Nanophotonics and Negative Index Materials

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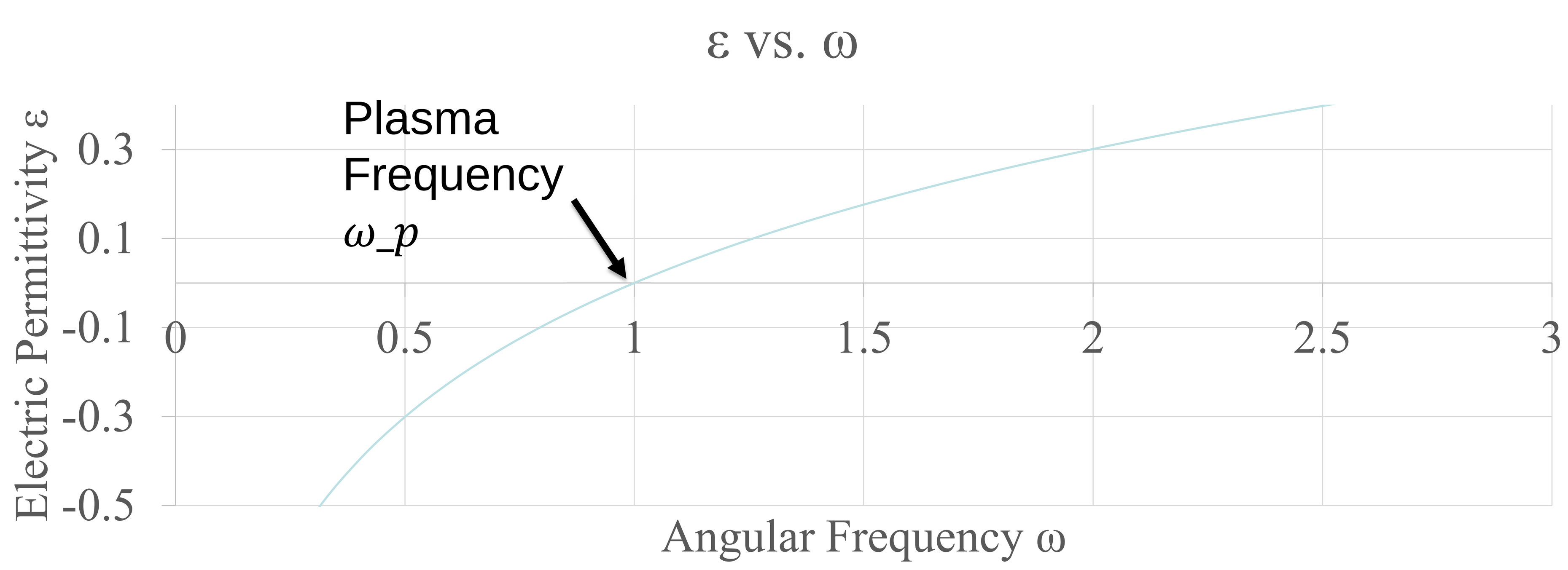
Abstract: Recent advancements in nanophotonics reveal new types of materials with negative refractive indexes. By altering the permittivity and permeability of a material, we can engineer new materials called metamaterials, into obtaining a negative refractive index. This project describes the operation and construction of a particular Negative Index Material (NIM) involving the use of Split Ring Resonators (SRR) and a wire frame. These designs will open the gateway to discovering new NIMs with disorderly systems, classifying them as isotropic materials.

