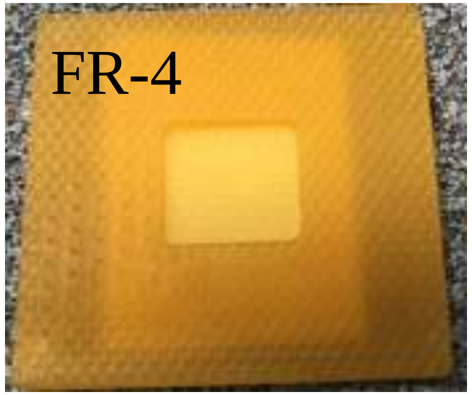
Why do need to study the microwave microscopy?

Detecting element	Spatial resolution	Operating Frequency	Detecting type	Method	Feature	Resolution Ratio (λ)
Open ended coaxial	>3mm	0.3-12 GHz	Surface/subsurface	Boardband	Contact	$\sim \frac{1}{10}$
Coaxial probe with sharpened tip	~1µm	1.2 GHz	Surface	Resonant	AFM additional	$\sim \frac{1}{250000}$
Coaxial resonator probe	~1µm	1.5-2.7 GHz	Surface	Resonant	SFM additional	$\sim \frac{1}{150000}$
Microstripline with sharpened tip	0.4µm	1 GHz	Surface	Resonant	AFM additional	$\sim \frac{1}{10^6}$
Waveguide slit	0.1mm	80 GHz	Surface	Resonant	Non contact	$\sim \frac{1}{40}$
Coupled planar spiral inductors	0.4 mm	10–500 MHz	Surface	Boardband	Non contact	$\sim \frac{1}{1000}$
Metamaterial element						
SRR single ring	2mm	1-3 GHz	Surface	Resonant	Contact	$\sim \frac{1}{100}$
Microstripline SRR	0.7mm	9-10 GHz	Surface	Resonant	Contact	$\sim \frac{1}{50}$
Microstripline SRR unit	3mm	2-4 GHz	Bulk material	Resonant	Contact	$\sim \frac{1}{30}$
Active microstripline SRR	0.1mm	1.6 GHz	Surface/subsurface	Resonant	Non contact	$\sim \frac{1}{1800}$

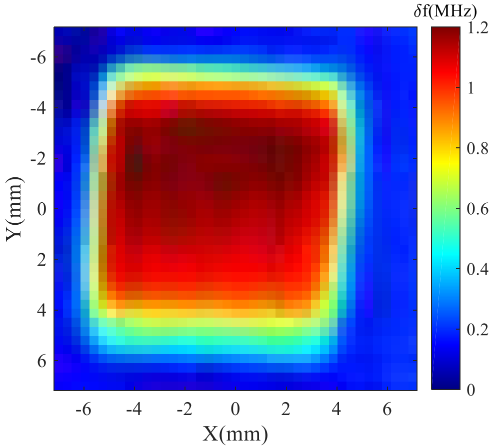
Penetration depth: 0.5 mm with 2.0 mm resolution

Great advantage for NDT for subsurface testing

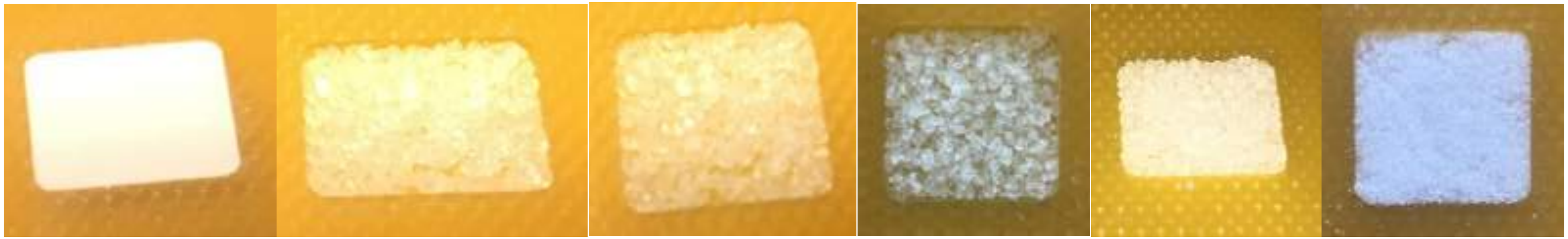
DRDC project: imaging on dielectric powers

