Frequency Reconfiguration of a Small Array Enabled by Functionalized Dispersions of Colloidal Materials

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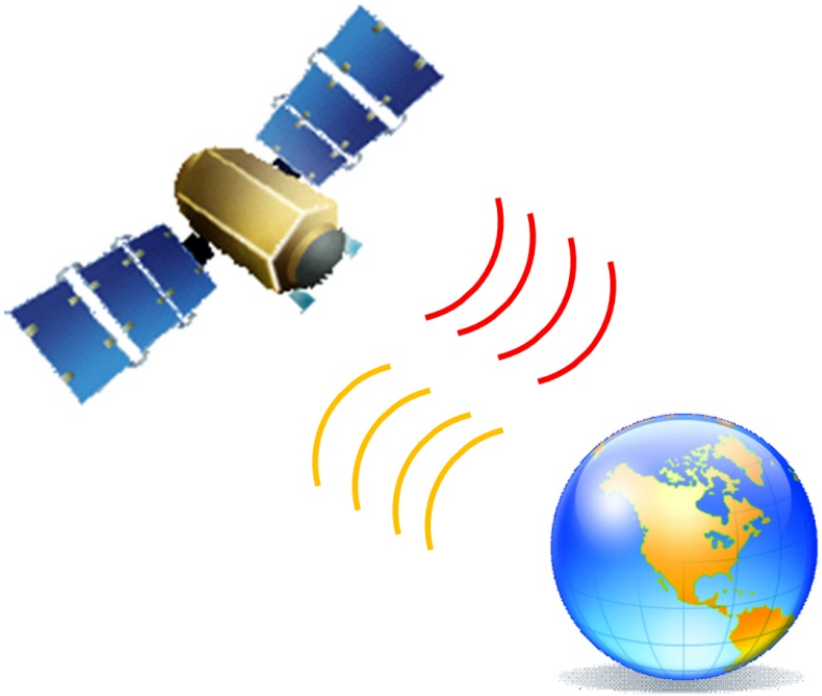
Outline

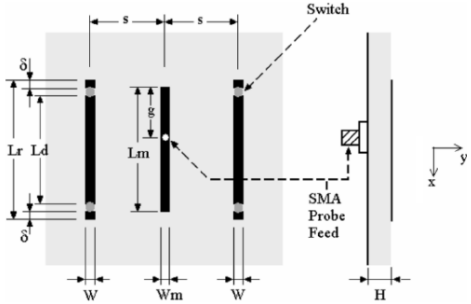
- Reconfiguration Technologies and Motivation
- Dispersions of Nanoparticles
- Frequency Reconfiguration of Single Element
- Small Array Behavior
  - H-plane Array
  - E-plane Array
- Ongoing and Future Research



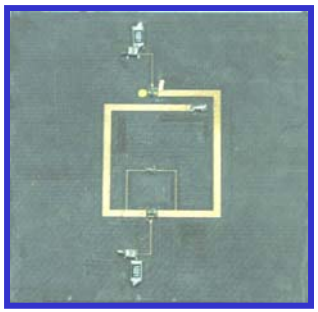
Reconfiguration Technologies and Motivation

Integrating the State-of-the-Art (SOA)

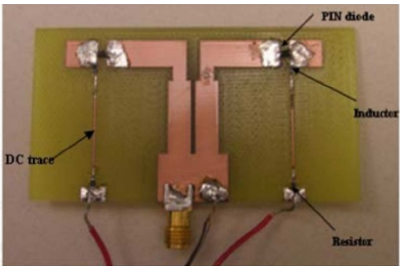
- SOA Reconfiguration Mechanisms
  - PIN diodes
  - RF MEMS
  - Varactors
  - Tunable bulk/thin film materials



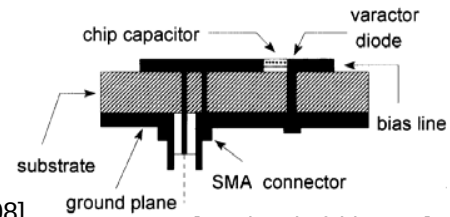
[Zhang, 2004]



[Huff, 2006]

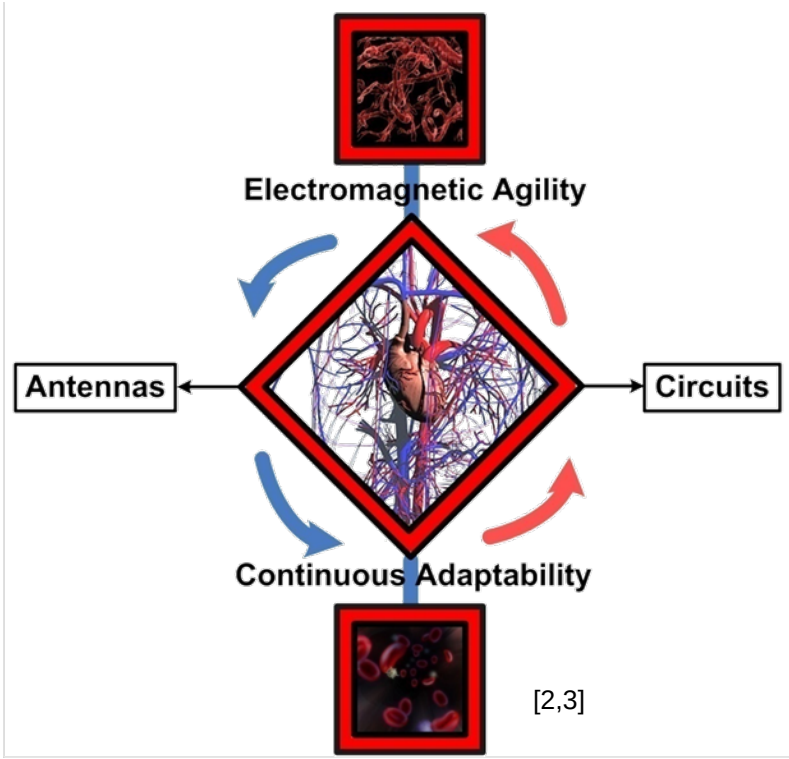


[Piazza, 2008]



[Al-Charchafchi, 1995]

Some designs are difficult to reconfigure using SOA reconfiguration mechanisms…



[2,3]

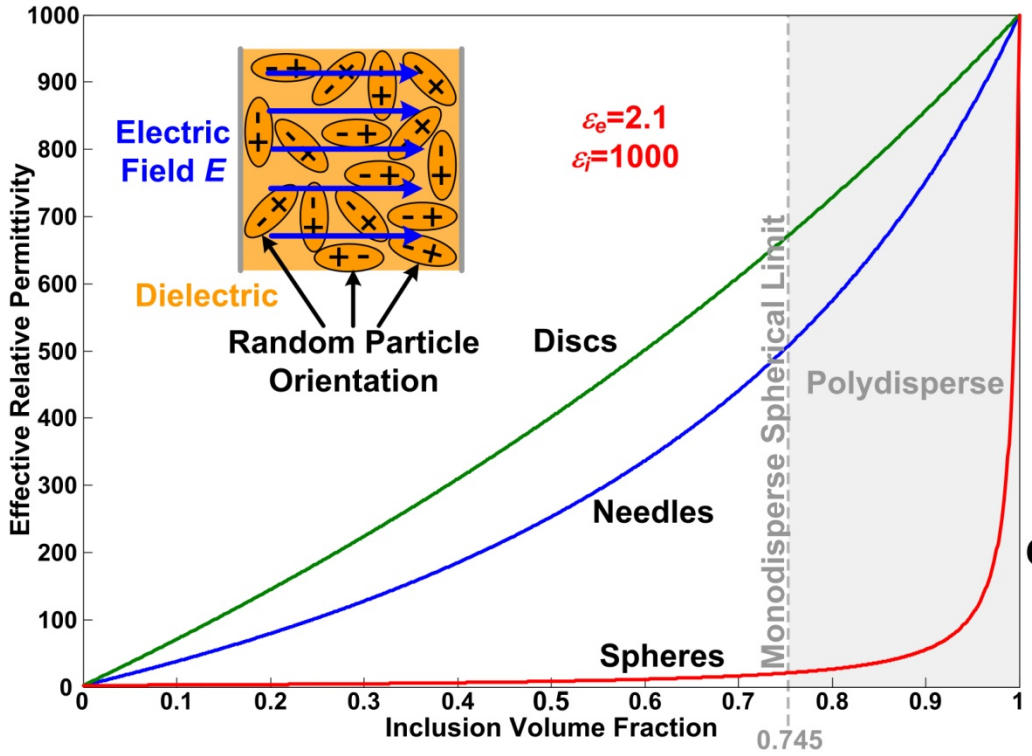
- No bias/control ‘wires’
- Continuous tuning
- No electrostatic discharge sensitivity
- Multifunctional

EFCD Characterization

Utilizing Dynamic Material/Fluidic-Based Material Systems

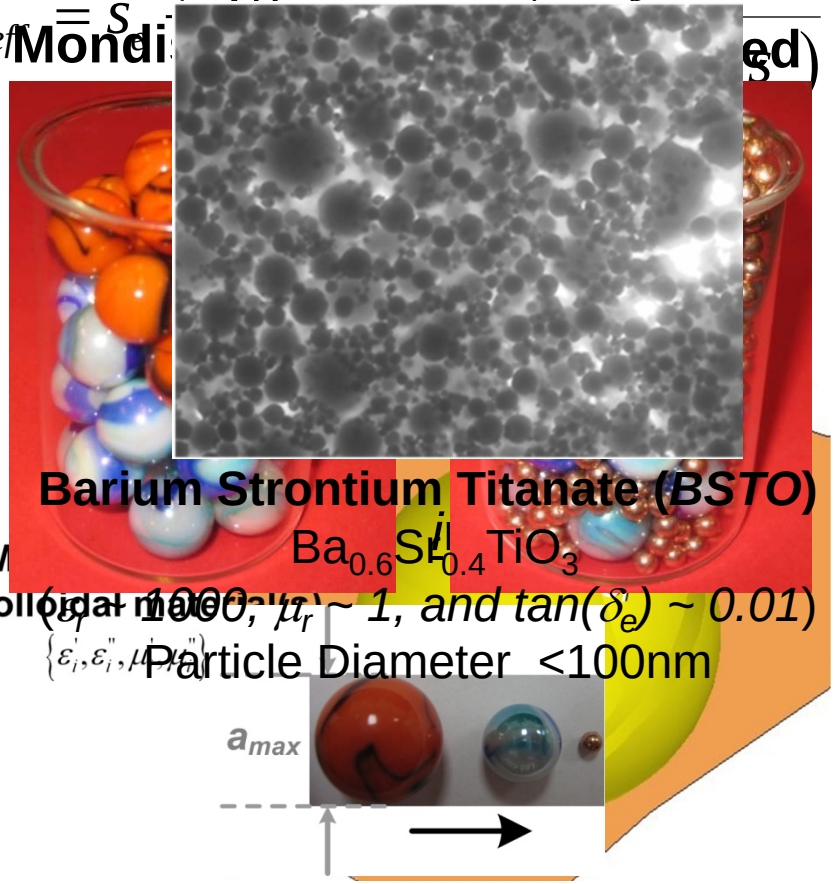
Maxwell-Garnett Mixing Rule

Good for dispersions of nanoparticles with different shapes and compositions



$$S_{eff} = S_e + 3\eta \frac{S_i - S_e}{3\eta + (1-\eta)\left(\frac{S_i}{S_e}\right)} \quad [4]$$

Mondi ... **ed**



Barium Strontium Titanate (*BSTO*)

$Ba_{0.6}Sr_{0.4}TiO_3$

(ε_i = 1000, μ_r ~ 1, and tan(δ_e) ~ 0.01)

