On the Use of an Untapered Plane Wave in Numerical Studies of Scattering from Randomly Rough Surfaces

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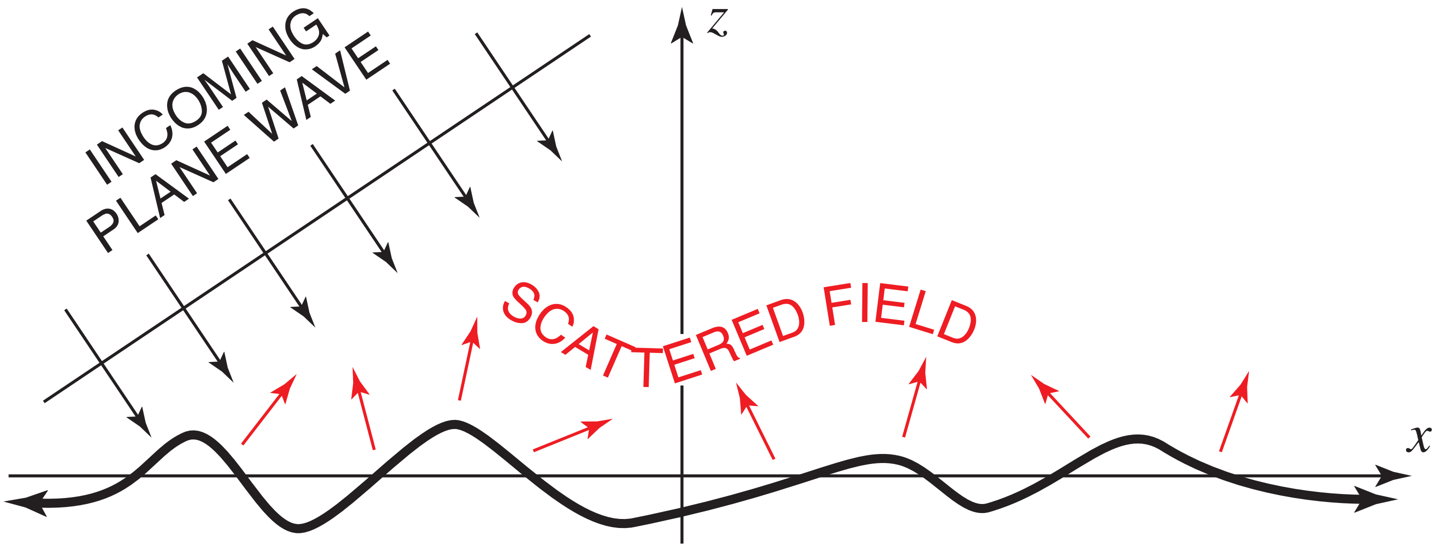
Outline

- General background and problem statement
- Tapered incident field approach
- Plane wave incident field approach
- Scattering from canonical surfaces
- Scattering from randomly rough surfaces
- Conclusions

Note: Concerned with FDTD solutions

Background/Problem Statement

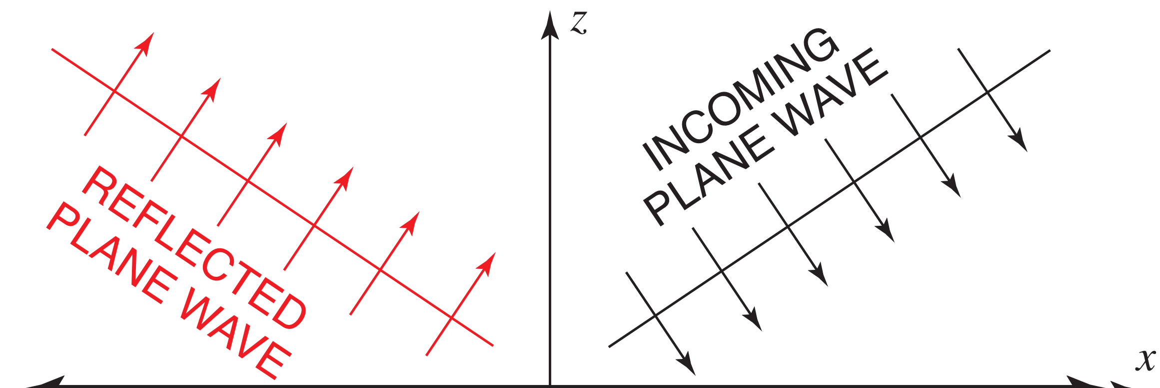


Want scattering from *infinite* randomly rough surface illuminated by plane wave

Monte Carlo technique:

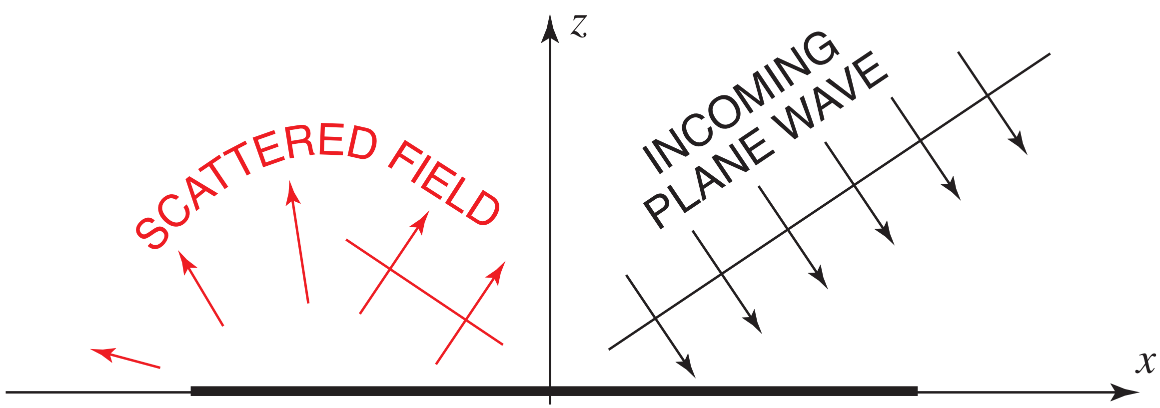
- Generate set of *finite* surface realizations
- Determine fields scattered from each realization
- Average results to obtain approximation for infinite surface

