NOVEL FEATURES OF SHORT PULSE ELECTROMAGNETICS

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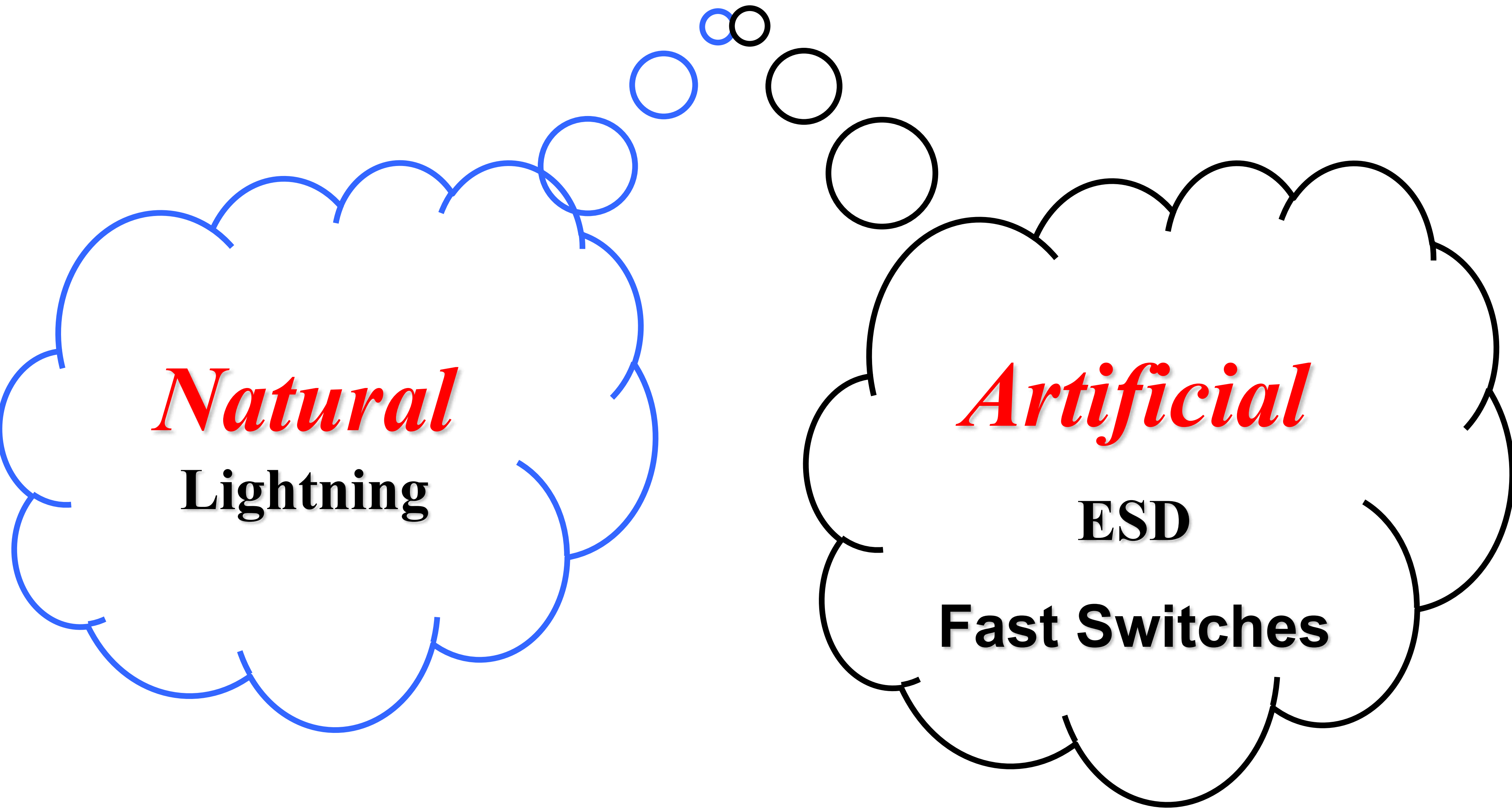
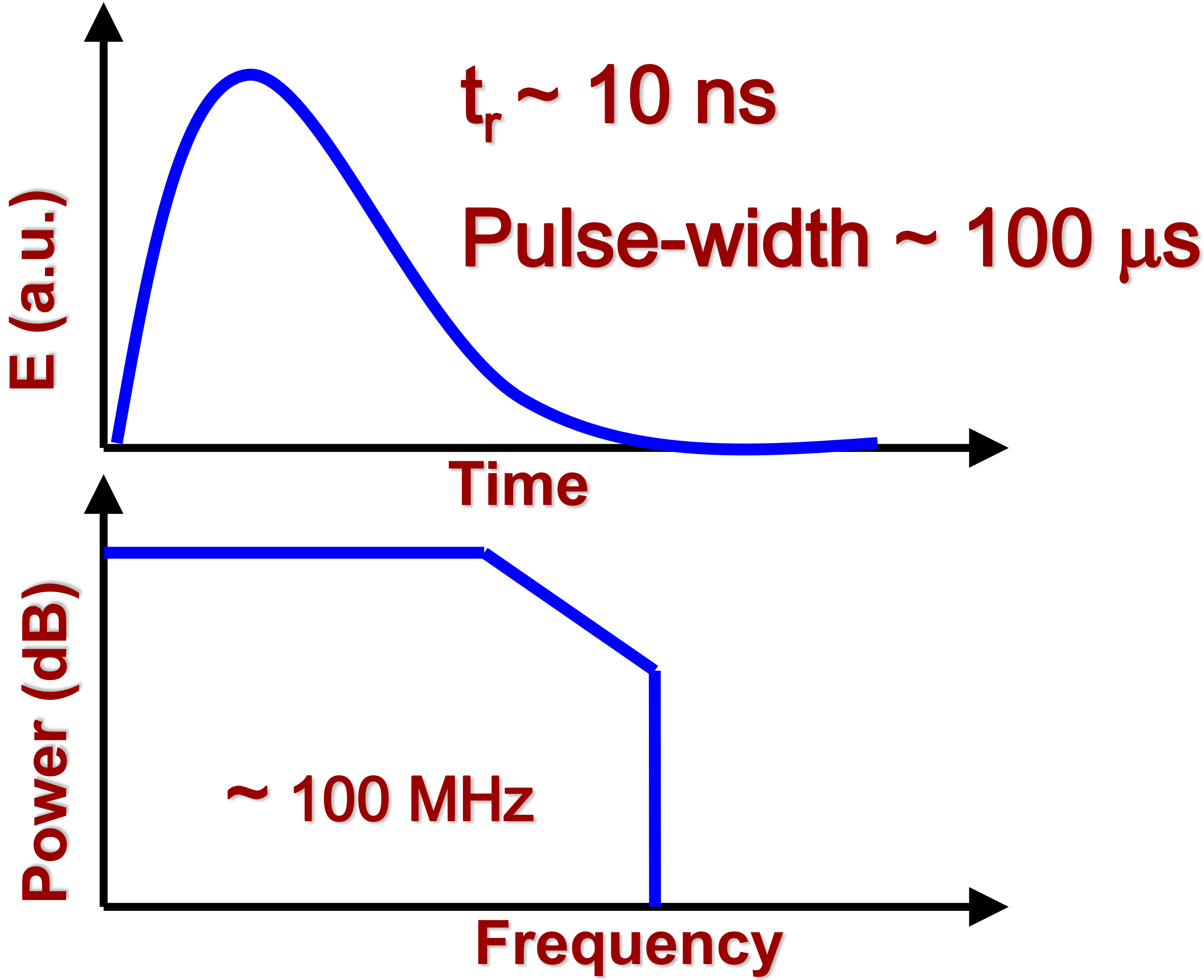
EMC SOCIETY

IEEE EMC Society
Washington DC/Northern Virginia
Chapter Meeting

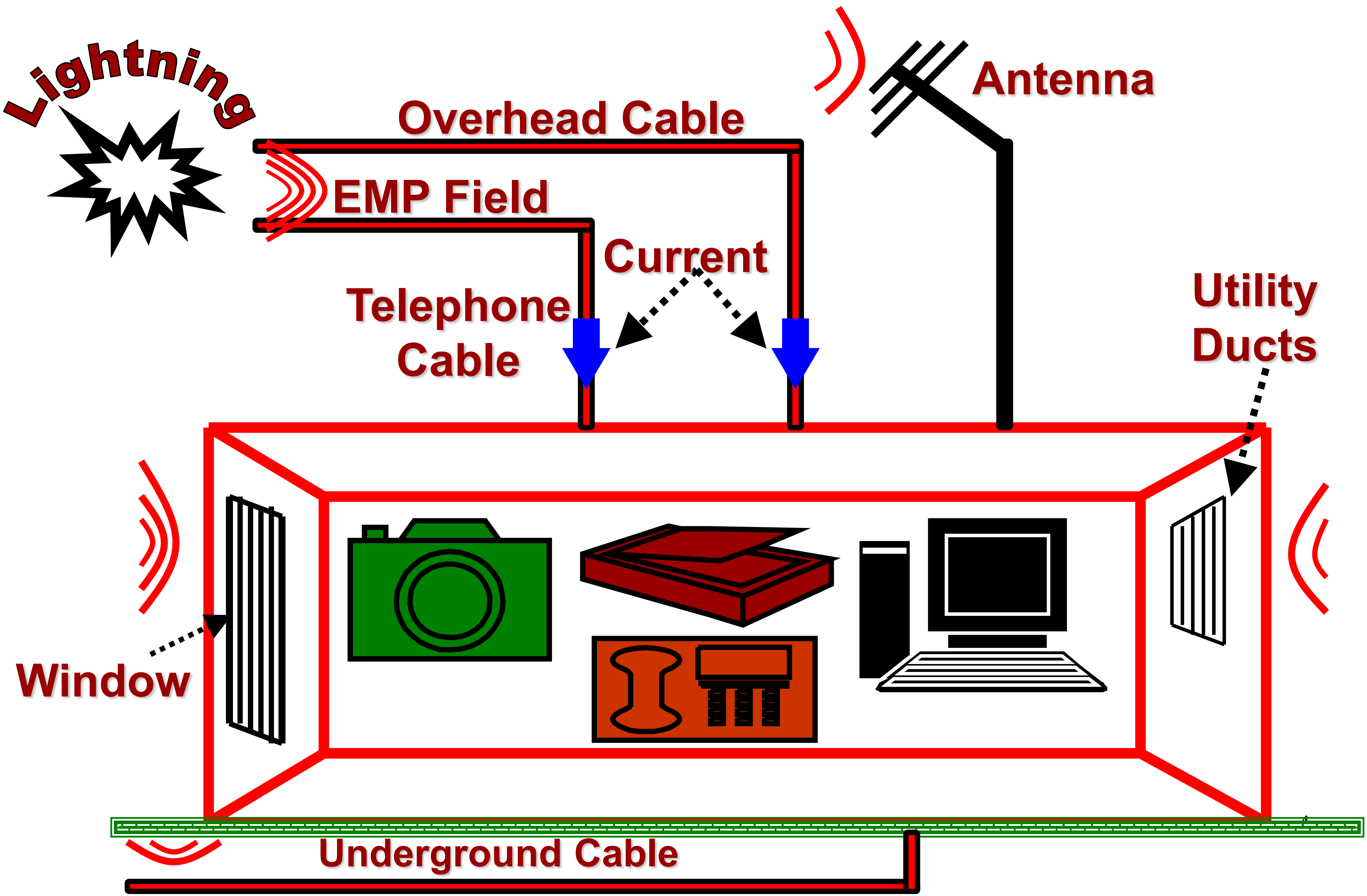
Sources of UWB Electromagnetics



Waveform & Spectrum



Coupling with Electrical/Electronic Equipment



Effects on Biological Tissues

Duration , Intensity

Advantage

Tumor Growth Reduction

Disadvantage

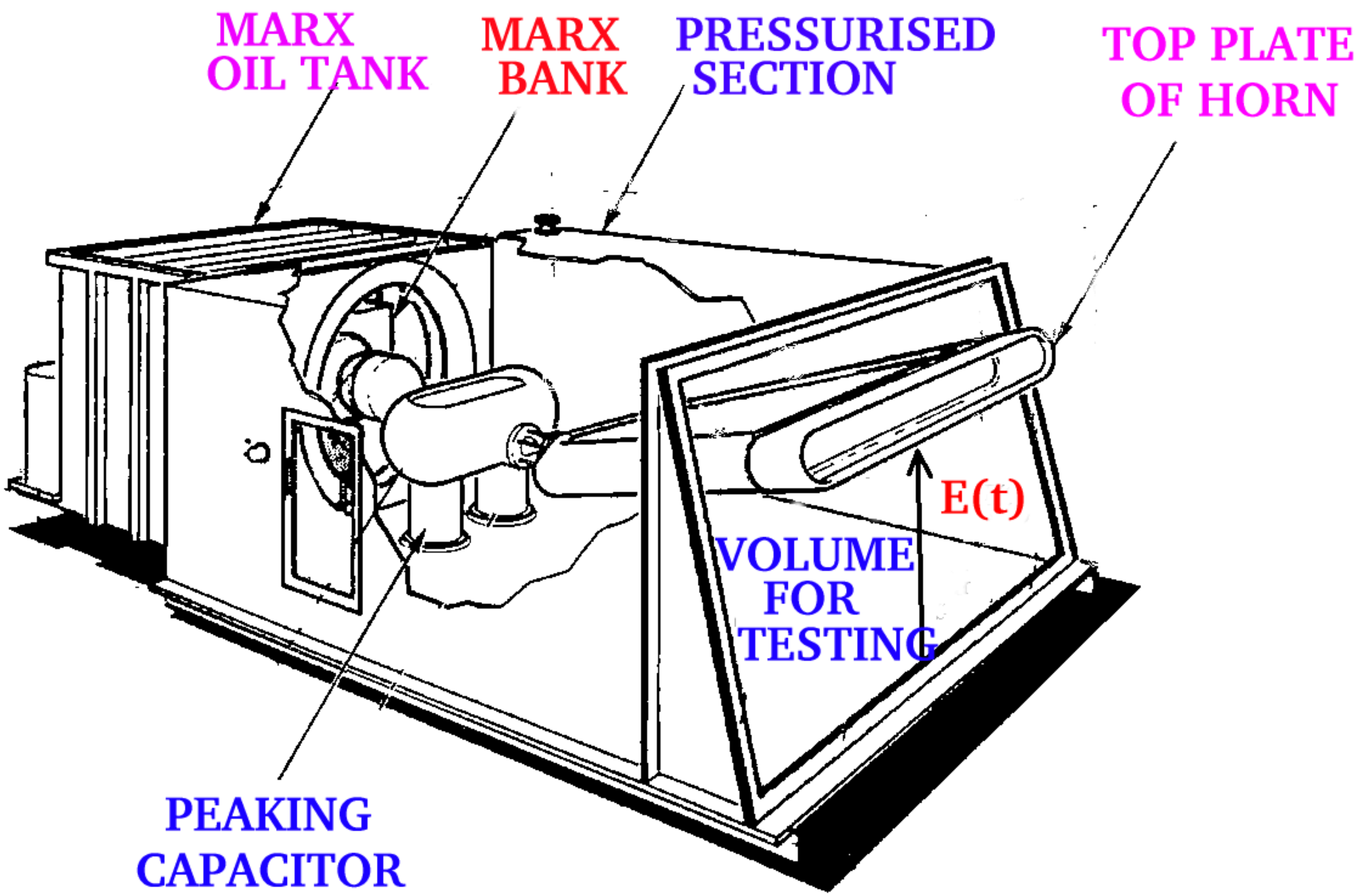
Neuropsychological Damage

Cardiopulmonary Arrest

Major Challenges

- Design and Optimization of EMP Simulator for Desired EMP Environment
- Modeling of a Complex 3D Test-object
- Self-Consistent Full-Wave Simulations

