Metamaterials for Magnetic Field Enhancement and Electric Field Suppression

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Introduction

- **Metamaterials** are engineered materials with unnatural properties
- Some can modify the electric and magnetic fields of terahertz light
- Design of metamaterials is currently ad-hoc
- The dragonfly [1] and question mark [2] are recent proposed geometries to **enhance magnetic field 5-fold** [1]
  - Dragonfly is also meant to suppress electric field
- **Question**: How can changing geometries further improve the magnetic enhancement/ decoupling?

Methods

1. Solidworks

- Metamaterial geometries were first built in Solidworks, a CAD software.

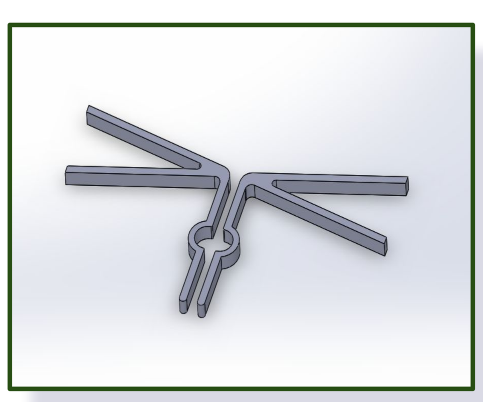

Figure 1: Original dragonfly model in Solidworks

2. COMSOL setup

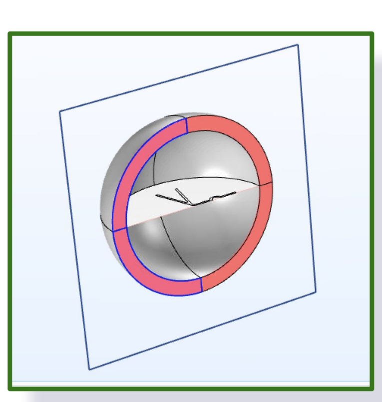

Figure 2: Simulation setup with gold metamaterial, air on top, quartz on bottom

- 40 micron sphere is semi-infinite space
- Top layer (20 microns) is perfectly matched layer
- Frequency range is 0.9 - 1.6 THz to include almost all resonant frequencies
  - It is also the typical terahertz range used in experiments

3. Running COMSOL

- Scattered background wave applied
- E and B fields plotted at center of circle of metamaterial
- Repeated for different geometries & antenna lengths

Results

Original Geometry: Dragonfly

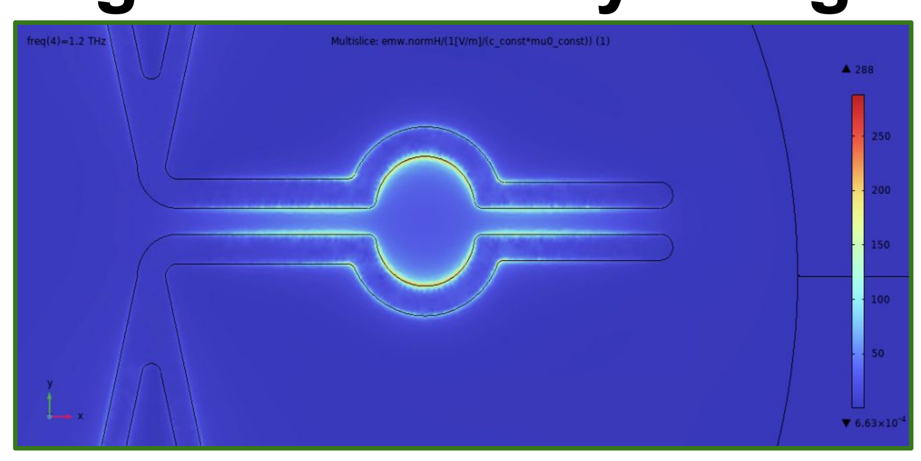

Figure 3: Original dragonfly magnetic field. Brightest regions show enhancement, such as in the inner circle whose center was the measurement point.

