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Novel Electromagnetic Media for Future HEP Accelerators

Prof R Seviour

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- 77K Superconducting materials – Proximity effect (Nb sputtered on HTC)
- Alloy composites – High temperature, low loss, higher conductivity
- III-IV’s – Solid state RF (SiC)
- Photonics – Acceleration/Amplification

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- Alloy composites – High temperature, low loss, higher conductivity
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- Photonics – Acceleration/Amplification
- Artificial EM Materials – (Artificial Dielectrics, Metamaterials)

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$$\hat{B} = \mu_0 \hat{H} + M = \mu \hat{H}$$

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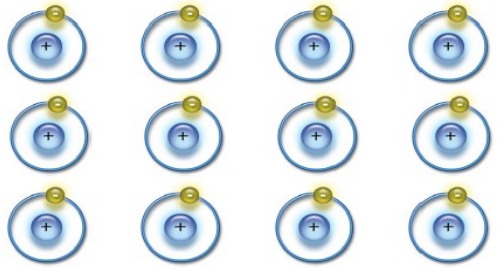

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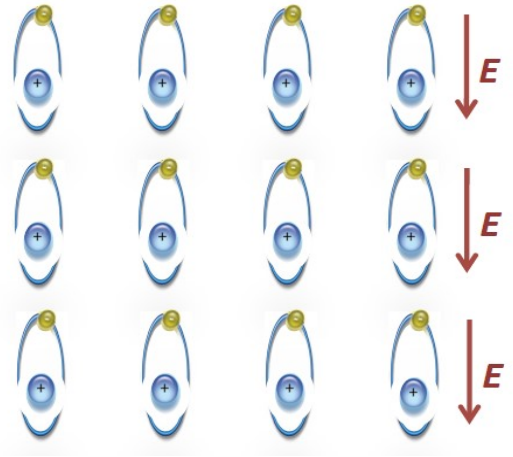

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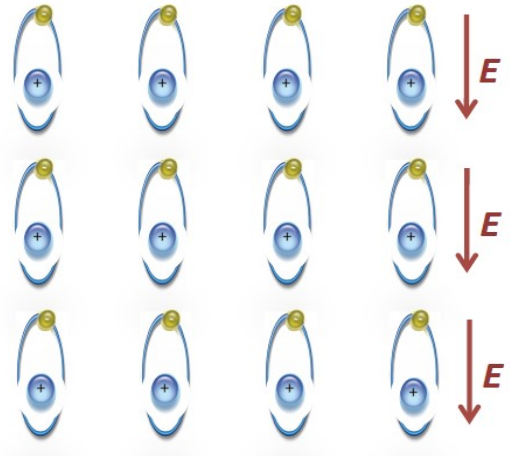

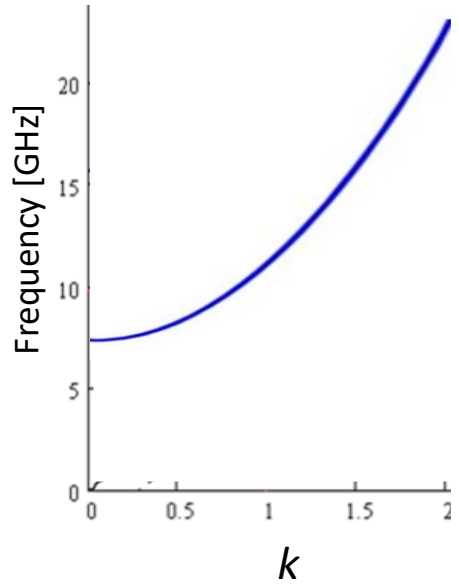

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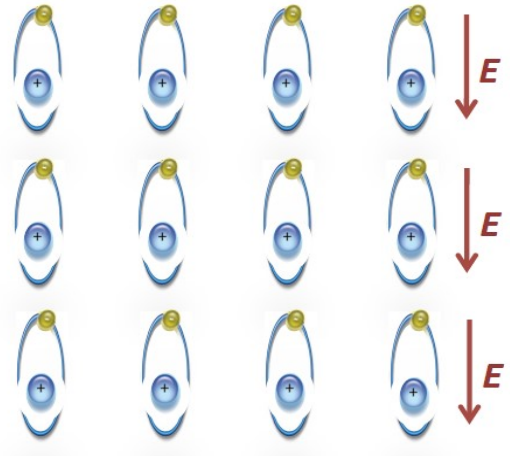

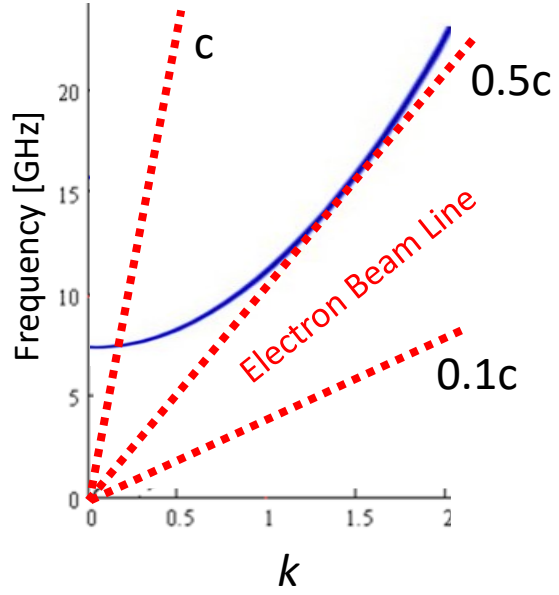

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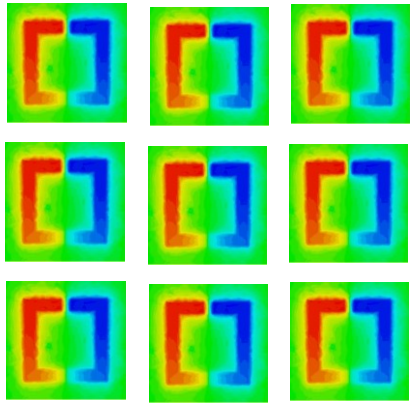

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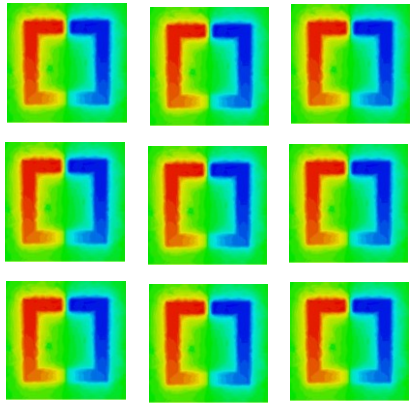
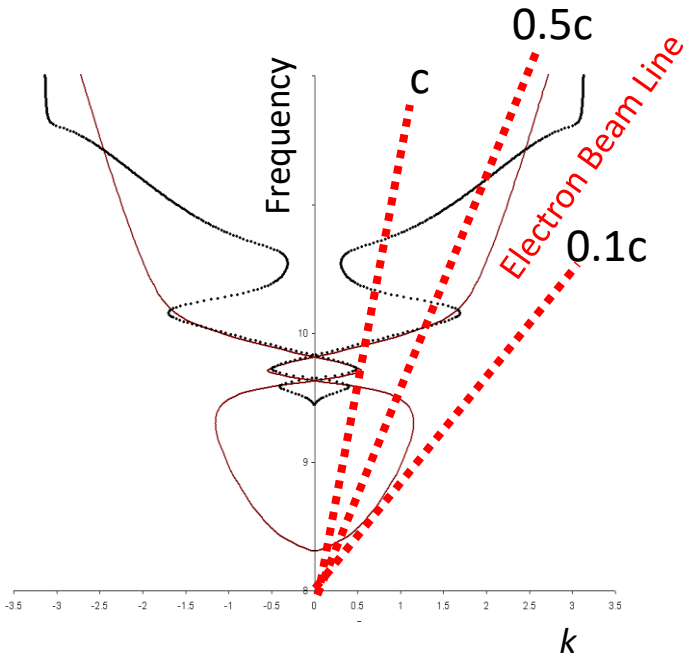


$$\beta_{mm}(\omega) = c^{-1}\sqrt{\omega^2 \epsilon_r(\omega)\mu_r(\omega) - \omega_c^2}$$