Experimental Setup

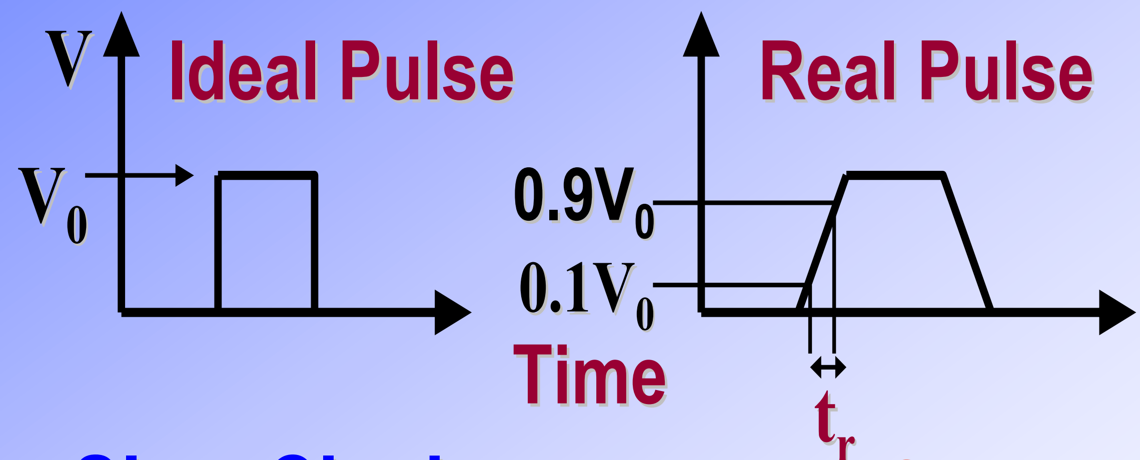


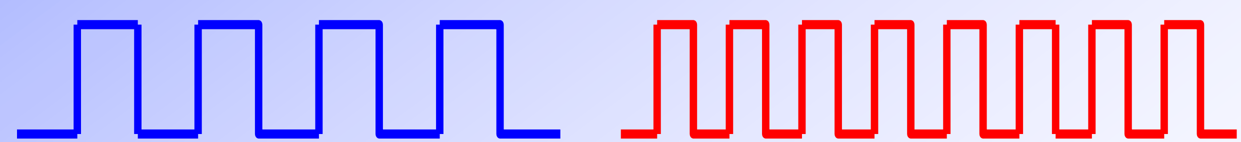
BOUNDED WAVE EMP SIMULATOR

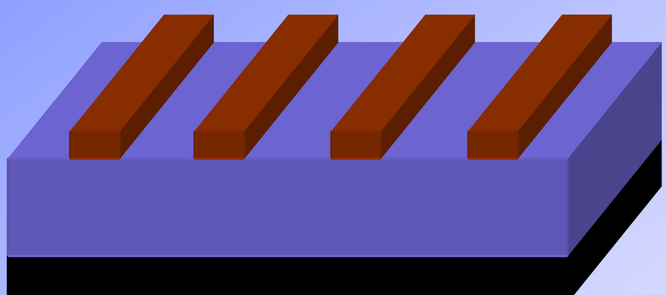
10th IEEE International Pulsed Power Conference -- 1995.

C_P = 82 pF, 1 MV, 90 Ω horn, risetime 7ns, 1ns

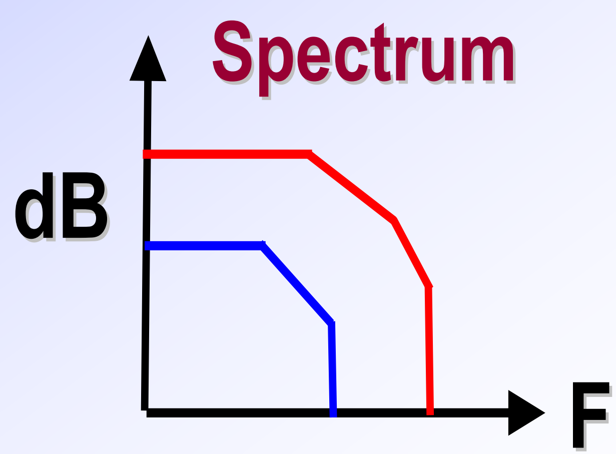
Modern High Speed ICs and Interconnects



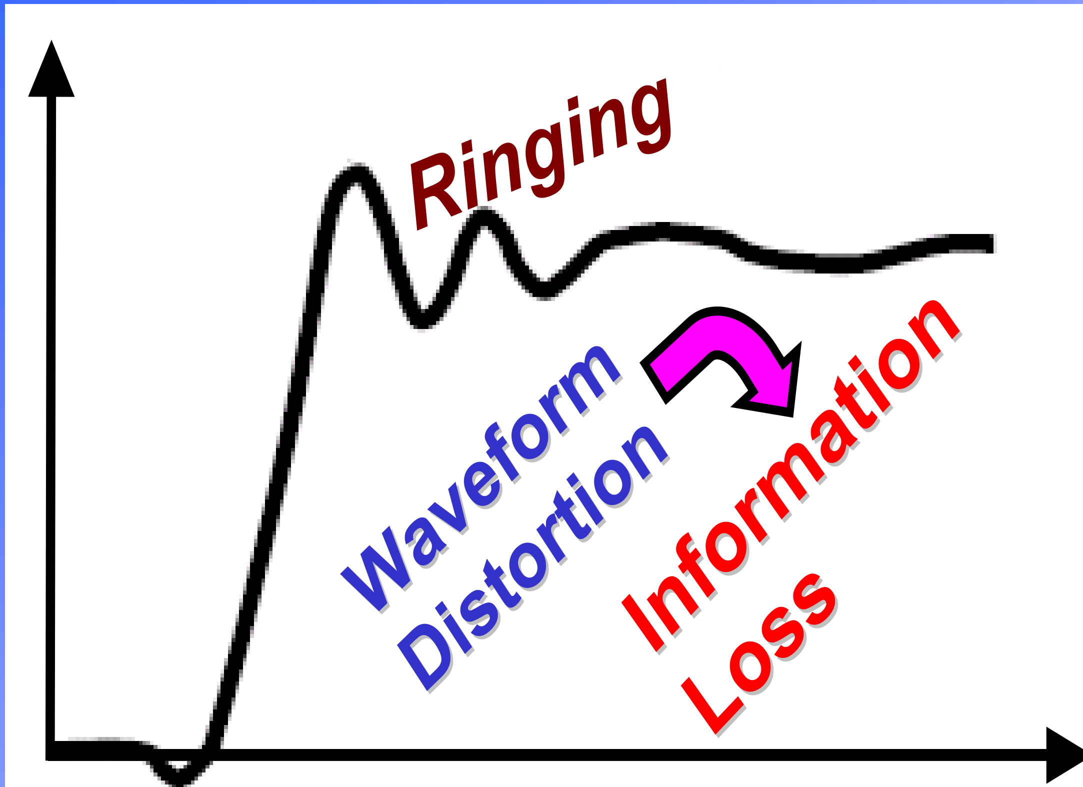


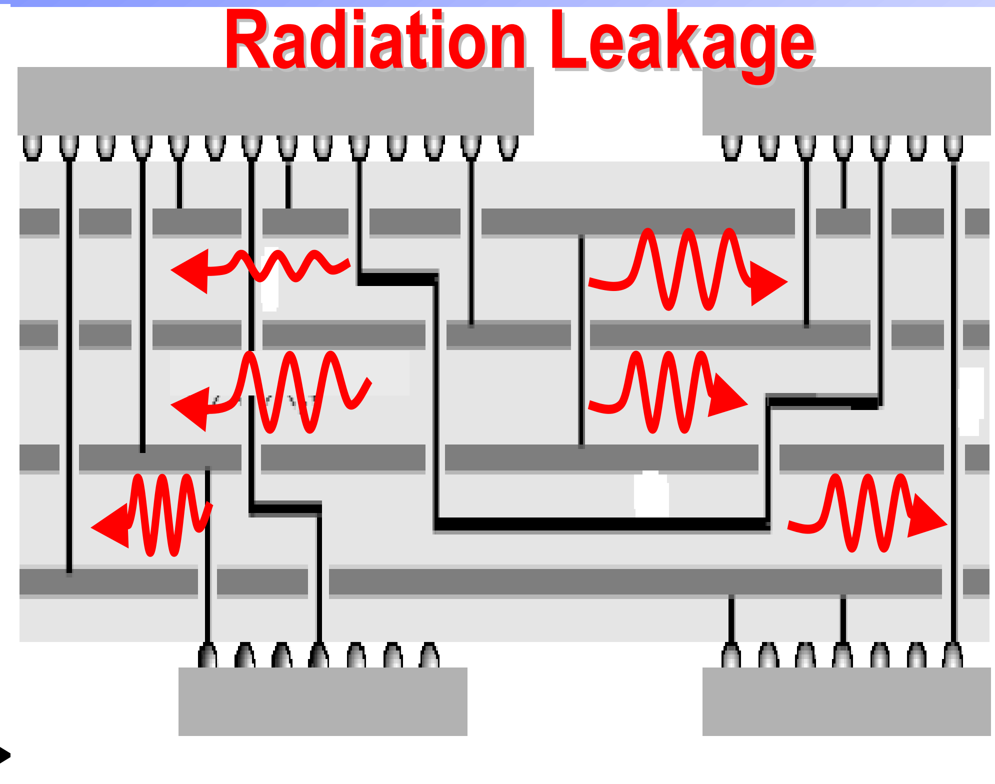


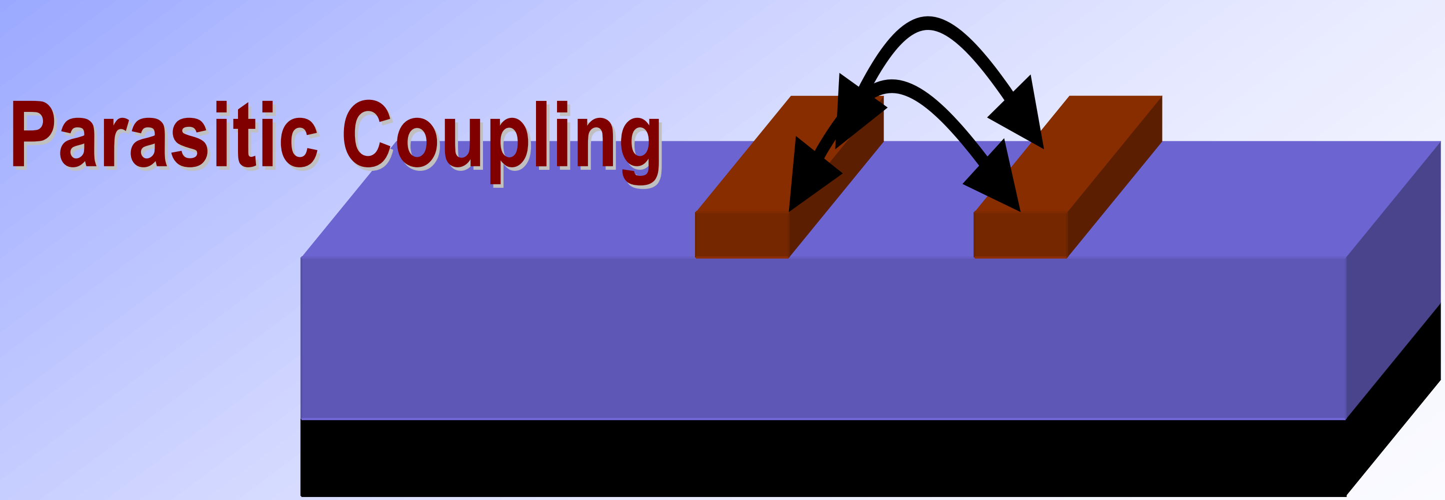
High Density Interconnects
(Micro-strip Lines)



Effects of High Speed Clocks







Need For Modelling

- **EMP Simulators are big and expensive**
- **Multi-physics: EM scattering, reflections, absorption, radiation, heating etc**
- **High power switch**
- **Complex geometry and multiple materials**
- **Wide range of frequencies in a single problem**

Need full 3D time-domain simulations before construction

3-D Finite Difference Time-Domain Code

Solves Maxwell's curl equations in time-domain:

$$\nabla \times E = -\frac{\partial B}{\partial t}; \nabla \times B = \frac{\partial D}{\partial t} \text{(Free Space)}$$

Divergence Equations Are Inherent To These Curl Equations.

