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

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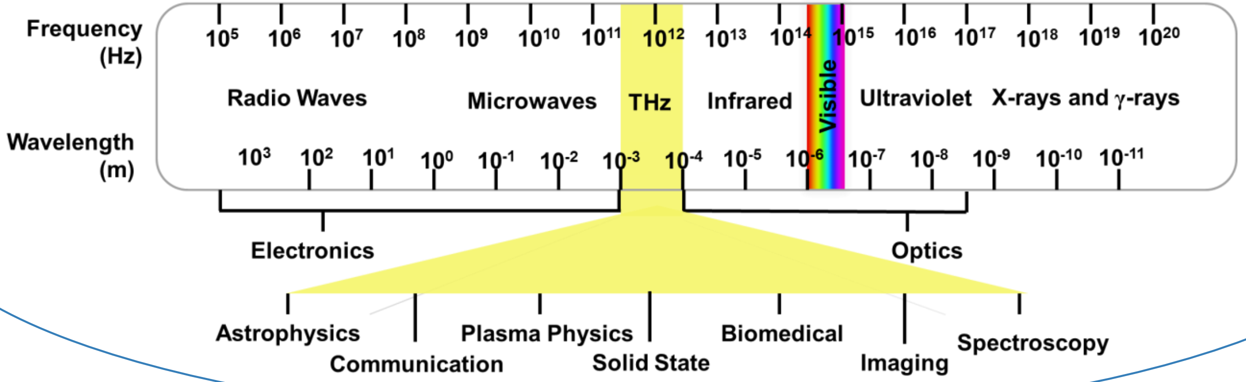
Tera Hertz Imaging and Spectroscopy Laboratory
THIS LAB
There is always more to be revealed

Outline

- Why Terahertz ?
- Physics of Scattering
- Scattering Limitations
- Why COMSOL ?
- Model of Interest
- Results
- Conclusions

Why Terahertz (THz)?



Unique Spectral Signatures

Penetrates dielectrics

Harmless to biological matter

Absorption in presence of water

Atmospheric attenuation

Scattering

Physics of Scattering

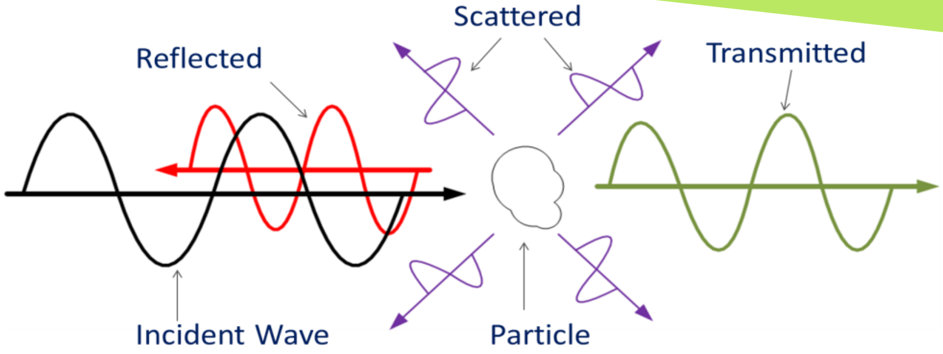
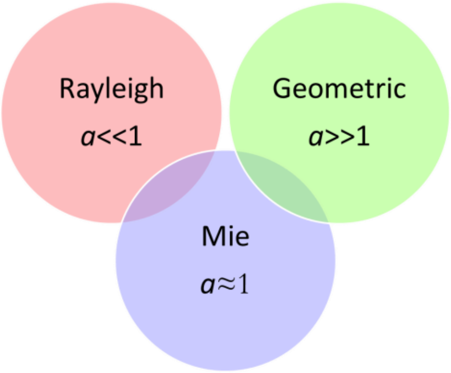


Figure 1:
Scattering of EM wave by irregular particle. Resultant intensity is attenuated due to scattering of light in random direction and absorption by particle.