Particle Diameter <100nm

Colloidal mixture

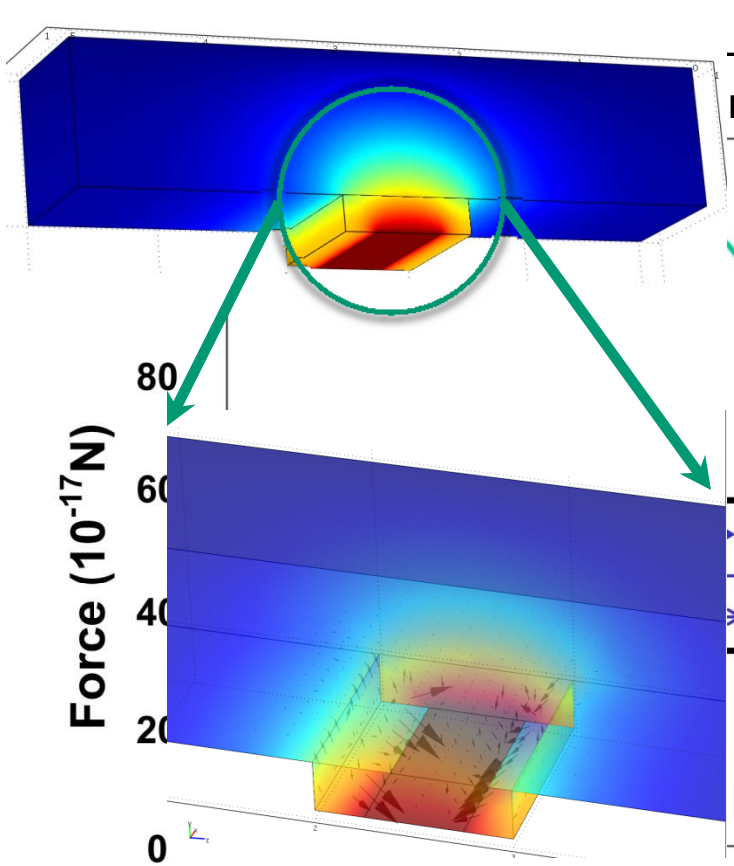
$\{\varepsilon_i', \varepsilon_i'', \mu_i', \mu_i''\}$

a_{max}

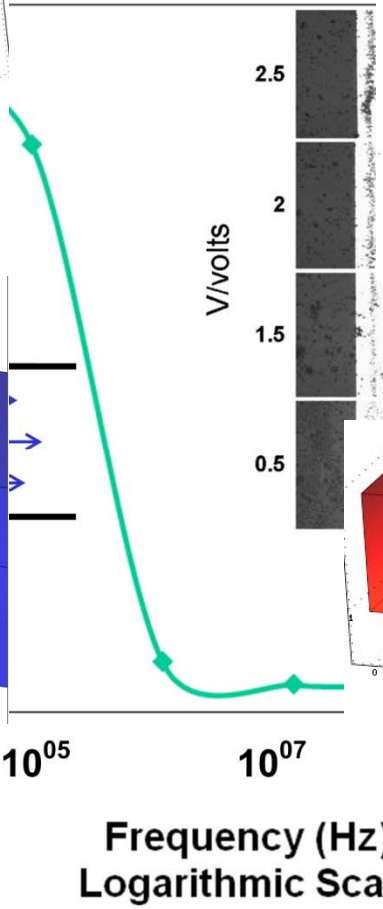
Dielectrophoresis Force Models

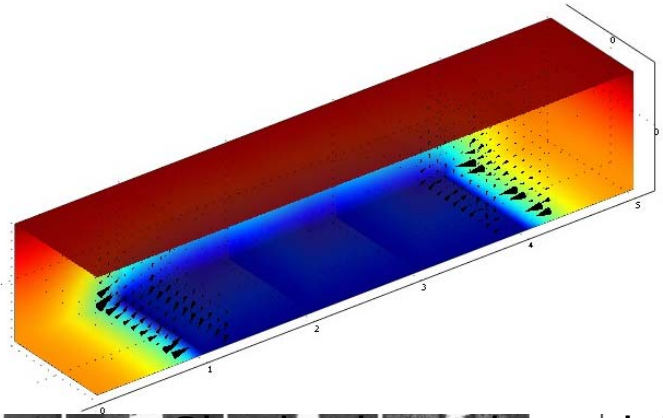
Kinetic Behavior of Nanoparticles

-dependent kinetic b
more advanced sys
in

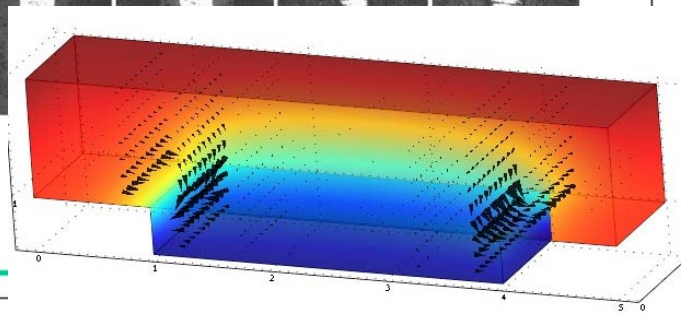


Thin reservoir model





Simple electrode model

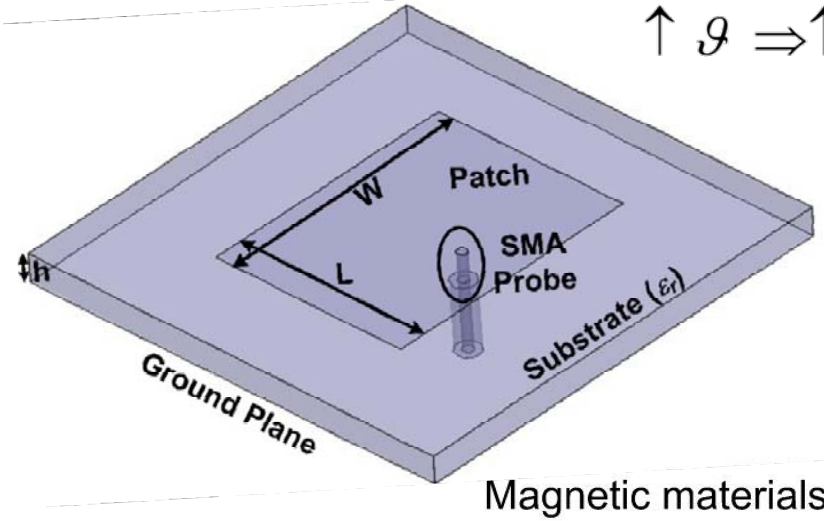


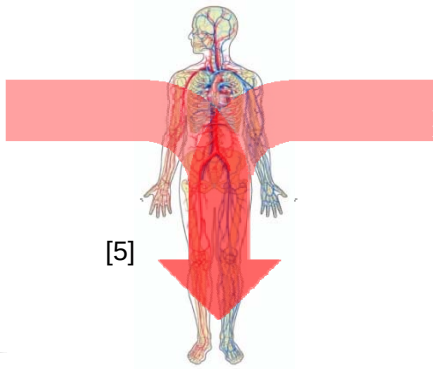
Wide reservoir model

EFCD Integration in Antenna

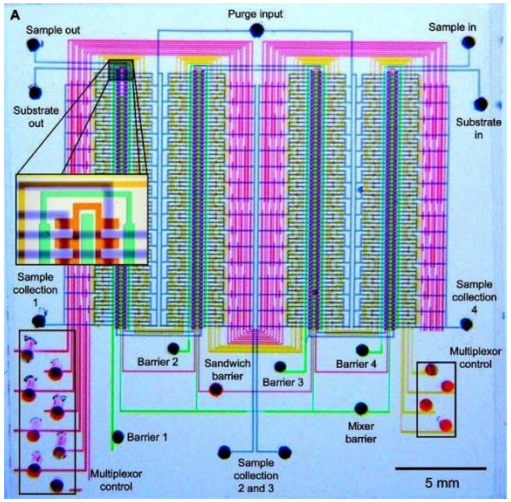
Frequency Reconfiguration of Single Antenna Element

$$\uparrow \vartheta \Rightarrow \uparrow \mu_{eff}, \uparrow \varepsilon_{eff} \Rightarrow \uparrow \beta_{eff} \Rightarrow \uparrow L_{eff}, \downarrow f_0$$

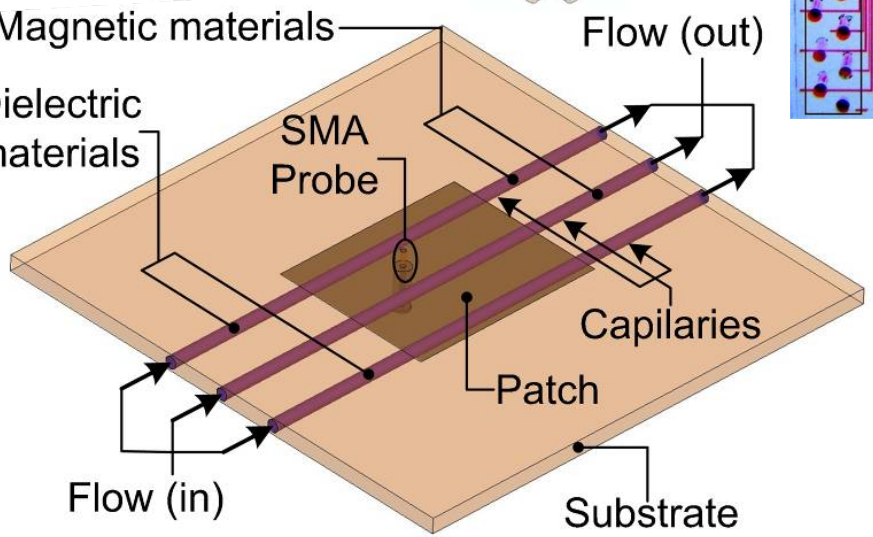




[5]



[Thorson, 2002]



Analytical Modeling

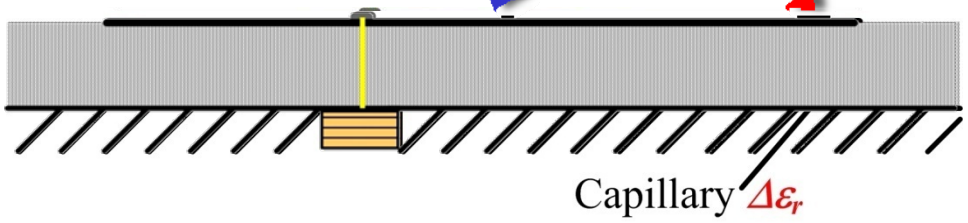
Where to place a network of pressure driven capillaries?