Model: Arbitrary 3-D Object With Multiple Materials
(Conductor / Dielectric)

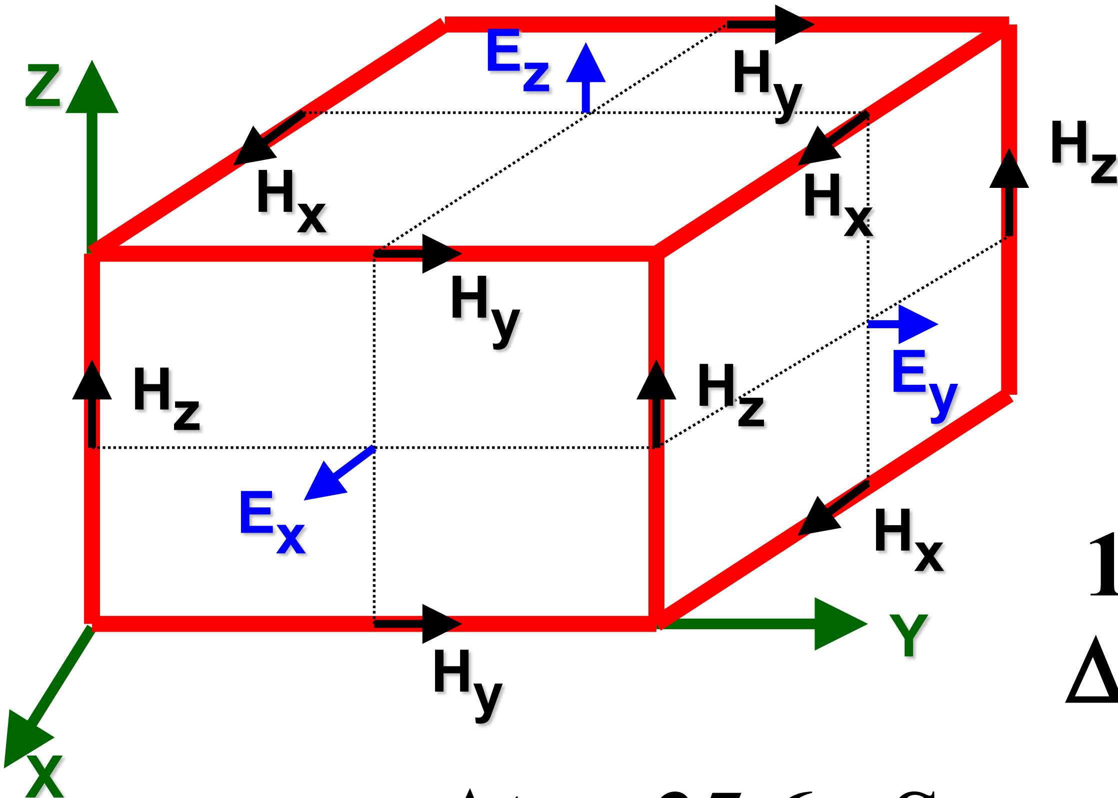
USES:

1. Antenna Radiation, EMP Simulators

2. EMP Coupling to Electronic & Electrical Equipment

3. Radar Cross-Section of Objects

Computational Domain



$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times B = \frac{\partial D}{\partial t} + J$$

100 x 156 x 600

$\Delta X = \Delta Y = \Delta Z = 1.85$ cm

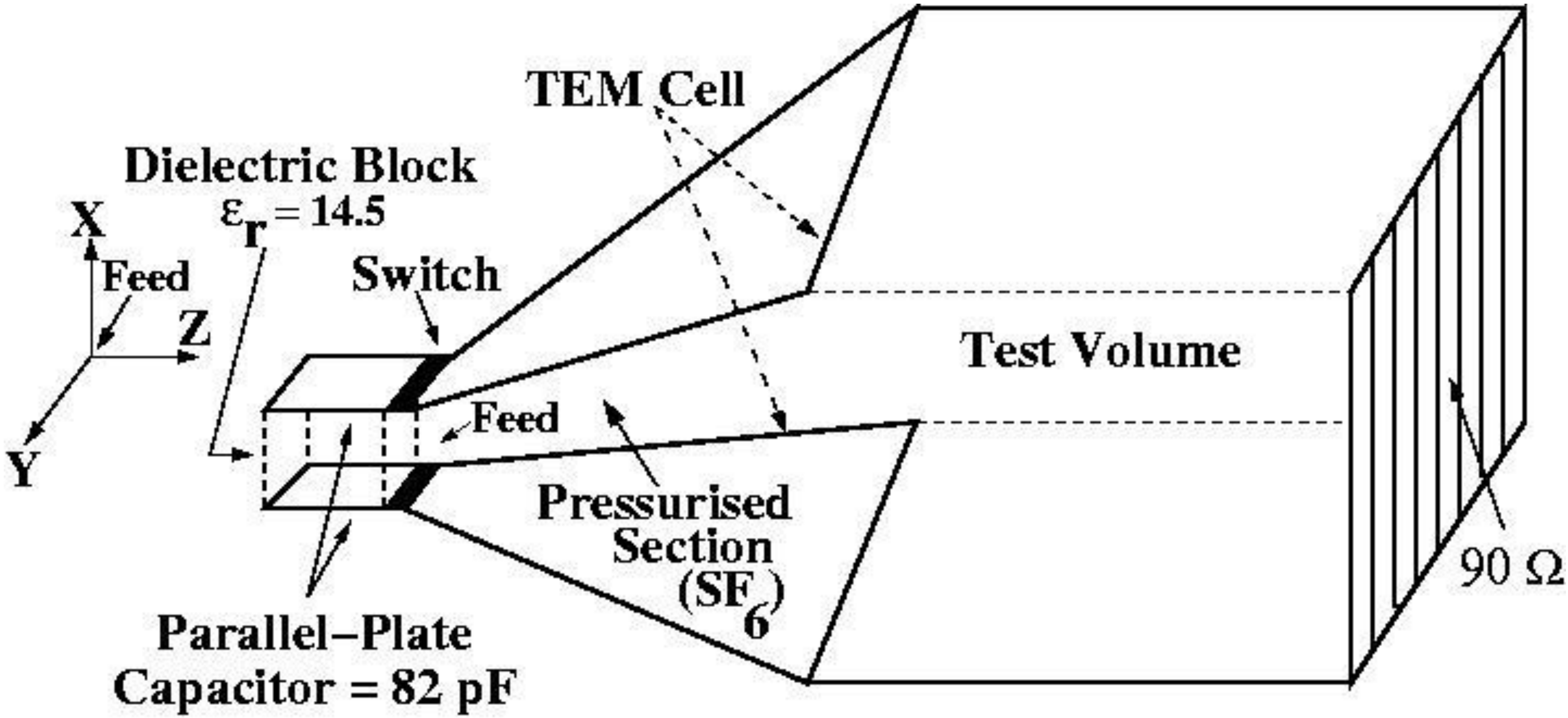
$\Delta t = 35.6$ pS

$$\Delta t \le 1/c \sqrt{1/\Delta x^2 + 1/\Delta y^2 + 1/\Delta z^2}$$

Platform : Shared Memory Linux Clusters

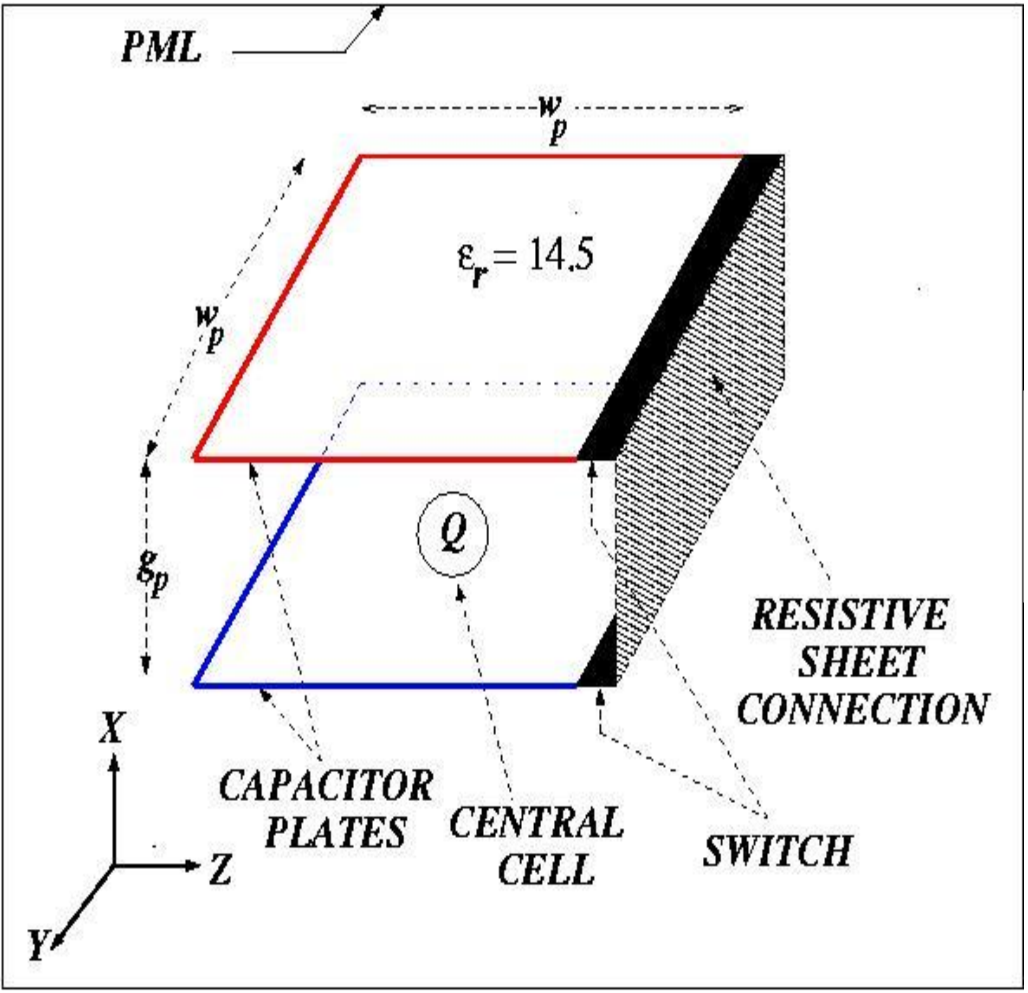
Run Time : 15 Hrs

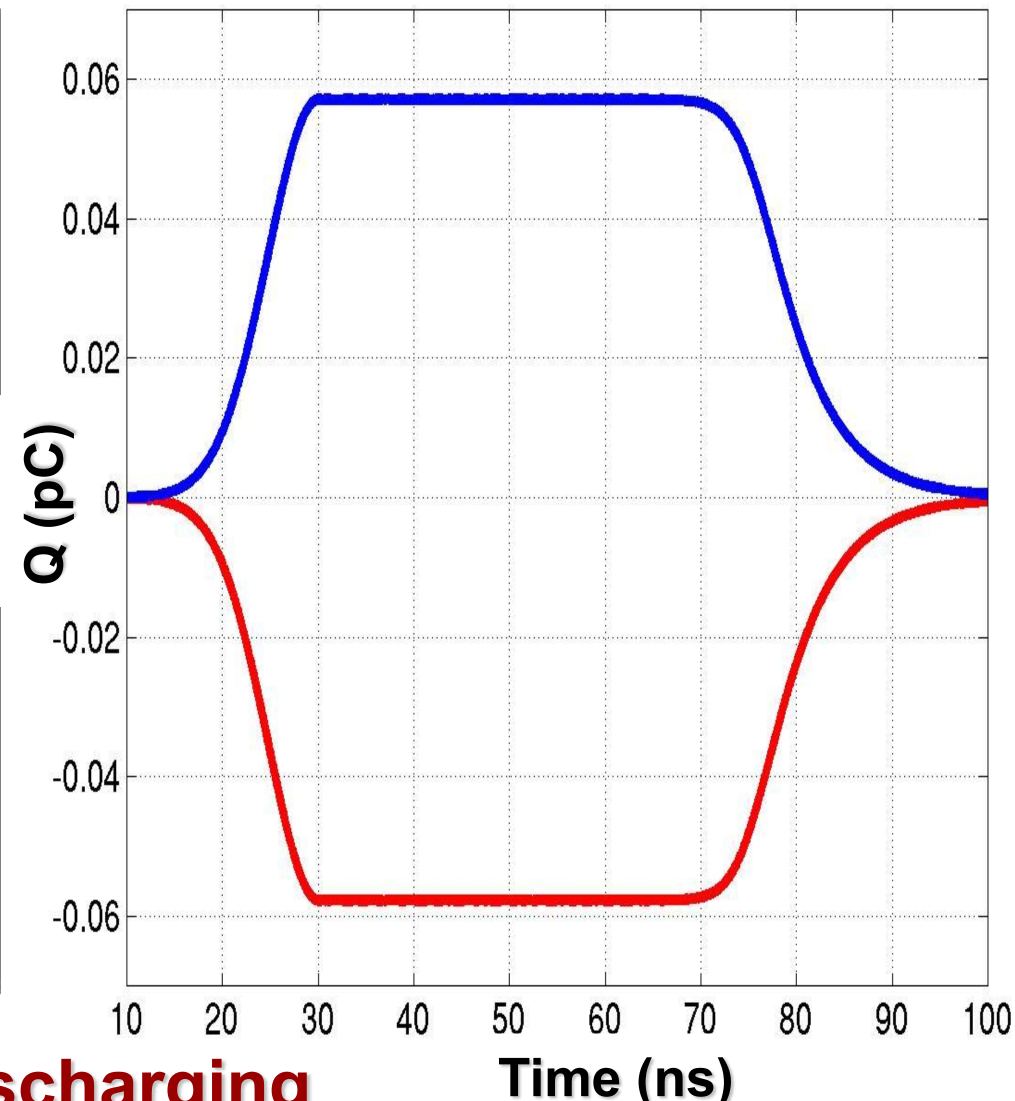
Simulation Setup



Validation Check

Switch : $\sigma(t) = \sigma_0 \exp[-\alpha (t - \tau_0 - \tau_s)^2]$; $\tau_0 \leq t \leq (\tau_0 + \tau_s)$