Tan & Seviour, EPL 87 (2009) 3, 34005

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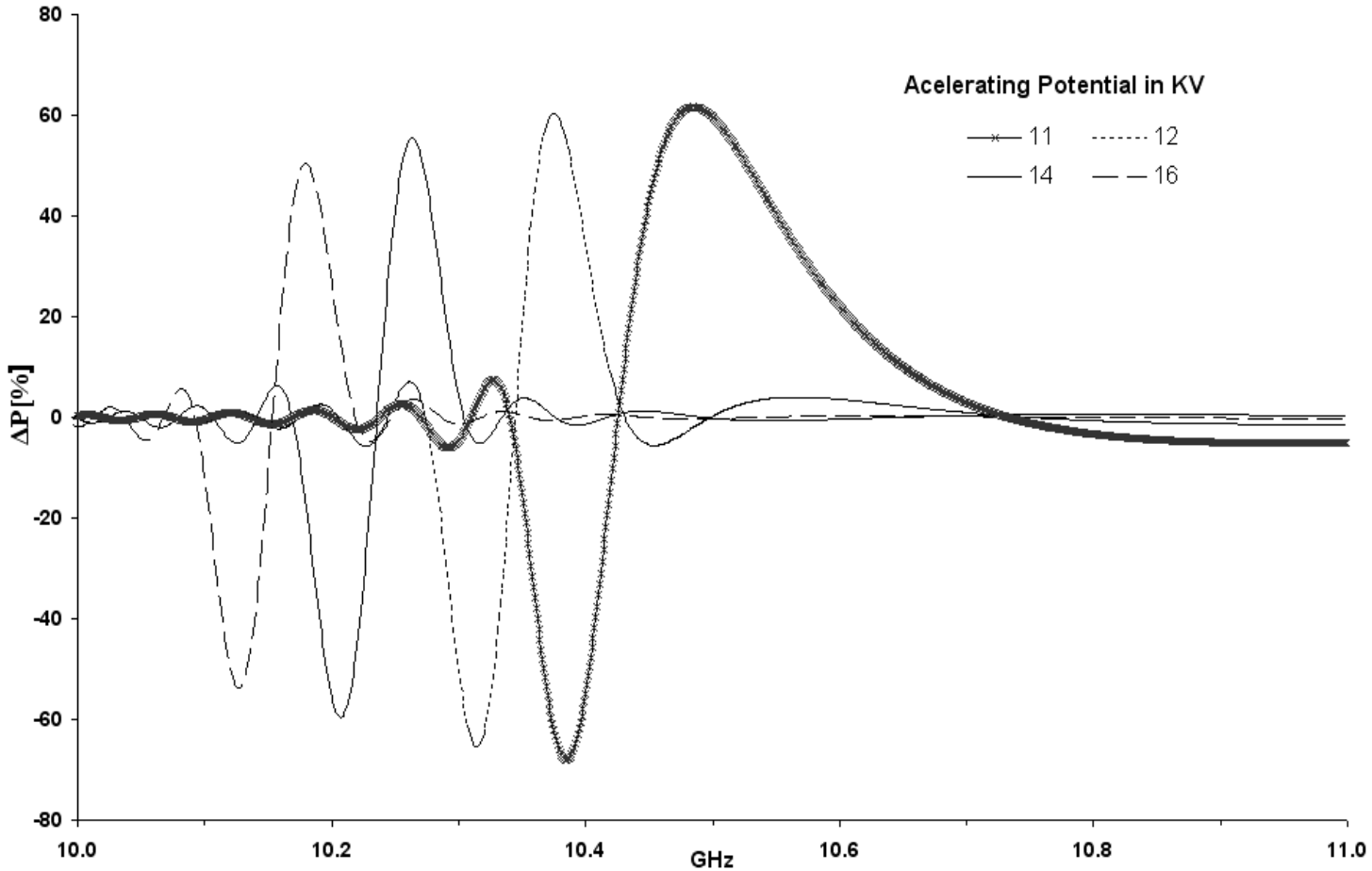

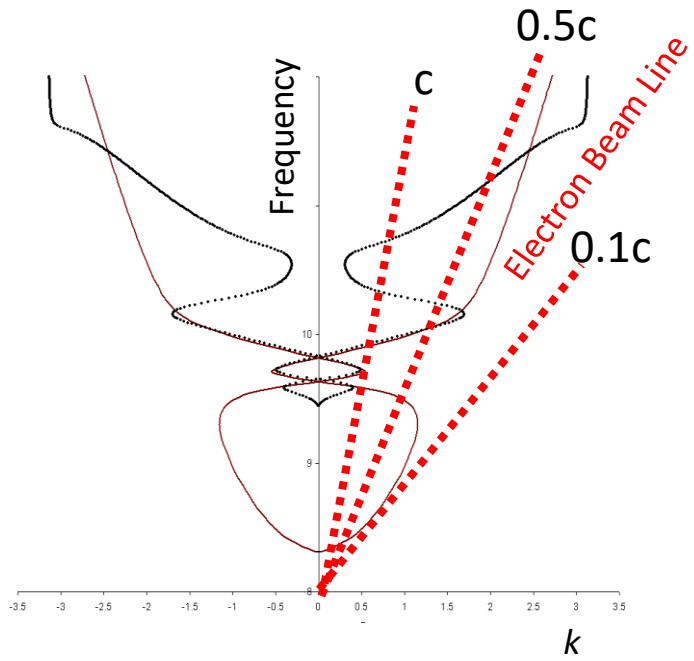

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$$c = \frac{1}{\sqrt{\varepsilon\mu}}$$

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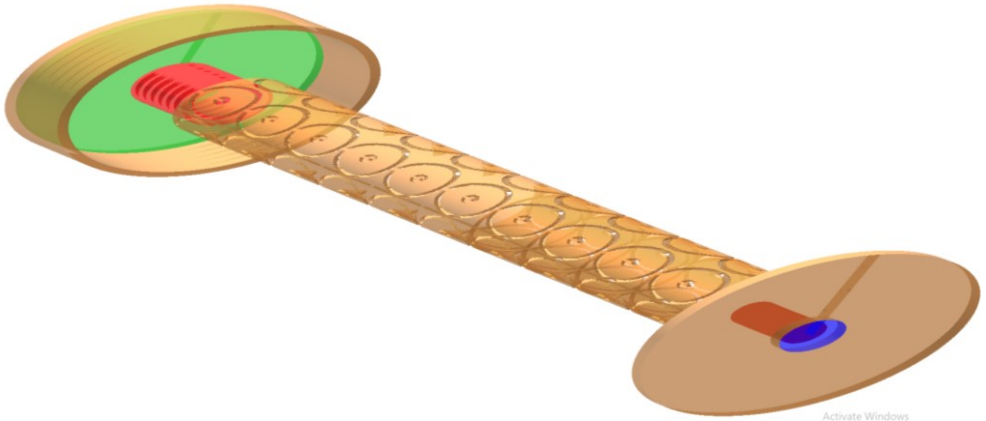
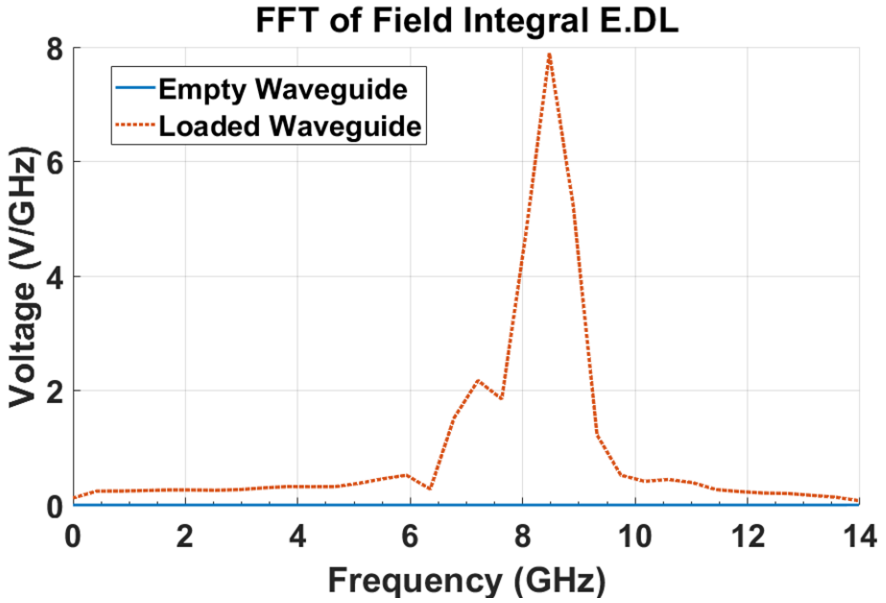
$$\varepsilon(\omega)$$
$$\mu(\omega)$$