Material perturbation theory [6]

$$\frac{f - f_o}{f_o} \approx -\frac{\iiint \left(\Delta\varepsilon \left(\vec{E} \cdot \vec{E}_o^* \right) + \Delta\mu \left(\vec{H} \cdot \vec{H}_o^* \right) \right) d\tau}{\iiint \left(\varepsilon \vec{E} \cdot \vec{E}_o^* + \mu \vec{H} \cdot \vec{H}_o^* \right) d\tau}$$

Center if magnetic

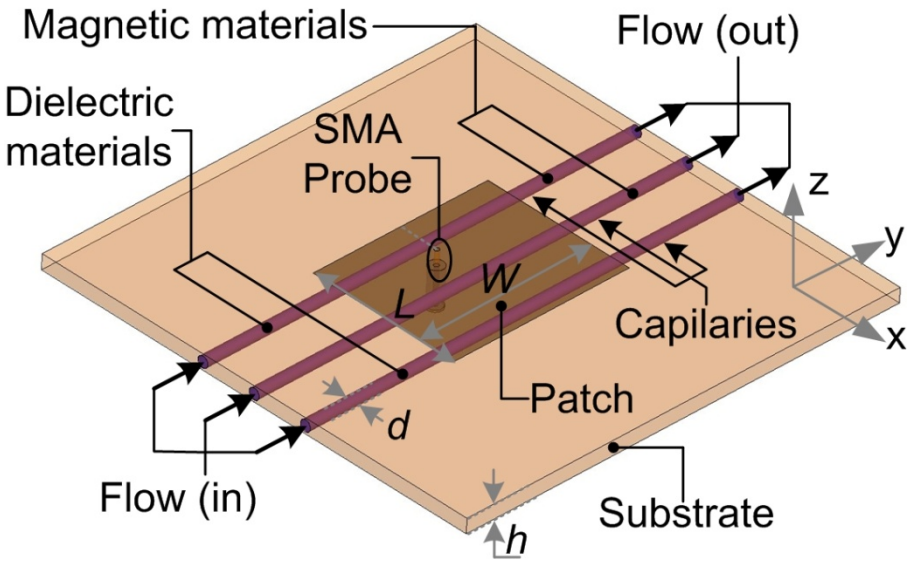
Radiating edge if dielectric

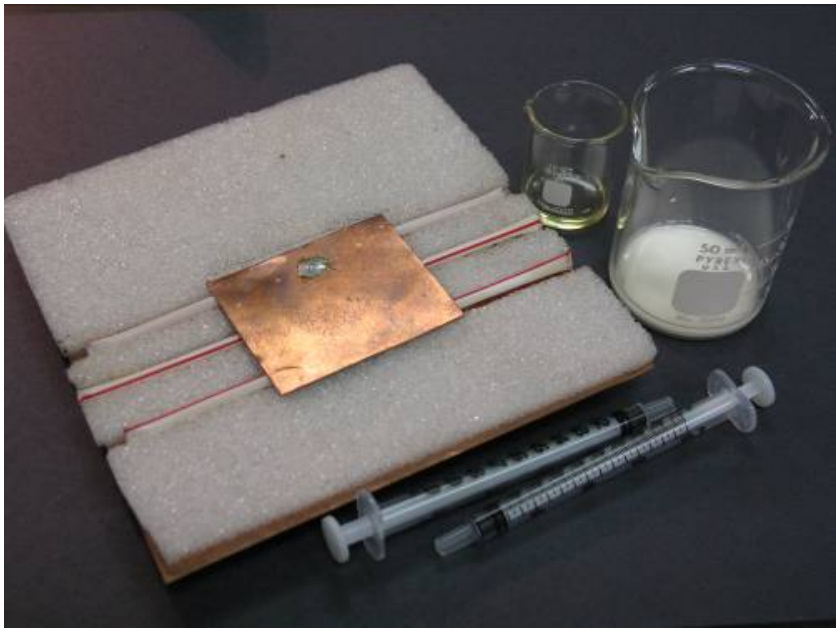


The placement and orientation of the capillary depends on the dominant constitutive parameter and its corresponding modal field distribution.

Physical Model

Microstrip Patch: Experimental Model (3 GHz Design)



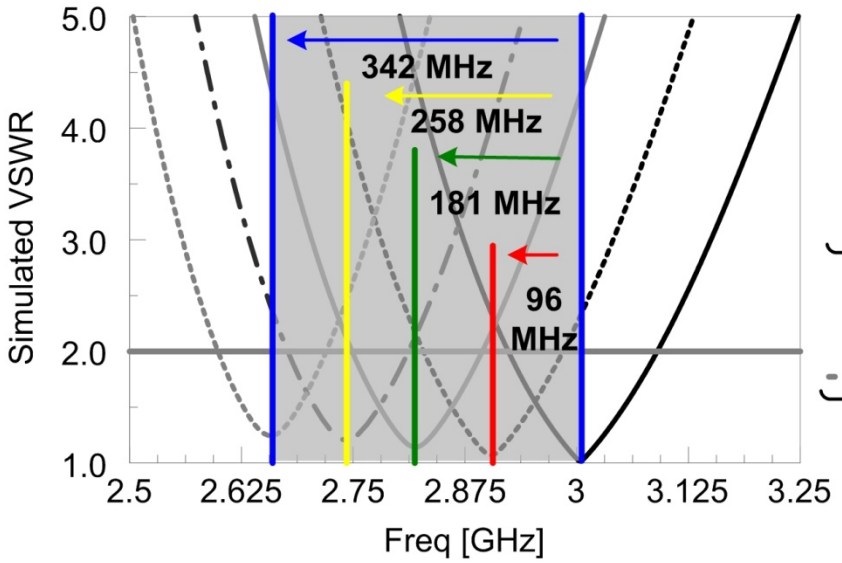


Dimensions (mm)

d	*L*	*W*	*h*
3.0	43.5	50.0	4.0

***EFCD* is 100 nm diameter colloidal Barium Strontium Titanate ($Ba_{0.6}Sr_{0.4}TiO_3$) dispersed in low viscosity, low loss petroleum distillate (oil)**

Results

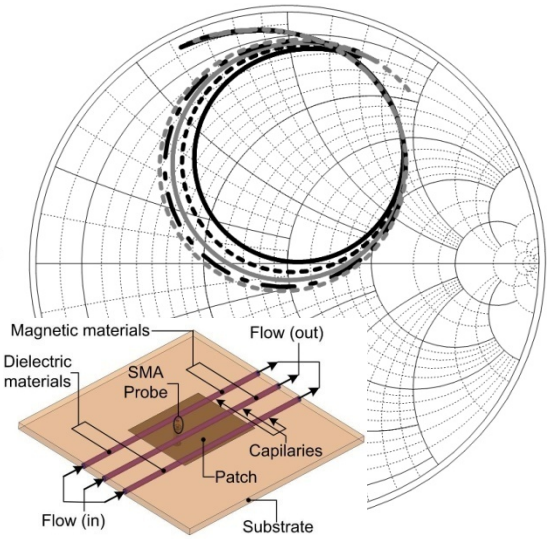


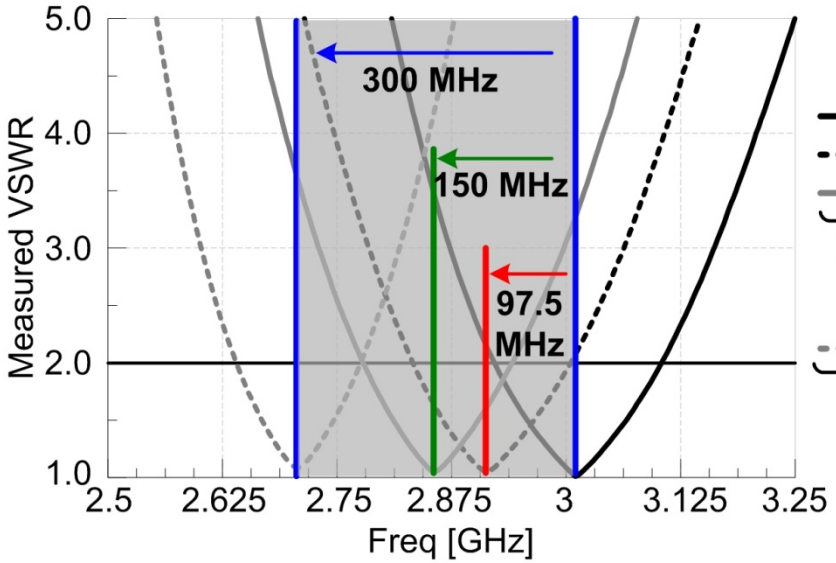
$\vartheta = 0$ ($\varepsilon_r = 2.1$)
$\vartheta = 0.25$ ($\varepsilon_r = 4.1$)
$\vartheta = 0.5$ ($\varepsilon_r = 8.3$)
$\vartheta = 0.745$ ($\varepsilon_r = 20$)

Petroleum distillate oil and colloidal $Ba_{0.6}Sr_{0.4}TiO_3$

$\vartheta_{Limit} = 0.925$ ($\varepsilon_r = 80$)

DI water



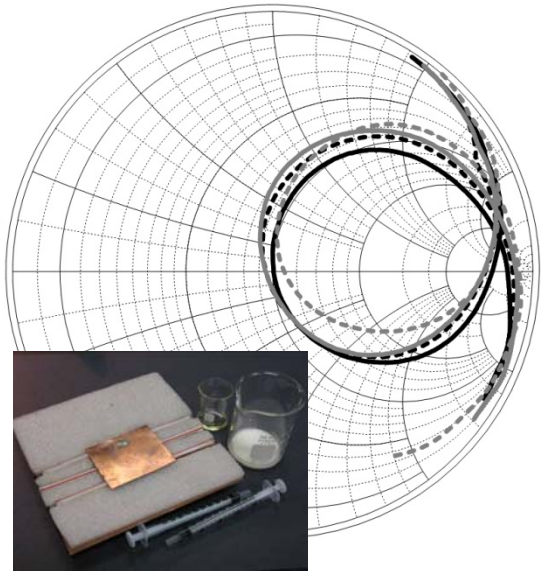


$\vartheta \sim 0$ ($\varepsilon_r \sim 2.1$)
$\vartheta \sim 0.25$ ($\varepsilon_r \sim 4.1$)
$\vartheta \sim 0.5$ ($\varepsilon_r \sim 8.3$)

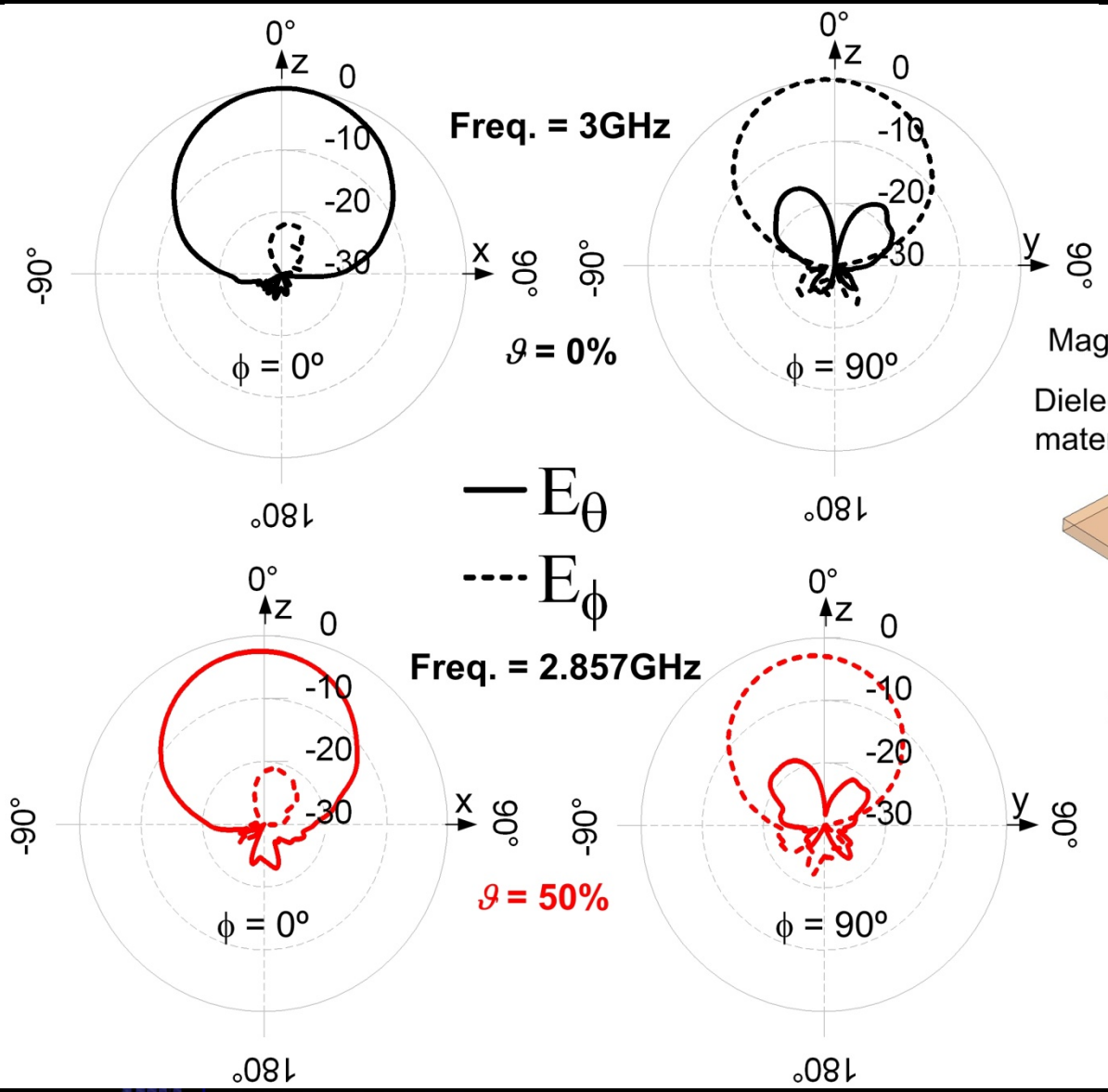
Petroleum distillate oil and colloidal $Ba_{0.5}Sr_{0.5}TiO_3$