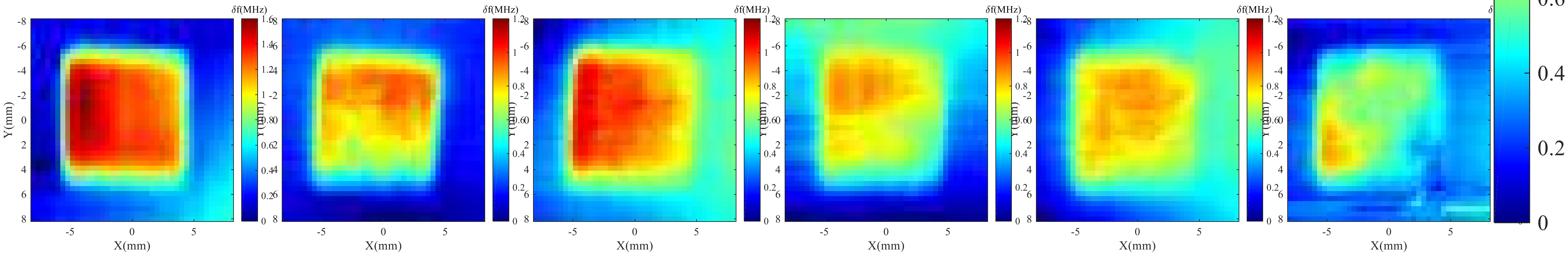


Sample holder



Icing sugar | $KClO_3$ | KNO_3 | NH_4NO_3 | NaCl | Na_2NO_3





DRDC project: imaging on dielectric powers

Evaluating the dielectric constant of chemical powders:

$\epsilon_{\text{eff}} \propto \delta f$

→ Combination of sample and air

$$\epsilon_{\text{eff}} = \frac{V_{air}\epsilon_{air} + V_{sample}\epsilon_{sample}}{V_{air} + V_{sample}}$$

$$V_{\text{sample}} = \frac{m_{\text{sample}}}{\rho_{\text{sample}}}$$

$$\epsilon_{air} \approx 1$$

$$V_{air} + V_{sample} = V_{\text{tester}}$$

$$\epsilon_{sample} = \frac{\left(V_t \cdot \epsilon_{eff}\right) - (V_t - m_s/\rho_s)}{m_s/\rho_s}$$

On long-distance coupling

Will the extra transmission line influence?

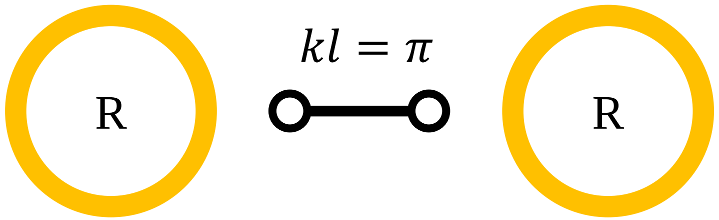
$$M_t = \begin{pmatrix} \cos(kl) & i \cdot \mathrm{Z}_0 \sin(kl) \\ i \cdot \mathrm{Z}_0^{-1} \sin(kl) & \cos(kl) \end{pmatrix} \qquad \mathrm{M}_{SSR} = \begin{pmatrix} 1 & 0 \\ 1/Z_{SRR} & 1 \end{pmatrix}$$

$$S_{21} = 1 - \frac{i\Delta\omega_{ext}}{\omega - \omega_c + i(\Delta\omega_{int} + \Delta\omega_{ext})}$$