Frequency Dispersion





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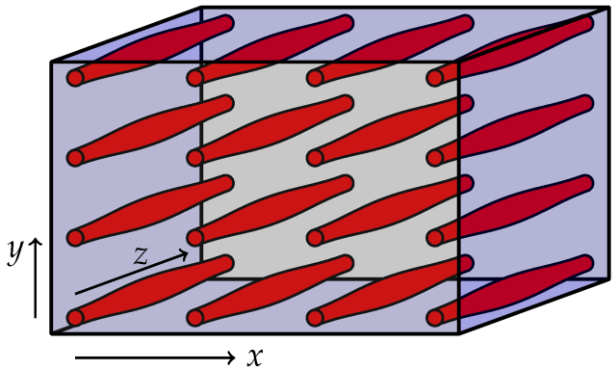
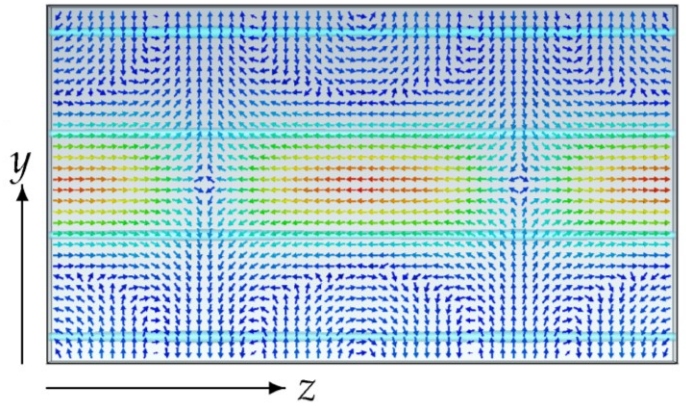
$\varepsilon(\omega)$
$\mu(\omega)$

Frequency Dispersion

$\varepsilon(\omega, X)$
$\mu(\omega, X)$

Spatial Dispersion





Boyd, T; Gratus, J; Kinsler, P; Letizia, R; Seviour, R. 2018. "Mode Profile Shaping in Wire Media: Towards An Experimental Verification" *Appl. Sci.* 8, no. 8: 1276

$$c = \frac{1}{\sqrt{\varepsilon\mu}}$$

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$\varepsilon(\omega)$ $\mu(\omega)$	Frequency Dispersion	
$\varepsilon(\omega, X)$ $\mu(\omega, X)$	Spatial Dispersion	
$\varepsilon(\omega, t)$ $\mu(\omega, t)$	Temporal Dispersion	Huddersfield (Seviour, Balakrishnan) Lancaster (Gratus) Imperial (Kinsler) Strathclyde (Jaroszynski)

Time Dependent Media

What are they, why are they interesting

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Media whose constitutive relationship changes in time, for example

A time dependent media that instantaneous switches from $\varepsilon_1 > 0$ to $\varepsilon_2 < 0$ at a time t_0

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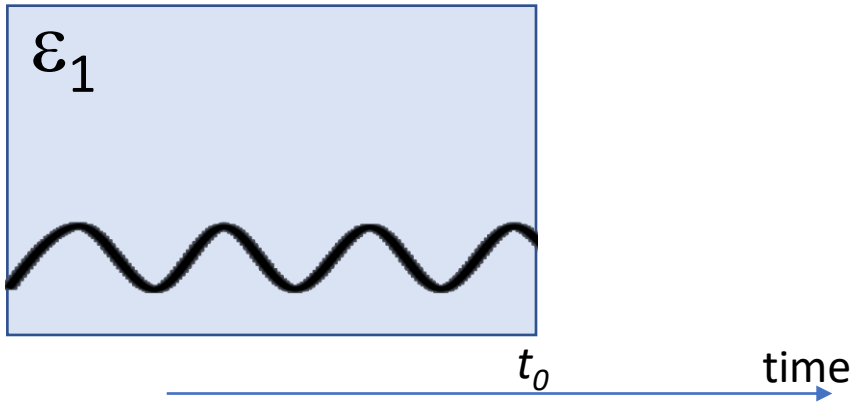
$t < t_0$ $\quad\quad$ $\varepsilon_1 \, E_1 e^{-i(\omega_1 t_0 - k_1 x)}$



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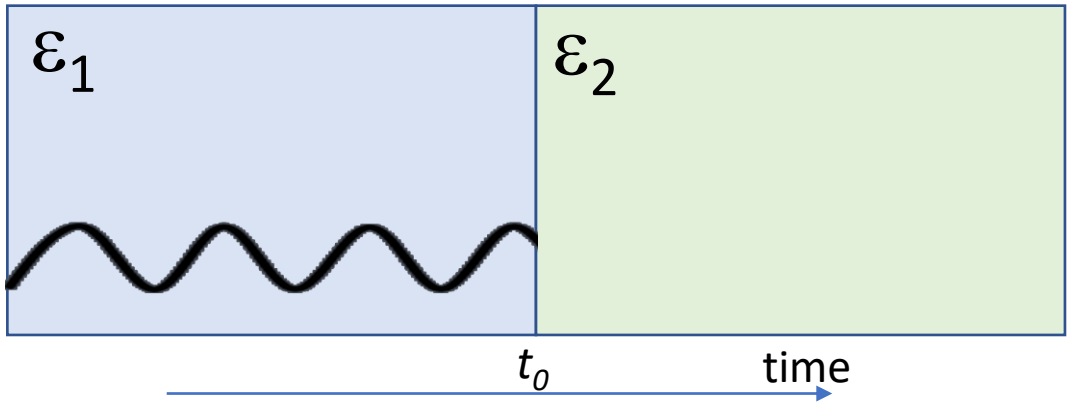

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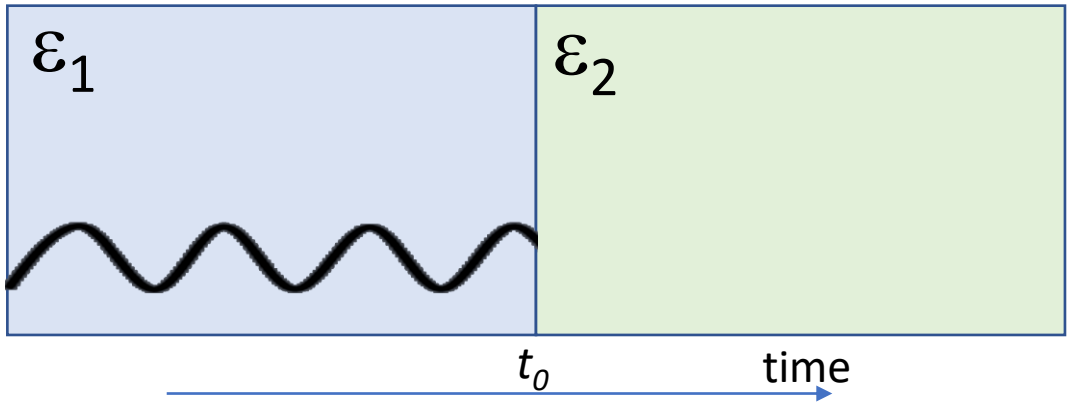
Temporal Boundary Conditions

$D_1|t_{0-} = D_2|t_{0+}$ $\quad B_1|t_{0-} = B_2|t_{0+}$



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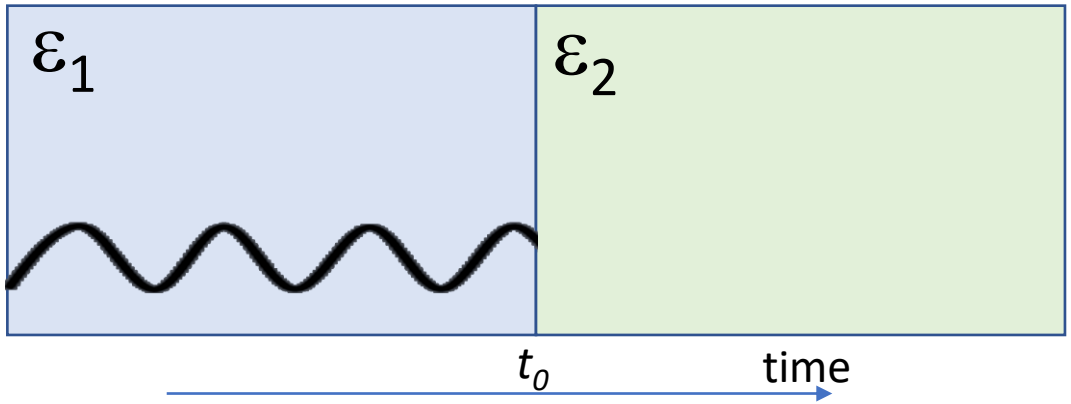
$$\varepsilon_1 E_1 e^{-i(\omega_1 t_0 - k_1 x)} = \varepsilon_2 E_F e^{-i(\omega_2 t_0 - k_2 x)} + \varepsilon_2 E_B e^{-i(-\omega_2 t_0 - k_2 x)}$$