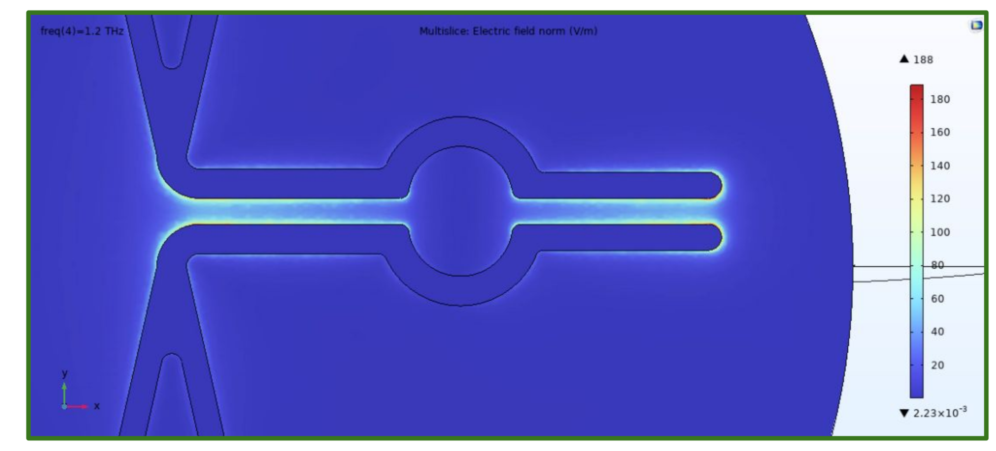

Figure 4: Original dragonfly electric field. The dimmer inner circle highlights the electric field suppression

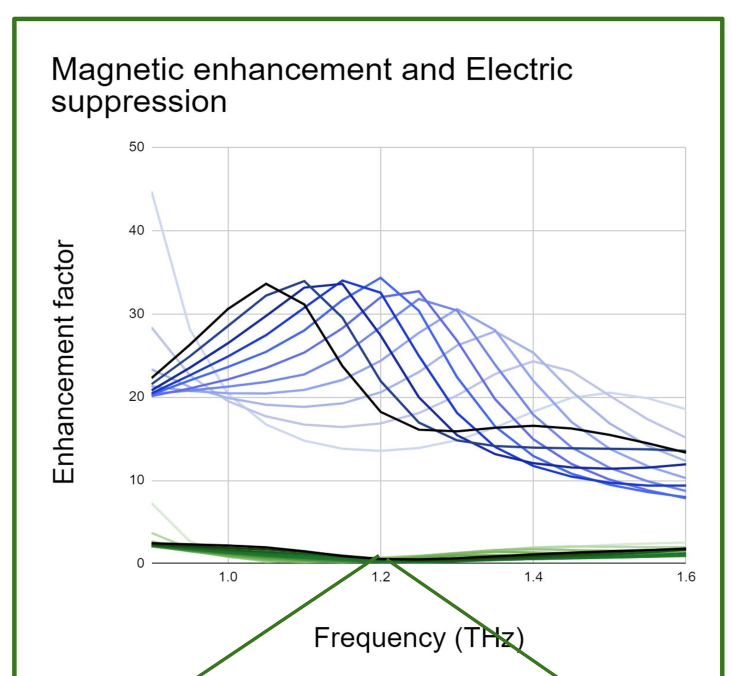

Figure 5: Magnetic enhancement for various antenna lengths from 0.9 - 1.6 THz. Length increases from right to left