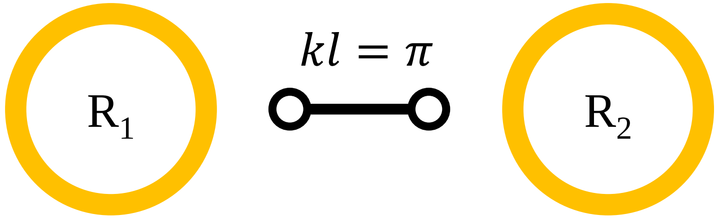
$$M = M_t\, M_{SRR} M_t = \begin{bmatrix} \mathrm{A} & B \\ C & D \end{bmatrix}$$

$$S_{21} = e^{2ikl} \left(1 - \frac{i\Delta\omega_{ext}}{\omega - \omega_c + i(\Delta\omega_{int} + \Delta\omega_{ext})} \right)$$

On long-distance coupling (2)



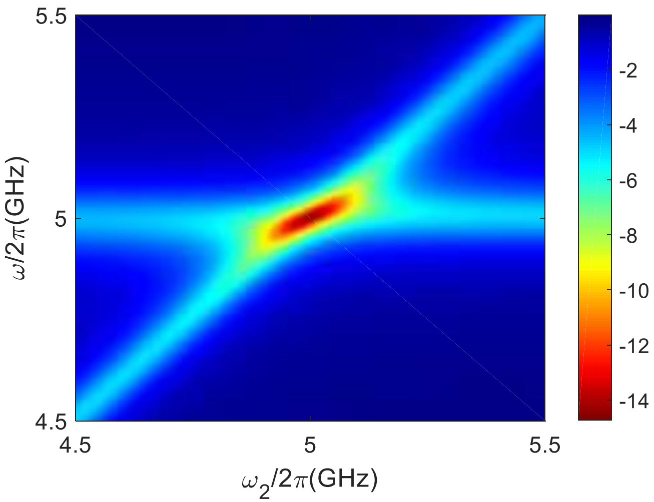
$$S_{21} = 1 - \frac{i2\Delta\omega_e}{\omega - \omega_c + i(\Delta\omega_i + 2\Delta\omega_e)}$$



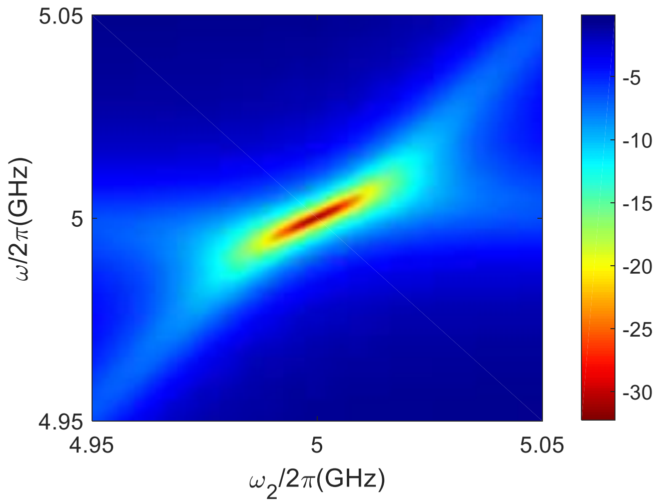
$$S_{21} = 1 - \frac{i\Delta\omega_{e1}}{\omega - \omega_1 + i\left(\Delta\omega_{i1} + \Delta\omega_{e1} + \frac{\omega_1}{\omega_2}\Delta\omega_{e2}\right)} - \frac{i\Delta\omega_{e2}}{\omega - \omega_2 + i\left(\Delta\omega_{i2} + \Delta\omega_{e2} + \frac{\omega_2}{\omega_1}\Delta\omega_{e1}\right)}$$

