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(FDTD)

(PEM)

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PEM

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PEM []

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FDTD (FE)

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PEM

Archive of SID

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$$\psi(x, z)$$

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial z^2} - \gamma^2 \psi = 0 \quad (1)$$

$$\gamma = \alpha + j\beta \quad [2]$$

$$\psi(x, z) = u(x, z) e^{j\beta x}$$

$$\frac{\partial^2 u}{\partial x^2} + 2j\beta \frac{\partial u}{\partial x} + \frac{\partial^2 u}{\partial z^2} - (\gamma^2 + \beta^2)u = 0 \quad (3)$$

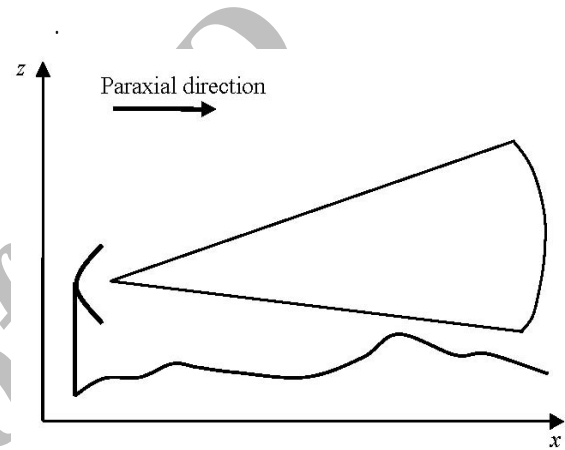
$$\left\{ \frac{\partial u}{\partial x} + j\beta(1-Q)u \right\} \times \left\{ \frac{\partial u}{\partial x} + j\beta(1+Q)u \right\} = 0 \quad (4)$$

$$Q = \frac{\gamma}{j\beta} \sqrt{1 - \frac{1}{\gamma^2} \frac{\partial^2}{\partial z^2}} \quad (5)$$

$$\gamma = j\beta = jk_0 \quad (6)$$

$$Q = \sqrt{1 + \frac{1}{k_0^2} \frac{\partial^2}{\partial z^2}} \quad (7)$$

$$Z = -\frac{1}{\gamma^2} \frac{\partial^2}{\partial z^2} \quad (8)$$



PEM

$$M = \frac{z_{\max}}{\Delta z} \quad v_i^m = v_i(x + \Delta x, m\Delta z) \quad ()$$

$$u(x + \Delta x, z) = e^{-j\beta\Delta x \left(1 - \frac{\gamma}{j\beta} \sqrt{1+Z}\right)} u(x, z). \quad ()$$

$$v_i^{M+1} \quad v_i^{-1}$$

(NLBCs)

SSP

Δx

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$$\frac{\partial v_i(x, z_{\max})}{\partial z} = j \int_0^x \frac{\partial v_i(\xi, z_{\max})}{\partial \xi} w(x - \xi) d\xi + j \frac{\partial v_i(x, z_{\max})}{\partial x} + G_i^0(x, z_{\max}) \quad ()$$

$$J_1 \quad J_0) \quad w(x) = J_0(-k_0 x) - jJ_1(-k_0 x) \quad ()$$

$$G_i^0(x, z_{\max}) = -j \int_0^x \frac{\partial v_i^0(\xi, z_{\max})}{\partial \xi} w(x - \xi) d\xi + \frac{\partial v_i^0(x, z_{\max})}{\partial z} - j \frac{\partial v_i^0(x, z_{\max})}{\partial x} \quad ()$$

$$v_i^0(0, z_{\max}) = v_i(0, z_{\max}) \quad ()$$

$$e^{-j\beta\Delta x \left(1 - \frac{\gamma}{j\beta} \sqrt{1+Z}\right)} \approx 1 + \sum_{l=1}^N \frac{a_l Z}{1 + b_l Z} \quad ()$$

$$u(x + \Delta x, z) \approx u(x, z) + \sum_{l=1}^N \frac{a_l Z}{1 + b_l Z} u(x, z). \quad ()$$

$$\frac{\partial v_i(x, z_{\min})}{\partial z} + \alpha_1 v_i(x, z_{\min}) = 0 \quad ()$$

$$\frac{\partial v_i(x, z_{\max})}{\partial z} - \alpha_2 v_i(x, z_{\max}) = 0 \quad ()$$

