Finite element modeling of localized surface plasmon resonances in nano-antenna structures

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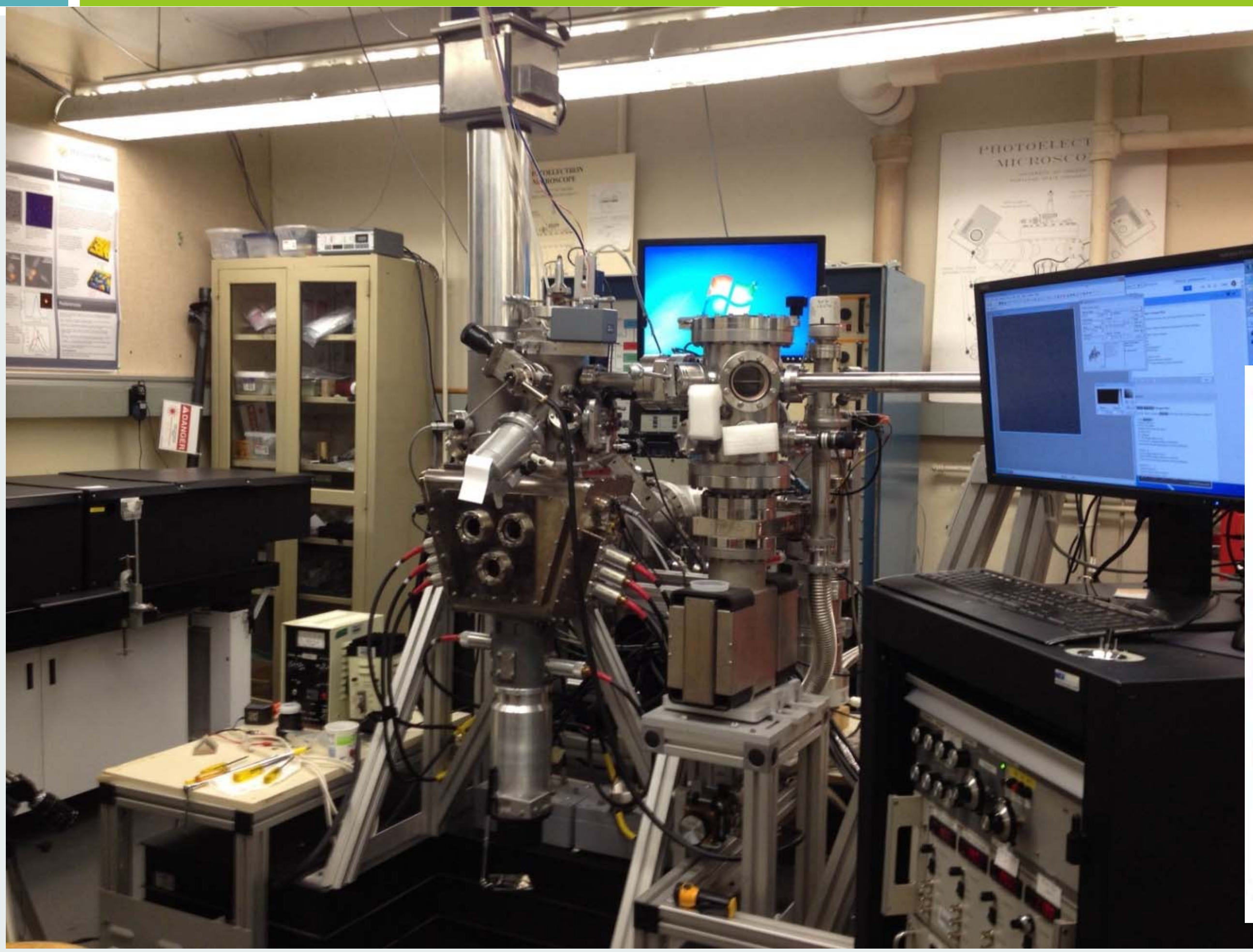
The Renewed Field of Plasmonics