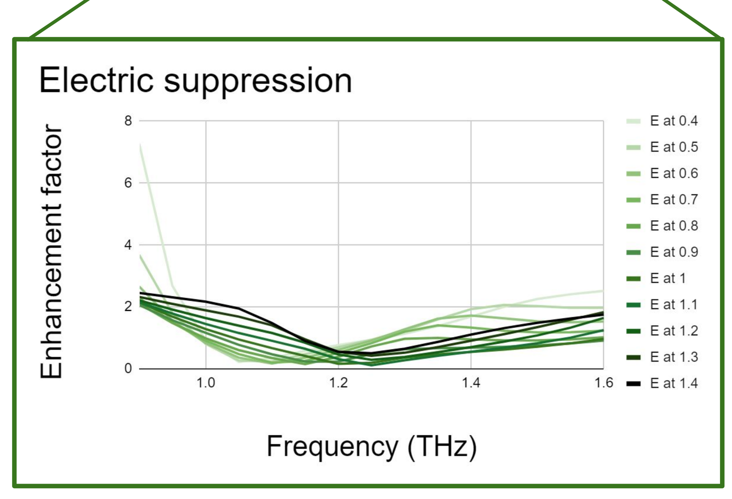

Figure 6: Expanded electric suppressionplot from Figure 8

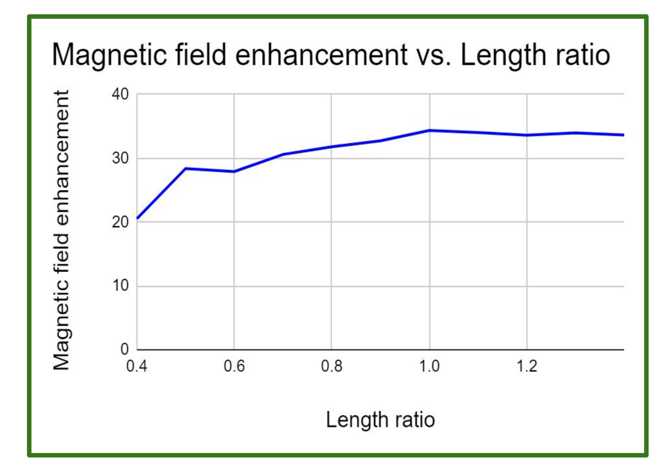

Figure 7: The magnetic field enhancement after running a parameter sweep through length ratios from 0.4 - 1.4

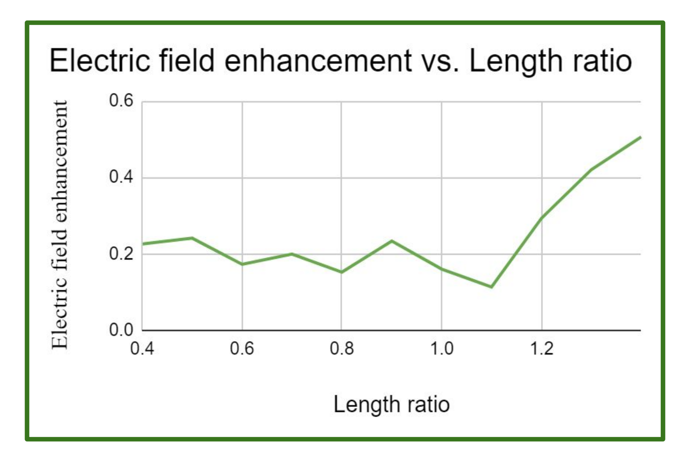

Figure 8: The electric field suppression after running a parameter sweep through length ratios from 0.4 - 1.4

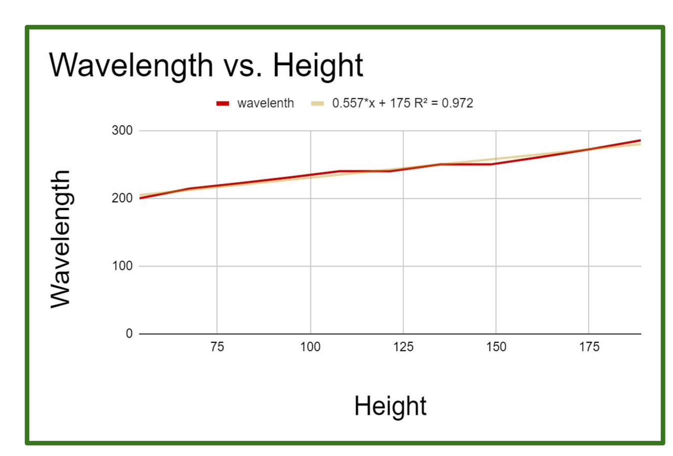

Figure 9: The wavelength vs antenna height at resonant frequency after running a parameter sweep through length ratios from 0.4 - 1.4. Plot suggests linear relationship.