Plane Wave Illumination



INFINITE FLAT SURFACE

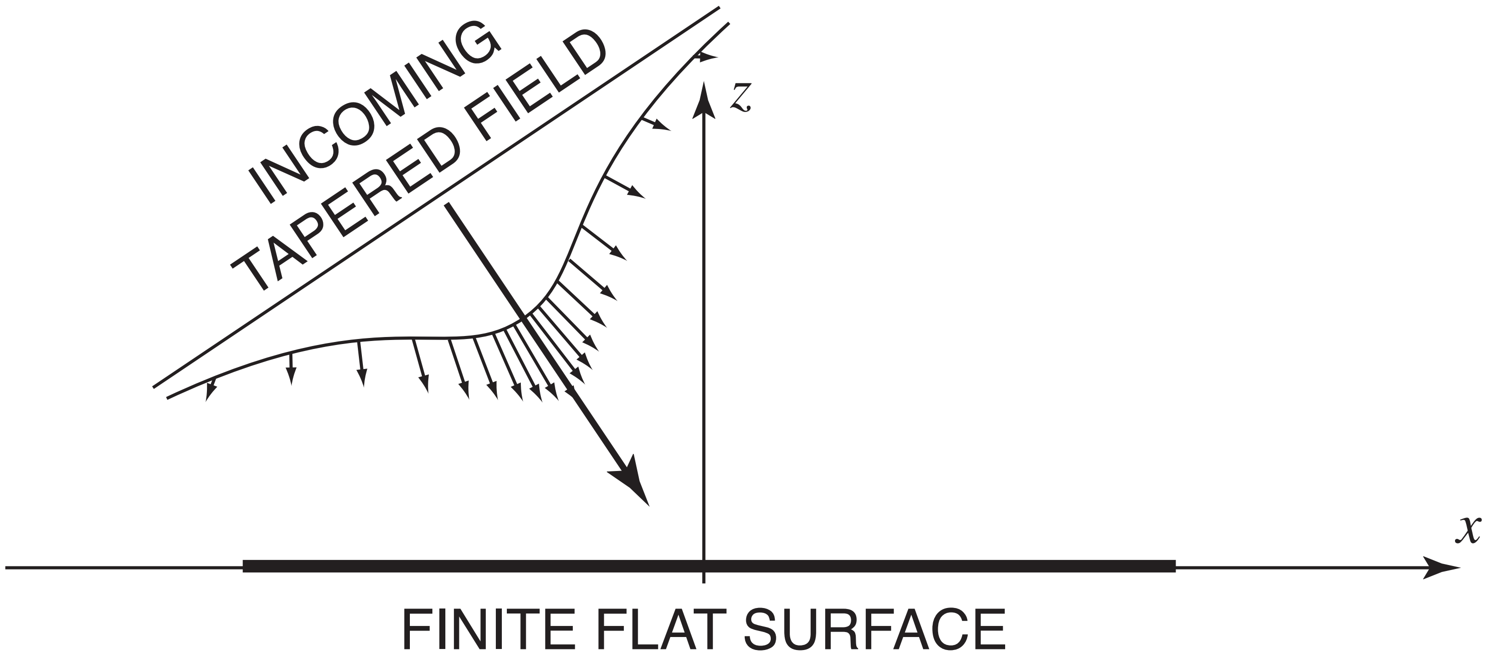
Scattered field is perfect plane wave



FINITE FLAT SURFACE

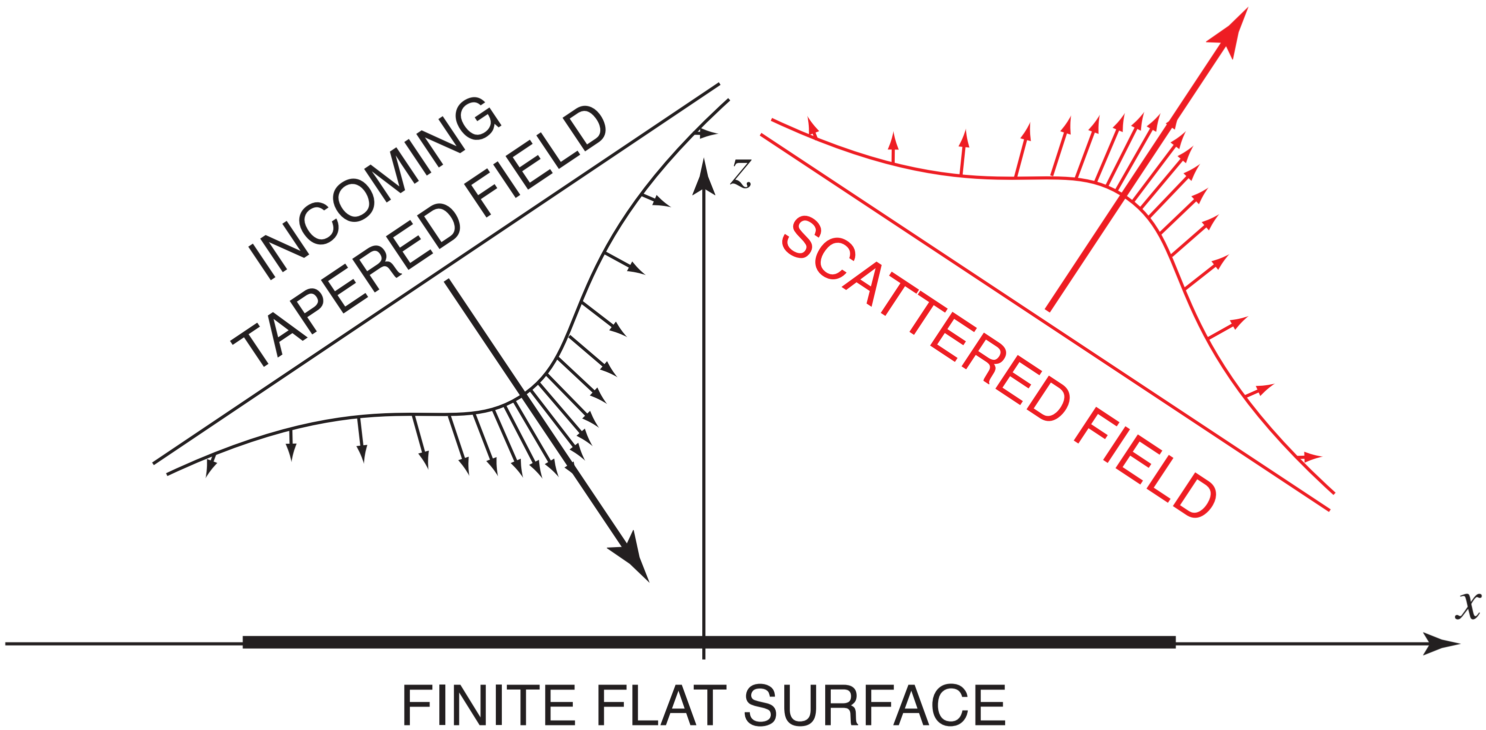
Scattered field includes edge diffraction

Tapered Illumination, I



- Tapered illumination ensures incident field small at surface edges
- Effectively eliminates edge diffraction

Tapered Illumination, I



- Tapered illumination ensures incident field small at surface edges
- Effectively eliminates edge diffraction

Tapered Illumination, II

- Approximate solution to wave equation
  - Quality of solution depends on taper factor
  - If *length* of taper fixed, lower frequencies have larger errors
- May require large computational resources to obtain desired field over particular region
- Due to dispersion and anisotropy of FDTD grid, incident angle not exact