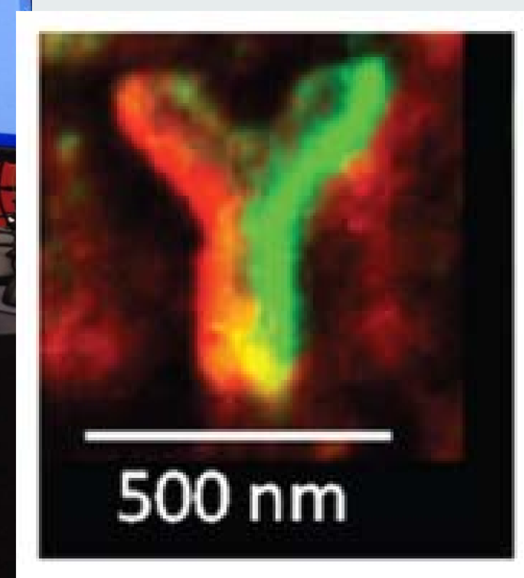
- Plasmon: unit of electron “plasma”
- Have a certain resonance frequency corresponding to their energy
- Can induce a response of these plasmons by laser excitation
- Plasmons amplify the incident electric field at the interface between the metal and the dielectric (air)
- Generally ~100-1000x amplification

The Renewed Field of Plasmonics

- Amplification effect depends on the refractive index of the metal
- Can control the location of the induced amplification by geometry of nanoparticles
- Amplification occurs in localized regions focused past the limit of diffraction
  - ~$\lambda/20$ rather than ~$\lambda/2$
- Ability to couple optical signals with electronic transmission

Photoemission Electron Microscope (PEEM)





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Theoretical Model

- Explore software used to model physical events
- Goal: Compare the results of a software model with the results of a theoretical model
  - Use different numerical method of calculation
- Establishes the software as a valid means of modeling plasmonic phenomena on the nanoscale
  - Provides a valuable initial step to experimentation