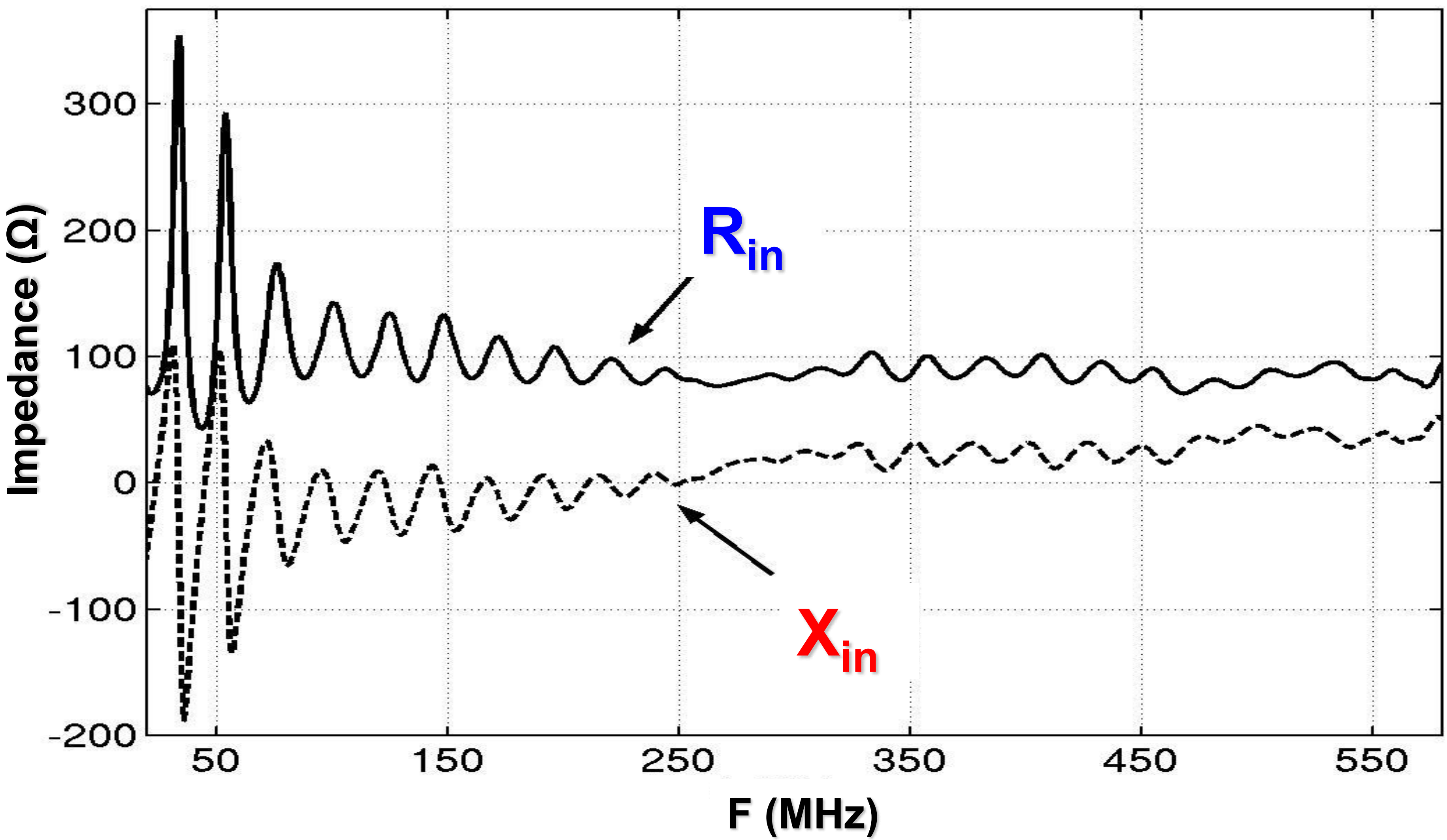




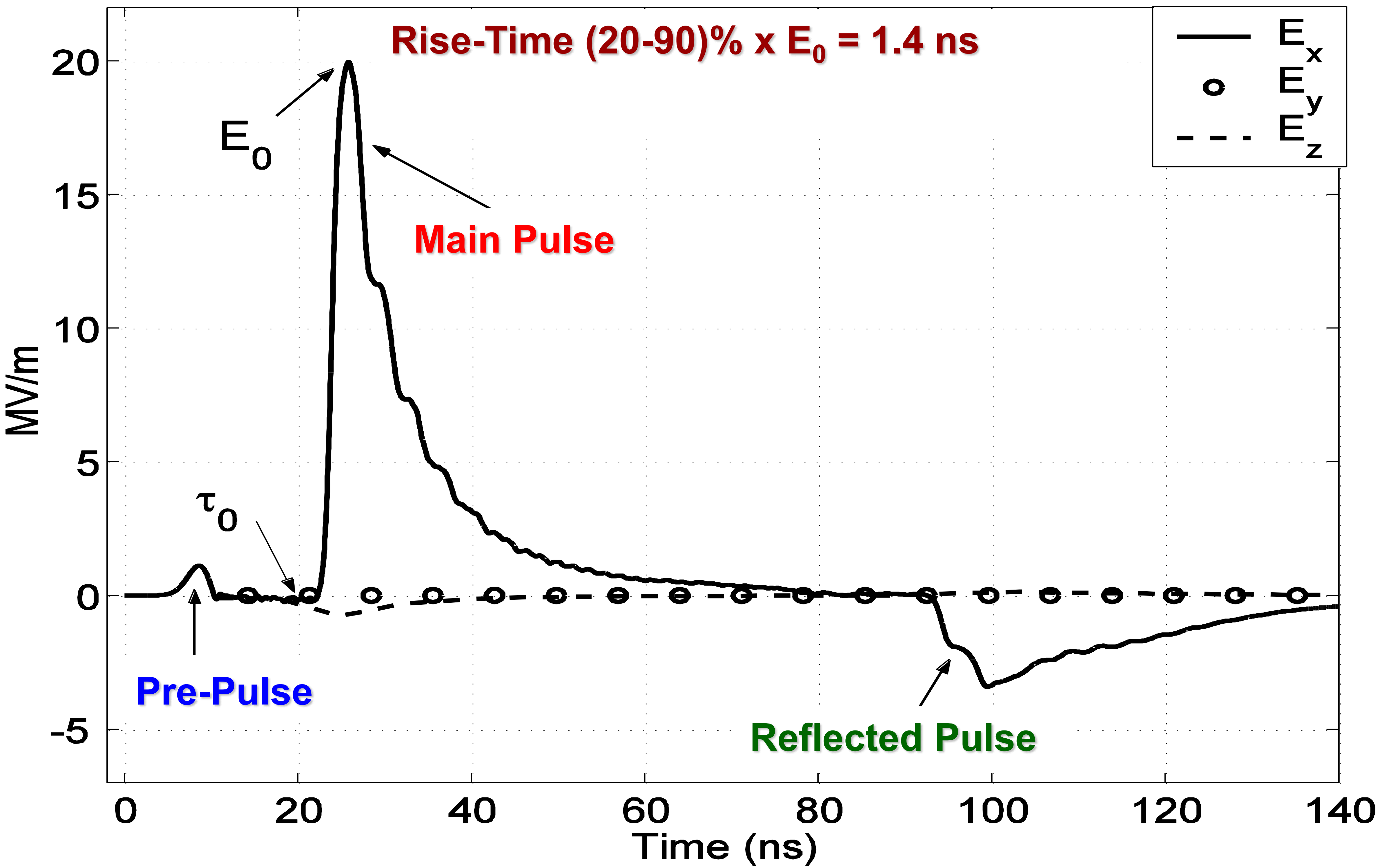
Capacitor Charging Discharging

Validation Check --- Cont'd

Input impedance of TEM Structure
-- Design Confirmation

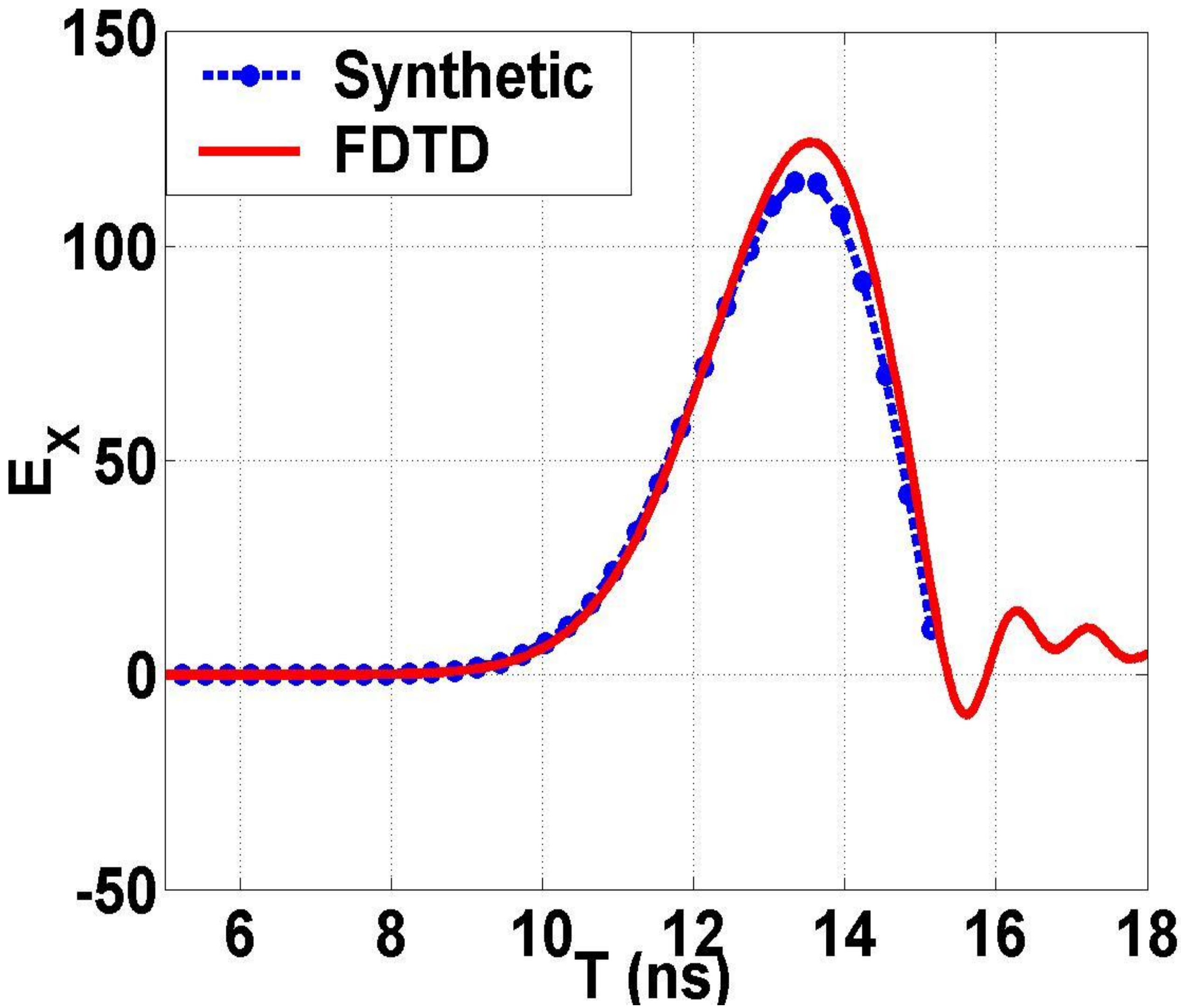


E-fields Near Feed



Pre-Pulse

Almost all pulsed power experiments -- source coupled with load through a switch -- R. S. Clark, Sandia Nat. Lab.