$$\omega_1\sqrt{\varepsilon_1} = \omega_2\sqrt{\varepsilon_2}$$



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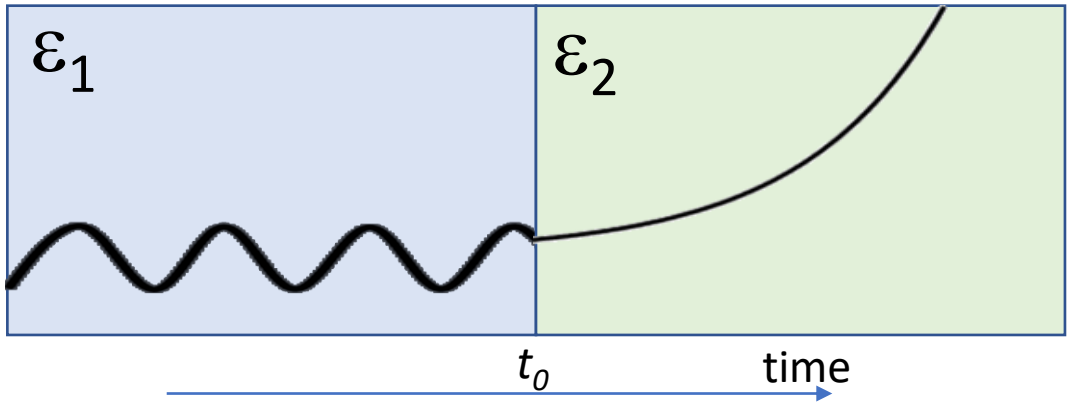

Crossing TB → ω cmplx, E_B decays exp & E_F grows exp

$$E_B e^{-\omega_2'' t}\left[e^{-i(-\omega_2' t - kx)}\right]$$

$$E_F e^{\omega_2'' t}\left[e^{-i(\omega_2' t - kx)}\right]$$

G – Band [4 - 6 GHz, 7.5 – 5 cm]

X – Band [8 - 12 GHz, 3.75 – 2.5 cm]

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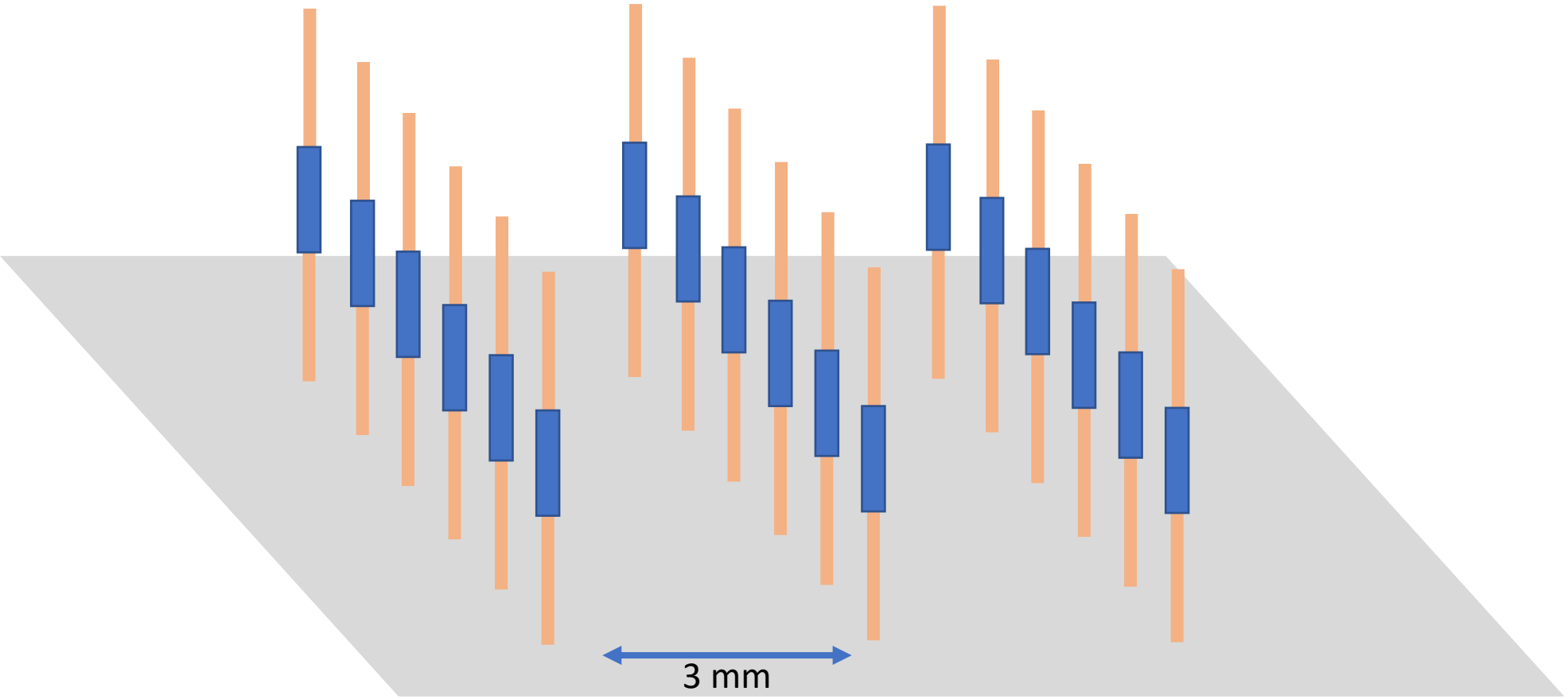
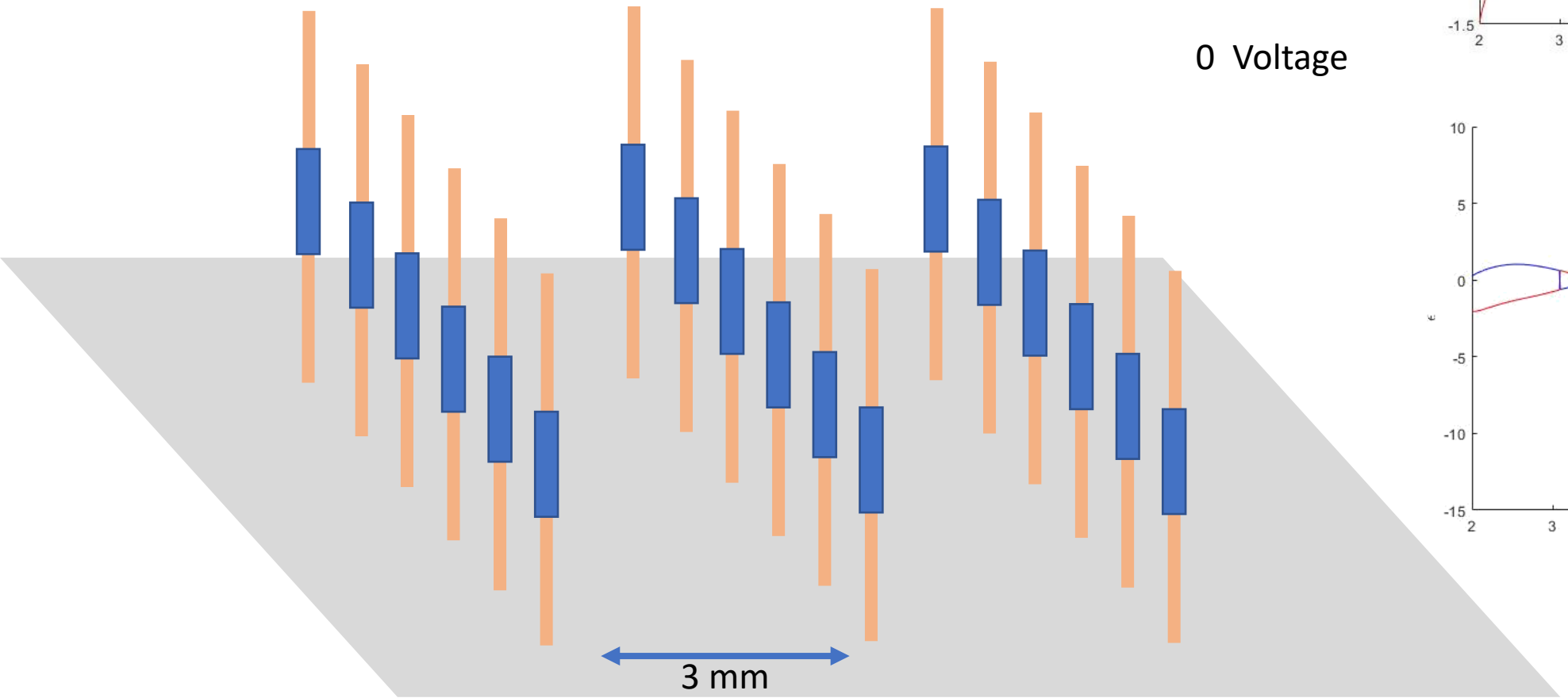
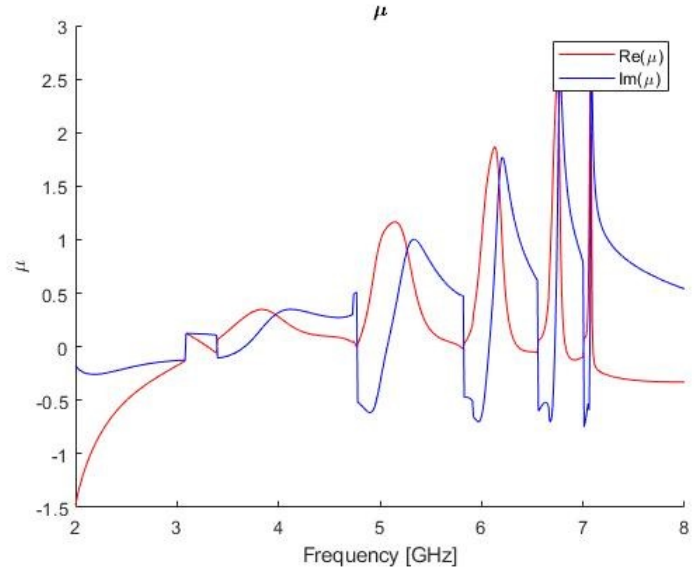
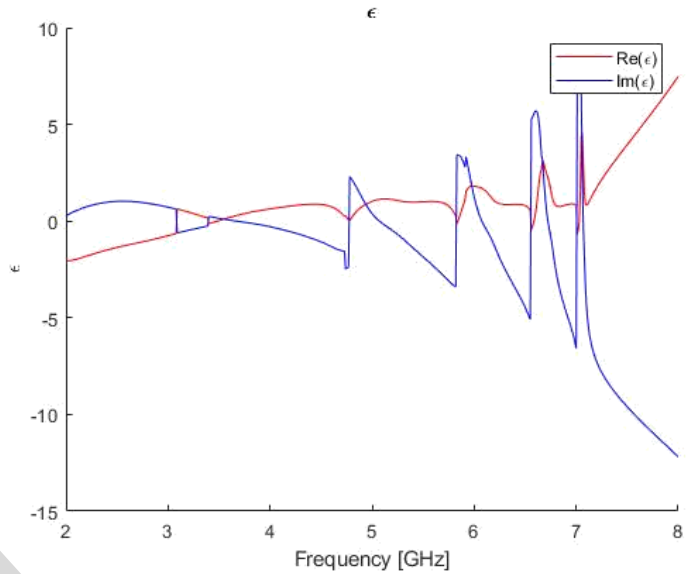