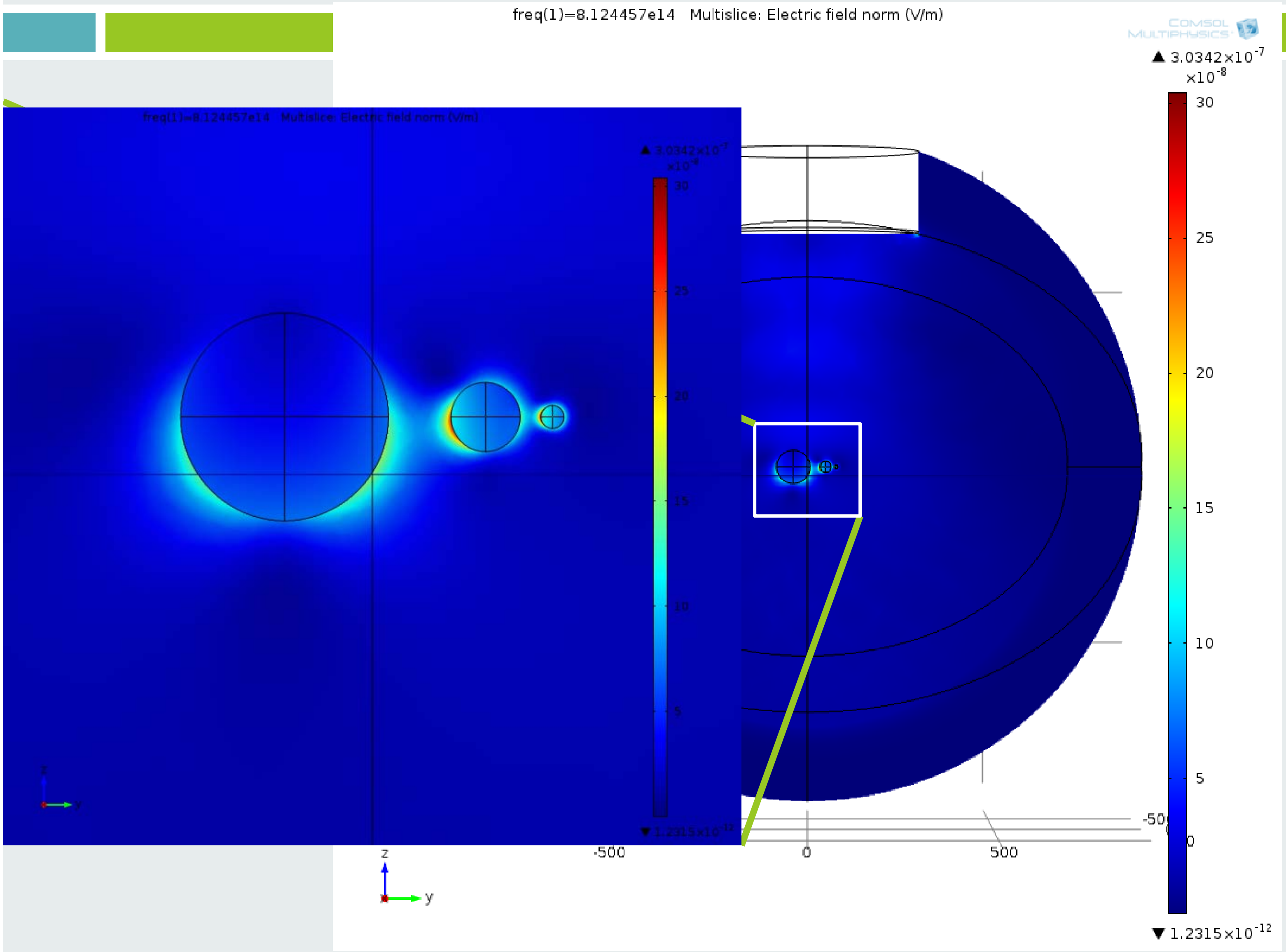
COMSOL Multiphysics

- Tailors a general master differential equation to the specific types of physics applied to the model
- The Radio Frequency (RF) module solves for electromagnetic waves in the medium
- Evaluates the resulting electric field for a given geometry, set of materials, and frequency of incoming light
- Solution in the frequency domain: dependent on frequency rather than time

COMSOL Multiphysics

- Uses the finite element method (FEM)
- Mesh creates triangle and tetrahedral shapes on the geometry, creates finite space
  - Mesh must be fine enough to give accurate results (~λ/10); large enough for reasonable computation time
- Maxwell's equations are evaluated on the outline of each mesh element, and integrated over the area of the triangle to give a value
- Each value summed to give final solution