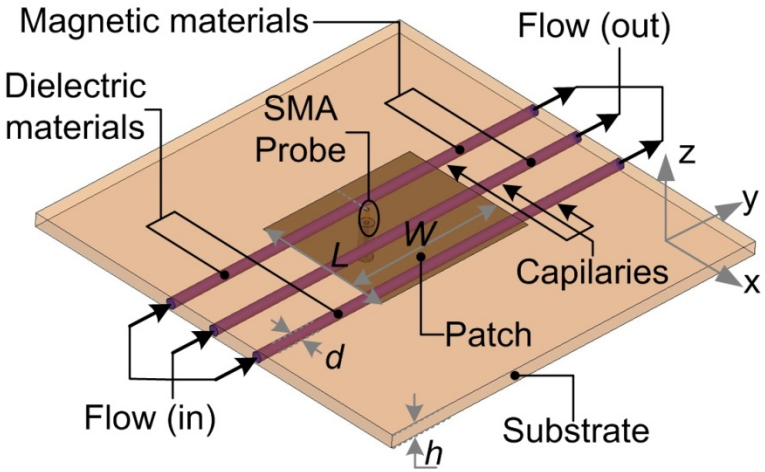
$\vartheta_{Limit} \sim 0.925$ ($\varepsilon_r \sim 80$)

DI water



Measured Results

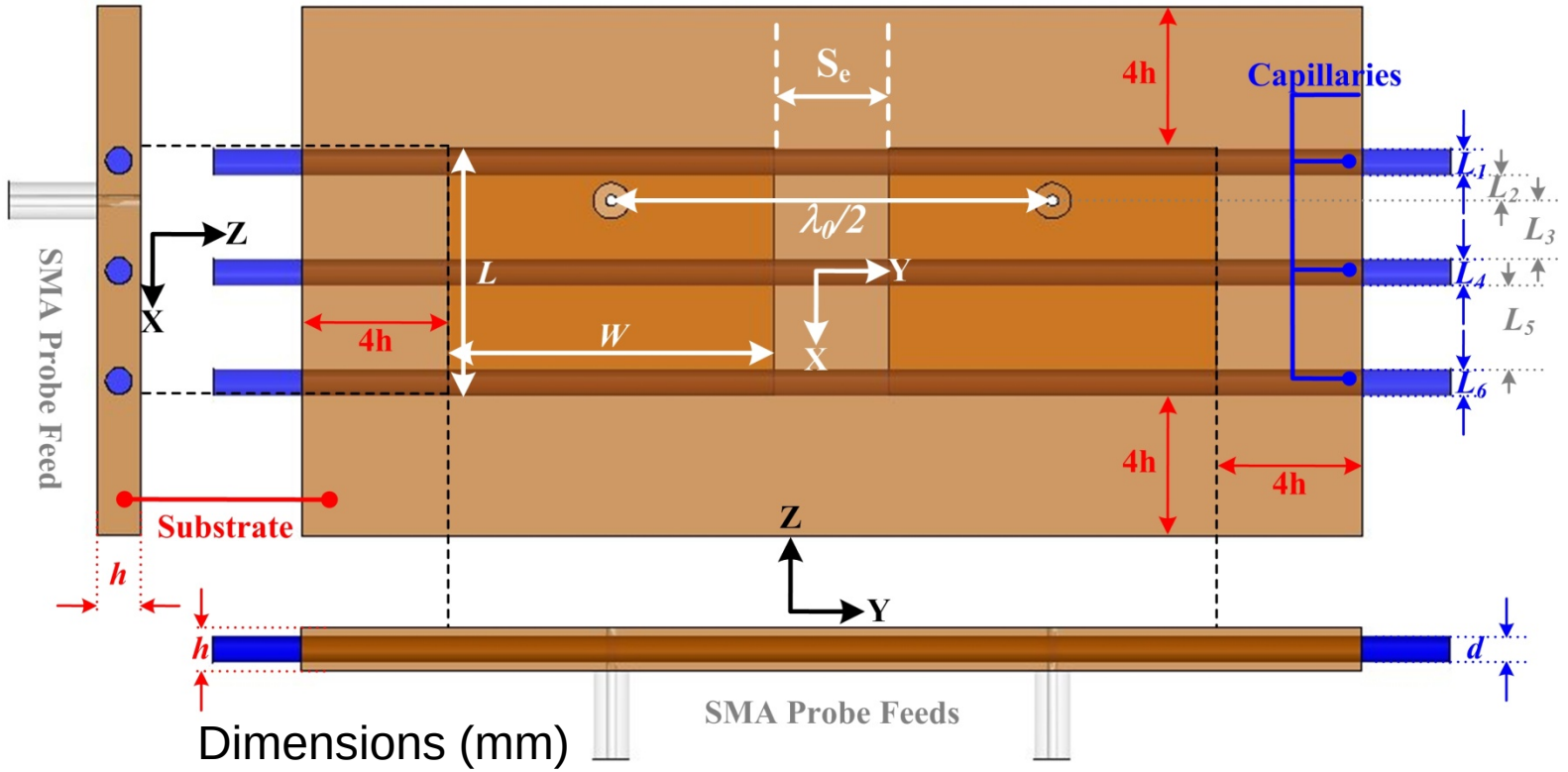




Small Array Behavior (H-Plane)

Microstrip Patch Array: Experimental Model (3 GHz Design)

3 capillary structures filled with identical volume fractions of magnetodielectric *colloidal material* in *liquid* to reconfigure the frequency of the patches on a PDMS dielectric



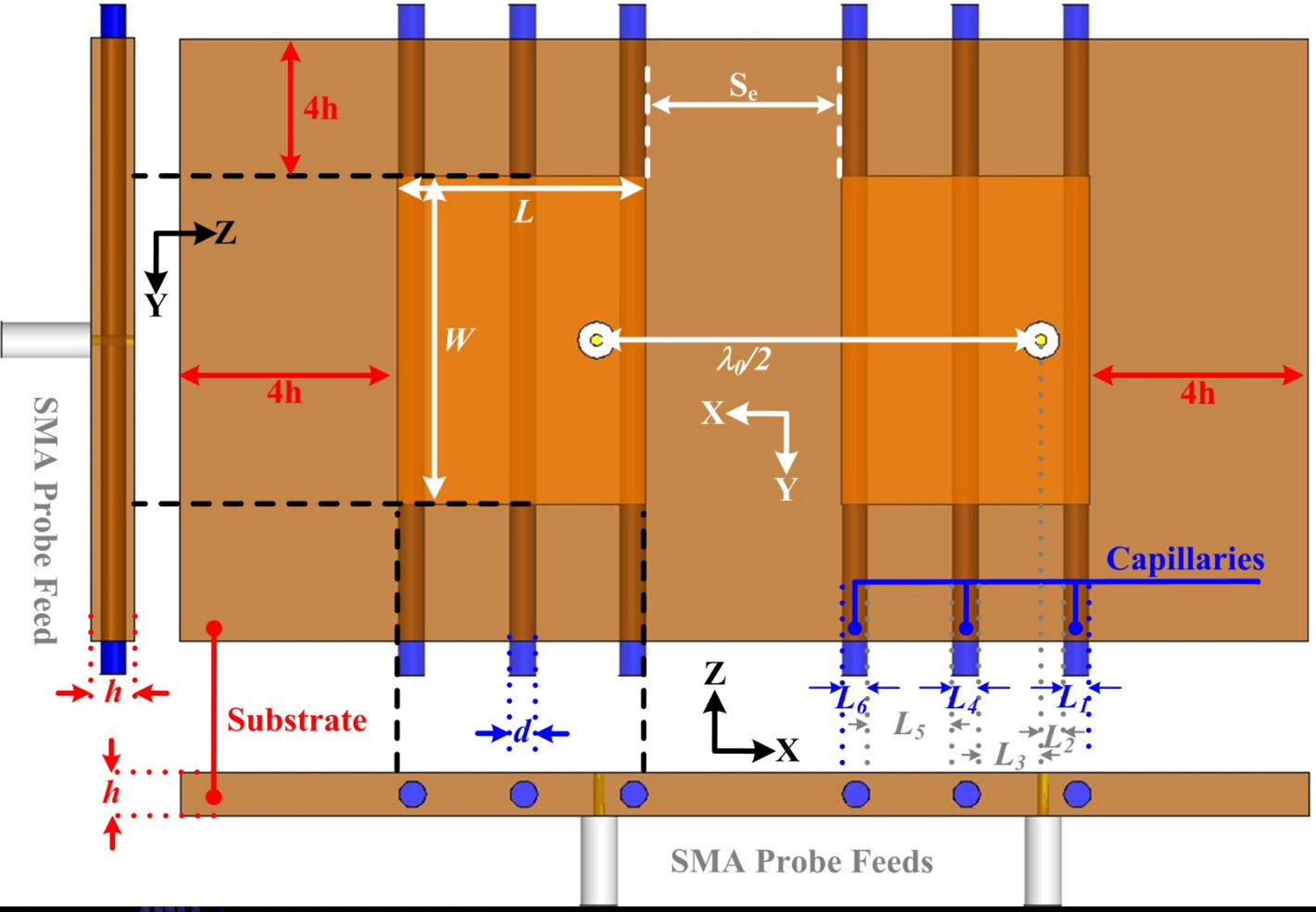
Dimensions (mm)

L_1	L_2	L_3	L_4	L_5	L_6	L	W	h	d	S_e
3.0	3.0	6.5	3.0	9.5	3.0	28	37	5	3	15

Small Array Behavior (E-Plane)

Microstrip Patch Array: Experimental Model (3 GHz Design)