G – Band [4 - 6 GHz 7.5 – 5 cm]

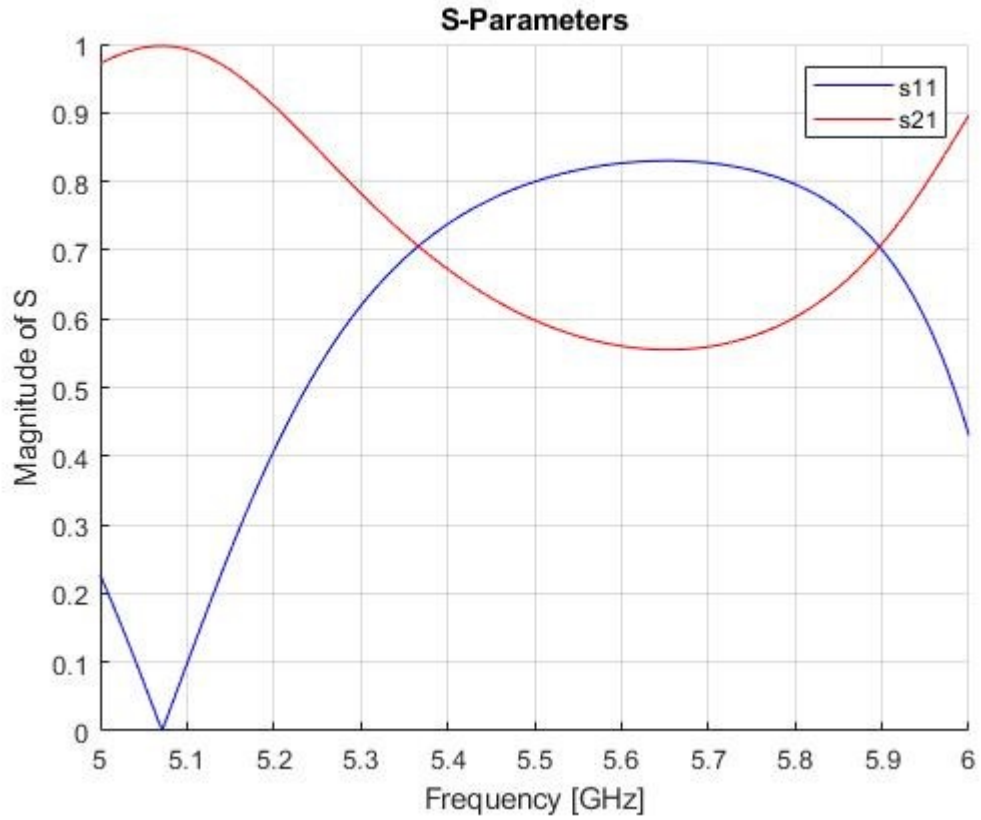


0 Voltage

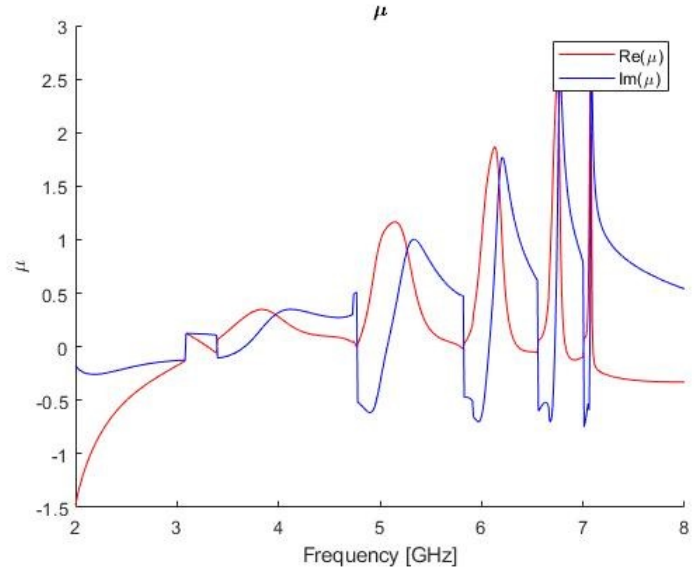


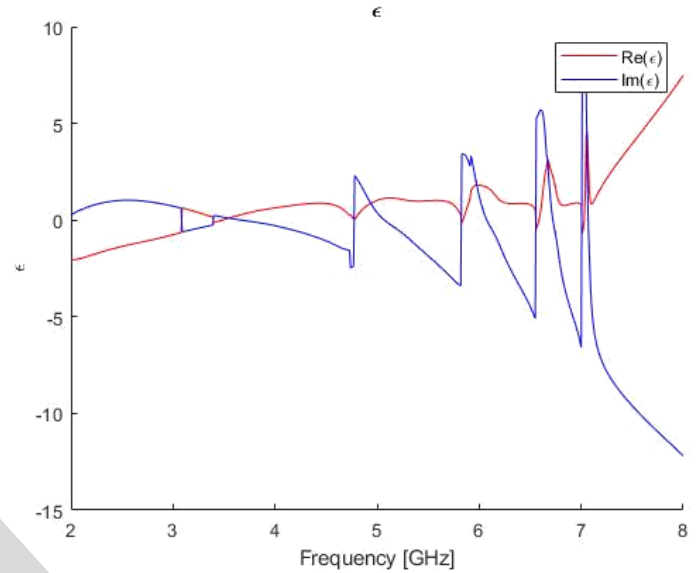


G – Band [4 - 6 GHz 7.5 – 5 cm]