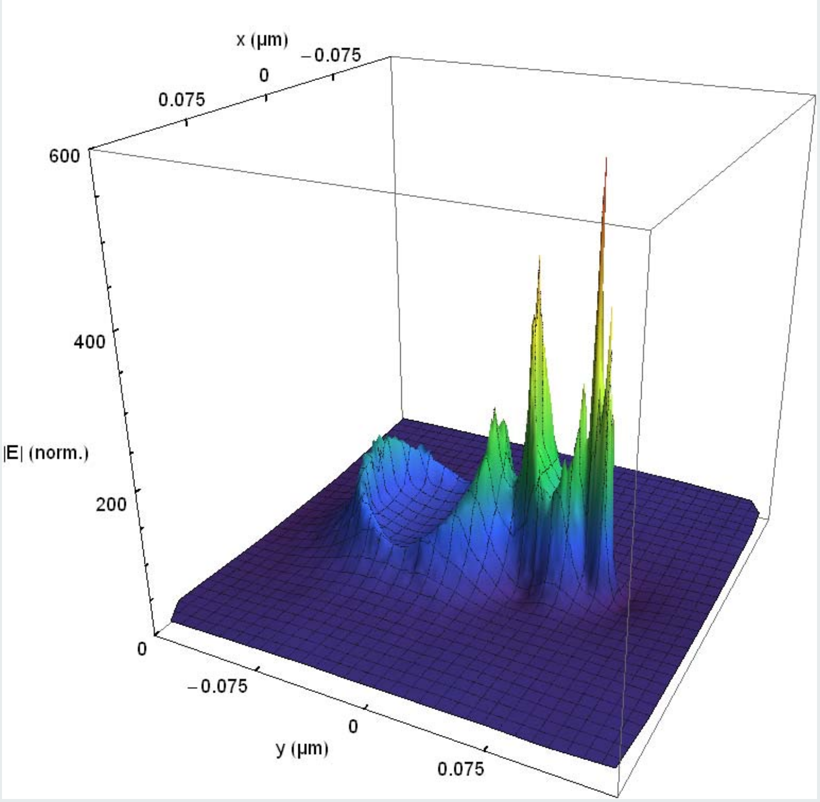
COMSOL Model: Nanolens



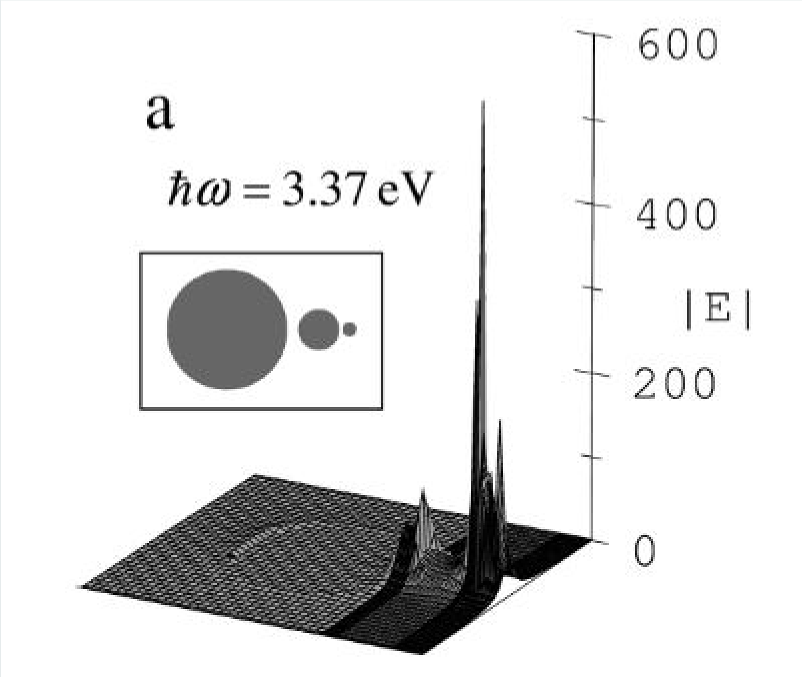
Model Parameters

- Wavelength of light: 369 nm
- Size of spheres, relative radius ratio: 5, 15, and 45 nm; $R_{i+1}/R_i=1/3$
- Distance between spheres: $D_{i,i+1}=.6R_{i+1}$
- Sphere material: silver
- Polarization of light: tranverse electric
- Incidence angle of light: normal