Equations:

- Scattering + Absorption = Extinction
- Irradiance, $\mathcal{J}_i$ $= |\boldsymbol{\mathcal{P}}_{avg}| = \frac{1}{2}|Re[\boldsymbol{E} \times \boldsymbol{H}^*]| = \frac{1}{2\eta}|E|^2$
- Scattering Cross-section = $CSA_{sca} = \frac{W_{sca}}{\mathcal{J}_i}$

  where, W_{sca} : rate at which EM energy is scattered

H. C. van de Hulst, *Light Scattering by Small particles*, Dover, 1981

Scattering : Limitations

Scattering

- Blurring in Images
- Unwanted artefacts
- Significant effects owing to non-availability of high-power THz sources
- Complex data analysis techniques because of non-uniformity

Rigorous theoretical scattering solutions available :

- Deal only with regular geometries like spheres and cylinders in free space
- Does not deal with dependent scattering and multiple scattering because of the increased complexity

Exceptions : biological media (leaf, skin, petals), food materials, packaging material, pharmaceutical drugs, powered substances

Why COMSOL ?

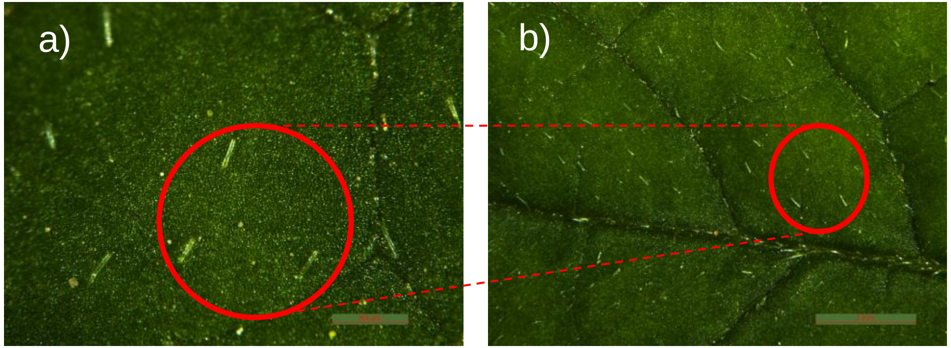
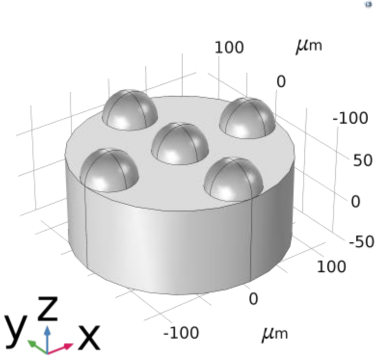


Figure : Microscopic images of bitter gourd leaf showing presence of trichomes (hair-like structures) acquired with Leica M205C microscope of resolution a)$500\mu m$ b) $2mm$. Leaf thickness: $0.12mm$.

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

- Provides a flexible and reliable platform to model such compound 3D structures.
- Aids to understand the nature of interaction for specific frequency ranges.
- Includes inbuilt feature for the simulation of the scattered far-field.

Model & Results



Model 1:
For base, $height = 0.1, radius = 0.12$;
For hemispheres (HS) , $radius = 0.03$;
Dimensions are in mm.
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Model 1-a