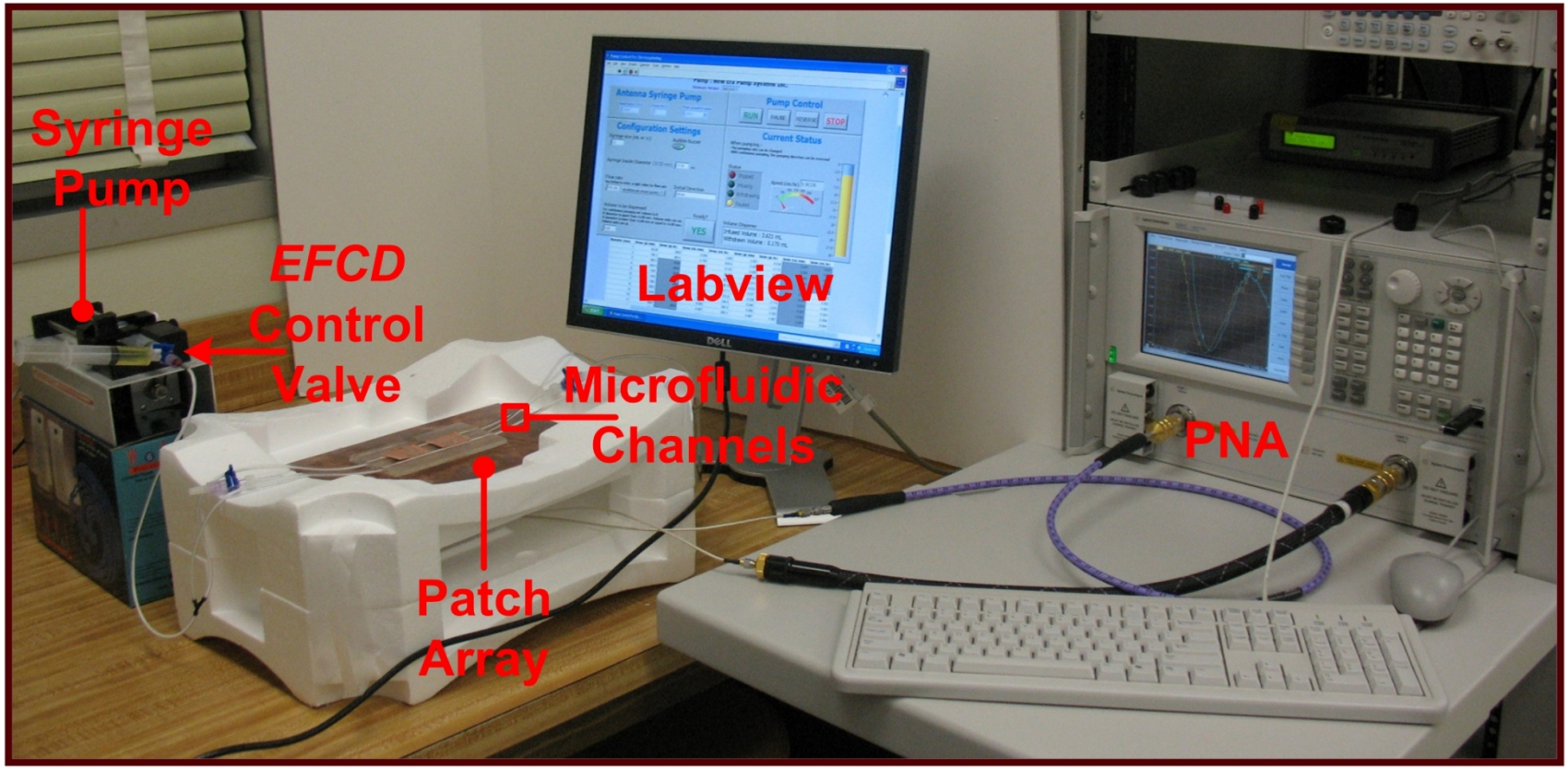
3 capillary structures filled with identical volume fractions of magnetodielectric *colloidal material* in *liquid* to reconfigure the frequency of the patches on a PDMS dielectric



Dimensions (mm)

L_1	L_2	L_3	L_4
3.0	3.0	6.5	3.0
L_5	L_6	L	W
9.5	3.0	28	37
h	d	S_e	
5	3	22	

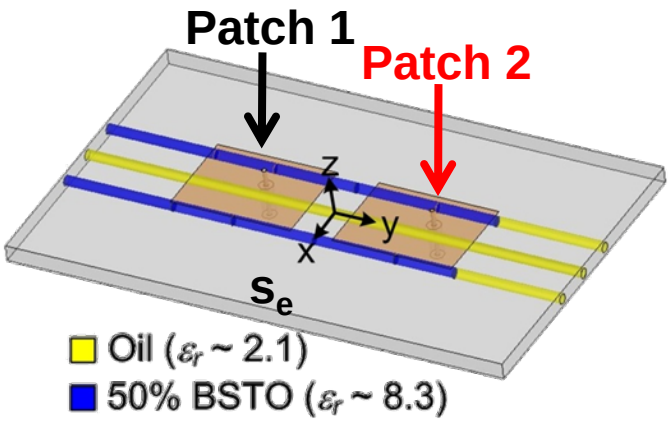
Antenna Design and Fabrication



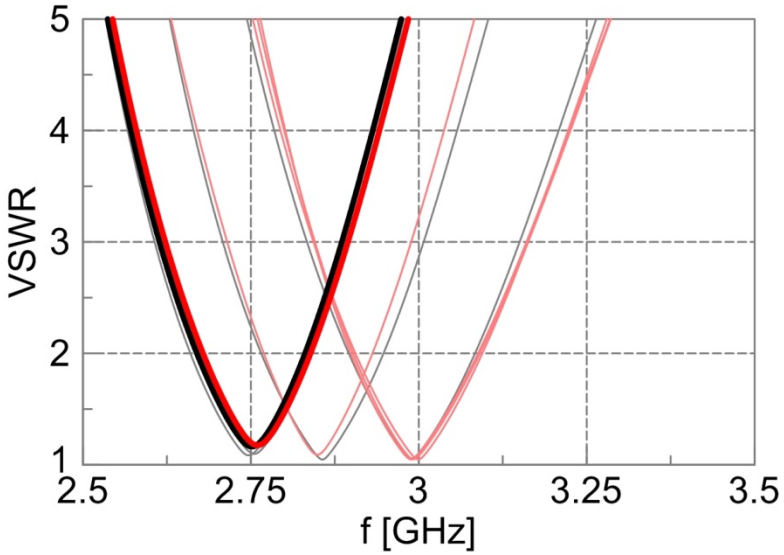
Entire Reconfigurable Antenna Setup

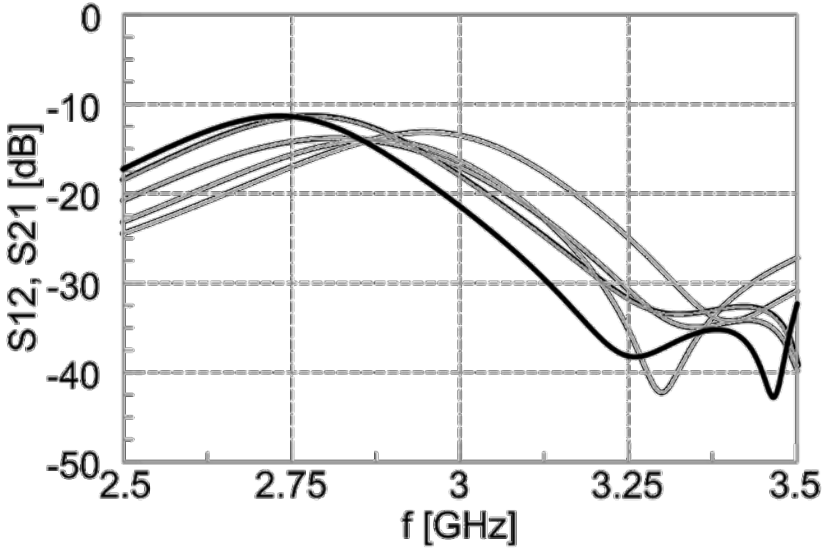
- System connected by tubing, valves and Y-splitters.
- Inner capillary of antenna filled with oil.
- *EFCD* material flows through outer capillaries of antenna.

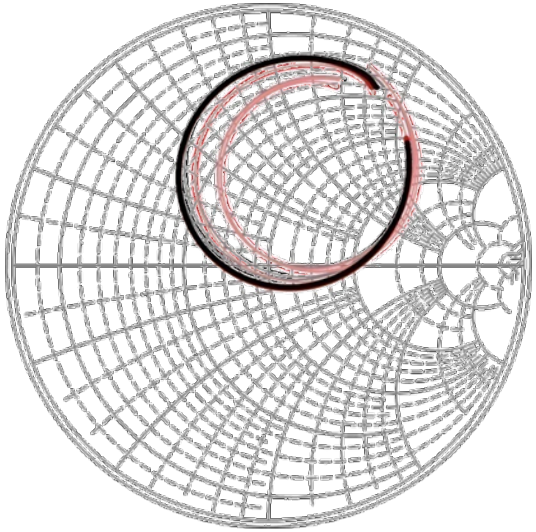
H-Plane Array Simulation



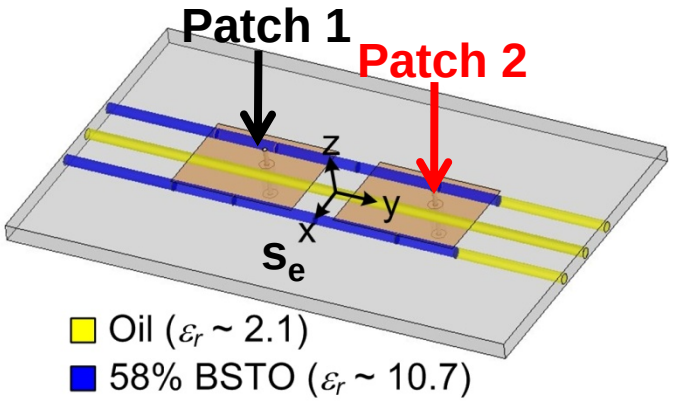
S_e = Edge to edge element spacing 15 mm