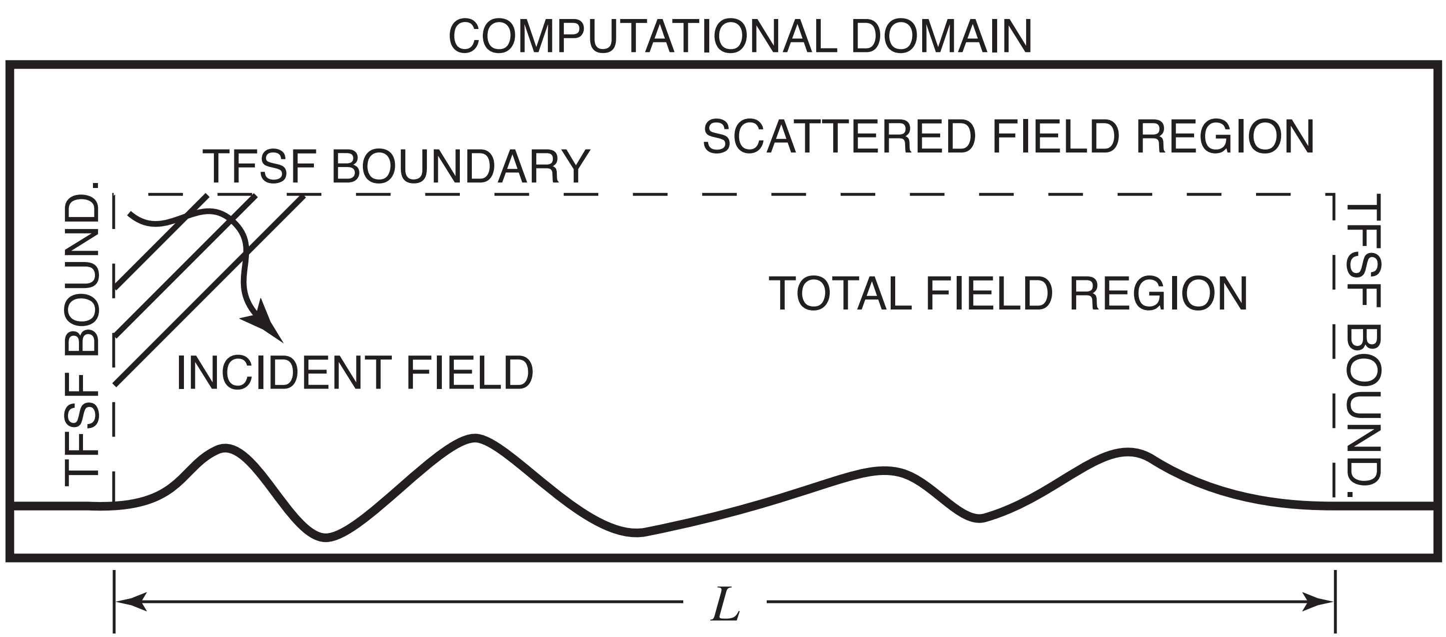
Plane Wave Illumination

Frequency-domain approaches employing plane-wave illumination:

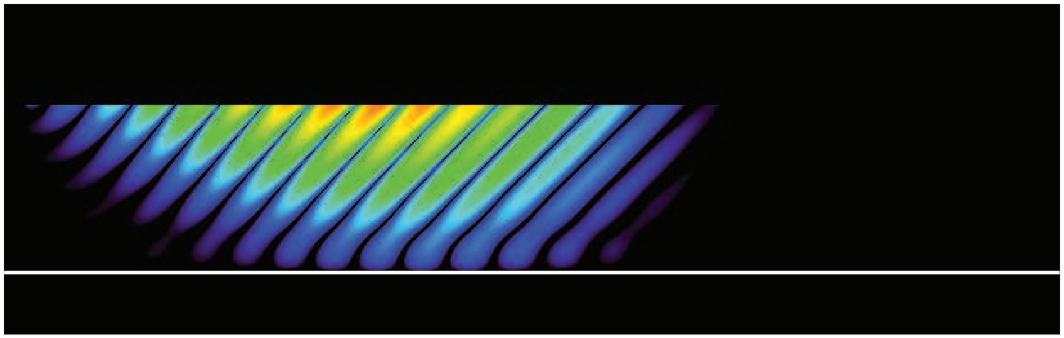
- Y. Oh and K. Sarabandi[1]
  - conducting surfaces
  - edge diffraction reduced by adding resistive surfaces to ends
- J. C. West[2]
  - finite conductivity surfaces
  - diffraction reduced by tapering resistance
- Z. Zhao, L. Li, J. Smith, L. Carin[3]
  - **used Green's function for conducting half-space**
  - **tapered surface height at ends to match a flat plane**
  - compared half-space and resistive taper approaches

FDTD-Based Solutions

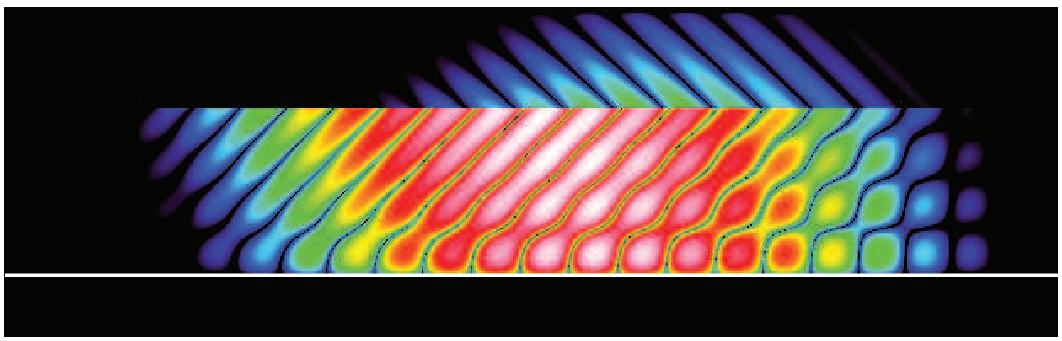
- Differential-equation based method
- Discretize surface and space adjacent to surface
- Incident field introduced over total-field/scattered-field (TFSF) boundary
- Grid divided into scattered-field region and total-field region (incident plus scattered field)



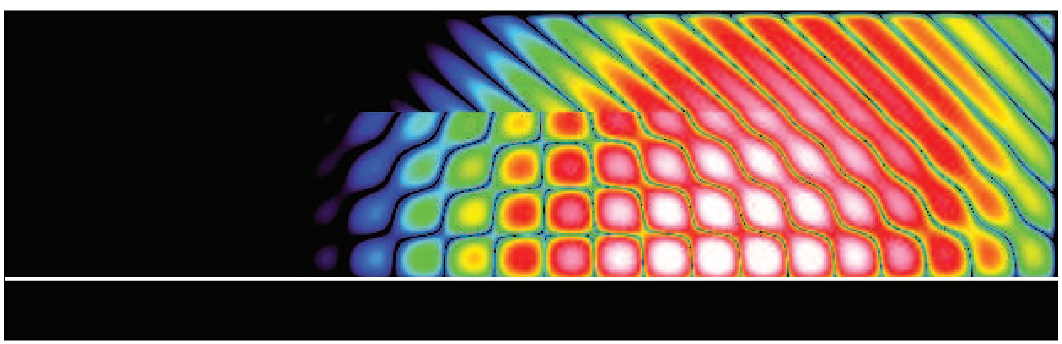
Flat Surface with Tapered Incidence



Snapshot 1: Incoming pulsed beam visible in TF region

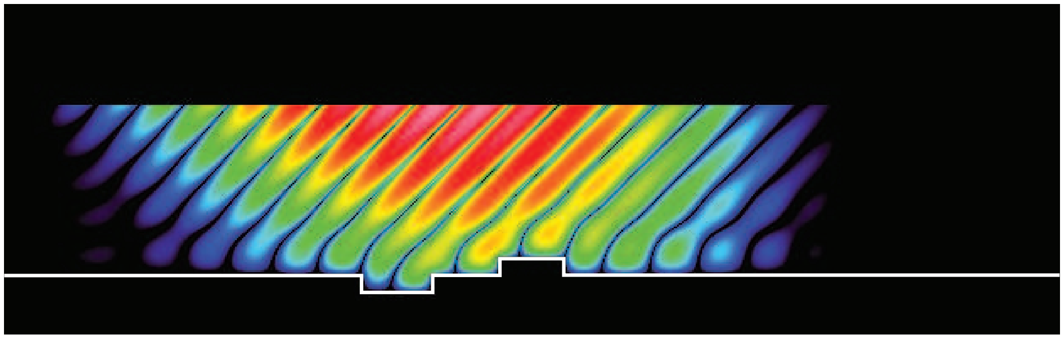


Snapshot 2: Beam reflects; interference visible in TF region; reflected wave seen in SF region