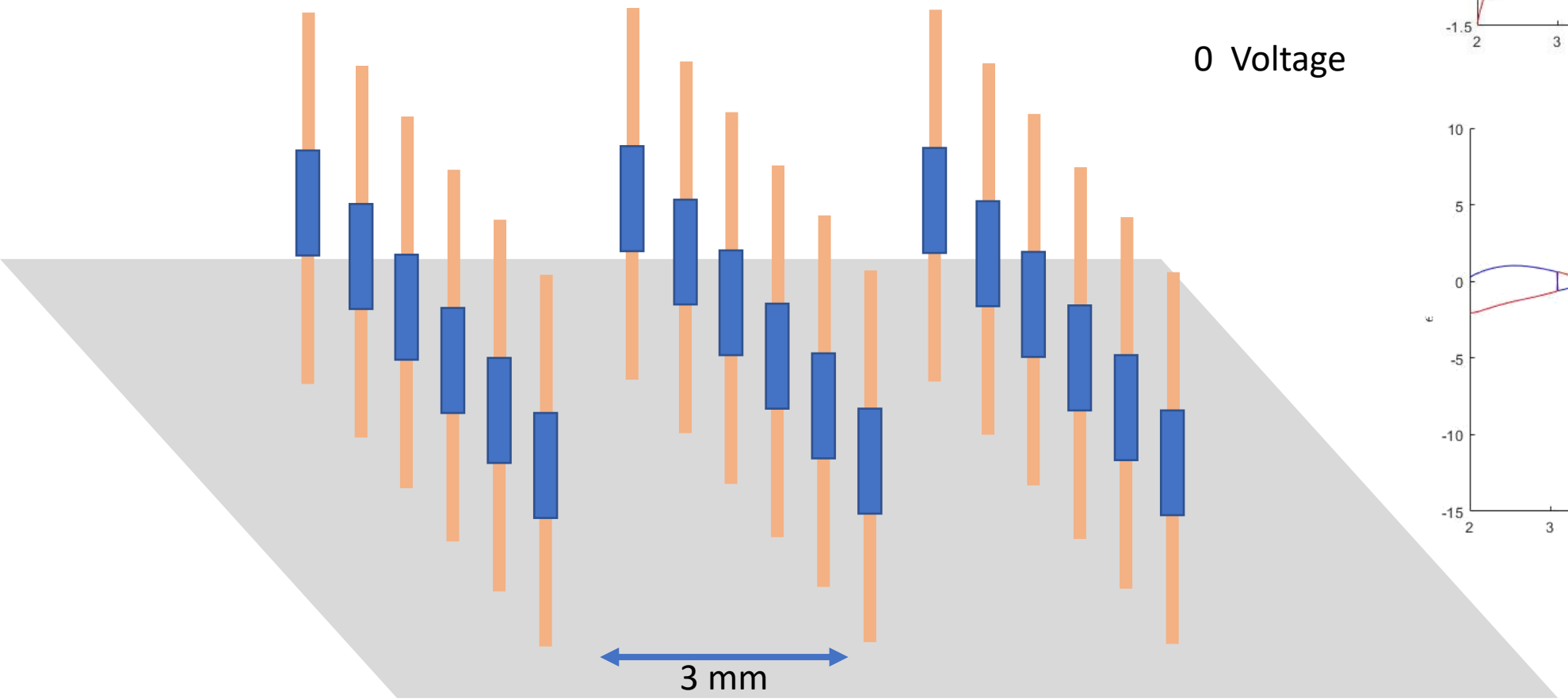


0 Voltage





Wave propagation



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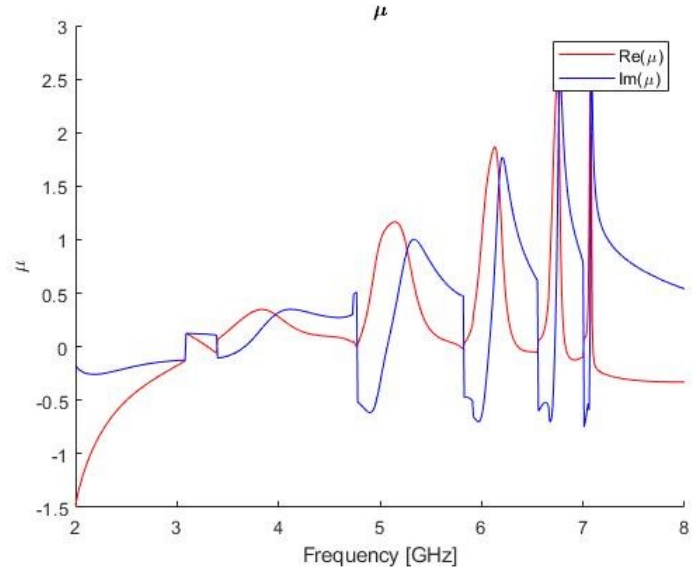