Physical Significance

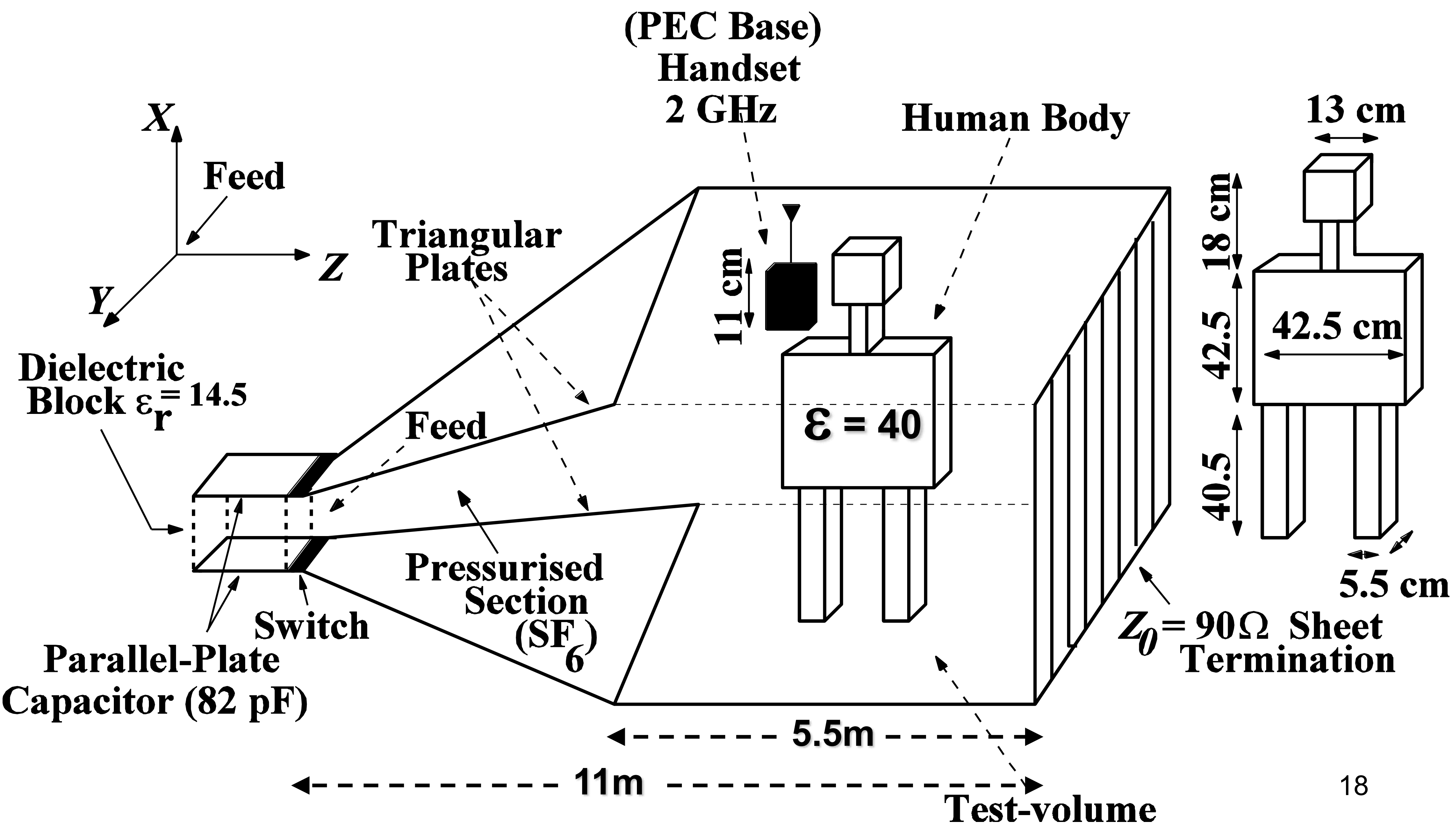
$$\tau_{chgsrc} \sim \tau_{clswt}$$

Method

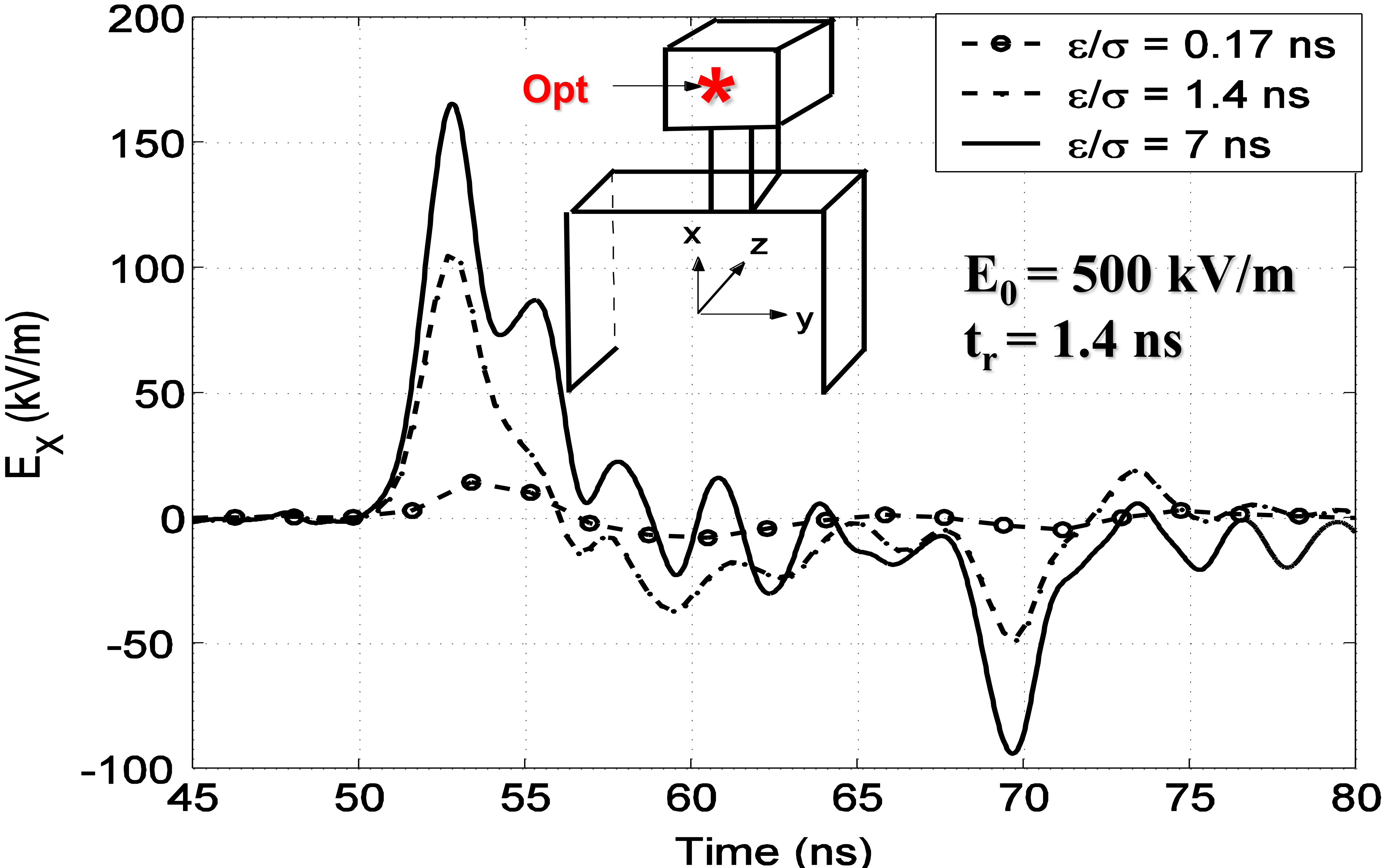
$$I_D(t) = C_{sw}\, dV(t)/dt$$

$$E_P(t) = I_D(t)\, Z_{in} / g$$

Simulation Setup

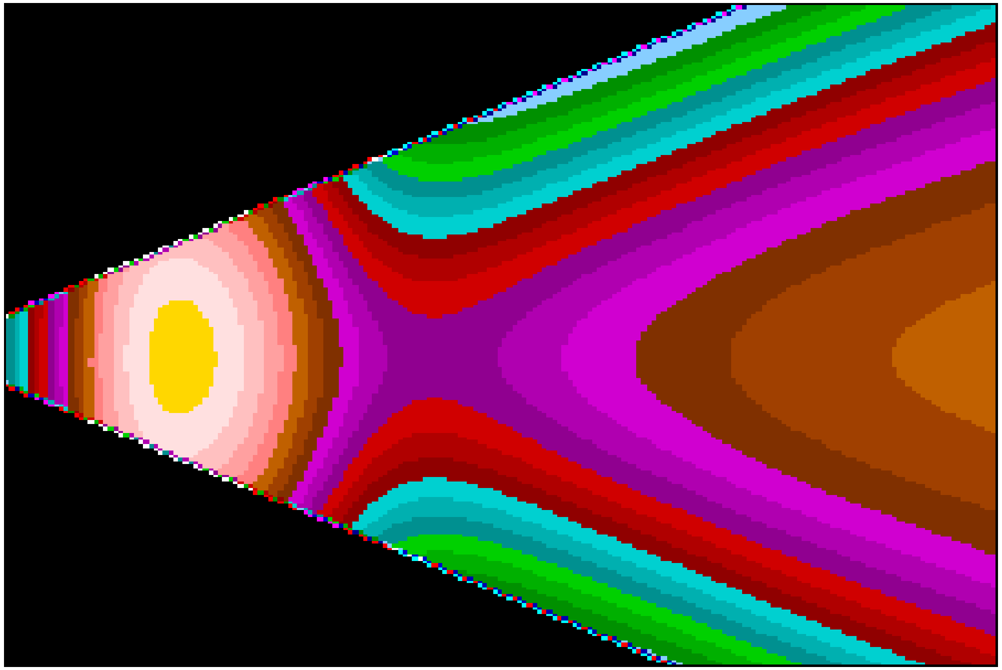


Induced E-field



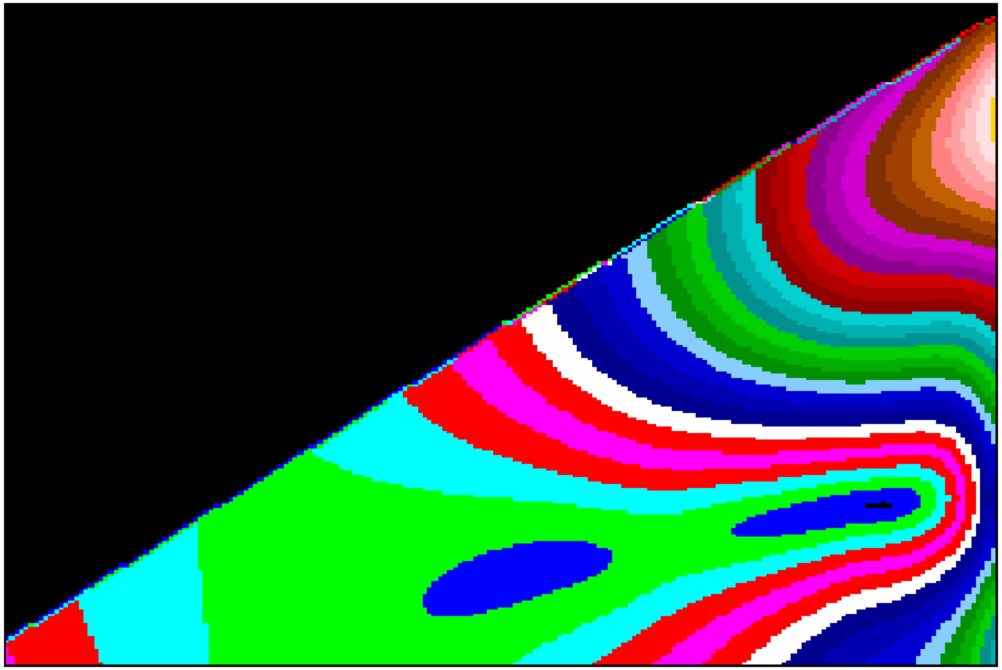
Mode Structures Inside Tapered Section

TOP VIEW



Mode Structures Inside Tapered Section

SIDE VIEW



Singular Value Decomposition (SVD)

Physical quantity '*E*' : E_{ij}

i → **Channels** , ***j*** → **times**

SVD [E] = [U][S][V^T]

Temporal Vectors | **Singular Values** | **Spatial Vectors**

TM$_m$ Mode Waveform inside a parallel-plates waveguide:

$$E_x(x) = E_{x0}\, \mathrm{Cos}[m\pi\, x/\, h(z)],\ f_c = mc/2h(z)$$

h(z) = inter-plate separation **(h** ~ 1.5 m)**, i = 25, j** = 11000 (t_s **= time step size)**

Setup for Modal Analysis

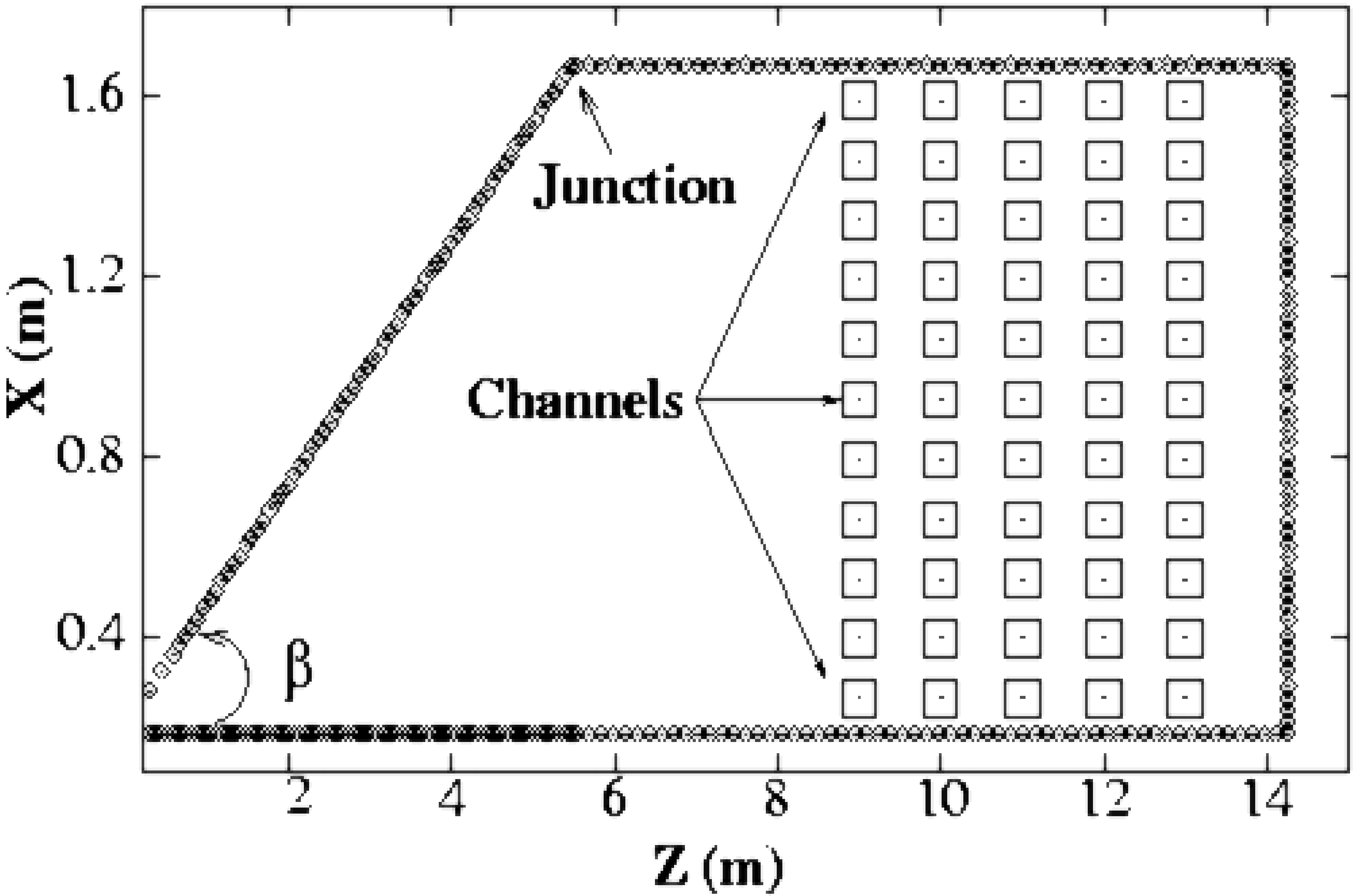
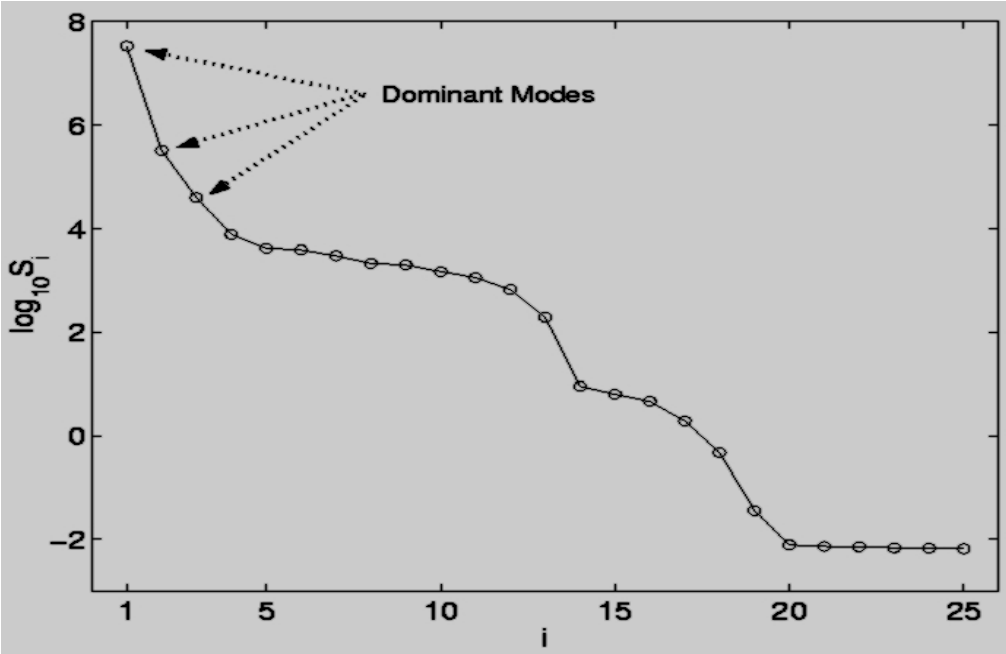
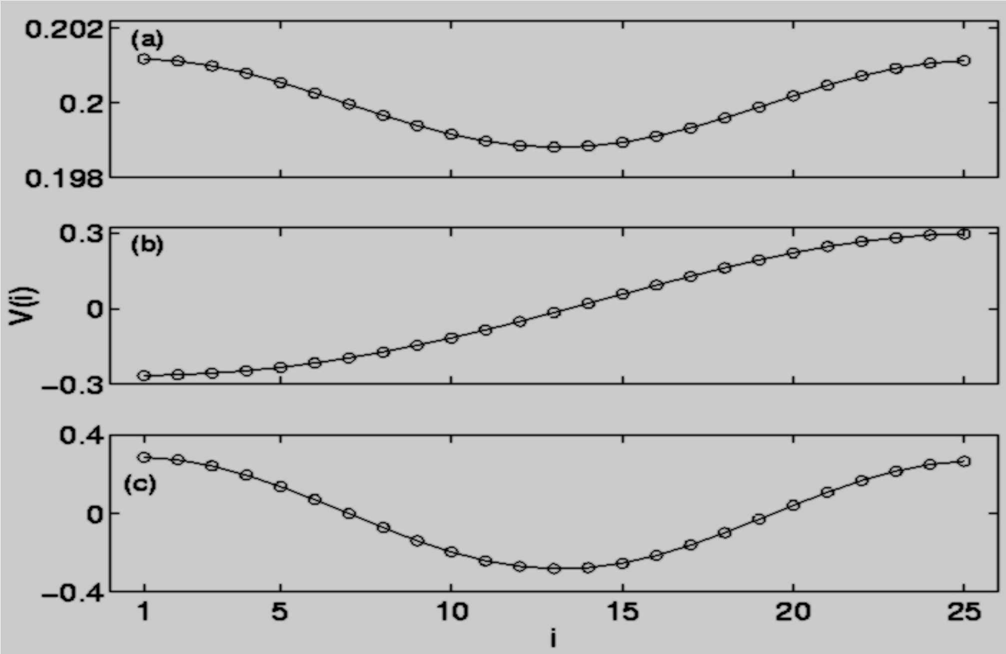
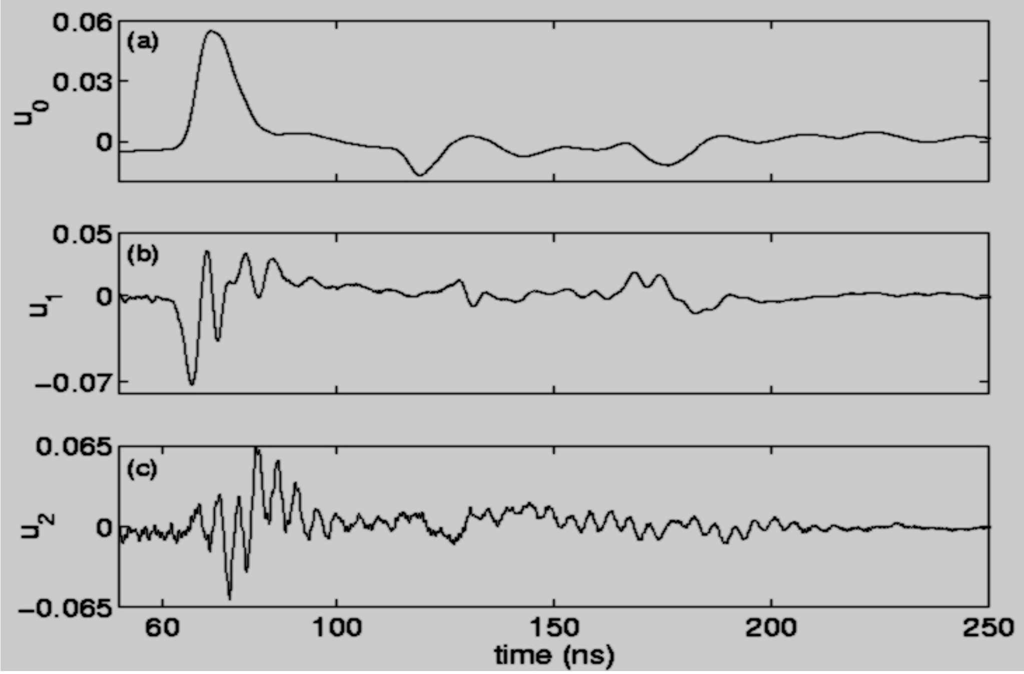