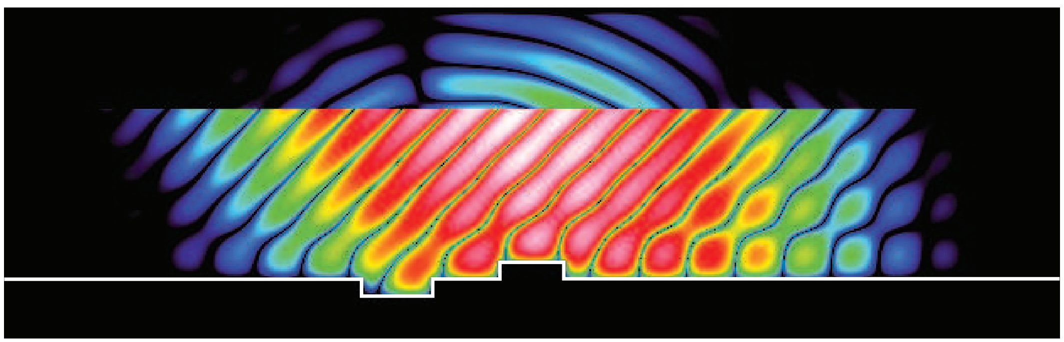


Snapshot 3: Reflected beam a "copy" of incident beam; more visible in SF region

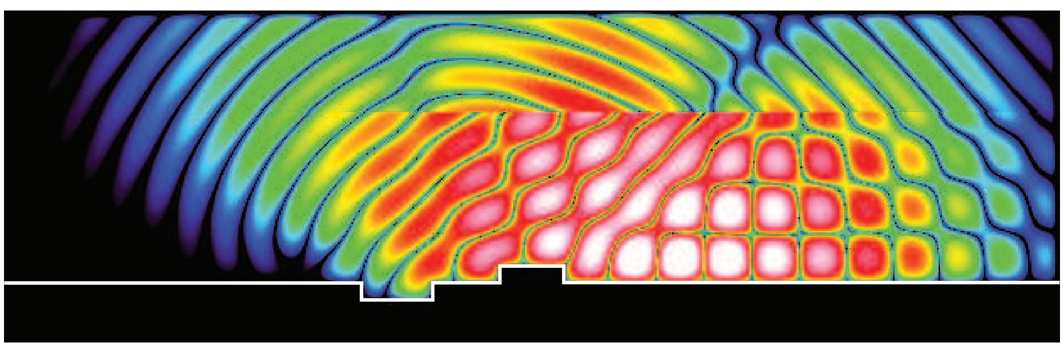
Non-Flat Surface with Tapered Incidence



Snapshot 1: Incident field illuminates notch and bump in surface



Snapshot 2: Scattering from surface visible in SF region



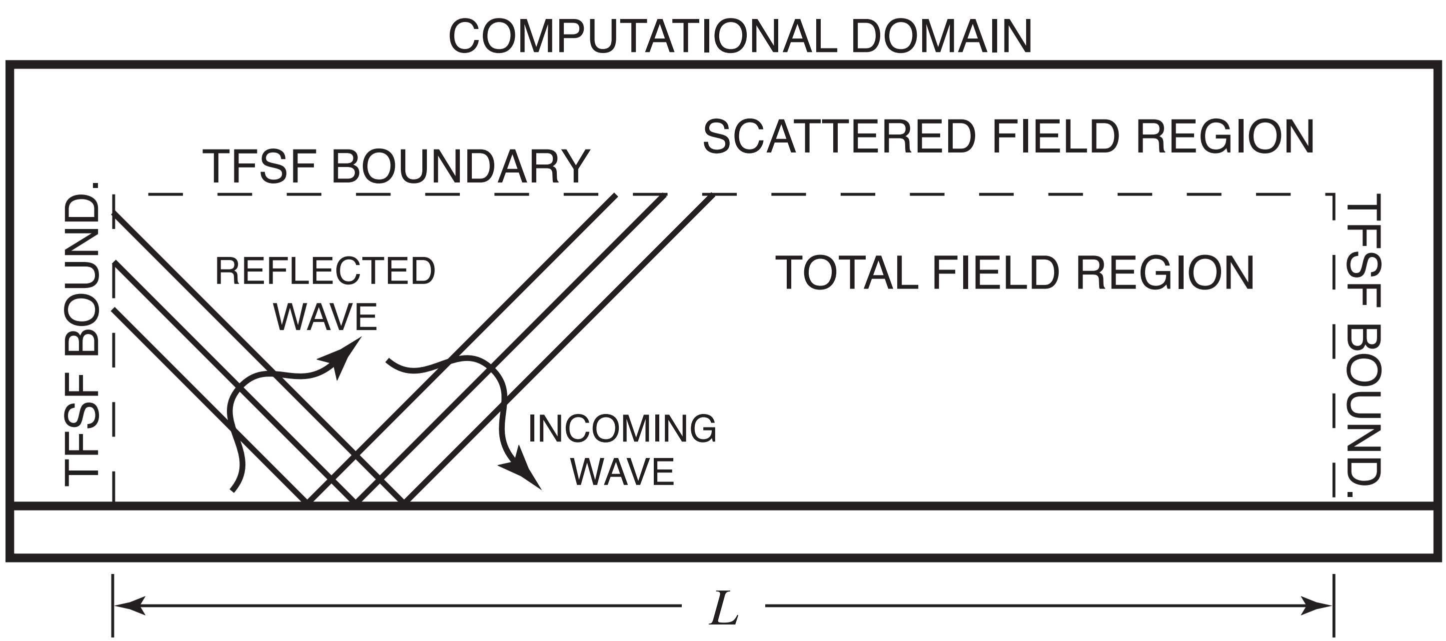
Snapshot 3: Specular reflection now visible in SF region

FDTD-Based Plane Wave Solution

For true plane-wave illumination, incident field composed of:

(1) incoming plane wave **and**

(2) corresponding reflected plane wave



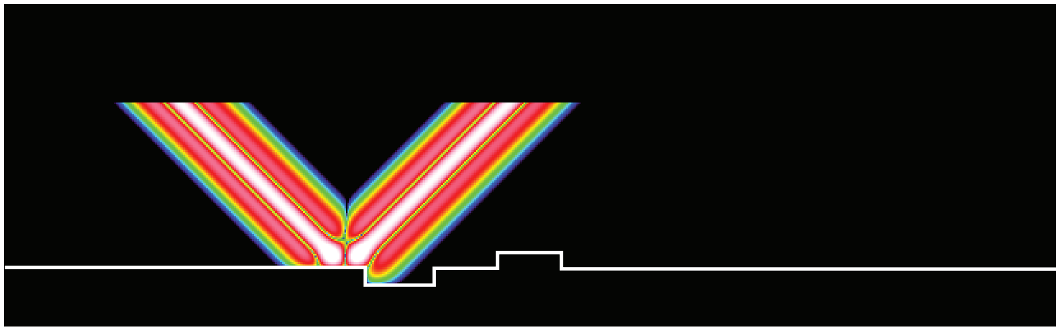
Flat Conducting Surface with Plane Wave Incidence

Snapshot 1: “Incoming” pulsed plane wave visible in TF region

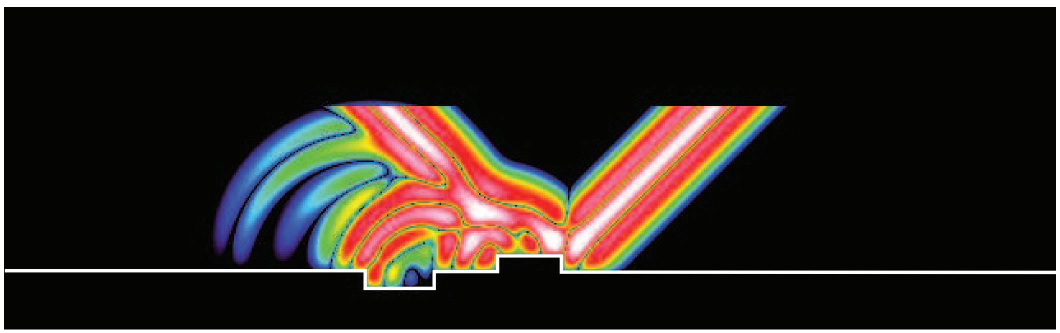
Snapshot 2: Incoming and reflected plane waves visible in TF region

