Studying the Scattering of Electromagnetic Wave by a Composite 3D Model at Terahertz Frequencies

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INTRODUCTION:

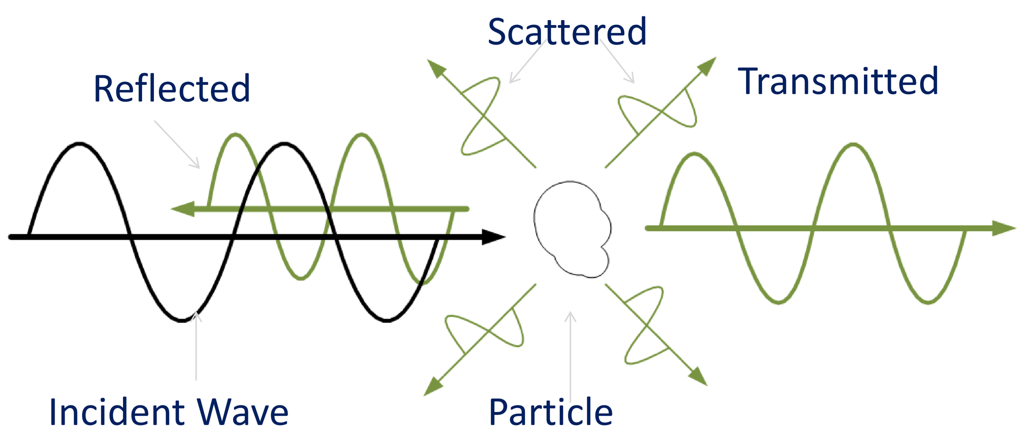
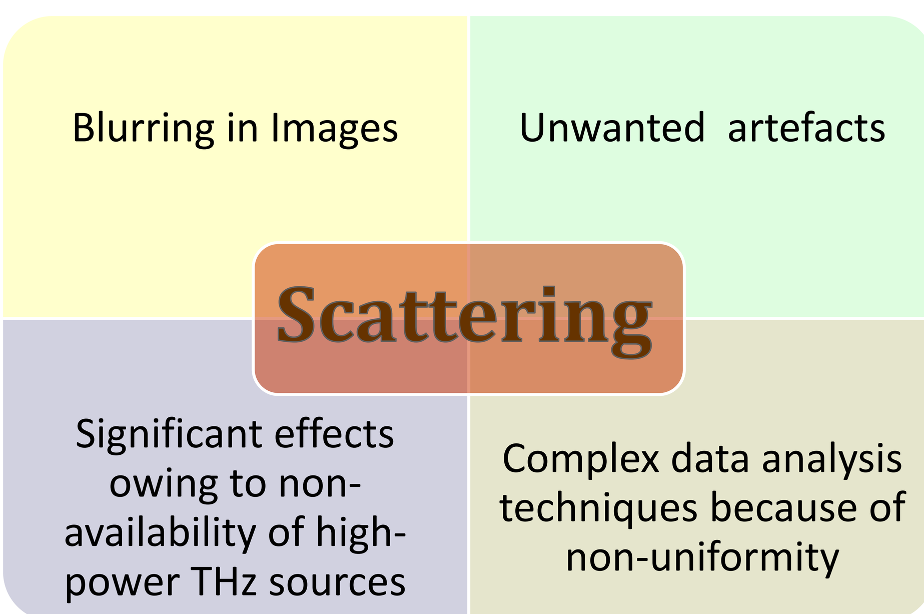
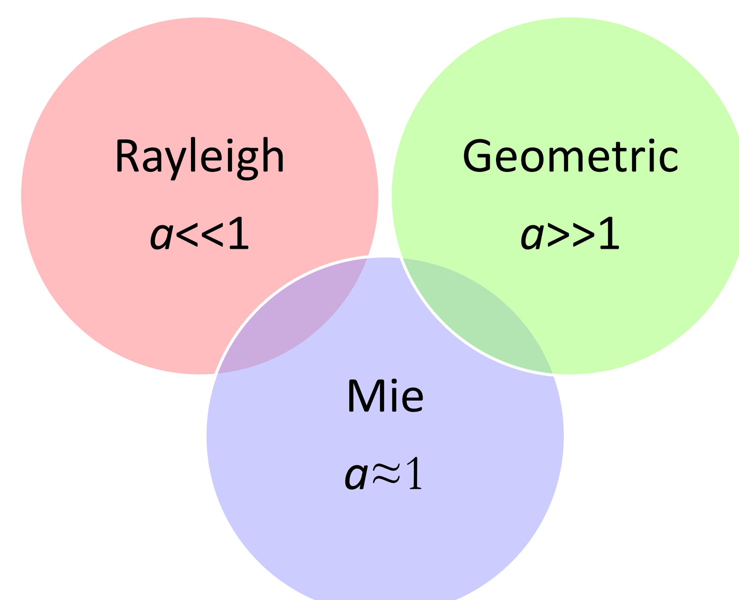


Figure 1: Scattering of EM wave by irregular particle. Resultant intensity is attenuated due to scattering of light in random direction and absorption by particle.