Superposition of R_1 and R_2

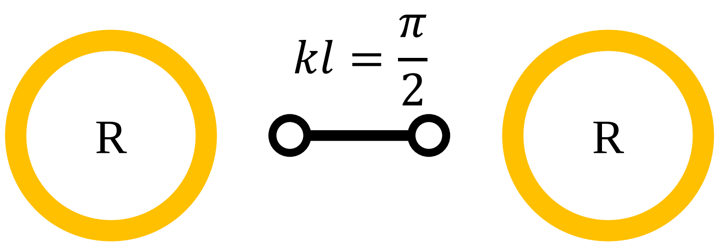
Calculation:
$\Delta\omega_e \approx \Delta\omega_i$



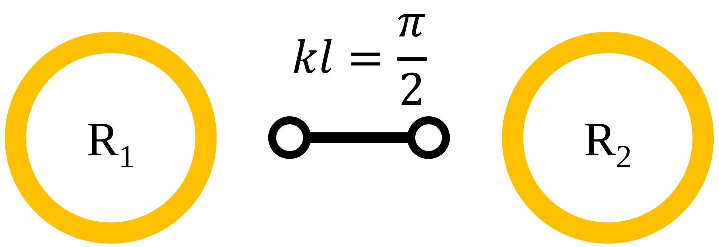
Calculation:
$\Delta\omega_e \gg \Delta\omega_i$



On long-distance coupling (3)



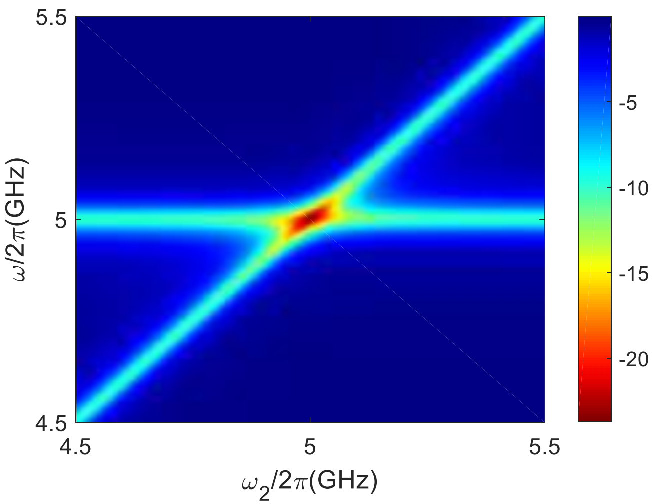
$$S_{21} = 1 - \frac{i\Delta\omega_e}{\omega - \omega_c + i(\Delta\omega_i + \Delta\omega_e) - \frac{\Delta\omega_e^2}{\omega - \omega_c + i(\Delta\omega_i + \Delta\omega_e)}}$$



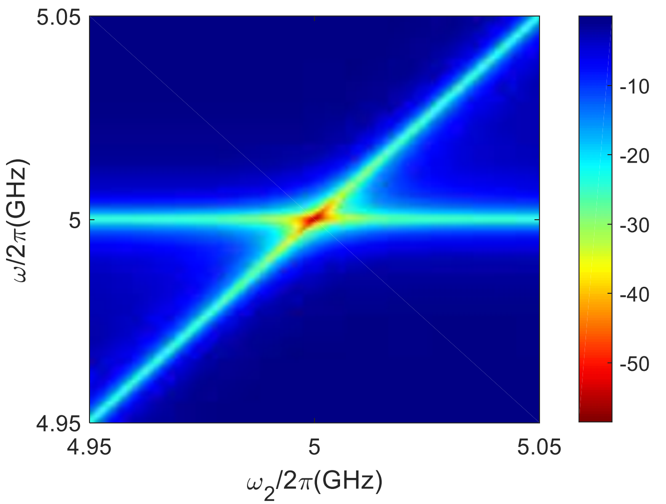
$$S_{21} = 1 - \frac{i\Delta\omega_{e1}}{\omega - \omega_2 + i(\Delta\omega_{i2} + \Delta\omega_{e2}) - \frac{\Delta\omega_{e1}\Delta\omega_{e2}}{\omega - \omega_1 + i(\Delta\omega_{i1} + \Delta\omega_{e1})}} - \frac{i\Delta\omega_{e2}}{\omega - \omega_1 + i(\Delta\omega_{i1} + \Delta\omega_{e1}) - \frac{\Delta\omega_{e1}\Delta\omega_{e2}}{\omega - \omega_2 + i(\Delta\omega_{i2} + \Delta\omega_{e2})}}$$