Snapshot 3: For a flat surface, incident field does not escape TF region

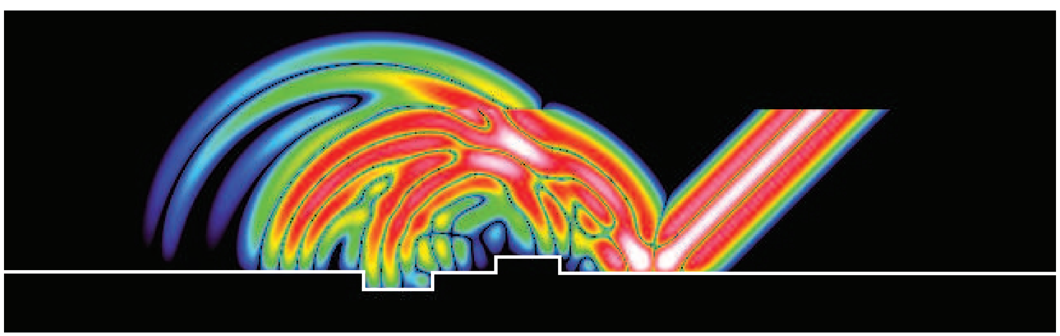
Non-Flat Surface with Plane Wave Incidence



Snapshot 1: Incident field reaches notch in surface illuminated



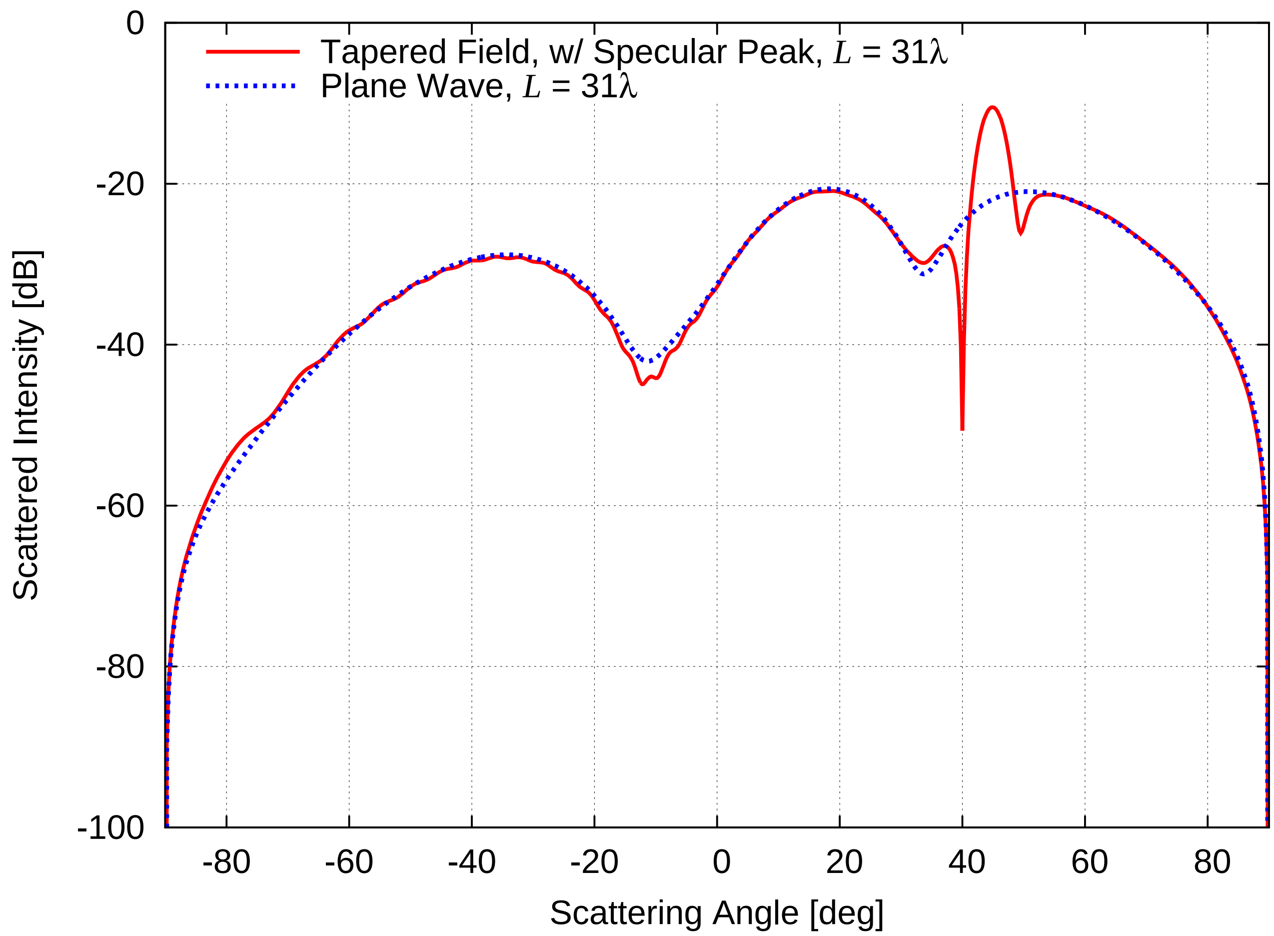
Snapshot 2: Incident field reaches "bump" in surface