Scattering based on size parameter, a (ratio of scatterer size to wavelength)

- Most of the rigorous theoretical scattering solutions deal only with regular geometrical patterns.
- COMSOL Multiphysics® provides a flexible and reliable platform to model such compound 3D structures, aiding to understand the scattered field behaviour.

COMPUTATIONAL METHOD:

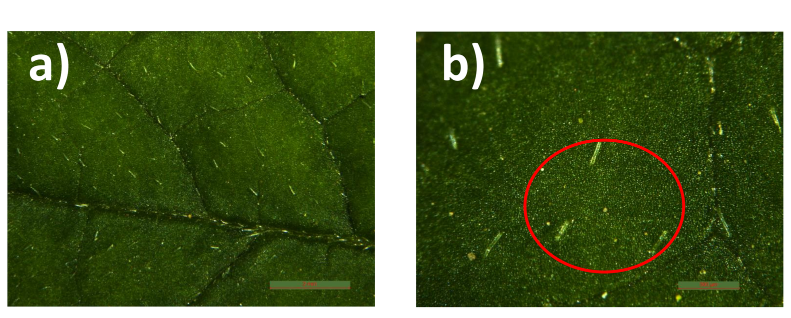
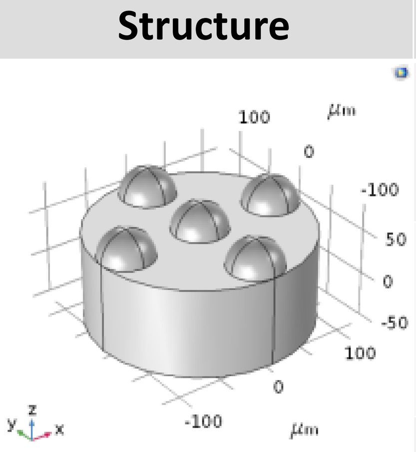


Figure 2: Microscopic images of bitter gourd leaf showing presence of trichomes (hair-like structures) acquired with *Leica M205C* microscope of resolution a) $2mm$ b) $500\mu m$. Leaf thickness: $0.12mm$.



Structure	Model	Description
	Model 1-a	Refractive Index (RI): $3.67 + 0.005i$
	Model 1-b	Base RI: $3.95 + 0.08i$ hemisphere RI: $3.67 + 0.005i$
	Model 1-c	RI: ref. Table 2

COMSOLE MODULE	Wave Optics
INTERFACE	Electromagnetic Wave, Frequency Domain
MESH	Physics Controlled Mesh (Wavelength)

Table 1: Simulation Model Structures and Description-Model 1. For base, $height = 0.1, radius = 0.12$; for hemispheres, $radius = 0.03$; Dimensions are in mm.