COMSOL Model: Results



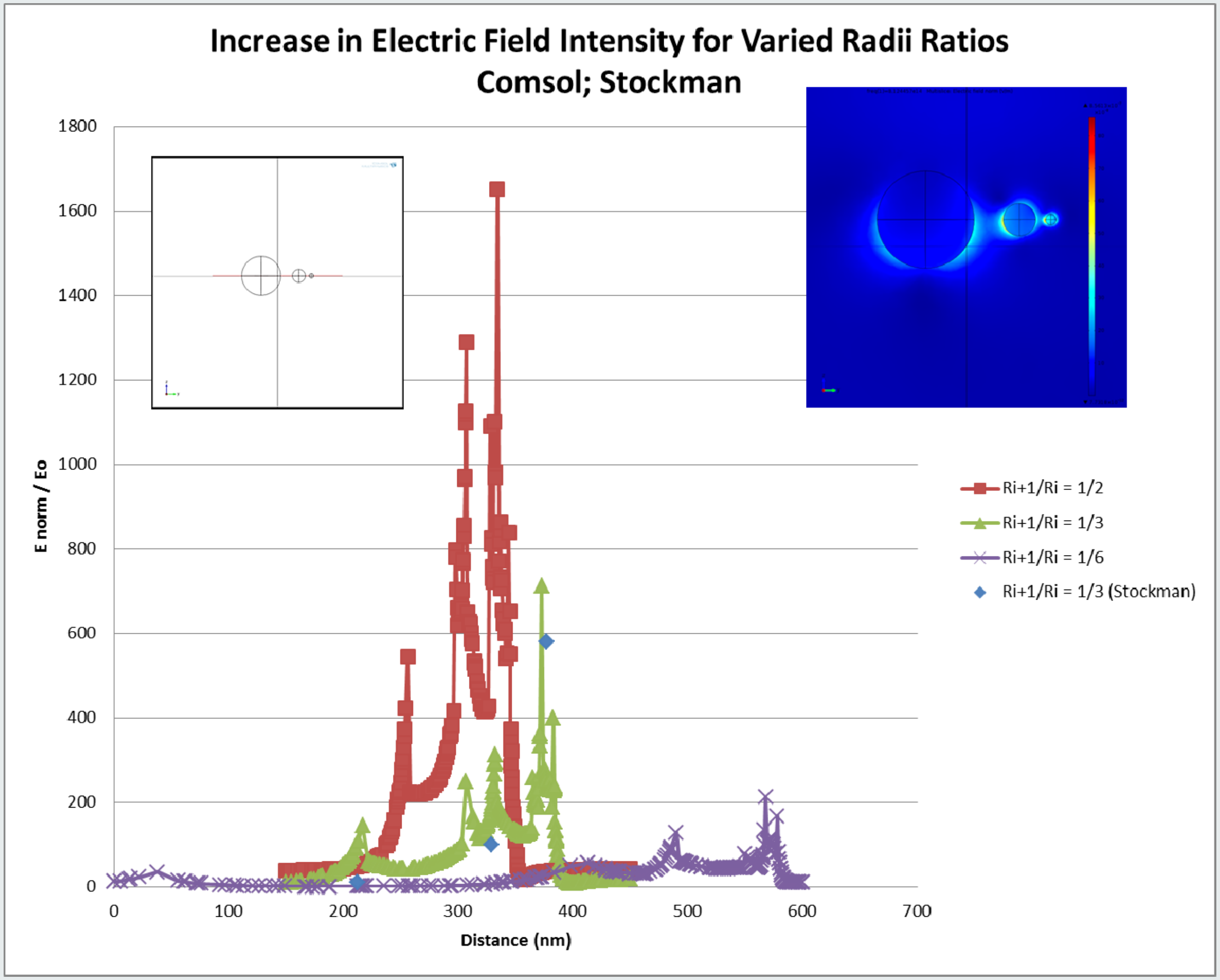
COMSOL model result



Stockman result*

*Li, Kuiru, Mark I. Stockman, and David J. Bergman. "Self-similar chain of metal nanospheres as an efficient nanolens." Physical review letters 91, no. 22 (2003): 227402.