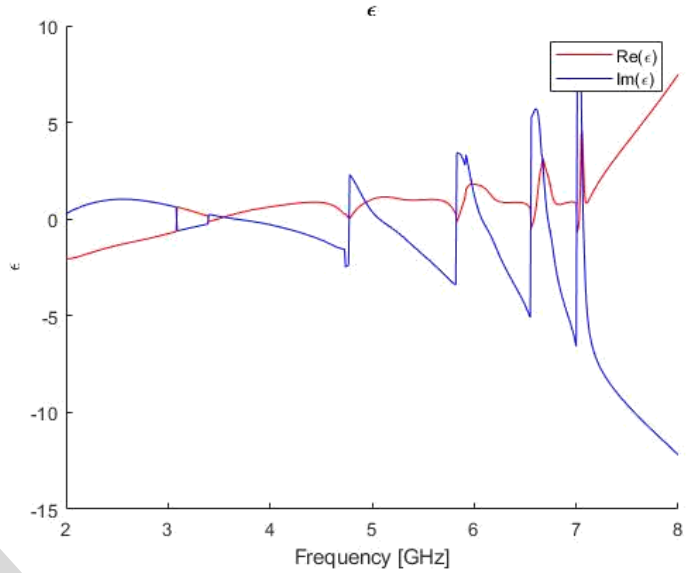

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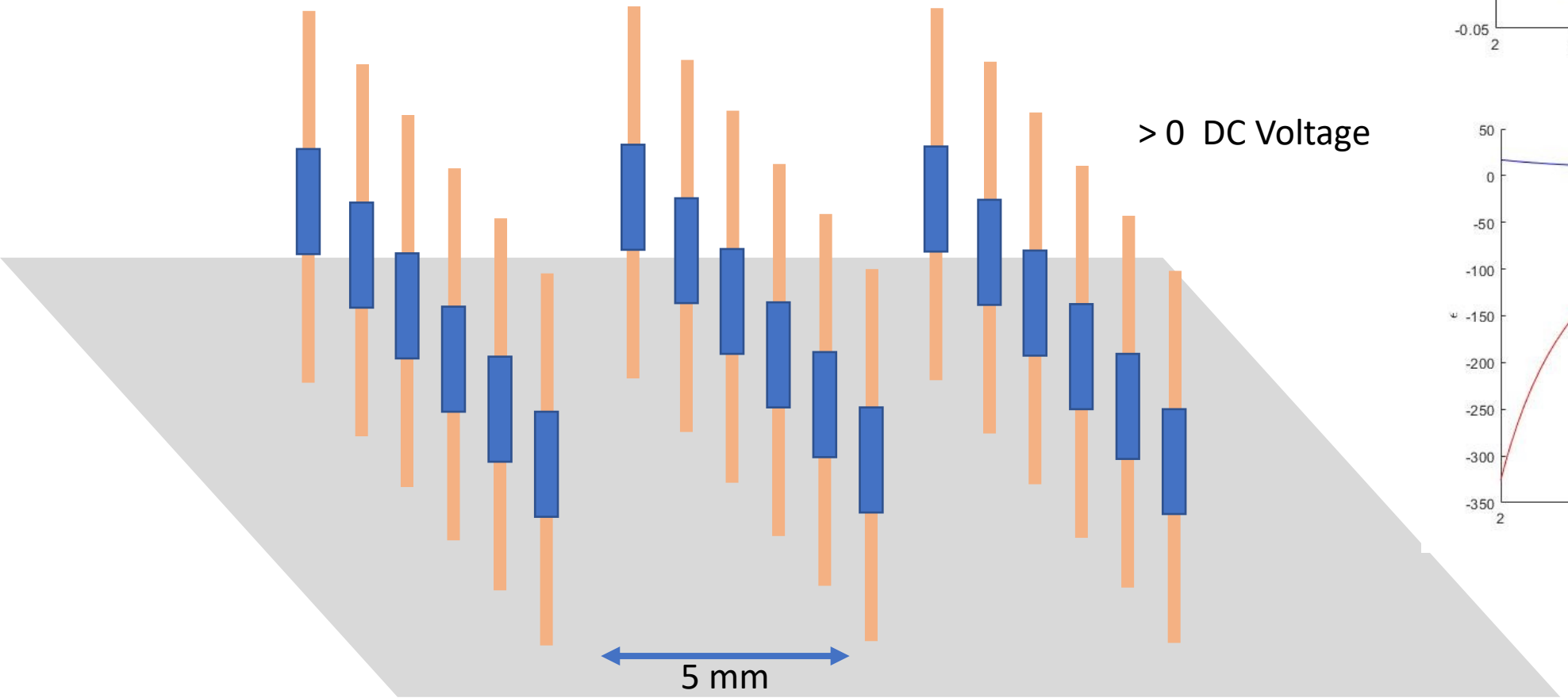
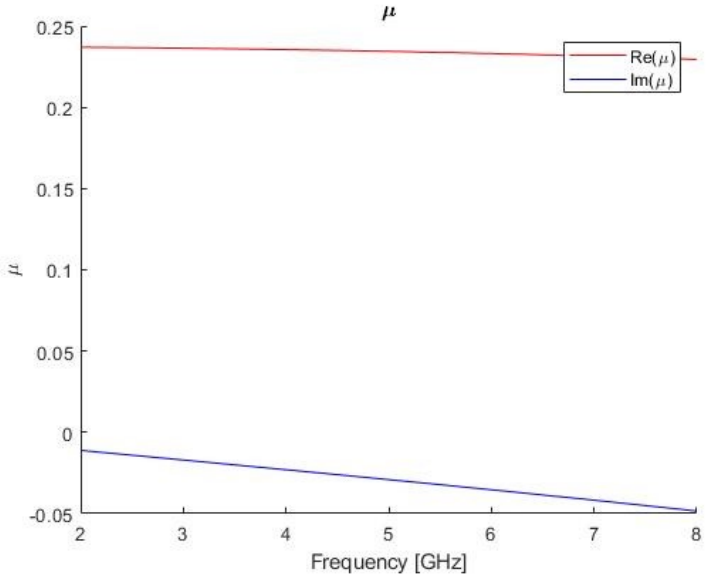
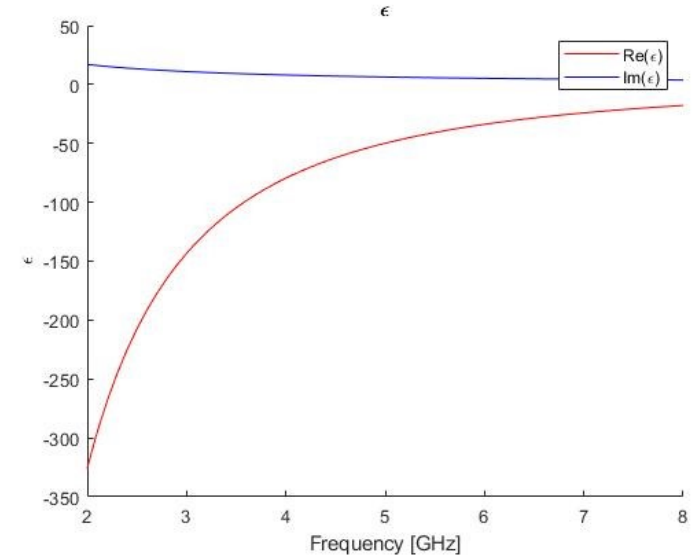
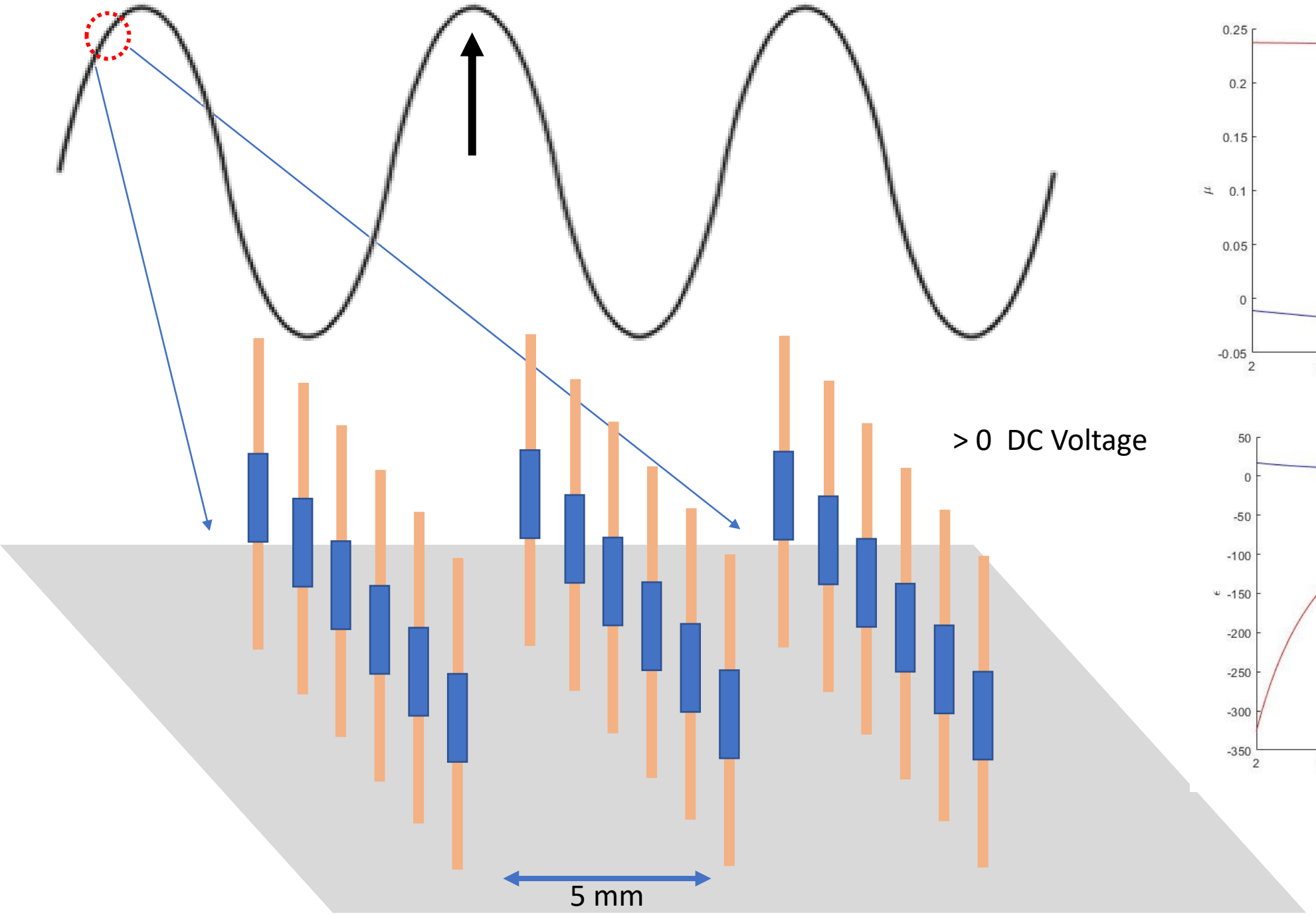
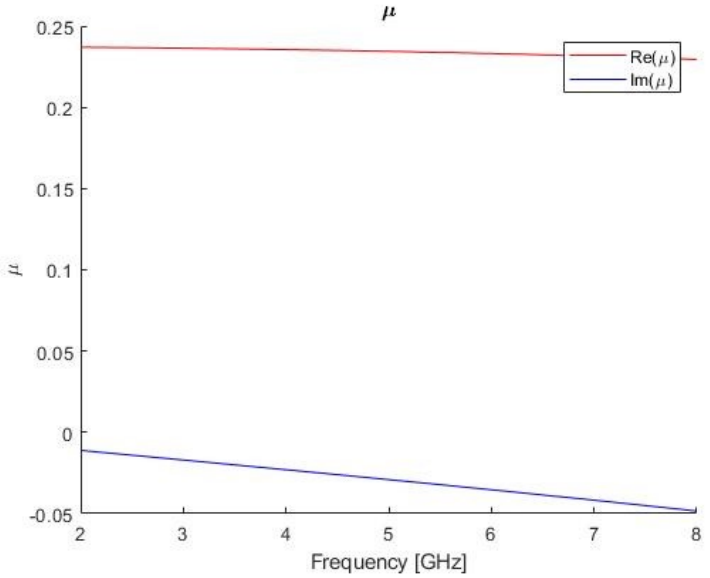