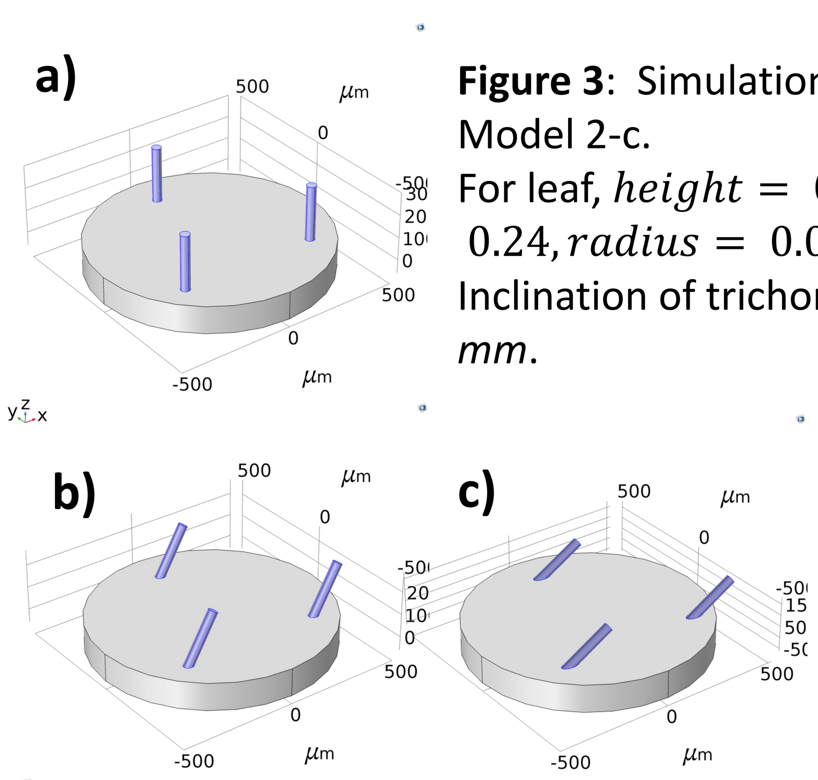


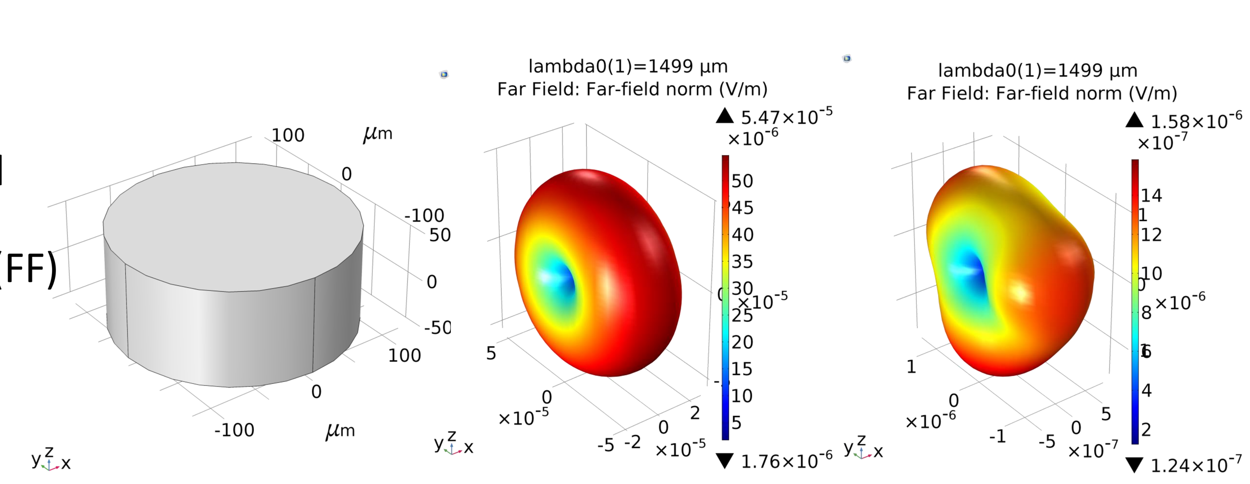
Figure 3: Simulation Model Structures for a) Model 2-a, b) Model 2-b, c) Model 2-c.
For leaf, $height = 0.12, radius = 0.5$; for trichome: $height = 0.24, radius = 0.02$.
Inclination of trichomes - @ $0^o, 30^o, 60^o$ for a), b), c); Dimensions are in mm.

Freq (THz)	0.2	0.6	1
RI: Leaf	$1.50 + 0.50i$	$1.45 + 0.45i$	$1.40 + 0.40i$
RI: Trichome	$1.45 + 0.45\,i$	$1.40 + 0.40i$	$1.35 + 0.35i$

Table 2: RIs for Models 1-c, 2-a, 2-b, 2-c

RESULTS:

Figure 4: Effect of embedded hemispheres on scattering pattern. At 0.2 THz, far field (FF) pattern for geometry in a) is given in b). c) FF Pattern for Model 1-b;
FF at b) is more uniform



RESULTS:

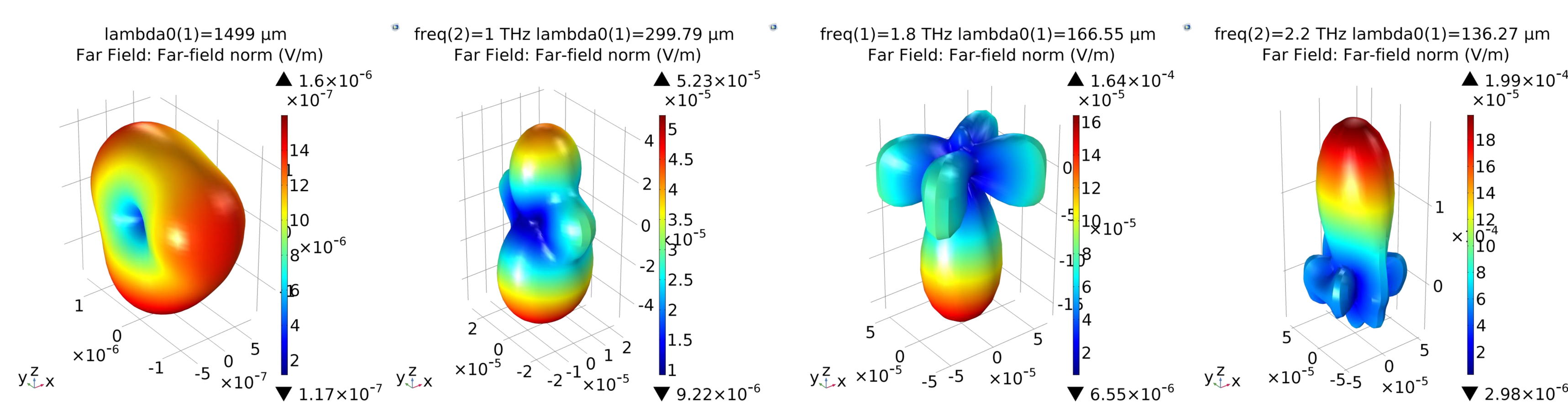


Figure 5: Scattered far-field radiation patterns for Model 1-a @ 0.2 THz, 1 THz, 1.8 THz and 2.2 THz (left to right); SCAs are in units of $10^{-8}m^2$.

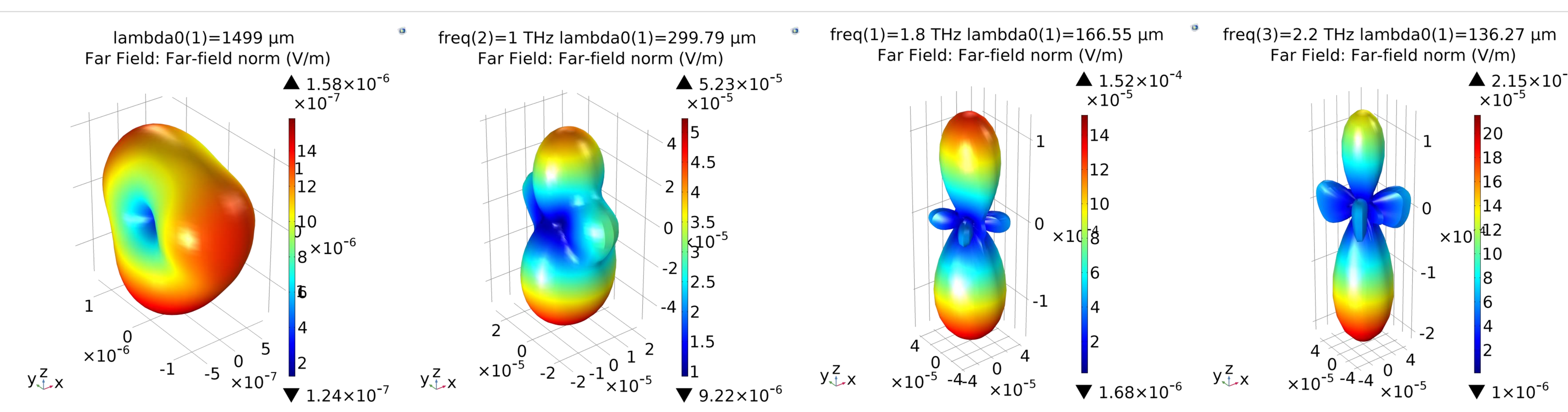
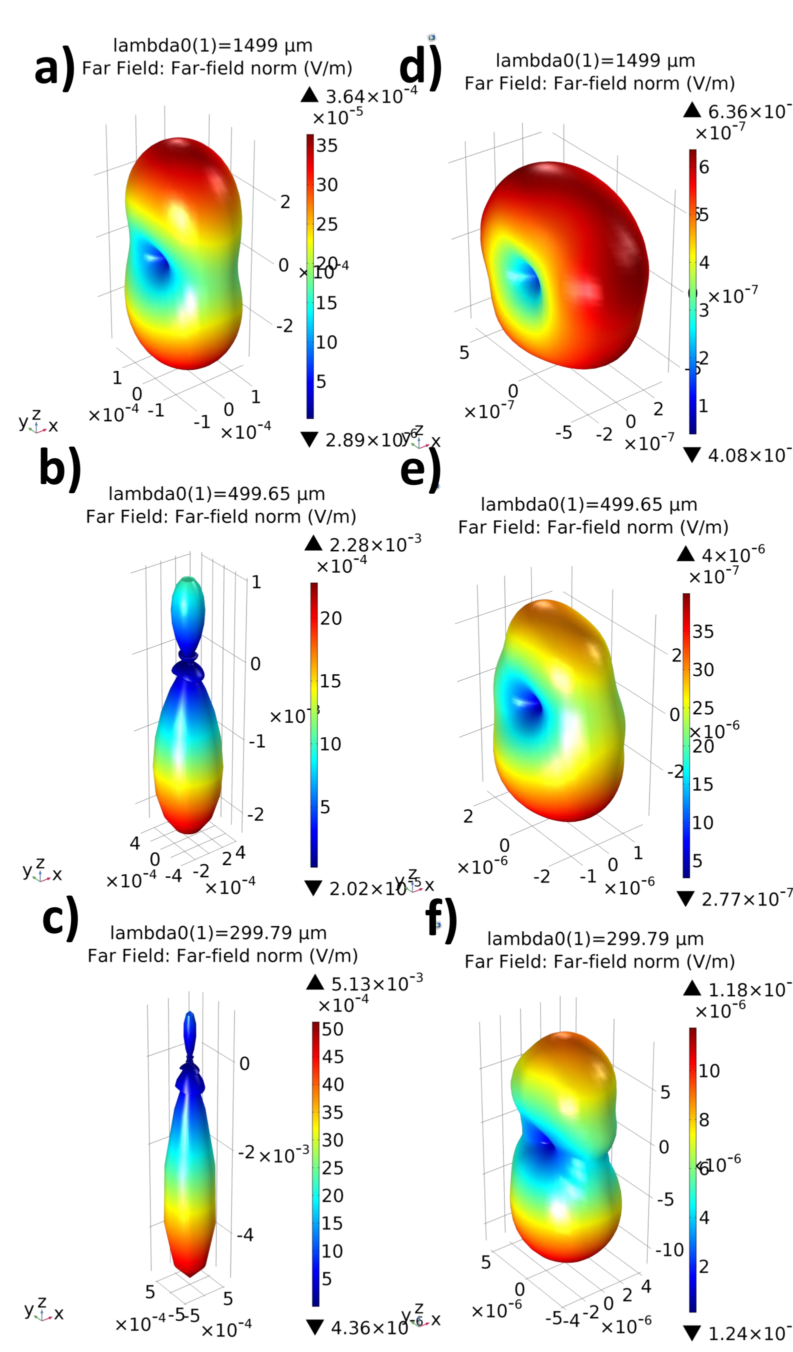