Snapshot 3: Scattered field evident in SF region

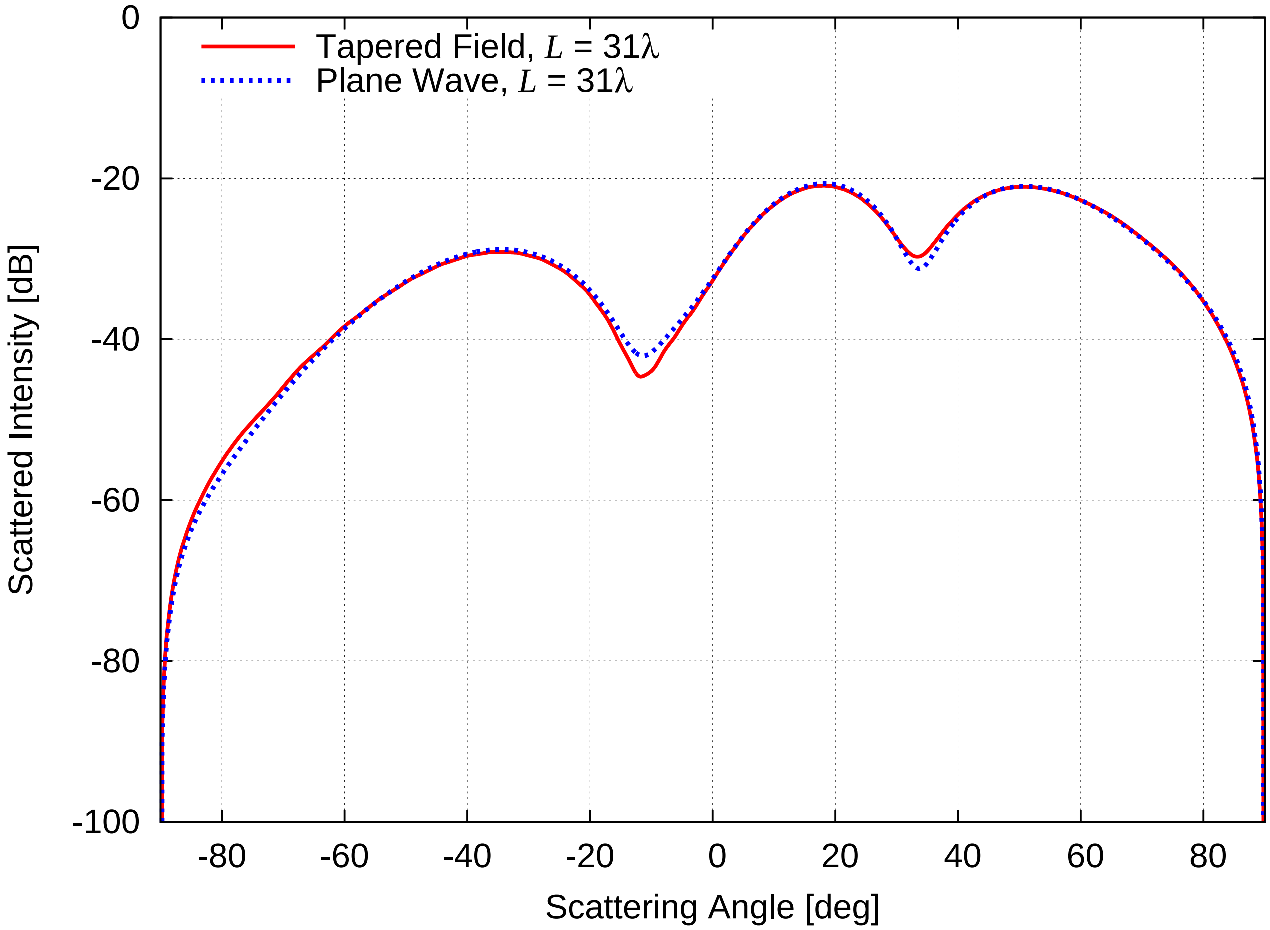
Scattering from a Notched Surface, I

45° incidence; surface length 31λ; beam waist size 5λ



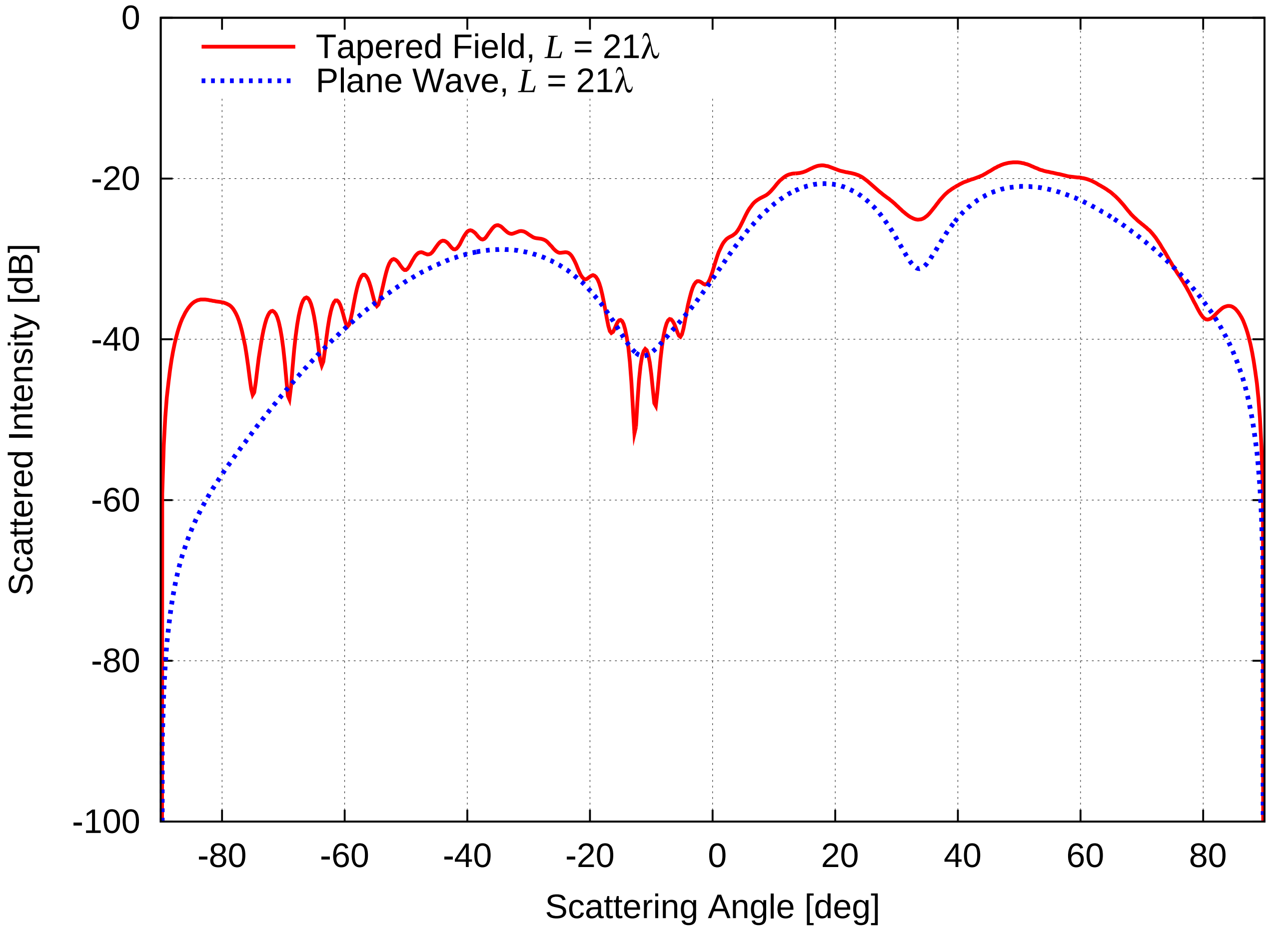
Scattering from a Notched Surface, II

45° incidence; surface length 31λ; beam waist size 5λ



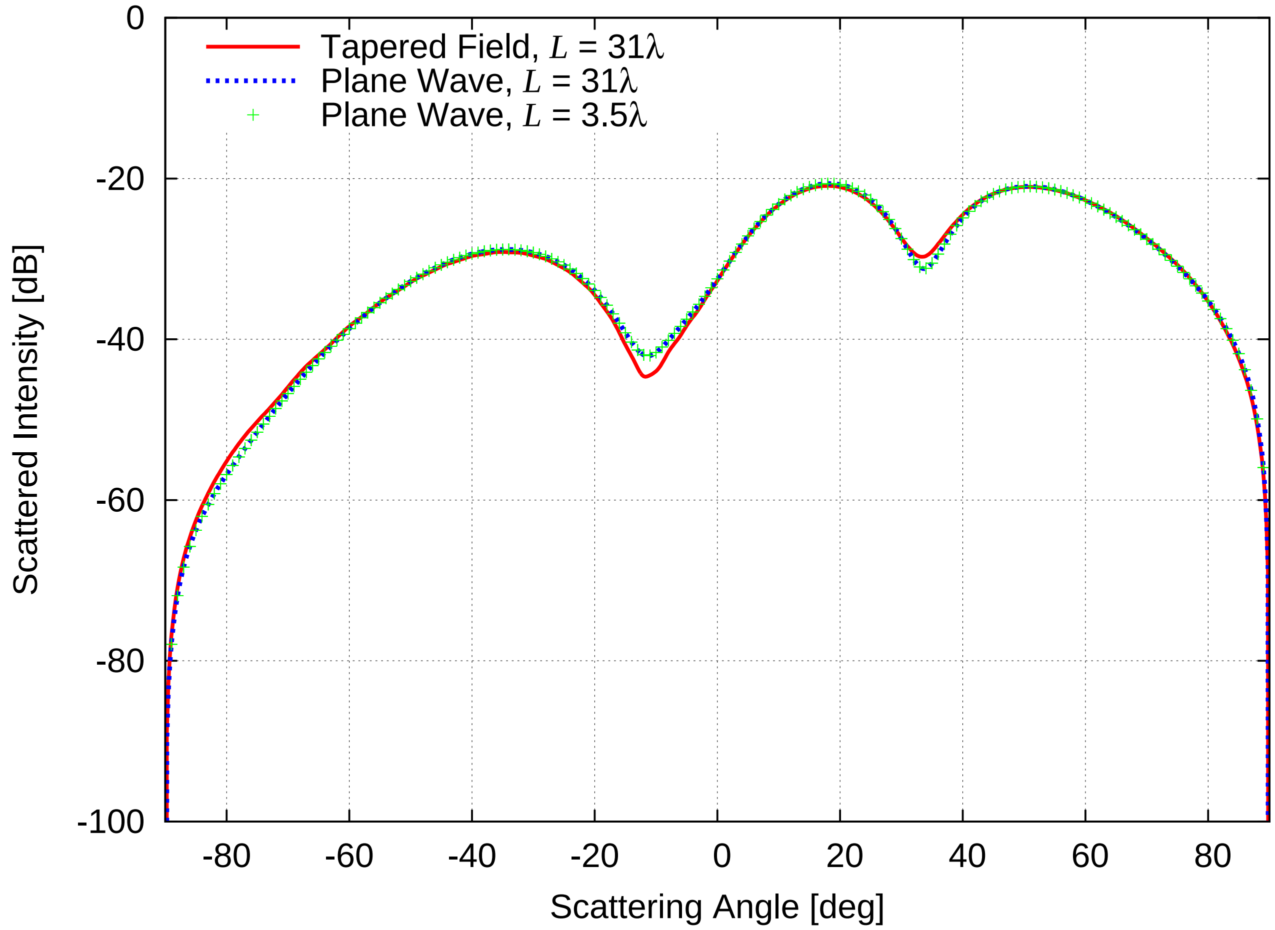
Scattering from a Notched Surface, III

45° incidence; surface length 21λ; beam waist size 5λ



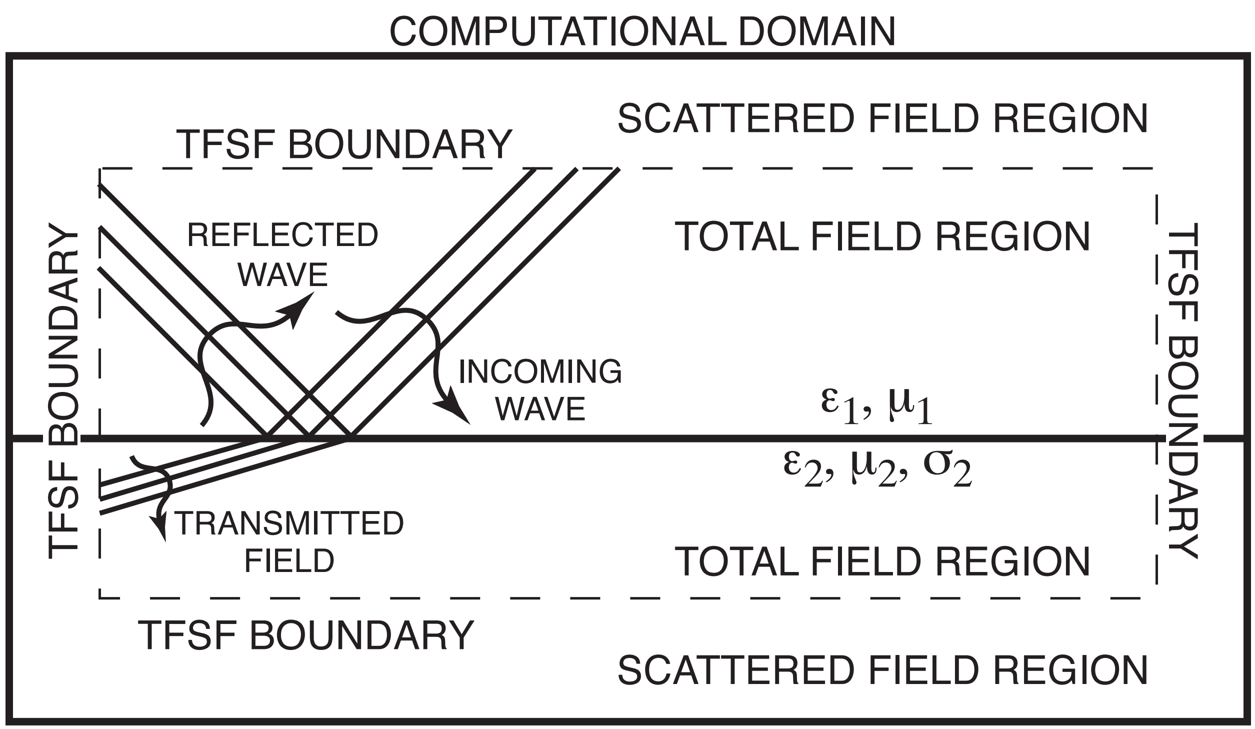
Scattering from a Notched Surface, IV