$\alpha_2 \quad \alpha_1$

$$v_i(x + \Delta x, z) = \frac{a_l Z}{1 + b_l Z} u(x, z) \quad ()$$

$$u(x + \Delta x, z) \approx u(x, z) + \sum_{l=1}^N v_l(x + \Delta x, z). \quad ()$$

PEM

$z \quad ()$

v_l

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$$v_i^{-1} = v_i^1, \quad v_i^{M-1} = v_i^{M+1}. \quad ()$$

$$v_i^{m+1} - \left(2 - \frac{\gamma^2 \Delta z^2}{b_l}\right) v_i^m + v_i^{m-1} = \frac{a_l}{b_l} (u^{m+1} - 2u^m + u^{m-1}) \quad ()$$

$m = 0, 1, \dots, M$

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PEM

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$\epsilon_r = 5$

Δx
/ λ

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PEM

[] FDTD

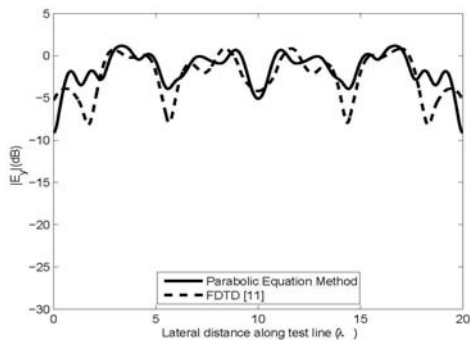
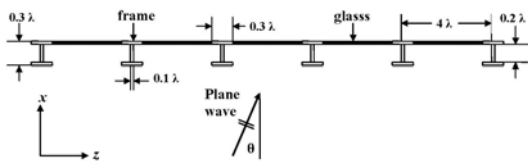
()

λ

PEM

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Transmission region



FDTD PEM

λ

$x + \Delta x$

x

$$\mathbf{A}_l \mathbf{V}_l(x + \Delta x) = \mathbf{U}_l(x) \quad ()$$

\mathbf{A}_l

$x + \Delta x$ \mathbf{V}_l

$$\mathbf{U}(x + \Delta x) = \sum_{l=1}^N \mathbf{V}_l(x + \Delta x) \quad ()$$

Δx

Δz z

$x = 0$

z

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($x = 0$
 $x = 0$)

b_l a_l γ Δz

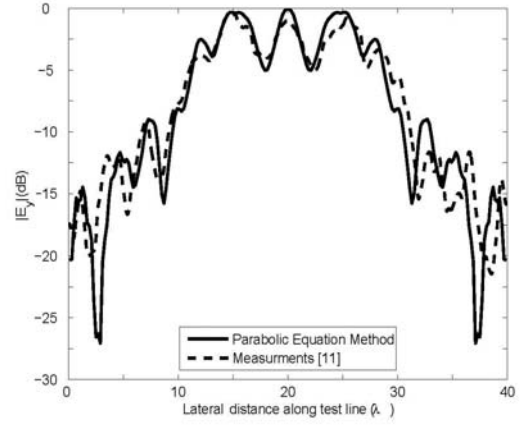
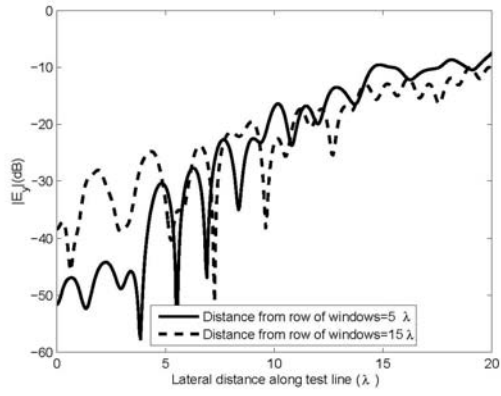
\mathbf{A}_l

()

$\mathbf{U}_l(x = 0)$

$x = \Delta x$

()