Interaction between R_1 and R_2

Calculation:
$\Delta\omega_e \approx \Delta\omega_i$



Calculation:
$\Delta\omega_e \gg \Delta\omega_i$



Simulation setup:

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Guiding Waves Along an Infinitesimal Line between Impedance Surfaces

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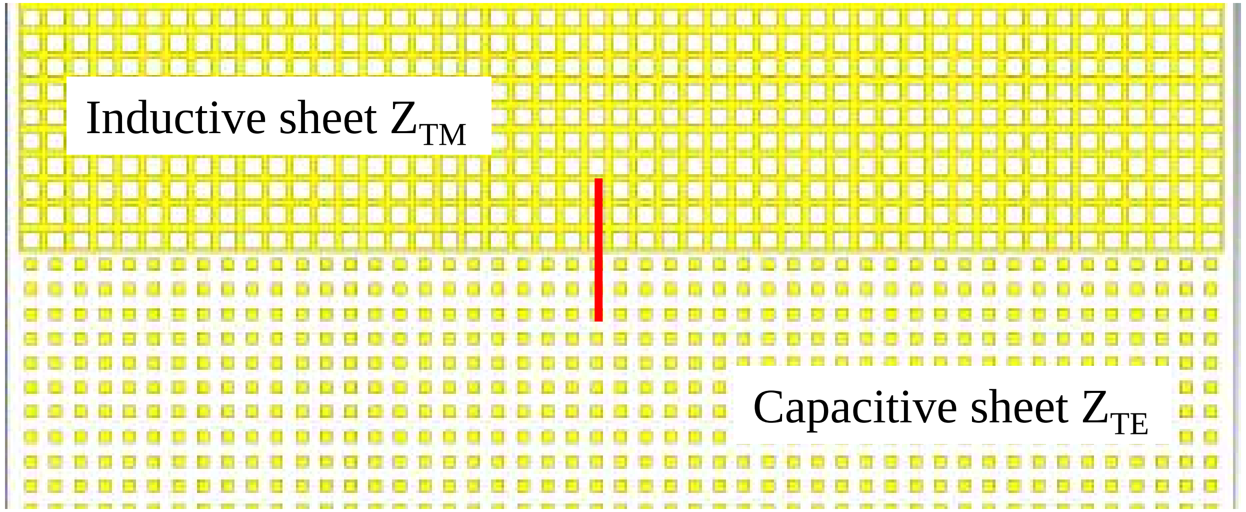
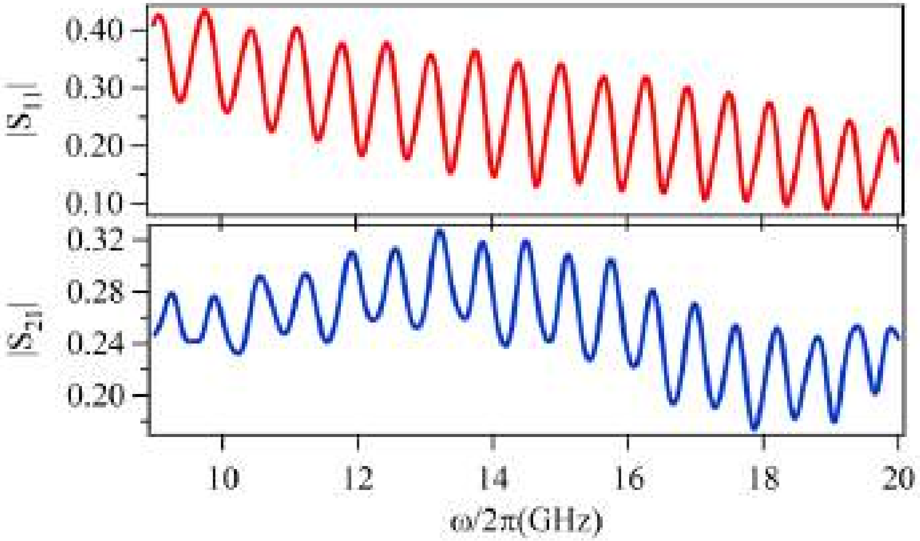
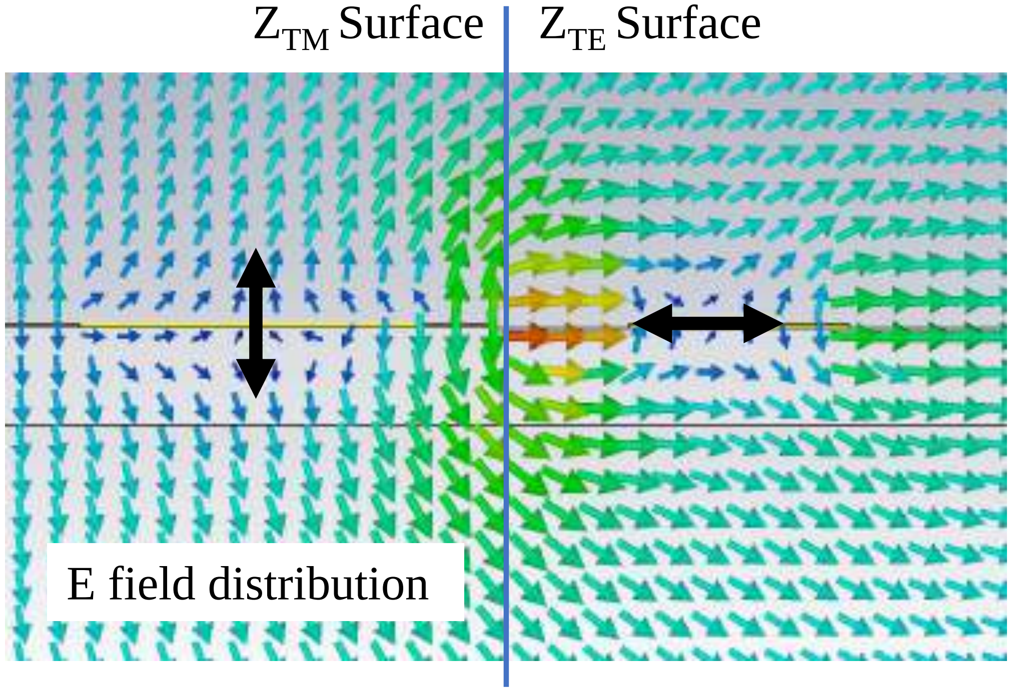
Port 1