45° incidence; surface length 31λ or 3.5λ



Dielectric Halfspaces

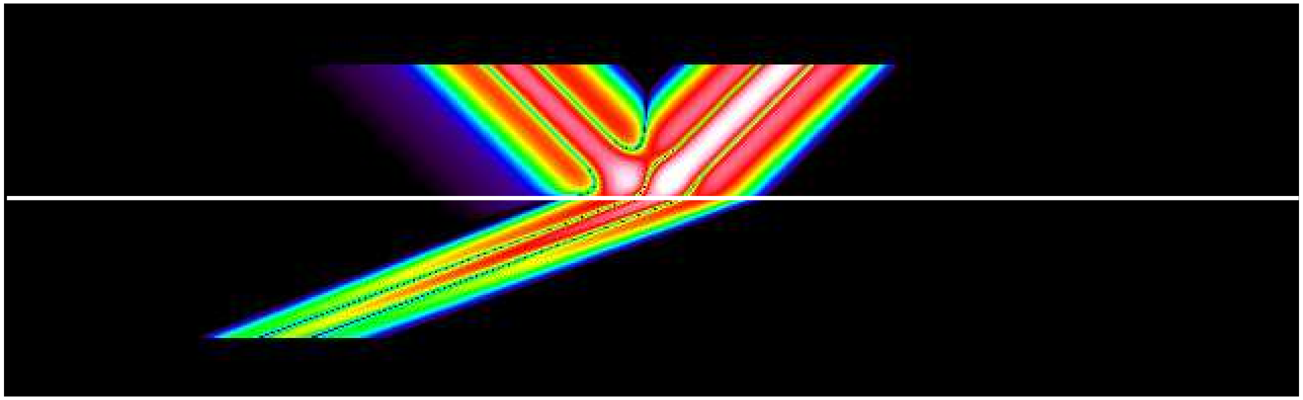
Incident field specified at TFSF boundary consists of:
(1) incoming plane wave **and**
(2) corresponding reflected plane wave **and**
(3) corresponding transmitted field (may be evanescent)



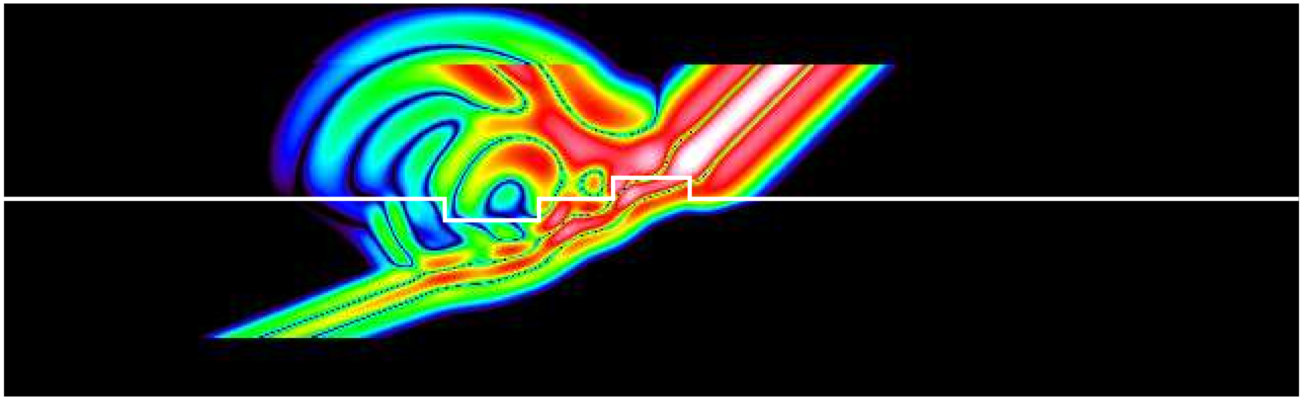
Plane Wave Incidence for Dielectric Surface

$$\epsilon_{1r} = 1,\ \mu_{1r} = 1, \text{ lossless}$$

$$\epsilon_{2r} = 4,\ \mu_{2r} = 1,\ \delta_{\text{skin}} = 0.575\lambda \text{ at 40 points per wavelength}$$