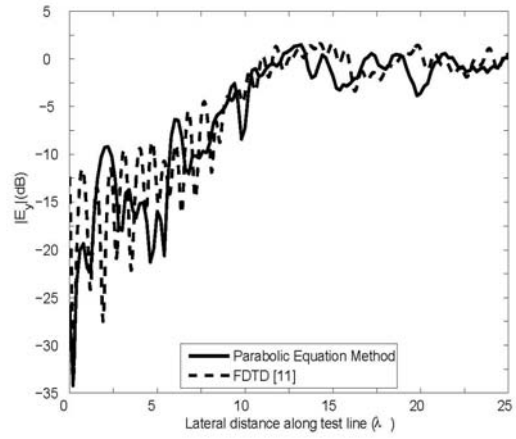
λ λ :

PEM

λ

λ

[] FDTD



FDTD PEM

15λ

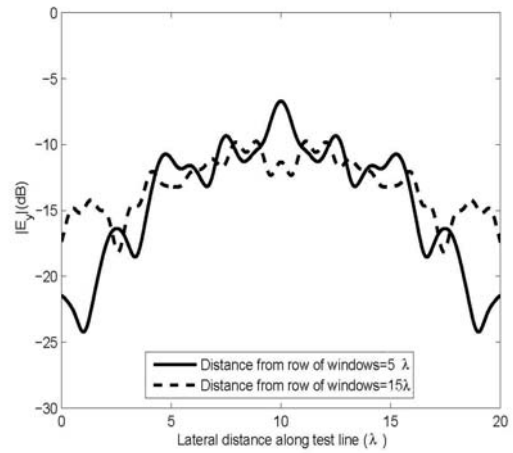
λ

PEM

() ()

PEM

()



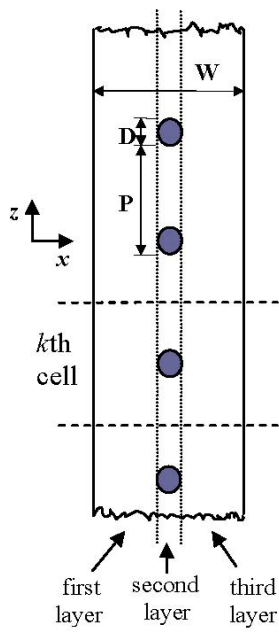
λ λ :

D

D

PEM

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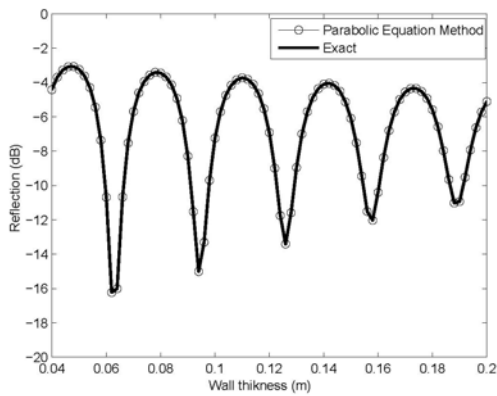
+x

PEM

+x

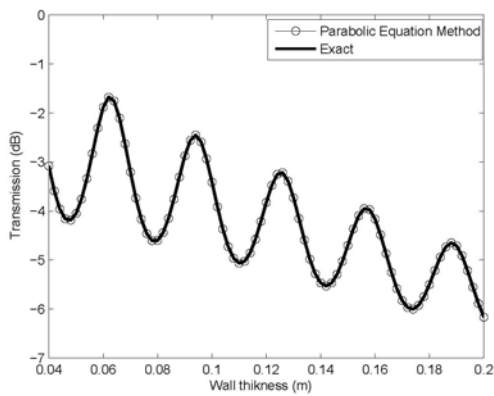
-x

+x



$$\epsilon_r = 7 - j0.3$$

MHz



$$\epsilon_r = 7 - j0.3$$

MHz

PEM

1800 MHz

$$\epsilon_r = 7 - j0.3$$

$$\Delta x = 0.05\lambda$$

() ()

PEM

()

PEM

PEM

$$\epsilon_r = 7 - j0.3 \quad ()$$

mm

MHz

()

() ()