Port 2

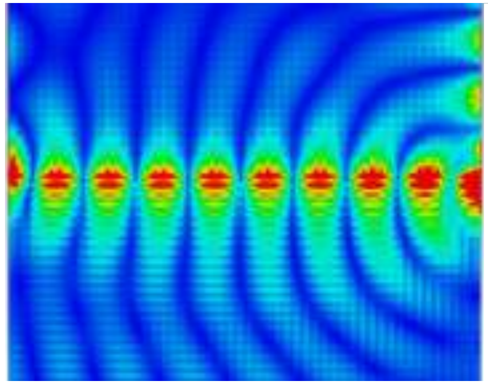
Substrate : RO5880 ; thickness = 0.8 mm



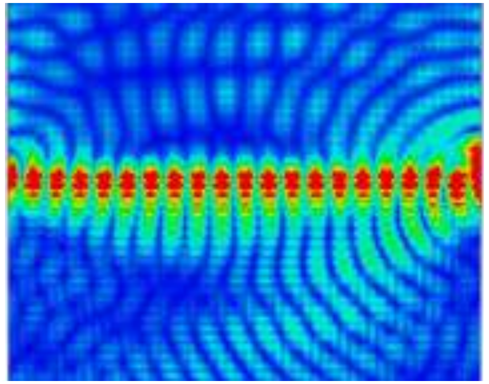


CST simulation:

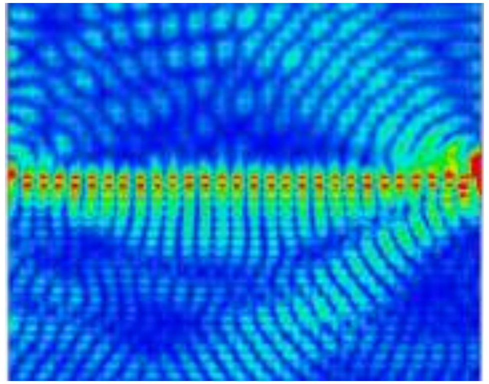
6 GHz



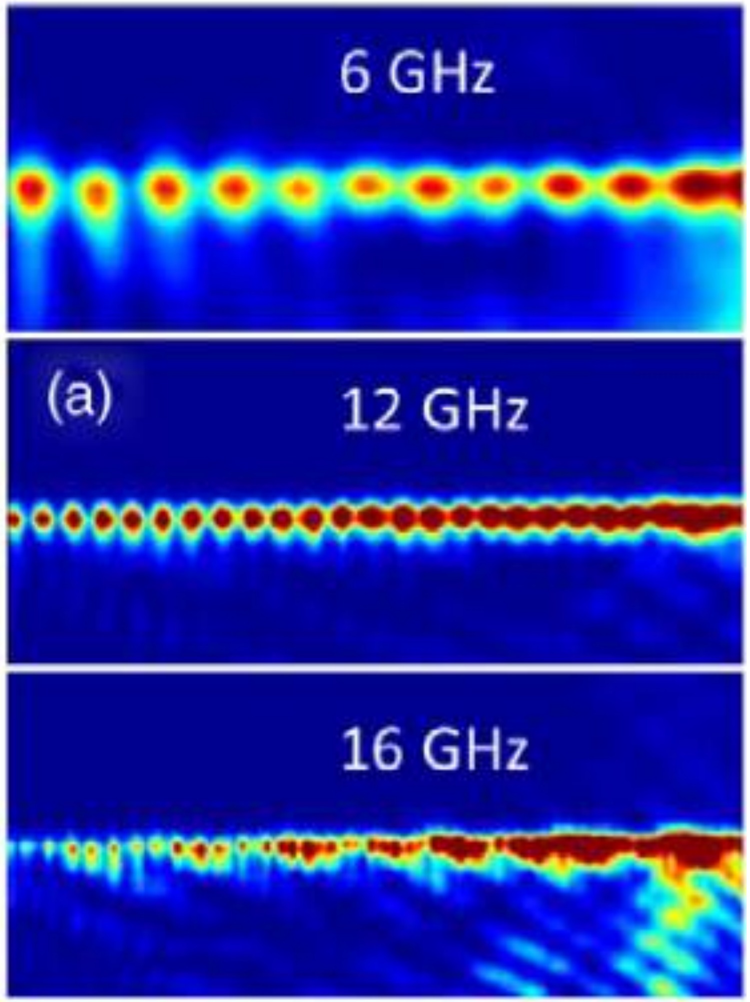
12 GHz

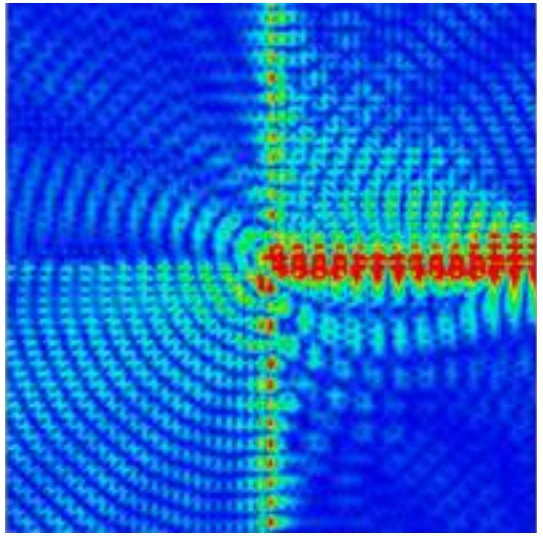


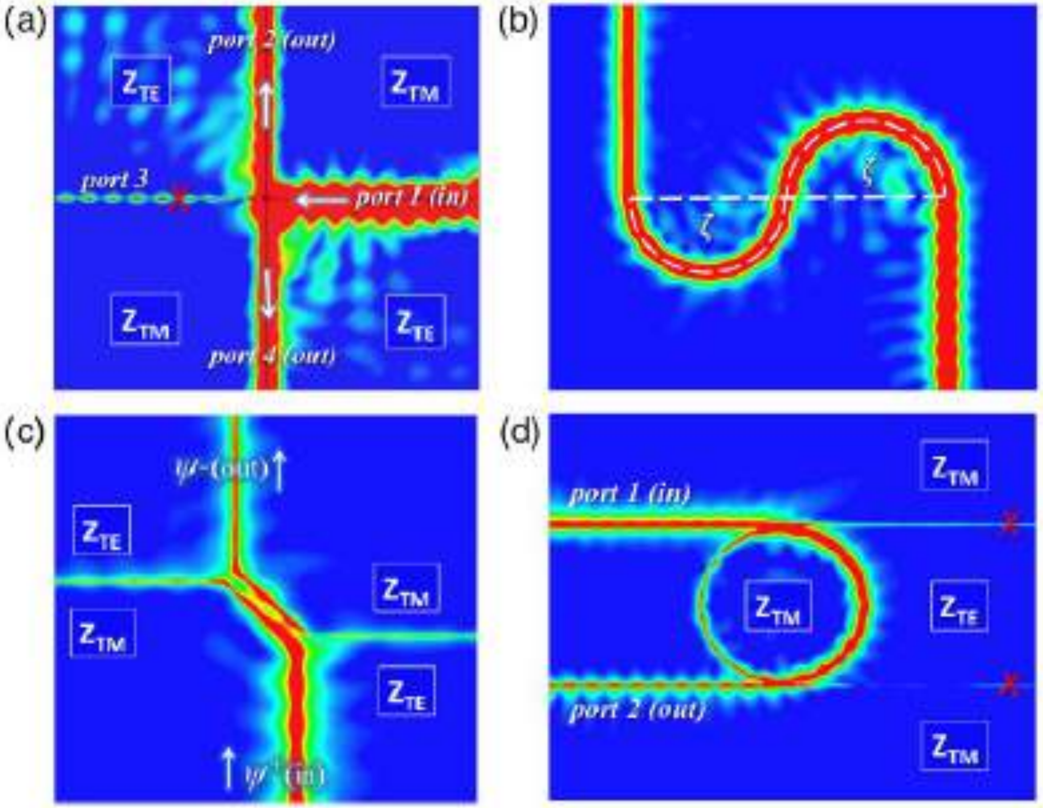
16 GHz



Measurements in paper:







(a)
port 2 (out)
ZTE
ZTM
port 3
port 1 (in)
ZTM
ZTE
port 4 (out)
(b)
ζ
ζ
(c)
ψ- (out)
ZTE
ZTM
ZTM
ZTE
ψ+ (in)
(d)
ZTM
port 1 (in)
ZTM
ZTE
port 2 (out)
ZTM