Figure 6: Scattered far-field radiation patterns for Model 1-b @ 0.2 THz, 1 THz, 1.8THz and 2.2 THz (right to left); SCAs are in units of $10^{-8}m^2$.



Model	Freq. (THz)	SCA ($10^{-8}\,m^2$)	Model	Freq. (THz)	SCA ($10^{-8}\,m^2$)
Model 2-a	0.2	13.522	Model 2-c	0.2	13.537
	0.6	39.277		0.6	38.975
	1.0	59.817		1.0	59.723
Model 2-b	0.2	13.490	Model 1-d	0.2	0.072
	0.6	39.207		0.6	1.853
	1.0	59.842		1.0	2.599

Table 1 (above): Scattering cross-section (m^2) for model 2-a, 2-b, 2-c and model 1-c, with frequency.

Figure 7 (left): Scattered far-field radiation patterns:
- Model 2-a @ a) 0.2 THz b) 0.6 THz c)1.0 THz
- Model 1-c @ d) 0.2 THz e) 0.6 THz f)1.0 THz
- Far-field patterns for Model 2-b, Model 2-c are almost similar to Model 2-a. Effect of inclination angle is negligible.

Surface inhomogeneity (structure or composition) affects resultant field.

For lower freq., forward scattering is comparable to backscattering; data can be acquired in reflection or transmission mode.

For higher frequencies, the SCA increases and high forward scattering is observed; data to be acquired in reflection mode.

For same frequency, scattering is significantly large for larger structures.

CONCLUSIONS:

- We have identified the frequency range for which data needs to be taken in reflection or transmission mode for optimal results.
- Model is relevant for other typical biological samples (leaves, petals, skin, etc.), common chemicals, food samples, patterned semiconductor heterostructures.

REFERENCES:

1. H. C. van de Hulst, *Light Scattering by Small particles*, Dover, 1981
2. Fabrizio Frezza, Fabio Mangini, and Nicola Tedeschi, Introduction to electromagnetic scattering: tutorial, J. Opt. Soc. Am. A 35, 163-173, 2018.

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