Flat surface: no fields enter SF region



Notched surface: scattered field present

Scattering from Pierson-Moskowitz Surface, I

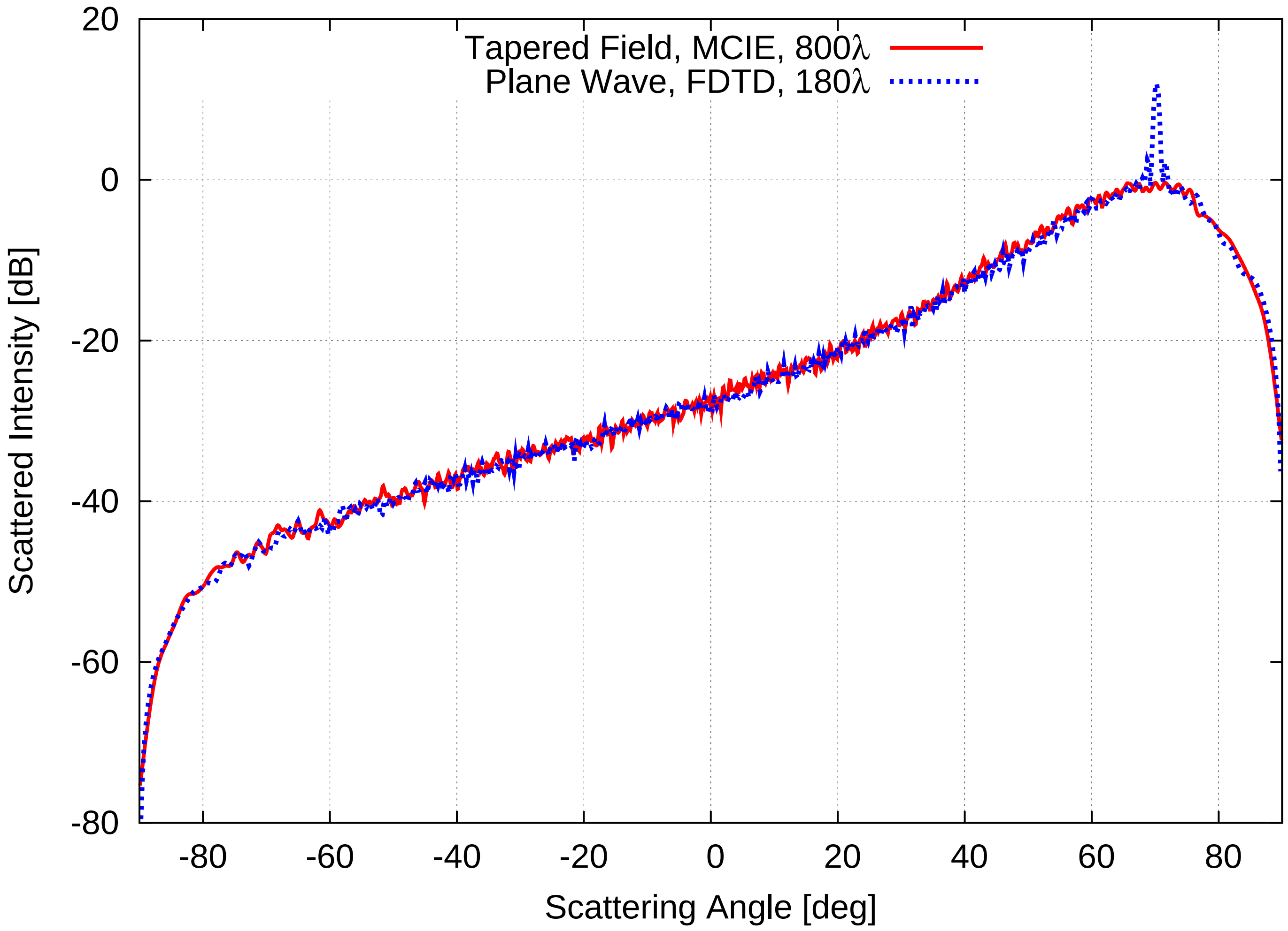
Results obtained using:

1. Monte Carlo Integral Equation (MCIE) with tapered field
2. FDTD with plane wave

Parameters:

- Wind speed 10 m/s
- 300 MHz
- 70° incident angle
- Points per wavelength: 10 for MCIE; 30 for FDTD
- Surface length: 800λ for MCIE; 180λ for FDTD
- 50 surface realizations
- Dirichlet boundary condition (conducting surface with TM^z polarization)

Scattering from Pierson-Moskowitz Surface, II



Conclusions

- Can use plane wave illumination with FDTD method to study scattering from rough surfaces
- Plane-wave approach can be more efficient than using tapered illumination
- Plane-wave approach eliminates several problems associated with tapered illumination
- Can be used for conducting or dielectric surfaces
- Can be used for 3D problems
- Total-field region may include any desired combination of inhomogeneities

References, I

1. Y. Oh and K. Sarabandi, “Improved Numerical Simulation of Electromagnetic Wave Scattering from Perfectly Conducting Random Surfaces,” *IEE Proc. Microw. Antennas Propag.*, **144**(4):256–260, 1997
2. J. C. West, “On the Control of Edge Diffraction in Numerical Rough Surface Scattering Using Resistive Tapering,” *IEEE Trans. Antennas Propag.*, **51**(11):3180–3183, 2003
3. Z. Zhao, L. Li, J. Smith, L. Carin, “Analysis of Scattering from Very Large Three-Dimensional Rough Surfaces Using MLFMM and Ray-Based Analysis,” *IEEE Antennas Propag. Mag.*, **47**(3):20–30, 2005
4. Z. Wang, Z. Zhang, Z. Xu, and Q. Lin, “Space-time profiles of an ultrashort pulsed Gaussian beam,” *IEEE J. Quantum Elec.*, **33**(4):566–573, 1997

References, II

5. Martin, Pettersson, “Modified Fresnel Coefficients for Huygens’ Sources in FDTD,” *ACES J.*, **17**(1):30-41, 2002
6. C. D. Moss, F. L. Teixeira, and J. A. Kong, “Analysis and compensation of numerical dispersion in the FDTD method for layered, anisotropic media,” *IEEE Trans. Antennas Propagat.*, **50**(9):1174–1184, 2002
7. J. B. Schneider and K. Abdijalilov, “Analytic field propagation TFSF boundary for FDTD problems involving planar interfaces: PEC’s, TE, TM,” *IEEE Trans. Antennas Propagat.*, **54**(9): 2531–2542, 2006
8. K. Abdijalilov and J. B. Schneider, “Analytic Field Propagation TFSF Boundary for FDTD Problems Involving Planar Interfaces: Lossy Material and Evanescent Fields,” *IEEE Antennas Wireless Propagat. Lett.*, **5**:454–458, 2006