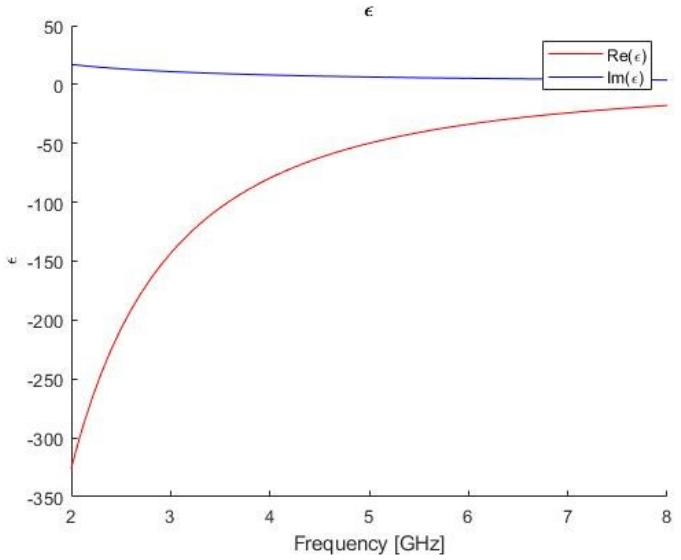
> 0 DC Voltage

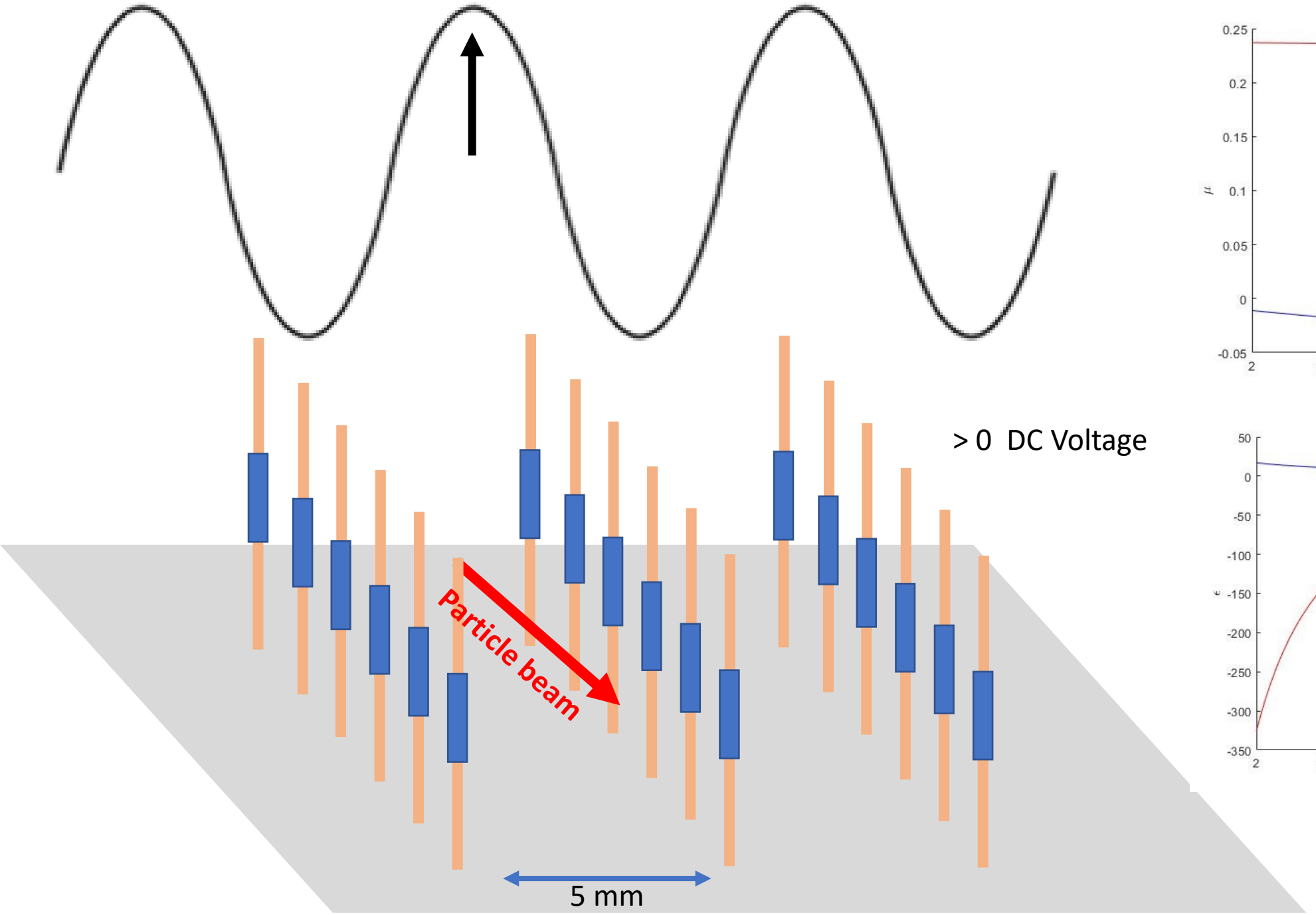




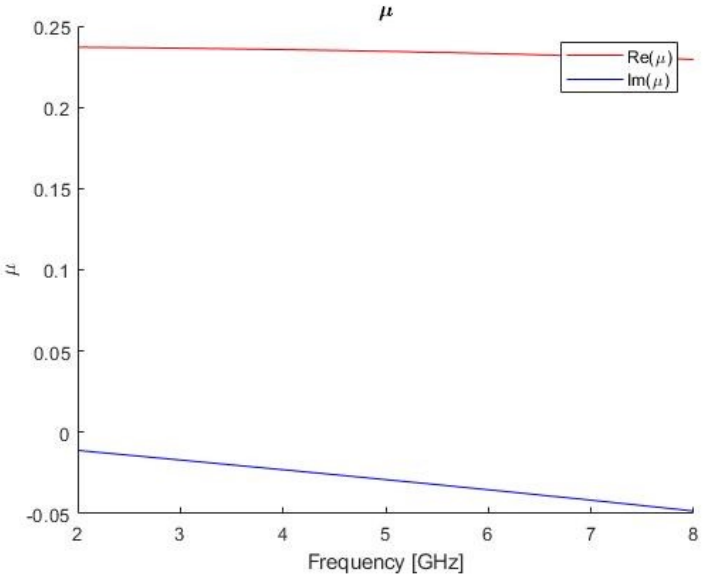

> 0 DC Voltage
5 mm


μ
Re(μ)
Im(μ)
0.25
0.2
0.15
0.1
0.05
0
-0.05
μ
2
3
4
5
6
7
8
Frequency [GHz]


ϵ
Re(ϵ)
Im(ϵ)
50
0
-50
-100
-150
-200
-250
-300
-350
ϵ
2
3
4
5
6
7
8
Frequency [GHz]


Particle beam
5 mm

> 0 DC Voltage


μ
Re(μ)
Im(μ)
0.25
0.2
0.15
0.1
0.05
0
-0.05
2
3
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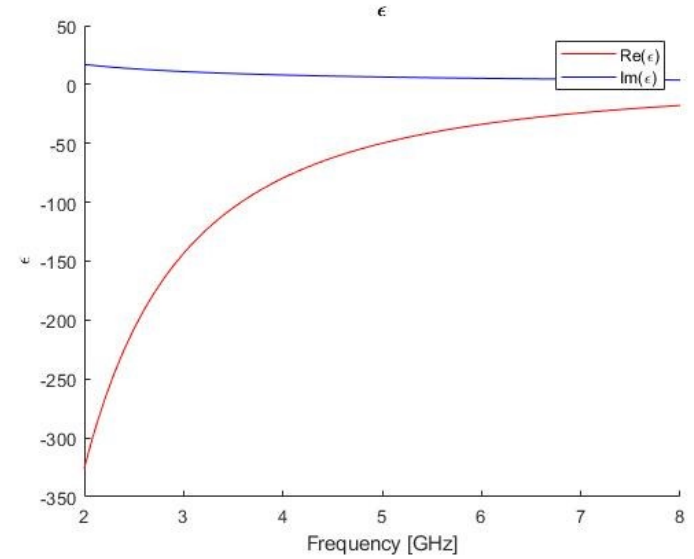
8
Frequency [GHz]


ϵ
Re(ϵ)
Im(ϵ)
50
0
-50
-100
-150
-200
-250
-300
-350
2
3
4
5
6
7
8
Frequency [GHz]

Conclusions

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Artificial EM Media

- Materials with tailored properties
- Amplify/Create RF signals
- Novel Slow wave Structures
- Compact sources
- Time Dependent Media Emerging Area
  - Amplification via DC voltage (Super radiance)

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