Negative Index Materials

- Naturally occurring materials have refractive index:
  $n > 1$, where $n = \frac{c}{v}$
- Negative Index Materials have:
  $n < 0$, where $n = \pm\sqrt{\varepsilon_r \mu_r}$
- Thus, $-n$ can only be achieved if $\varepsilon_r < 0$ AND $\mu_r < 0$

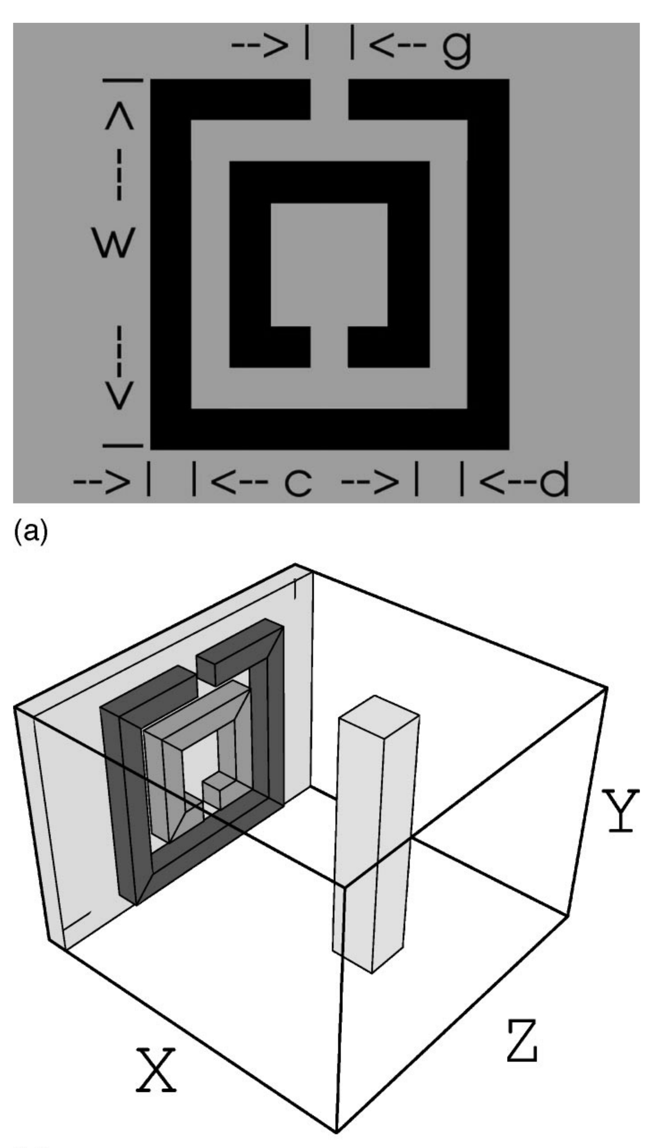
Negative Relative Permittivity, ε_r

- Relative Permittivity, ε_r:
  - Changed by altering electron density, n_e:
    - $\omega_p = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$, this changes plasma frequency, ω_p
    - Thus affecting permittivity: $\varepsilon = 1 - \frac{{\omega_p}^2}{\omega^2}$
  - Can be achieved by building wire-like frame:
    - $n_e \downarrow \Longrightarrow \varepsilon \downarrow < 0$, obtaining negative permittivity value



Negative Relative Permeability, μ_r

- Relative Permeability, μ_r:
  - Using split ring resonator (SRR) structured materials
- Basis of operation:
  - Energy ray via z-axis
  - B-field via x-axis
  - Induced current on ring
  - Split in ring acts as capacitor and inductor
  - L and C in same circuit yields resonance capabilities
- Concentric "rings" for added effect



Simulation & Results

Figure 1.