COMSOL Model: Results

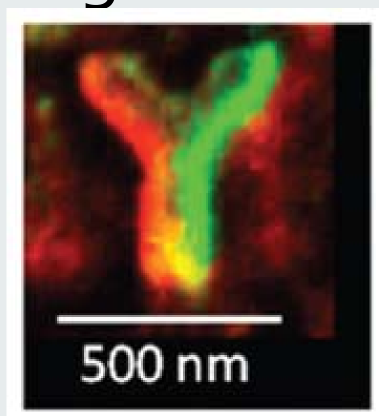


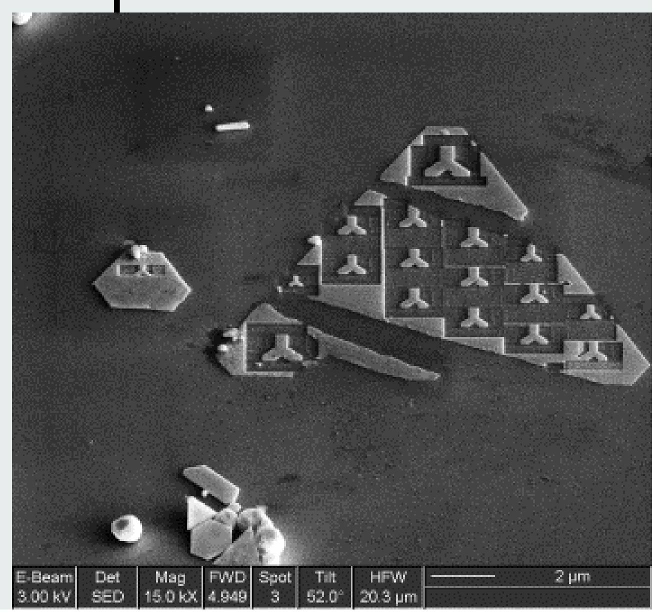
Theoretical Model Conclusions

- Results generally matched theory
- However, discrepancies may occur due to internal tolerances within the program; difficulties of obtaining values at sharp peaks
- COMSOL modeling can be used to explore different effects of surface plasmon resonance in nanoparticles.

Modeling Experimental Results: Y Router

- Based on a Y shape fabricated using a focused-ion beam microscope (FIB)
- Single-crystalline gold on indium tin oxide (ITO)
- Analyzed for its "routing" ability: response of surface plasmons changed based on polarization of the light





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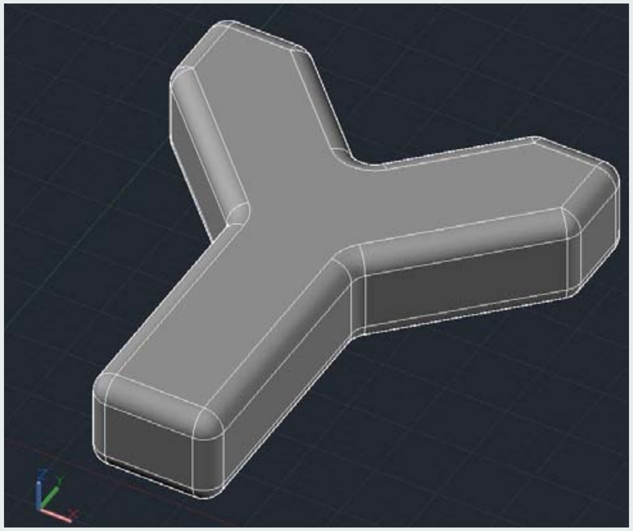
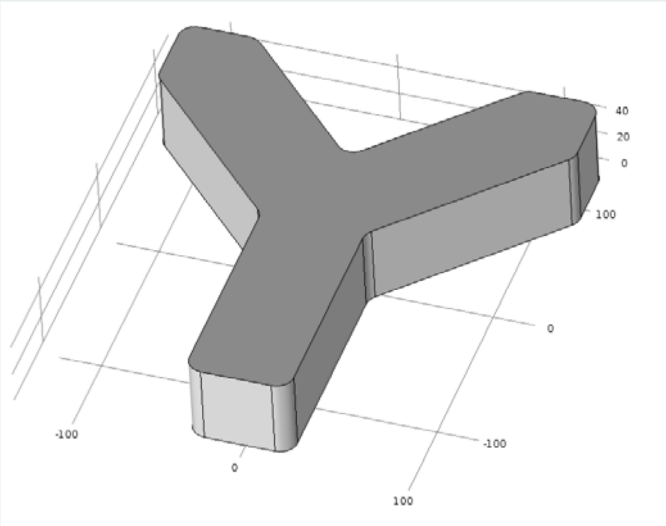
Modeling Experimental Results: Y Router

- Rounded edges necessary in making the model similar to the experiment; difficult for COMSOL
- Attempted to construct the shape using AutoCAD (computer-aided design)



Goal



Best COMSOL approximation

Future Steps

- Improve the Y Router model in COMSOL
  - Use rounded edges
  - Add glass and indium tin oxide (ITO) layer
- Design new antennas for testing

Acknowledgments

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Thank you!