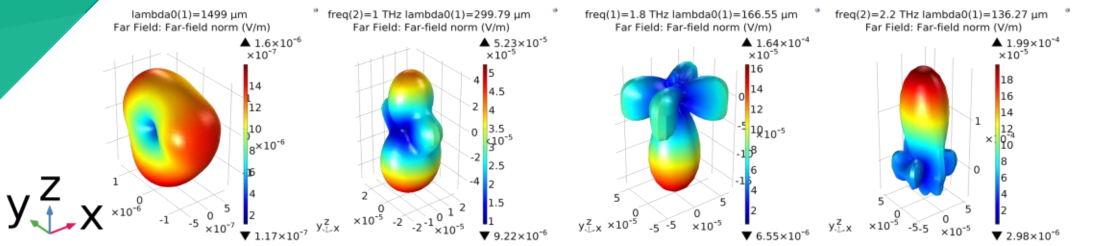
Refractive Index (RI):
$3.67 + 0.005i$

Model 1-b

Base RI: $3.95 + 0.08i$
HS RI: $3.67 + 0.005i$

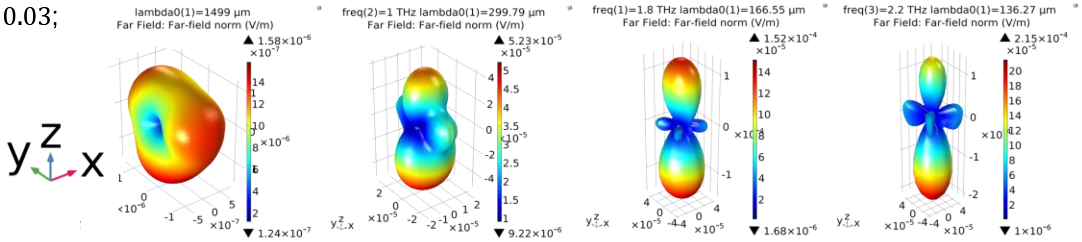
Model 1-c

Varying RI



SCA = 0.5135 SCA = 8.3472 SCA = 12.7790 SCA = 5.6013

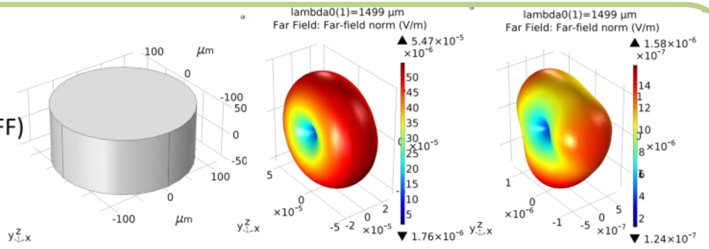
Figure : Scattered far-field radiation patterns for Model 1-a @ 0.2 THz, 1 THz, 1.8 THz and 2.2 THz (left to right); SCAs are in units of $10^{-8} m^2$.



SCA = 0.5633 SCA = 8.3472 SCA = 6.9774 SCA = 6.8164

Figure : 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 $10^{-8} m^2$.

Figure : 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



a) b) c)

Model & Results

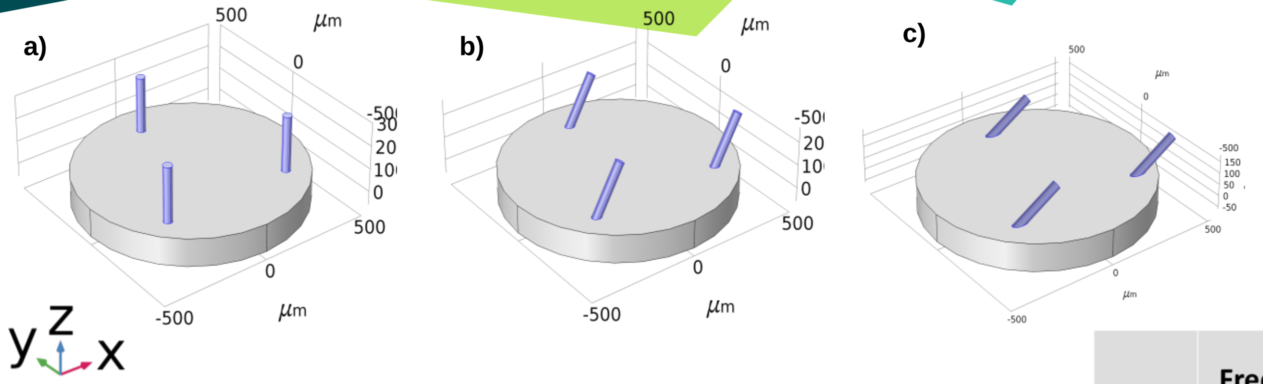


Figure : Simulation Model Structures for a) Model 2-a, b) Model 2-b, c) Model 2-c.
For leaf, $height = 0.12, radius = 0.5$;
for trichome: $height = 0.24, radius = 0.02$.
Inclination of trichomes - @ $0^o, 30^o, 60^o$ for a), b), c);
Dimensions are in *mm*.

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 : RIs for Model 1c, 2a, 2b, 2c .