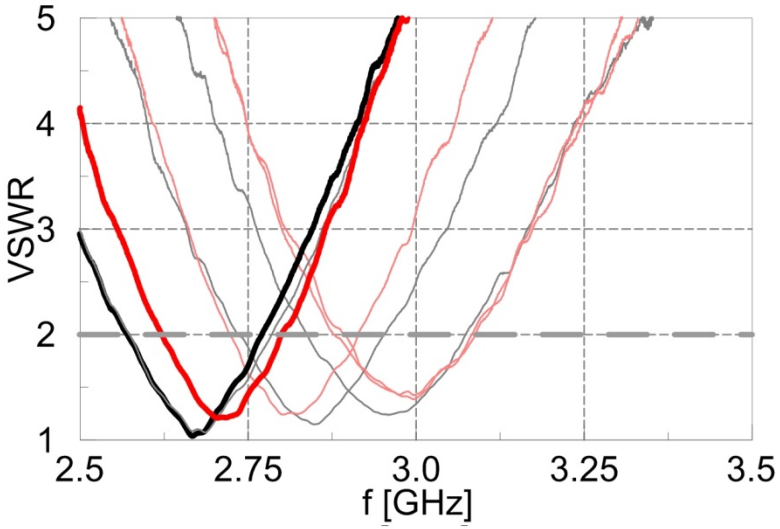




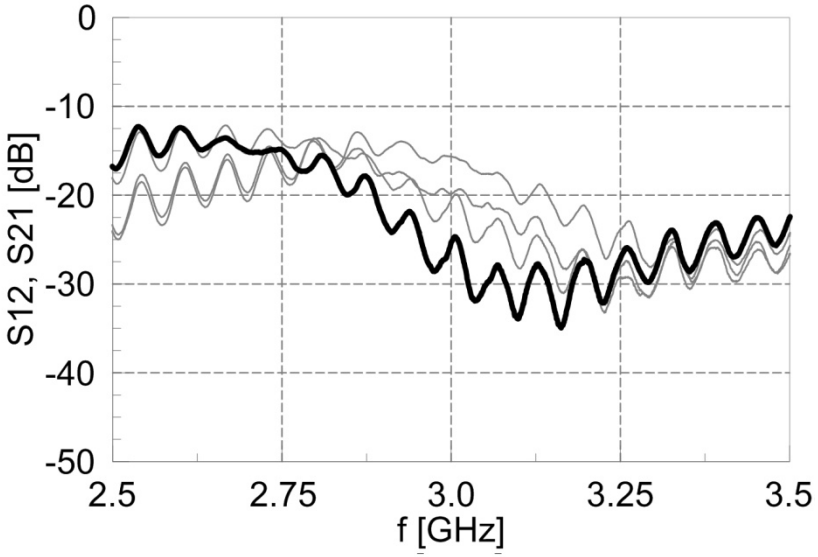


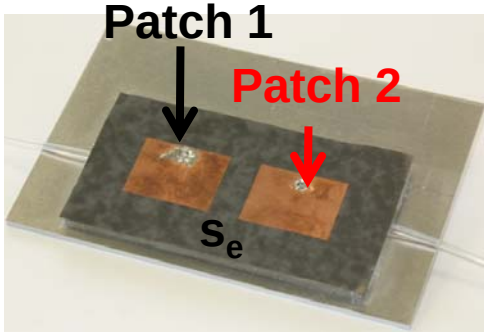
H-Plane Array Results

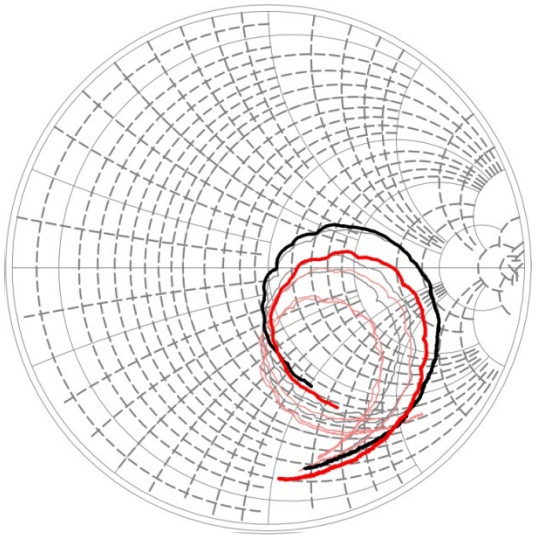




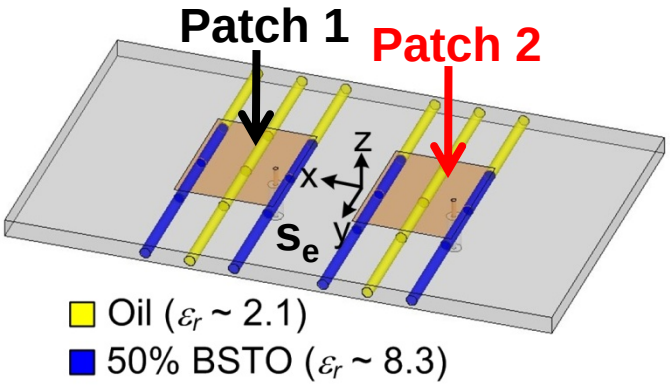
S_e = Edge to edge element spacing 15 mm



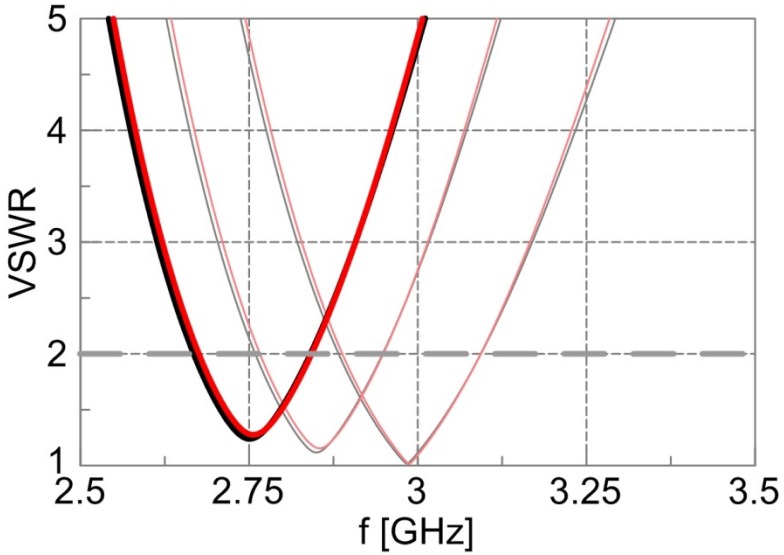


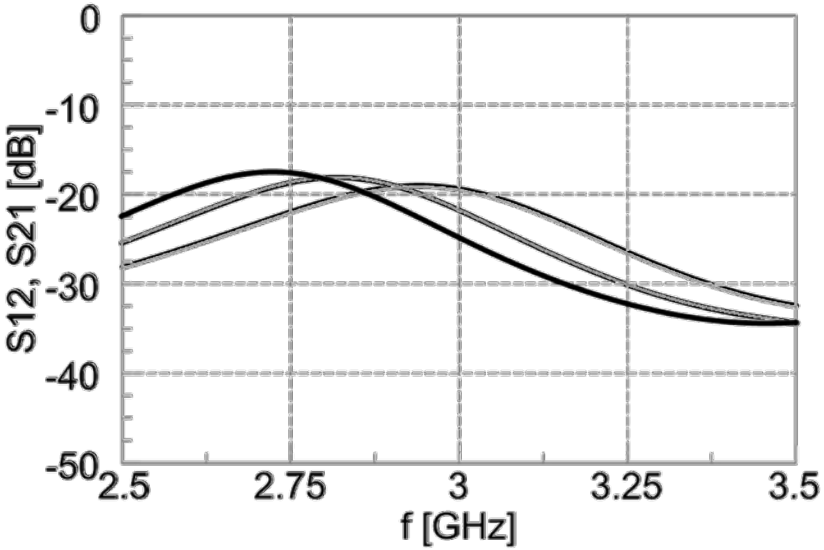


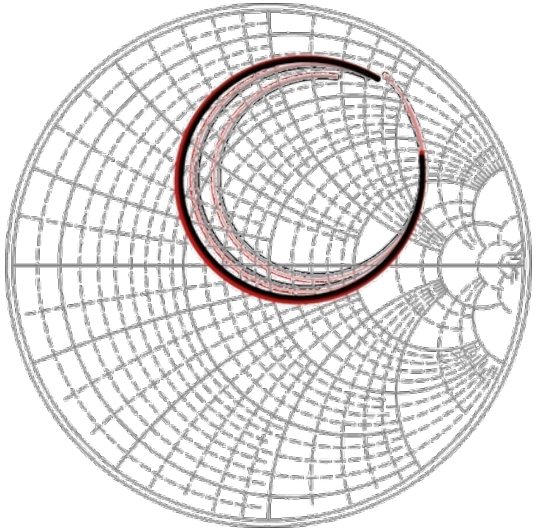
E-Plane Array Simulation



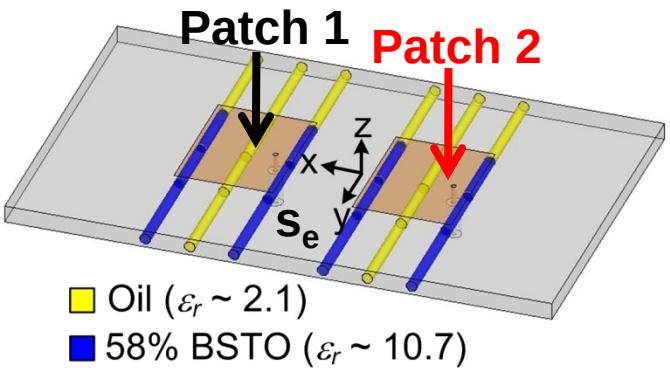
s_e = Edge to edge element spacing 22 mm

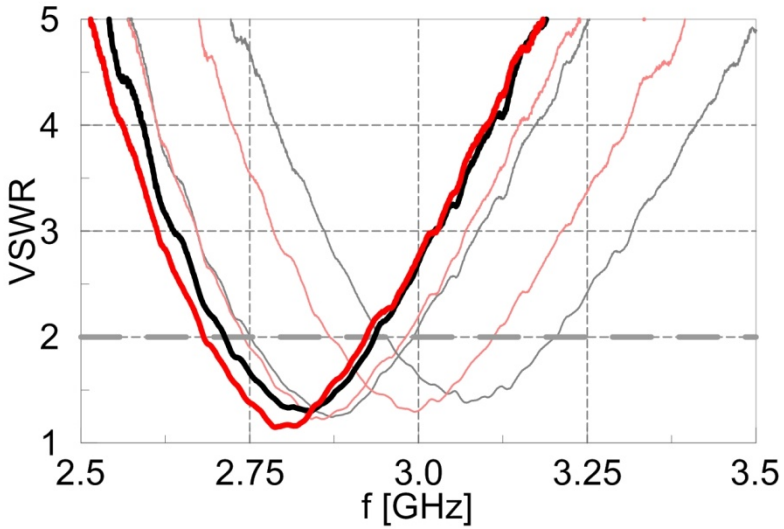




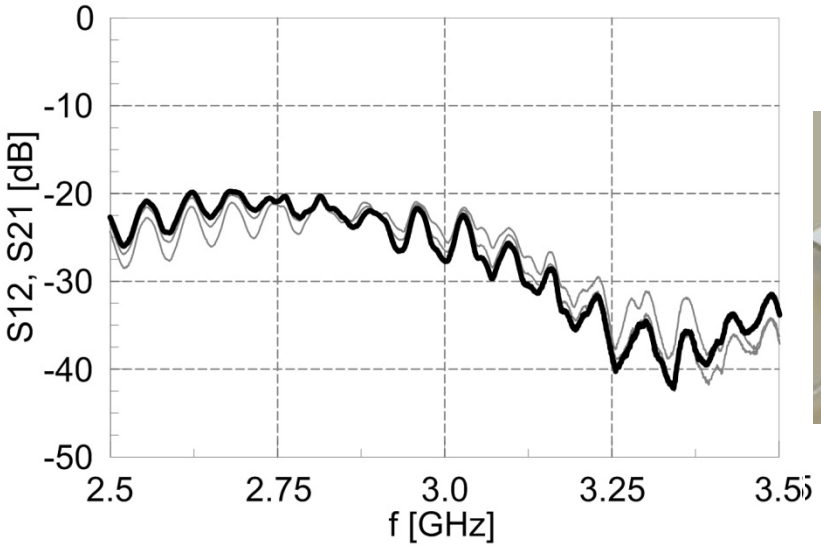


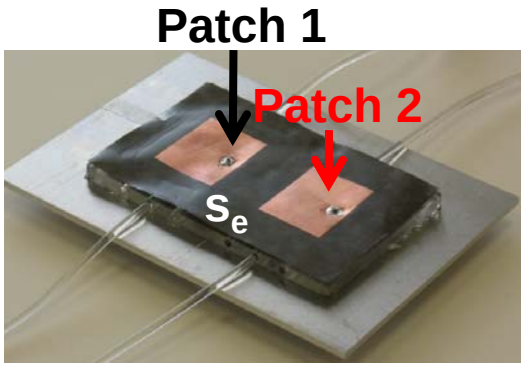
E-Plane Array Results

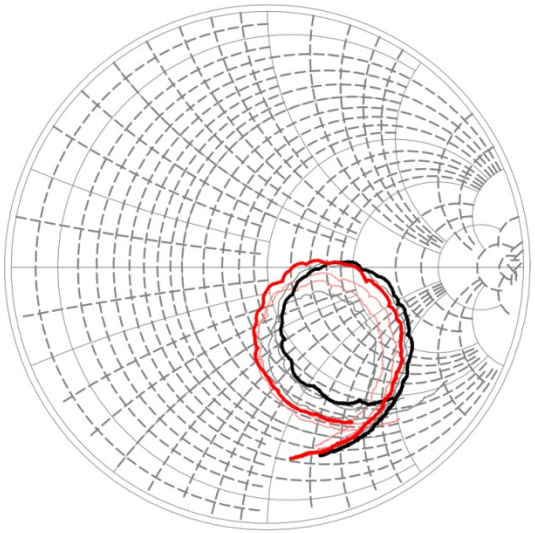




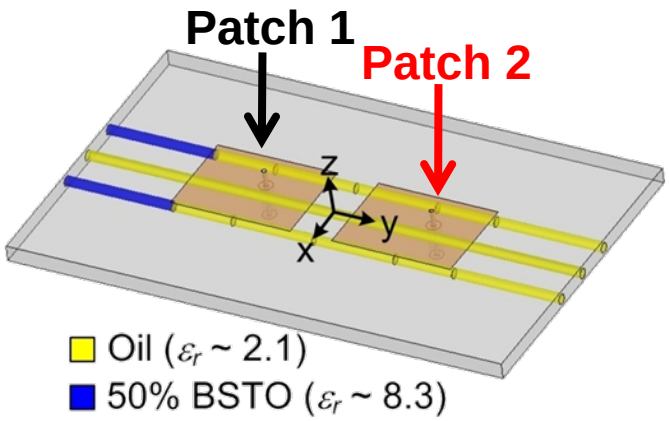
s_e = Edge to edge element spacing 22 mm