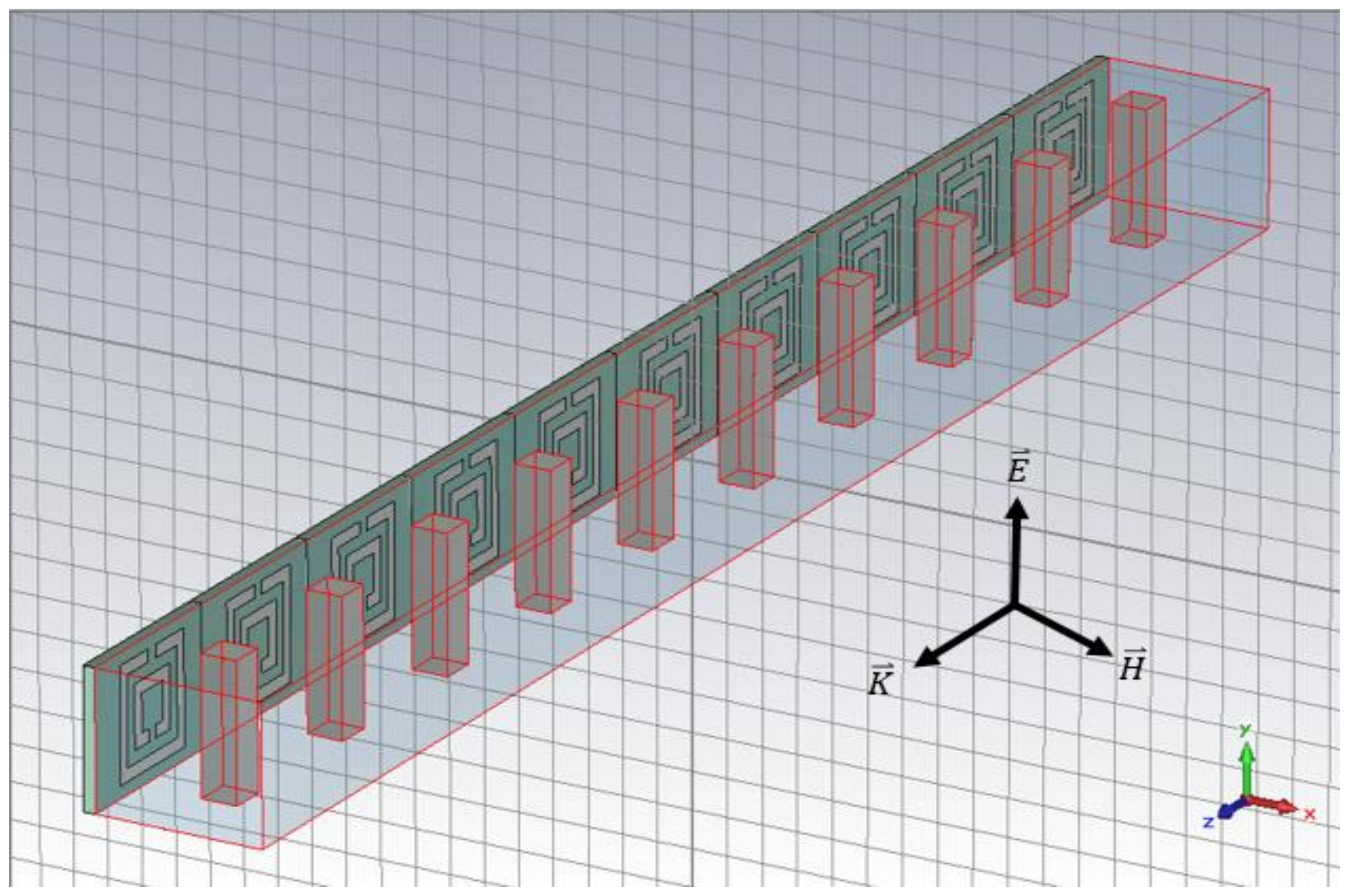


Figure 1. The replication of the 10-unit cell periodic configuration using CST MWS software.