New Geometry: Bunny

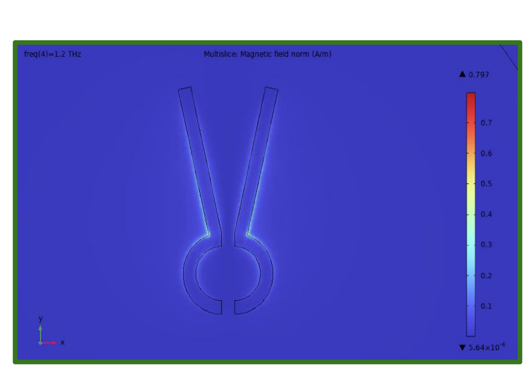

Figure 10: Bunny B field

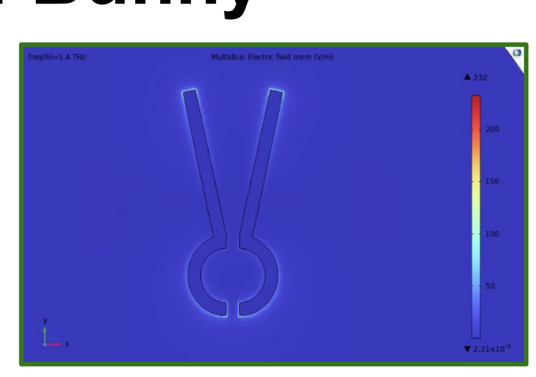

Figure 11: Bunny E field

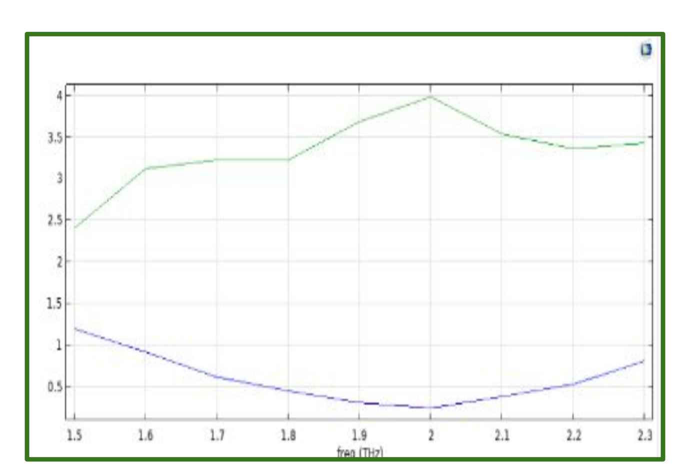

Figure 12: The bunny geometry plot. The maximum magnetic enhancement was 4, the minimum electric suppression was 0.11

- The bunny also had **both** magnetic enhancement **and** electric suppression
- Enhancement was not at the same level as the dragonfly

Discussion/Conclusions

- Increasing length of antenna increases magnetic enhancement only to a certain length
  - Shorter lengths have better electric field suppression
    - Increase in electric field comes rapidly after a certain length ratio
    - Optimal length ratio depends on desired effects from metamaterial
      - Convergence of enhancement and suppression likely lead to measurements in paper
- Shift in resonant frequency
  - Larger length ratio allows for longer wavelengths/shorter frequencies
- More asymmetrical structures lead to higher magnetic enhancement

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References

[1] Pancaldi, M.; Vavassori, P.; Bonetti, S. Terahertz metamaterials for light-driven magnetism. *Nanophotonics*, 2024, *13*(10), 1891-1898.

[2] Polley, D.; Pancaldi, M.; Hudl, M.; Vavassori, P.; Urazhdin, S., Bonetti, S. *J. Phys. D: Appl Phys.*, 2018, *51* 084001