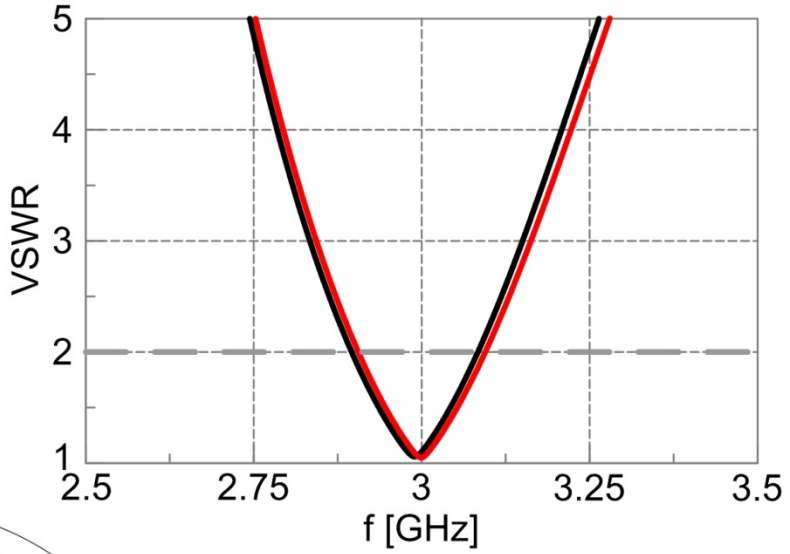


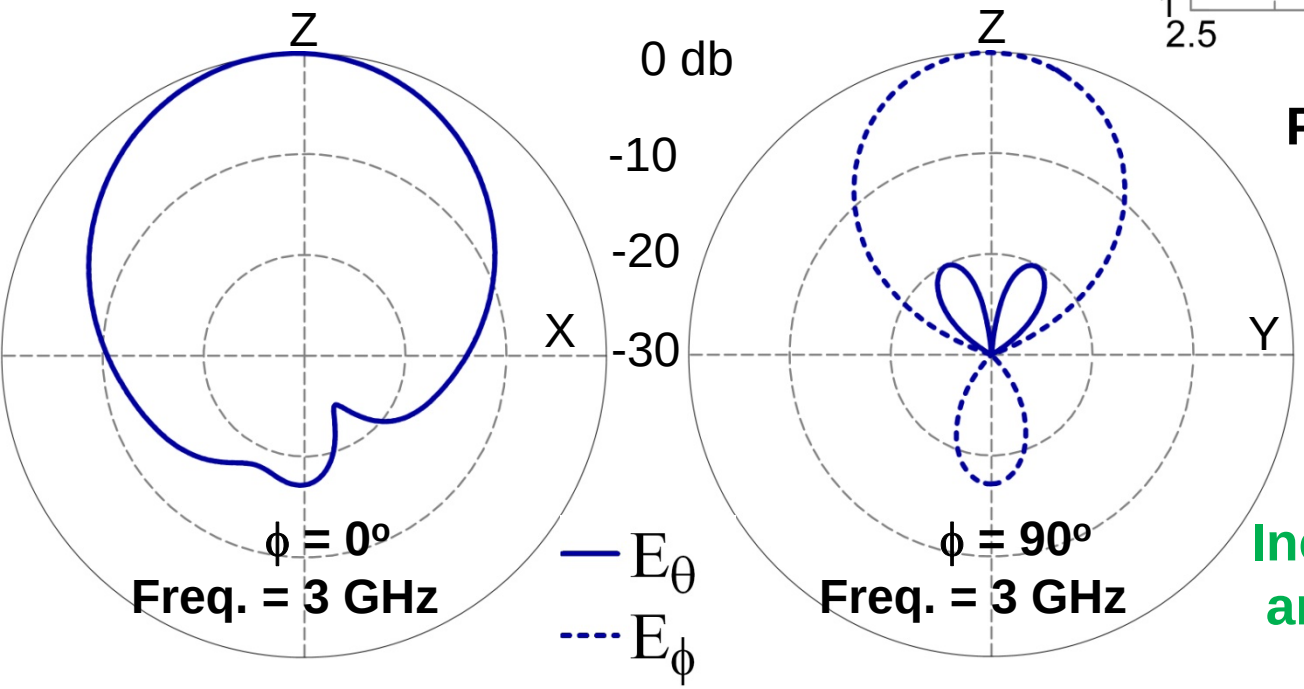




H-Plane Array Simulation







Patch 1 and patch 2 in phase

$$\frac{1}{N}\left\{\frac{\sin\left[\frac{N}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}{\sin\left[\frac{1}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}\right\}$$

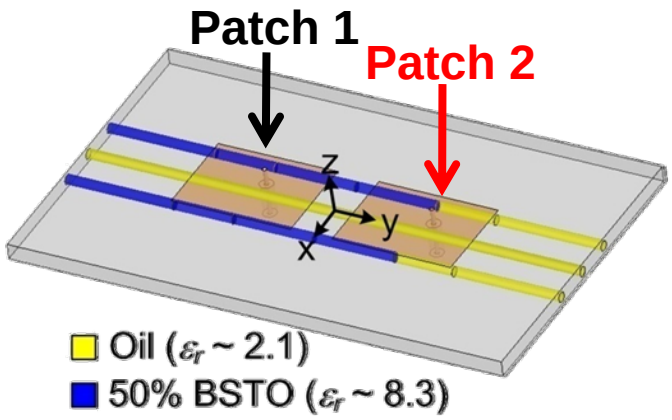
$N = 2$

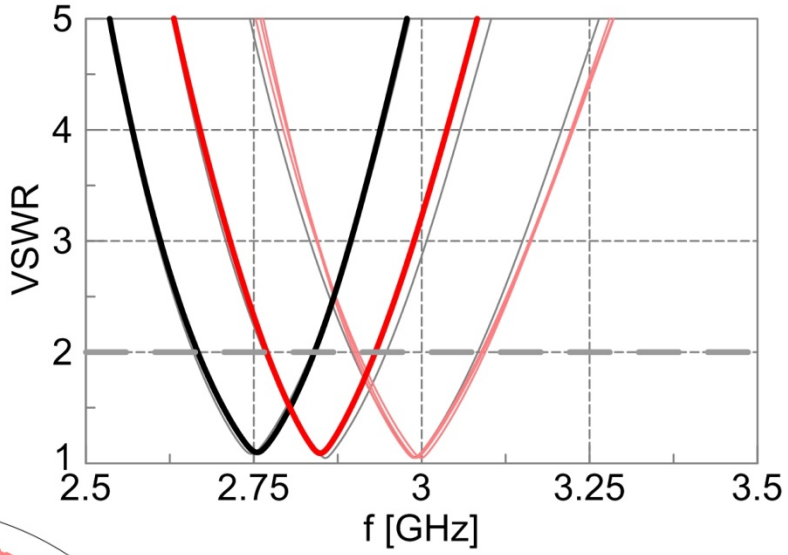
$d = 50mm$

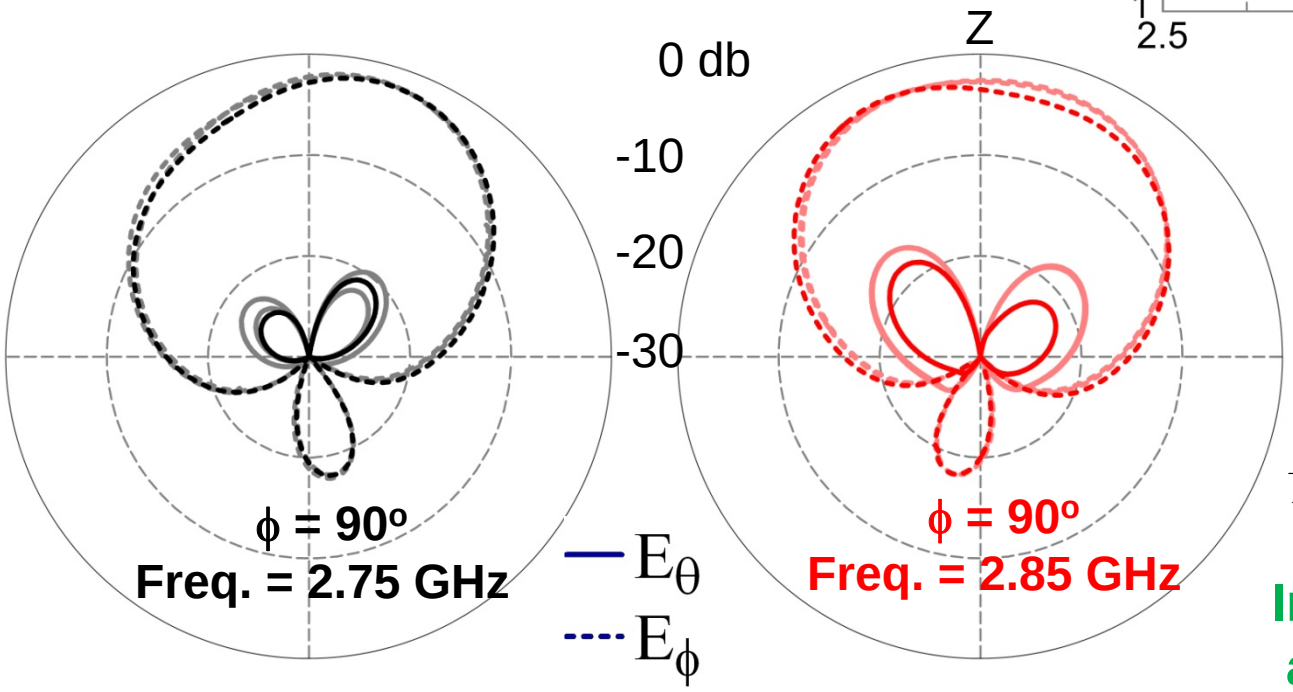
$$\lambda_{eff} = \frac{c}{f_o\sqrt{\mu_{rcm}\varepsilon_{rcm}}}$$

Increase in beam width and decrease in gain

H-Plane Array Simulation







Patch 1 and patch 2 out of phase

$$\frac{1}{N}\left\{\frac{\sin\left[\frac{N}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}{\sin\left[\frac{1}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}\right\}$$