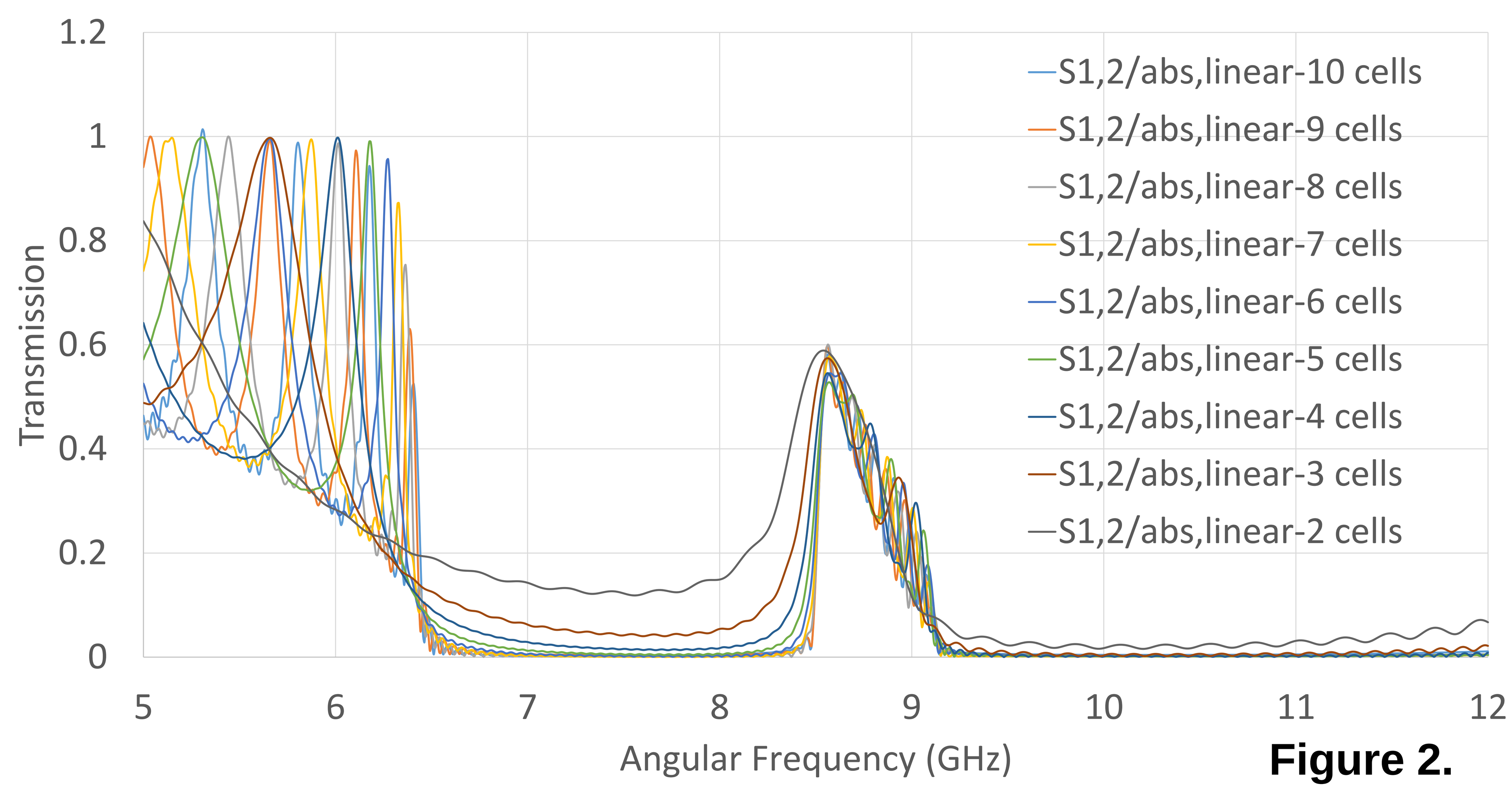


Figure 2.

Figure 2. Consolidated results of 1-10 unit cells arranged in PERIODIC manner with verification of transmission in 8.5 GHz range with NIR.

Analysis, Conclusion and Future

- Metamaterials can be built using anisotropic materials through the use of split-ring resonators and wire frames; this enables us to achieve a negative index of refraction.
- This leads us to push the boundaries into the unknown world of isotropic materials where the energy rays can be sent via any direction
- This requires metamaterials to have unit cells to have multi-directional orientation capabilities

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References:
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