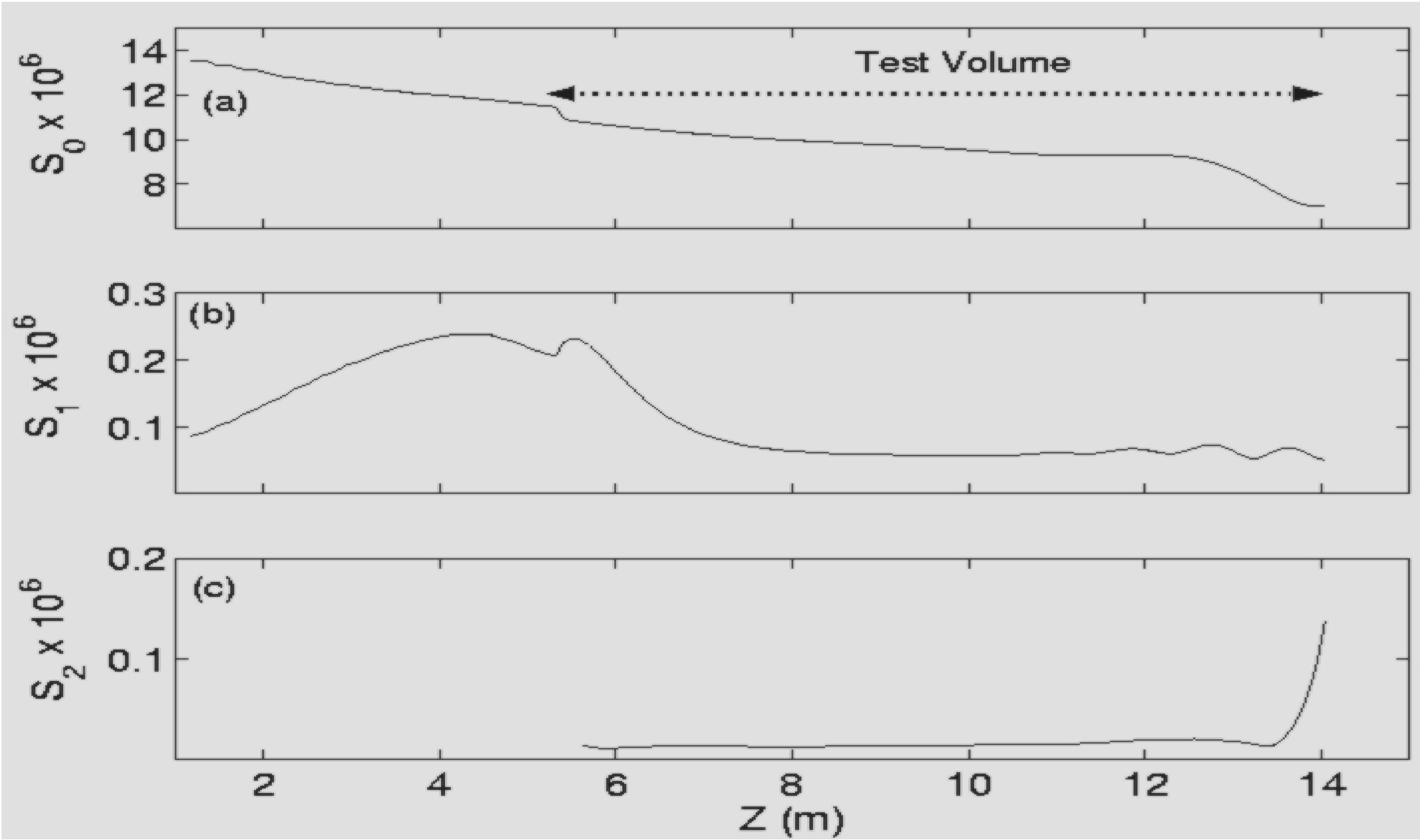
Illustration of SVD







Evolution of Modes Without Test Object



Cross-Correlation

Correlation Coefficient : $C(\tau) = \int y_1(t)\, y_2(t - \tau)dt$

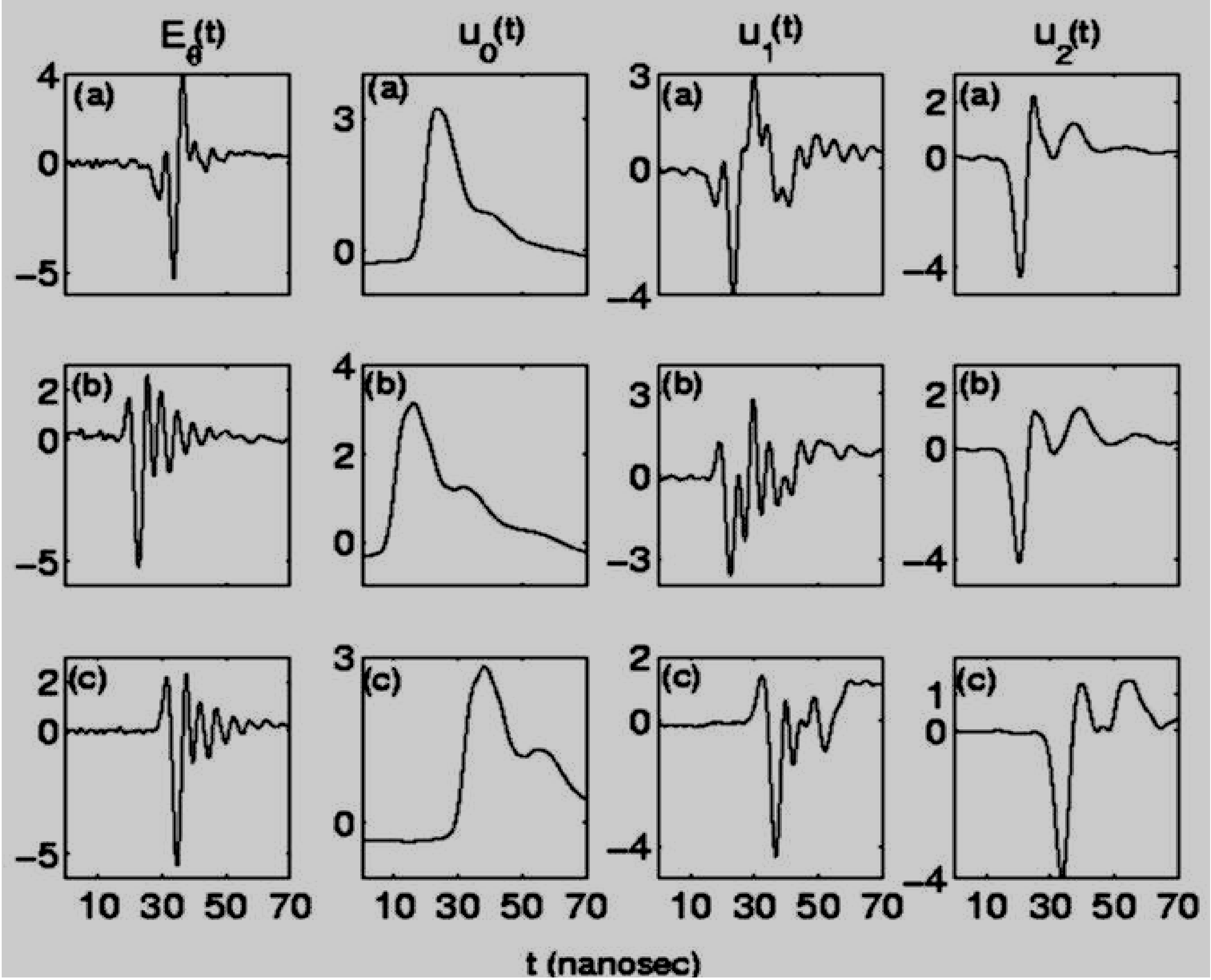
$$y_1 = u(t)/\sigma_u\ , \quad y_2 = V(t)/\sigma_v$$

$$\sigma_u = std(u(t)) = \sqrt{\frac{1}{(N-1)}\sum_{j=1}^{N}\left(u\left(t_j\right) - \overline{u(t)}\right)^2}$$

Advantage :