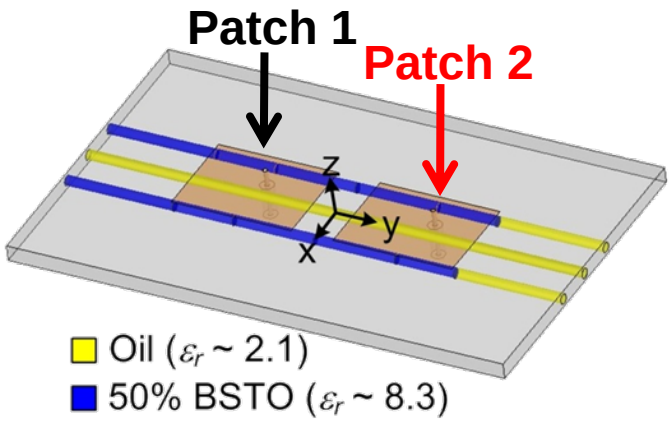
$N = 2$

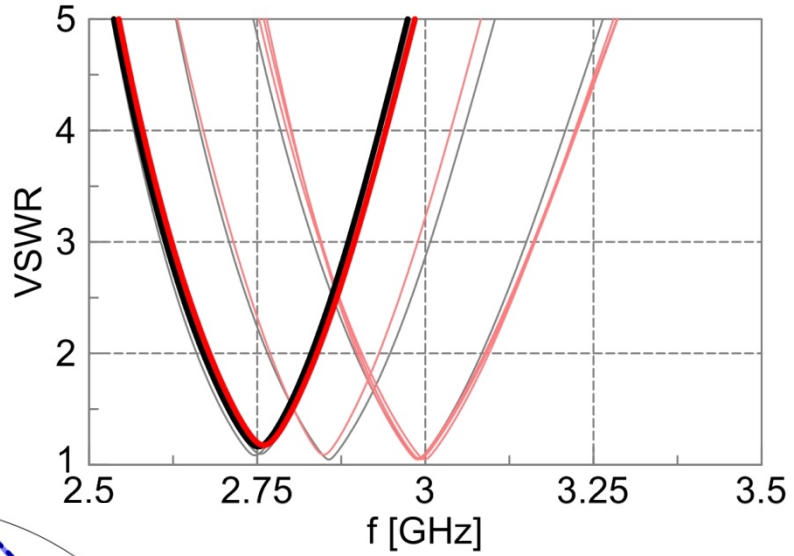
$d = 50mm$

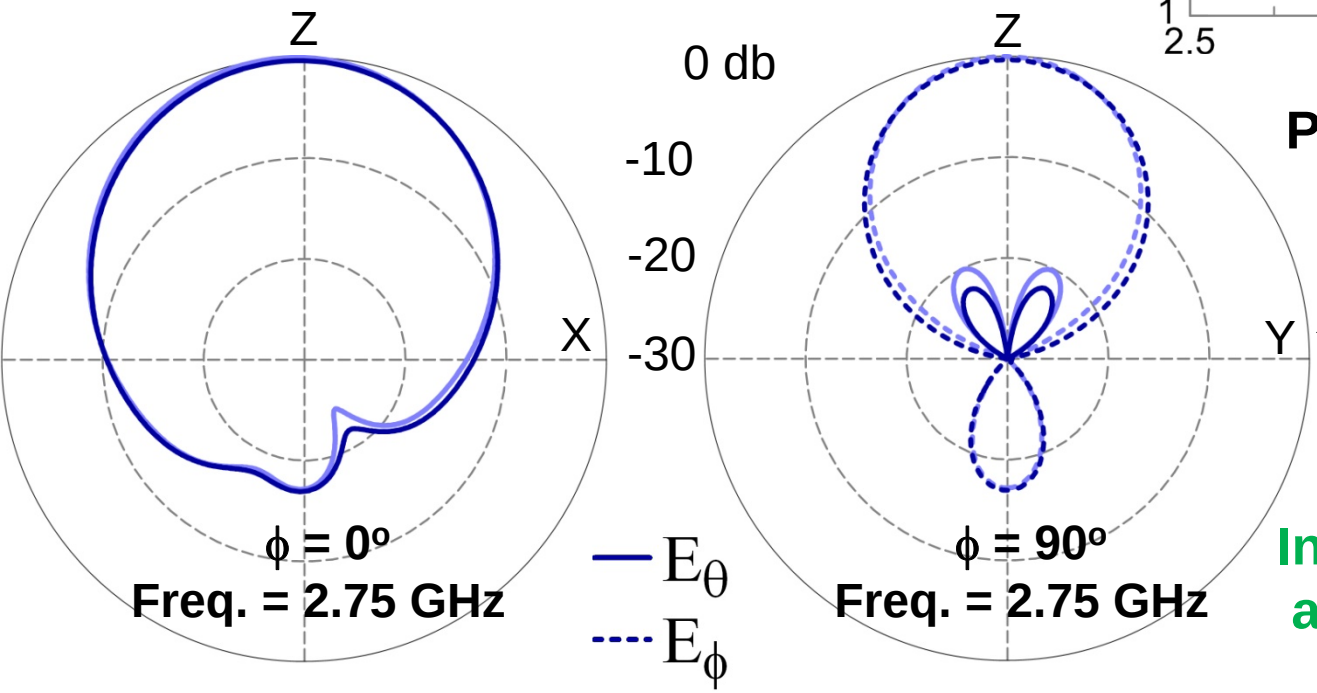
$$\lambda_{eff} = \frac{c}{f_o\sqrt{\mu_{rcm}\varepsilon_{rcm}}}$$

Increase in beam width and decrease in gain

H-Plane Array Simulation







Patch 1 and patch 2 in phase

$$\frac{1}{N}\left\{\frac{\sin\left[\frac{N}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}{\sin\left[\frac{1}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}\right\}$$

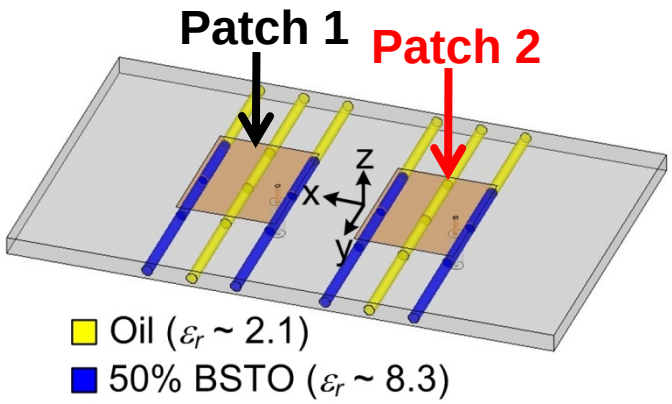
$N = 2$

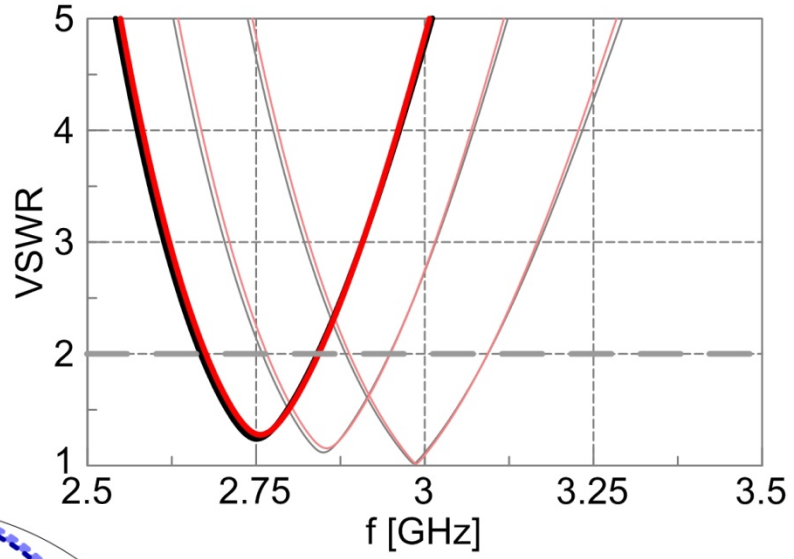
$d = 50mm$

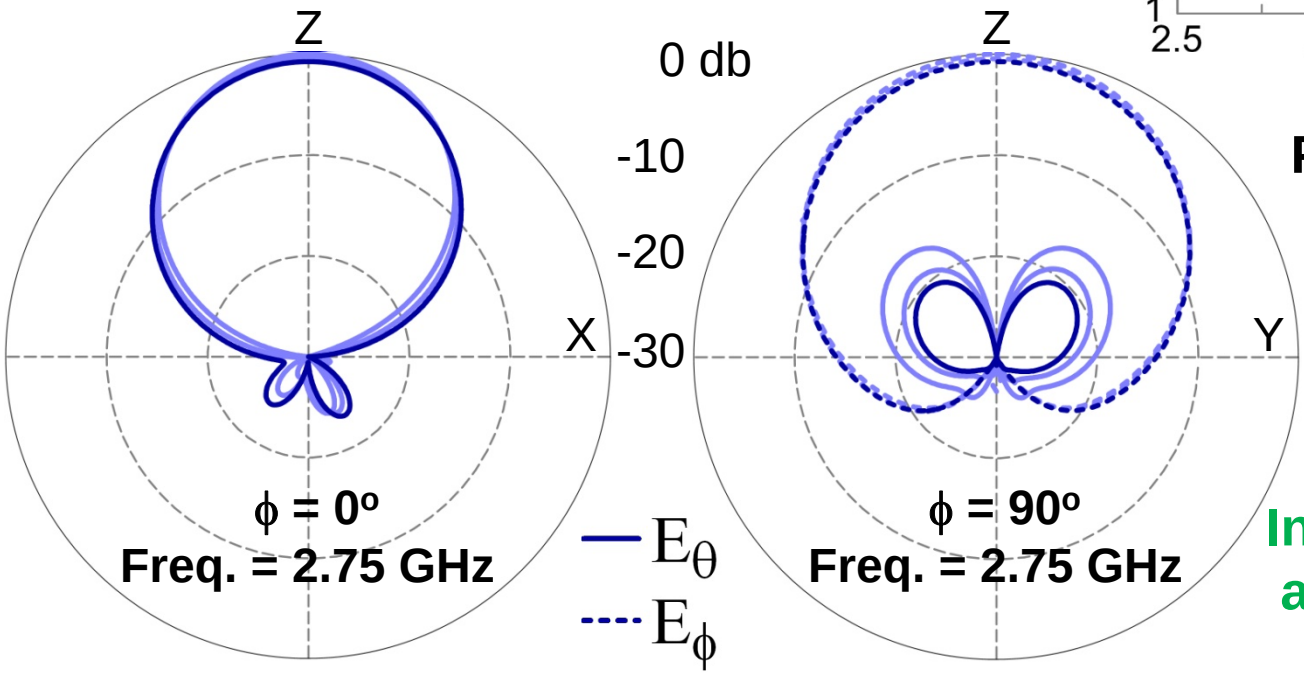
$$\lambda_{eff} = \frac{c}{f_o\sqrt{\mu_{rcm}\varepsilon_{rcm}}}$$

Increase in beam width and decrease in gain

E-Plane Array Simulation







Patch 1 and patch 2 in phase

$$\frac{1}{N}\left\{\frac{\sin\left[\frac{N}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}{\sin\left[\frac{1}{2}\left(\frac{2\pi}{\lambda_{eff}}d\cos\theta+\Phi\right)\right]}\right\}$$

$N = 2$

$d = 50mm$

$$\lambda_{eff} = \frac{c}{f_o\sqrt{\mu_{rcm}\varepsilon_{rcm}}}$$

Increase in beam width and decrease in gain

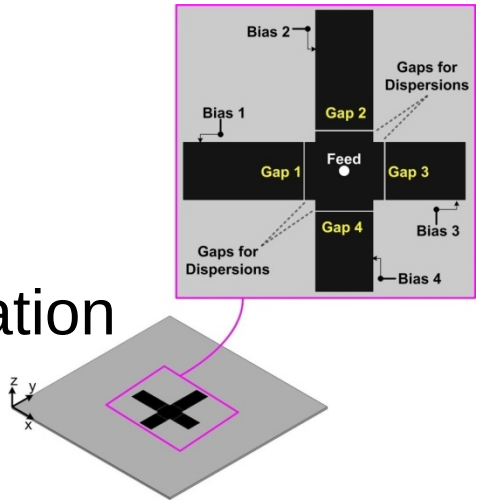
Summary and Future Research

Dielectrophoresis

- Design guidelines
- Fabrication

Single Element Reconfiguration

- Analytical verification
- 300 MHz Frequency shift



Polarization Reconfiguration

NASA KC-135 [8]

Small Array Behavior

- Orientation variation
- H-plane 292.5 MHz Frequency shift
- E-plane 230.6 MHz Frequency shift

- Feasibility testing of system in dynamic/harsh environment
- Micro gravity testing
- Pattern and polarization reconfiguration
- Software defined radio

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[13] WD-40, 3in1 Oil©, San Diego, CA.

Frequency Reconfiguration of a Small Array Enabled by Functionalized Dispersions of Colloidal Materials

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