/ m / m

$D = 1 \text{ mm}$

PEM

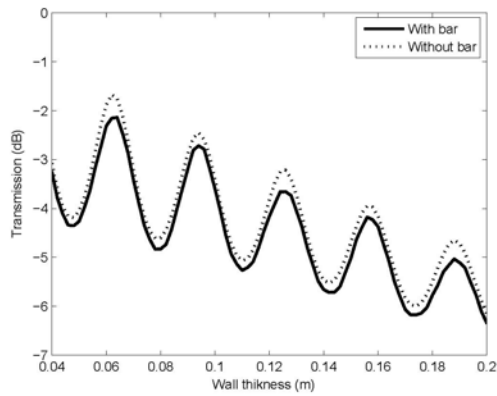
1 GHz

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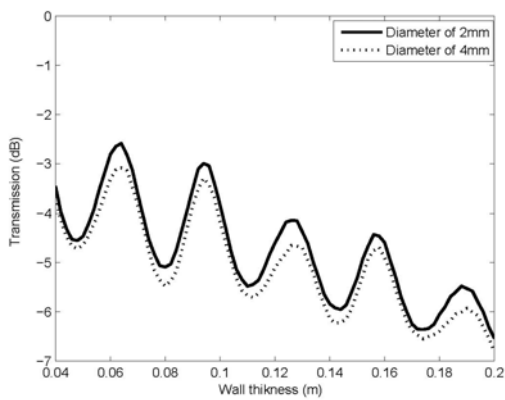
()

mm mm



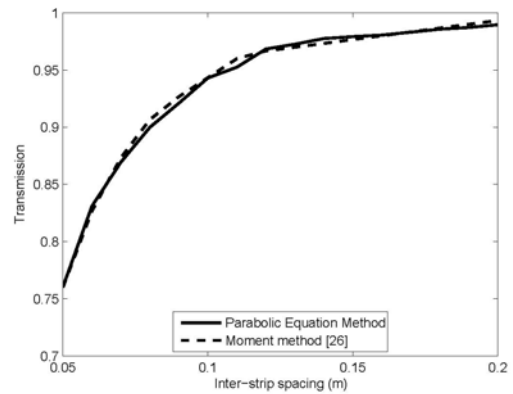
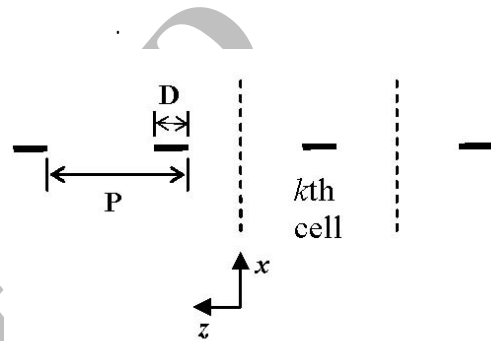
1800MHz

$D=2\text{mm}$ $P=2\text{m}$



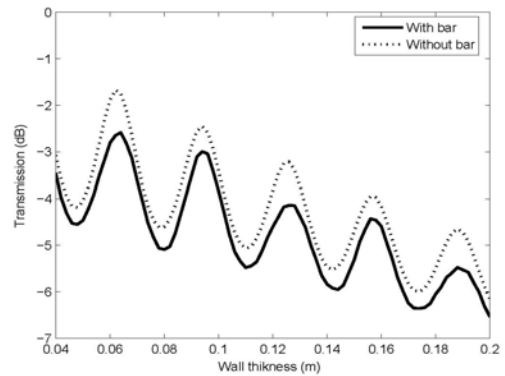
1800MHz

$D=4\text{mm}$ $D=2\text{mm}$ $P=1\text{m}$



1GHz

$D=2\text{mm}$



1800MHz

$D=2\text{mm}$ $P=1\text{m}$

()