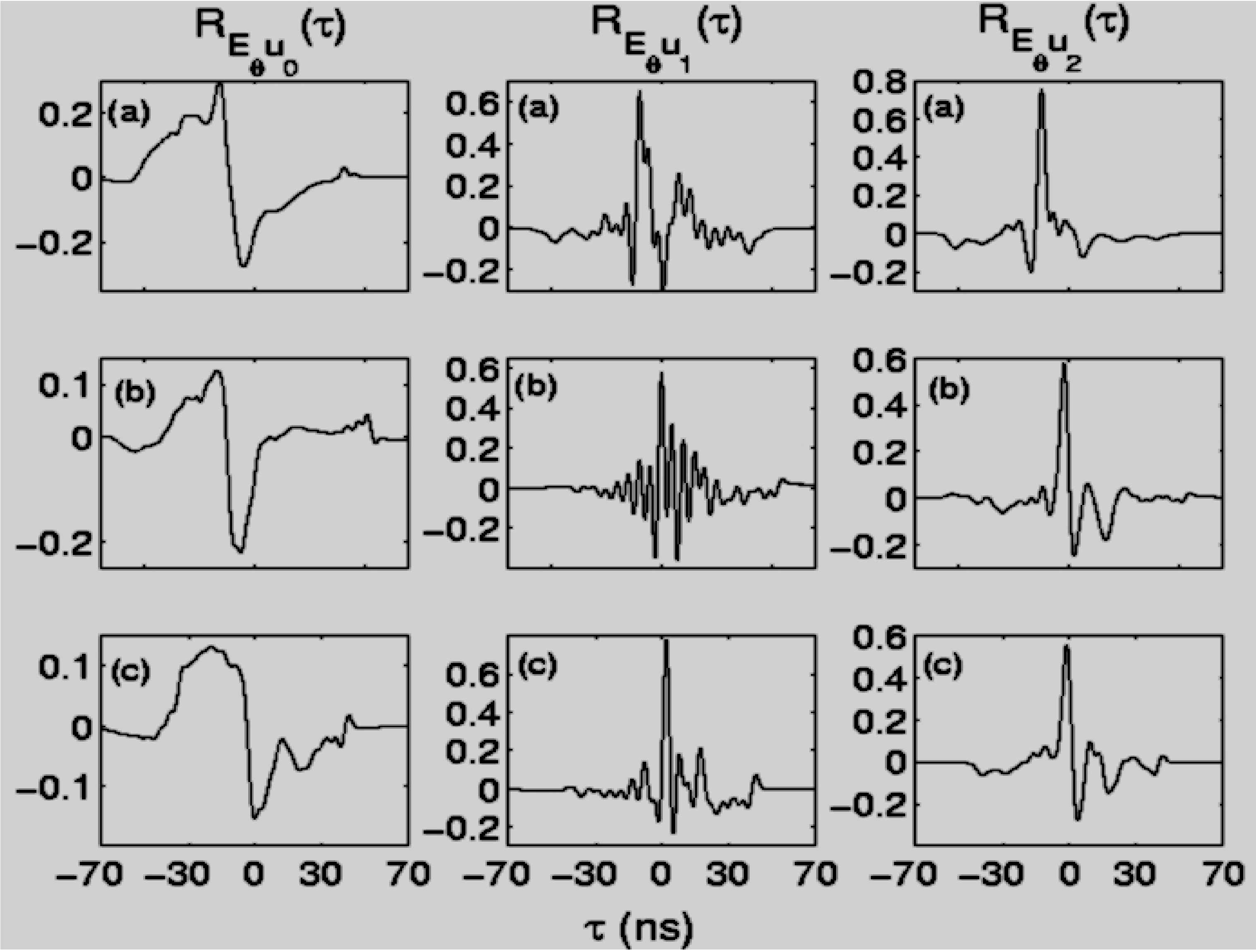
Prediction of Coupling

Prediction of Radiation Leakage



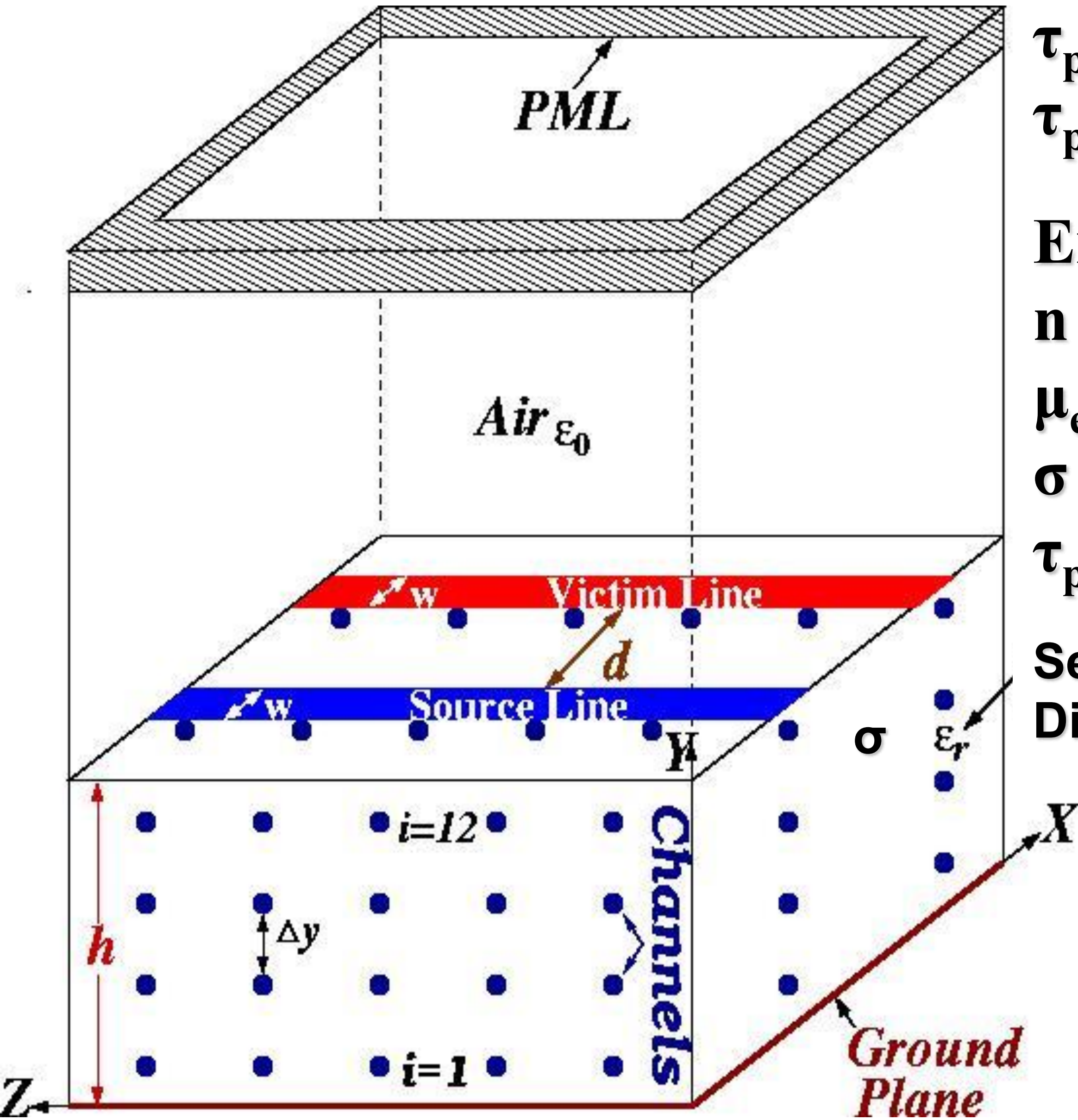
β = 10 (a), 15 (b) and 20 (c). Far-field strongly correlated with TM_1 & TM_2 and weakly correlated with TEM.

Cross-Correlation



TM_1 and TM_2 are strongly correlated and TEM is weakly correlated

Simulation Setup



$\sigma = nq_e\mu$, $J = \sigma E$, Heat = $J^2\eta$

$\tau_p = \mu m^*/qe$, $\tau_d = \varepsilon / \sigma$

$\tau_p \le t \le \tau_d$ and $E << E_{Br}$

Example: Si at 300K

$n = 1.0 \times 10^{16}\ m^3$, $m^* = 0.19m_e$

$\mu_e = 0.145\ m^2/V\text{-}m$

$\sigma = 2.32 \times 10^{-4}\ Sm^{-1}$, $\tau_d = 0.45\ \mu S$

$\tau_{pe} = 1.6 \times 10^{-13}$ Sec.

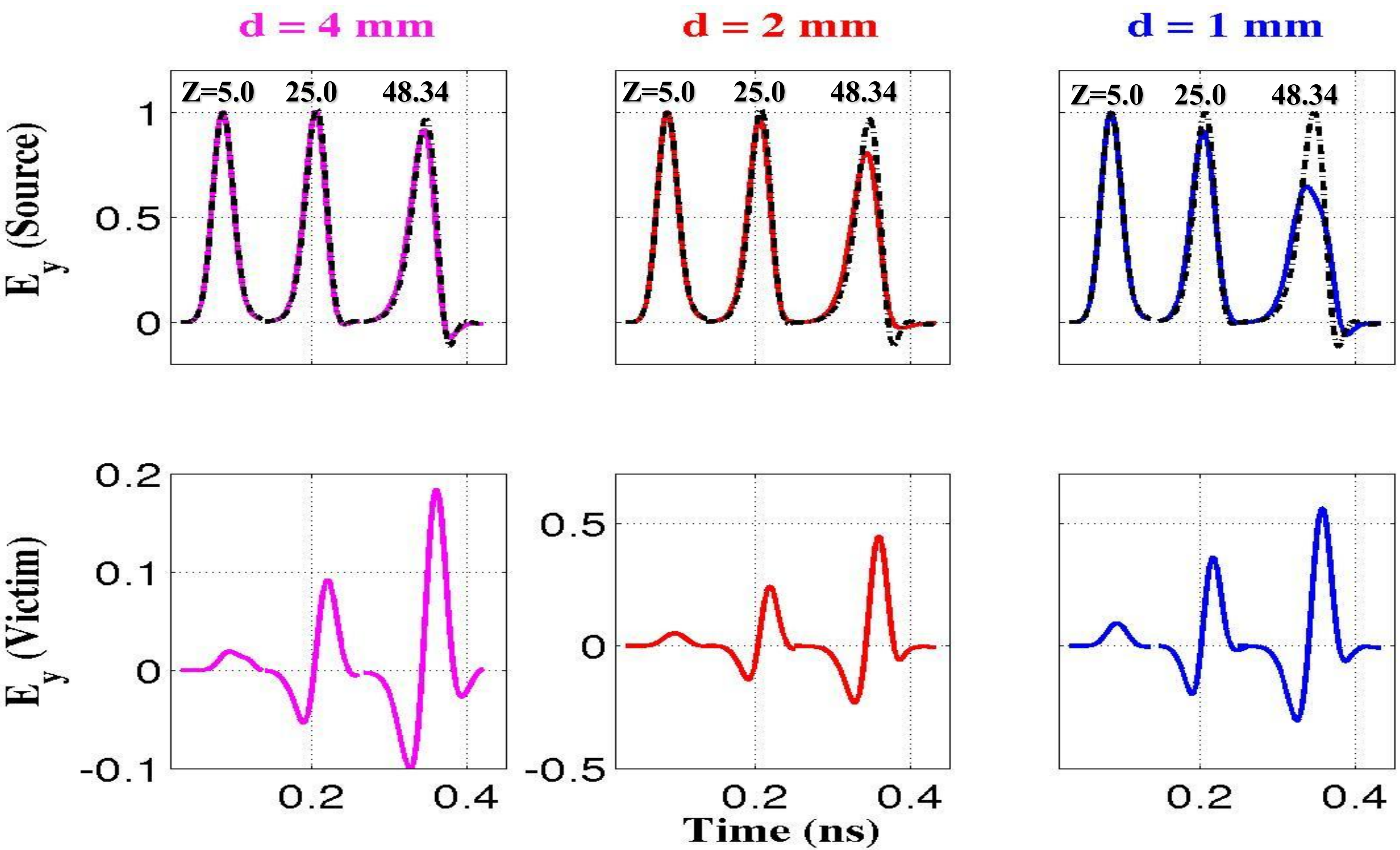
Semiconductor
Dielectric

Excitation Waveform:

$$E_y(t) = E_{y0}\, e^{-\alpha(t-\tau)^2} \ ; \ 0 \le t \le 2\tau$$

$$\alpha = (4/\tau)^2$$

Pulses on Printed Coupled Lines



A_S = w / h = 1 , τ = 66.67 ps , ε_r = 4 , Dashed Curves -- SMSL & Solid Curves – CMSL

Distortion and Coupling Increases (d < <)

Pulses on Printed Coupled Lines

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Finite-Difference Time-Domain Analysis of Electromagnetic Modes Inside Printed Coupled Lines and Quantification of Crosstalk

Shahid Ahmed, *Member, IEEE*

MODERN high-speed densely packed integrated circuits and interconnects are comprised of microstrip lines, which are operated at high clock rates for very high-speed digital applications. To preserve signal integrity, information conducted by these systems should be transported in the form of the transverse electromagnetic (TEM) mode. However, the fast rise and fall times of short pulses, scattering, and reflections from different subsystems and discontinuities result in the excitation of higher order transverse electric (TE) and transverse magnetic (TM) modes leading to parasitic electromagnetic coupling, crosstalk, and radiation leakage [1]. To minimize such kinds of unwanted physical phenomena, complete knowledge of the electromagnetic modes excited inside a system and their correlation with the crosstalk between parasitic elements is important. This paper would then be directly used as a tool for devising systems for suppressing undesirable modes. Since per-

Pulses on Printed Coupled Lines

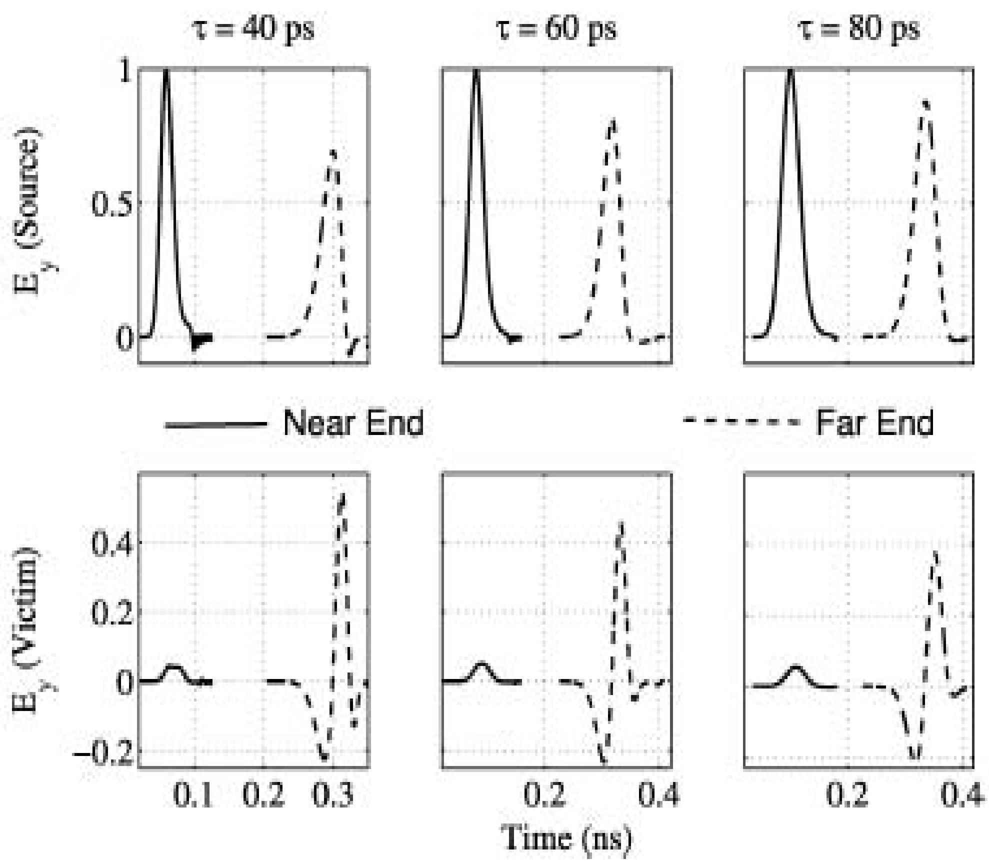

Fig. 10. Time waveform of pulses at near and far end on source and victim lines ($d = 2$ mm) printed on a dielectric substrate with $\epsilon_r = 4.0$ corresponding to $\tau_s = 40$, 60, and 80 ps.