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-c	0.2	0.072
	0.6	39.207		0.6	1.853
	1.0	59.842		1.0	2.599

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

Results

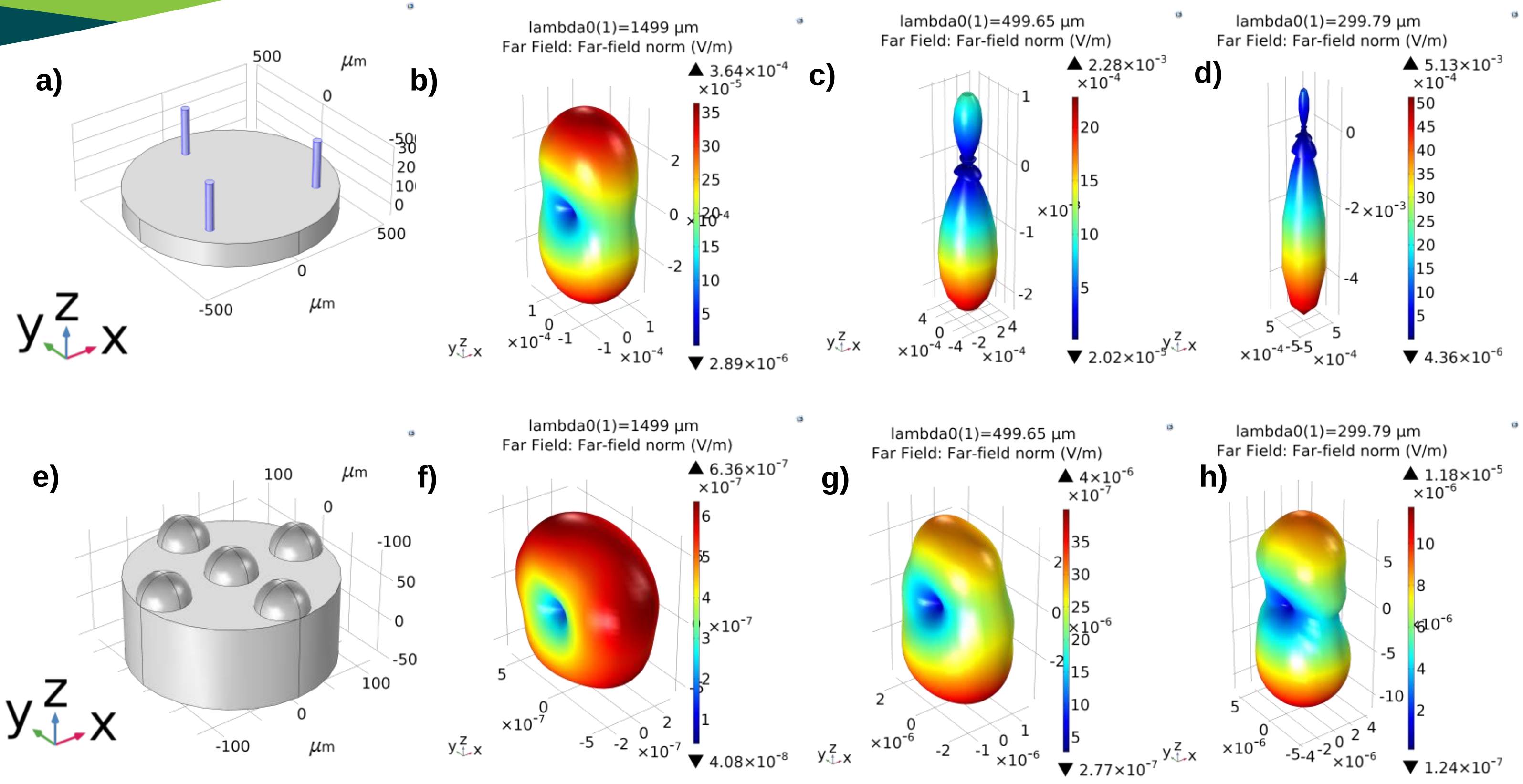


Figure : Scattered far-field radiation patterns:

a) Model 2-a @ b) 0.2 THz c) 0.6 THz d)1.0 THz and e) Model 1-c @ f) 0.2 THz g) 0.6 THz h)1.0 THz.

Conclusions

I

Surface inhomogeneity (structure or composition) affects resultant field.

II

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

III

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

IV

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

V

Identified the frequency range for which data needs to be taken in reflection or transmission mode for optimal results.

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VI

Model is relevant for other typical biological samples (leaves, petals, skin, etc.), common chemicals, food samples, patterned semiconductor heterostructures.

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