GHz

m

(0,1.2) m

(x,1.6) m

()

x

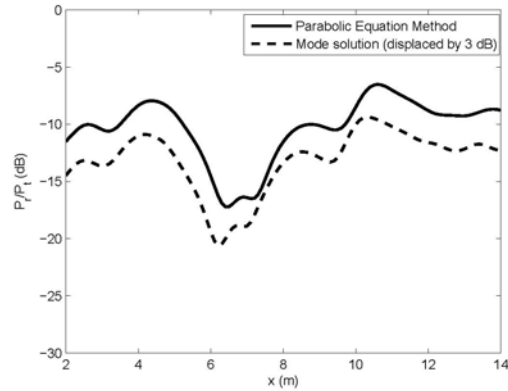
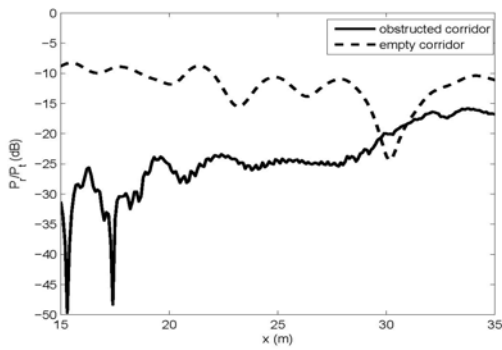
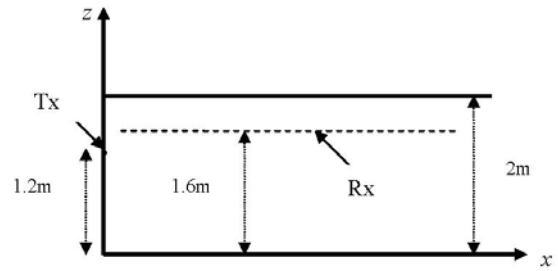
PEM

()

(x)

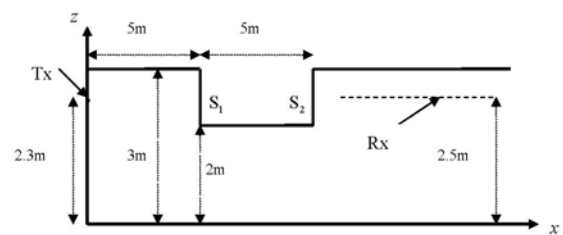
()

PEM



[]

PEM



m

(0,2.3) m

(0,2.5) m

m

m

m

$$\epsilon_r = 4 - j0.12$$

$$\Delta x = 1\lambda$$

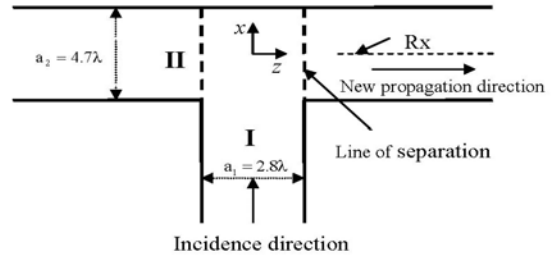
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S₁

PEM () S_2

TE (FVTD)

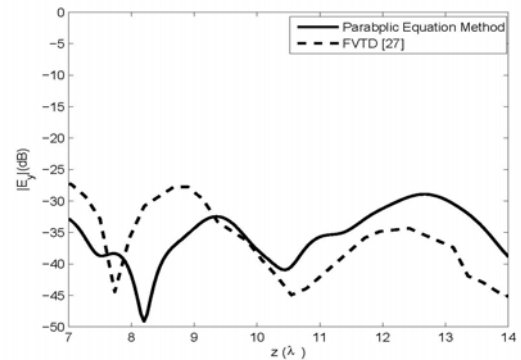
$f = 10$ GHz
 $\epsilon_r = 7 - j1$
 $a_2 = 4.7\lambda$ $a_1 = 2.8\lambda$



PEM ()
 FVTD PEM

SSP

FDTD PEM



PEM

PEM

PEM

PEM () I II I PEM II I

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- 1 - Site-Specific
- 2 - Ray Tracing
- 3 - Finite-Difference Time-Domain
- 4 - Parabolic Equation Method
- 5 - Paraxial
- 6 - Marching
- 7 - Split-Step Padé
- 8 - Modal
- 9 - Finite-Element
- 10 - Domain Decomposition
- 11 - Sub-Domain
- 12 - Scalar
- 13 - Non-Local Boundary Conditions
- 14 - Local Impedance Boundary Conditions
- 15 - Symmetric Boundary Conditions
- 16 - Beam Width
- 17 - Finite-Volume Time-Domain