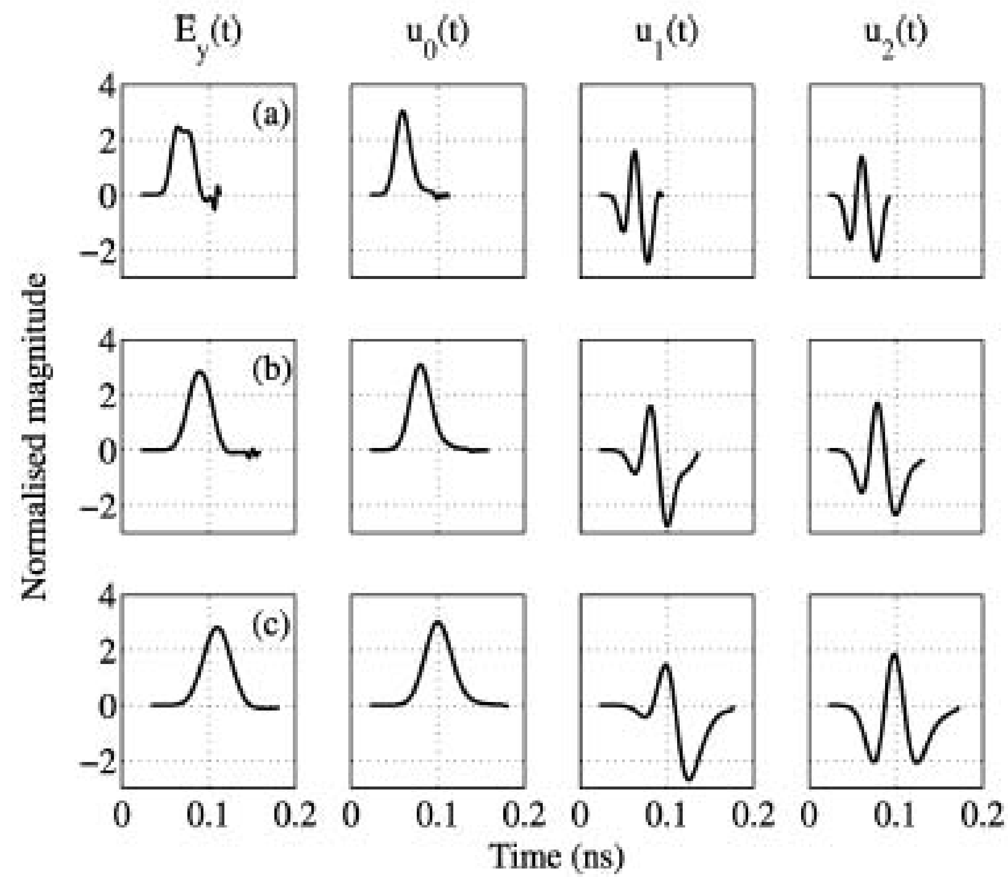

Fig. 11. Temporal evolution of normalized E_y, u_0, u_1, and u_2 at near end ($z = 5$ mm) for line separation $d = 2$ mm and $\epsilon_r = 4.0$. Cases (a)–(c) correspond to $\tau_s = 40$, 60, and 80 ps, respectively.

Cross-Correlation – Near End

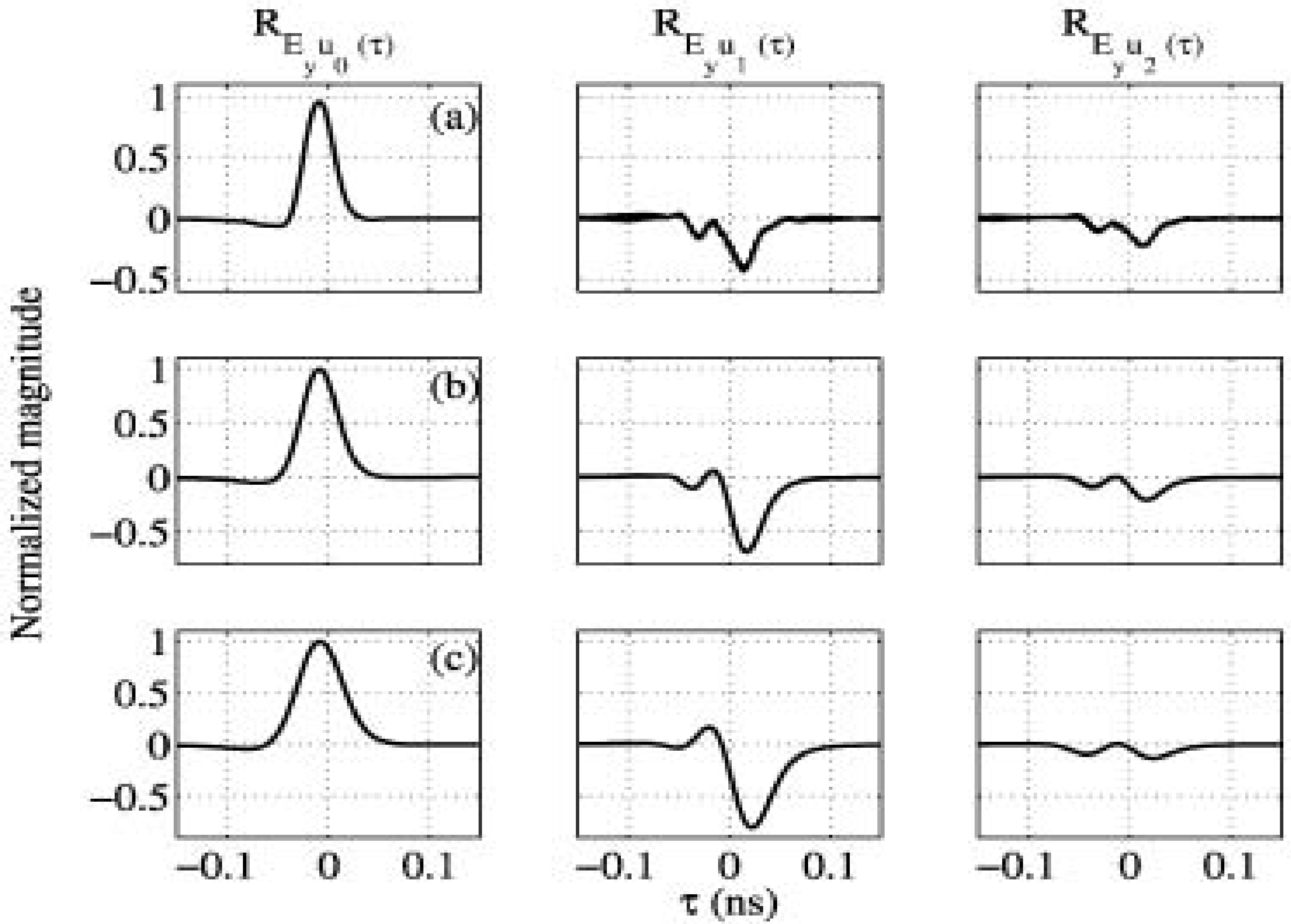

Fig. 12. Evolution of normalized cross correlation $R_{E_y u 0(\tau)}$, $R_{E_y u 1(\tau)}$, and $R_{E_y u 2(\tau)}$ with time delay τ corresponding to Fig. 11. Cases (a)–(c) correspond to $\tau_s = 40$, 60, and 80 ps, respectively.

Cross-Correlation – Far End

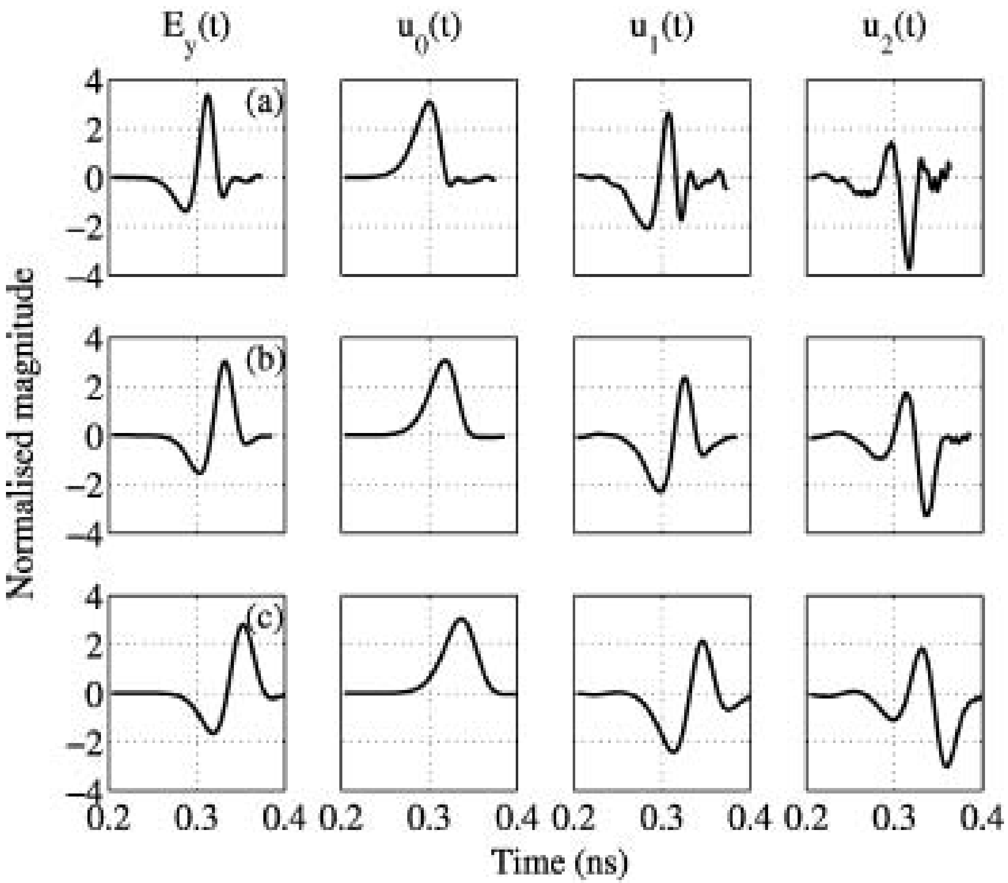

Fig. 13. Temporal evolution of normalized E_y, u_0, u_1, and u_2 at far end ($z = 48.34$ mm) for line separation $d = 2$ mm and $\epsilon_r = 4.0$. Cases (a)–(c) correspond to $\tau_s = 40$, 60, and 80 ps, respectively.

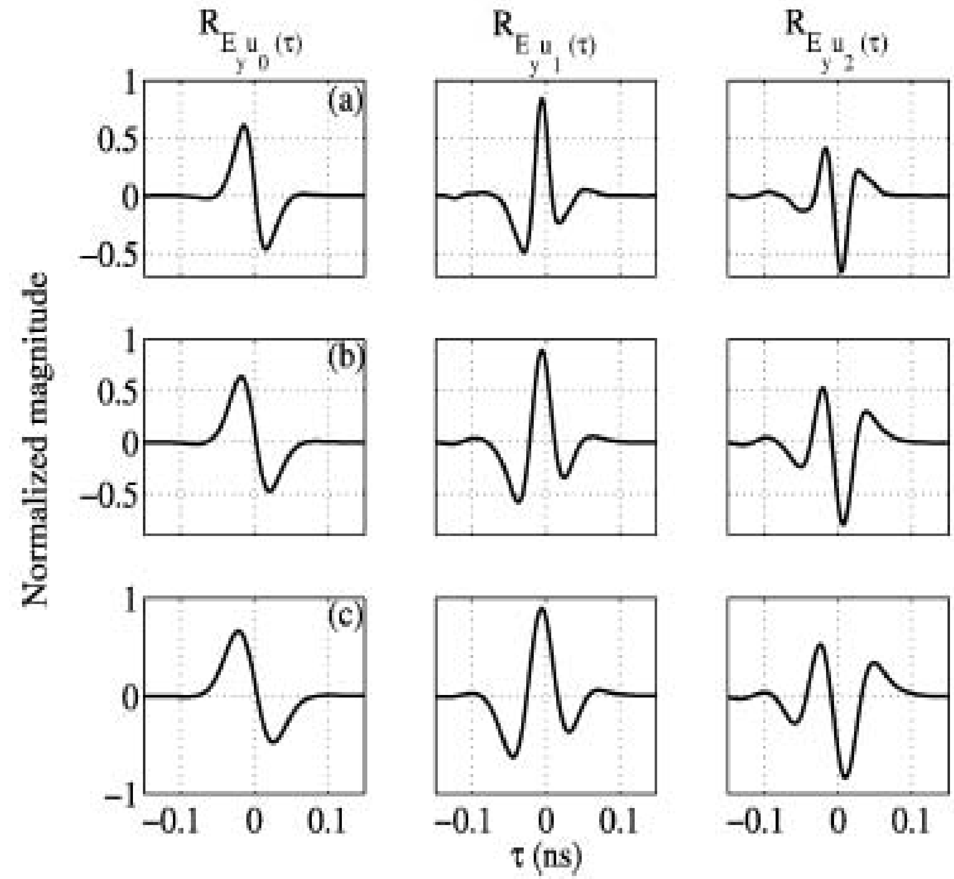

Fig. 14. Evolution of normalized cross correlation $R_{E_y u0(\tau)}$, $R_{E_y u1(\tau)}$, and $R_{E_y u2(\tau)}$ with time delay τ corresponding to Fig. 13. Cases (a)–(c) correspond to $\tau_s = 40$, 60, and 80 ps, respectively.

Conclusion

Short Pulse electromagnetics is potentially challenging

Provides wealth of information – need thorough investigation