

# X2D2

*The new 2D field solver with causal dielectric  
and surface roughness models*

Dr. Ching-Chao Huang

*[huang@ataitec.com](mailto:huang@ataitec.com)*

AtaiTec Corporation

# Outline

- What is X2D2
- Causal dielectric model
- Surface roughness model
- PCB extraction and modeling methodology
- Measurements for 6" differential trace extraction
- In-situ de-embedding (ISD)
- Extraction of material property (DK, DF, roughness)
- Summary

# What is X2D2

- A new 2D solver that creates S parameters with causal dielectric and surface roughness models.

**X2D2: The 2D Field Solver with Surface Roughness**

**Dielectric Property**

Mat ID	Er	tanD	Sigma (S/m)
1	1	0	0
2	3.49	3.51	0
3	3.51	0.001	0
4	3.8	0.02	0

**Material property**

**Dielectric**

Number of Layers: 1  
 Thickness: Mat ID  
 Layer 1: 0.178 | 31  
 Top: 0.114 | 31

**Stackup**

**Run Control**

Impedance  S parameters

Length: 0.1524 m  
 Minimum Frequency: 0 GHz  
 Maximum Frequency: 20 GHz  
 Number of Points: 1201

Linear  Log

Reference Impedance: 50 Ohm  
 Enforce causality  Plot S param

**Unit**

mm  
 um  
 mil  
 in

**Metal Property**

Mat ID	Sigma (S/m)	Roughness (um)
51	5.8e7	0
52	5.8e7	0.1
53	5.8e7	0.2
54	5.8e7	0.8
55	5.8e7	1
56	5.8e7	1.5
57	5.8e7	2

**Conductor**

	# Conductors	Thickness	Top Width	Bottom Width	Spacing	x Offset	Mat ID
<input checked="" type="checkbox"/> Bottom Ground		0.7					54
<input checked="" type="checkbox"/> Metal 1	2	0.014	0.1164	0.115	0.1456	0	54
<input checked="" type="checkbox"/> Top Ground		0.7					54

**Conductors**

**Causal Dielectric Property**

Mat ID	Eri	Erd	m1	m2	Sigma (S/m)
31	3.35	0.15	10	14.5	0
32	3	0.6	4	12	0
33	3	0.7	4	12	0
34	3	0.8	4	12	0
35	3	0.9	4	12	0
36	4.27	1.12	4	12	0

**Conductor**

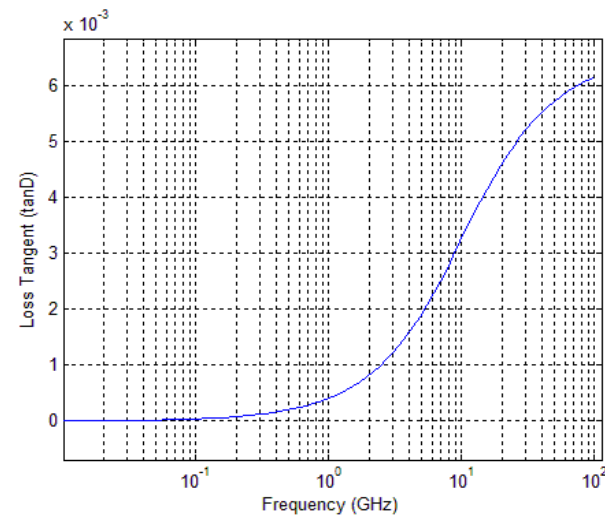
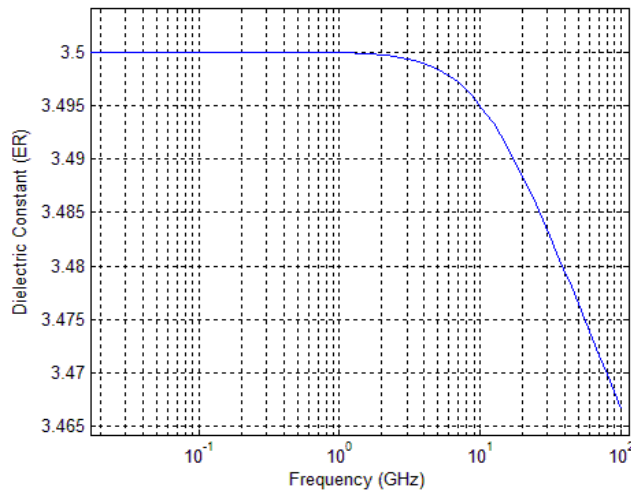
	Shoulder Width	No. of Meshes	Post-processing	Order of Differential Pair
Left	2	Min. per edge: 7	Ground	<input checked="" type="radio"/> (1,2), (3,4), ...
Right	2	Total: 800	Float	<input type="radio"/> (1, n/2+1), (2, n/2+2), ...

Buttons: View Material, Load .tp2 File, View & Save, Save As..., Run

# Causal dielectric model

- Wideband Debye (or Djordjevic-Sarkar) model
  - Need only four variables:  $\epsilon_\infty$  ,  $\Delta\epsilon$  ,  $m_2$  ,  $m_1$

$$\begin{aligned}\epsilon &= \epsilon_\infty + \Delta\epsilon \cdot \frac{1}{m_2 - m_1} \cdot \log_{10} \left( \frac{10^{m_2} + i \cdot f}{10^{m_1} + i \cdot f} \right) \\ &= \epsilon_r \cdot (1 - i \cdot \tan \delta)\end{aligned}$$



$$\epsilon_\infty = 3.35 , \Delta\epsilon = 0.15 , m_2 = 10 , m_1 = 14.5$$

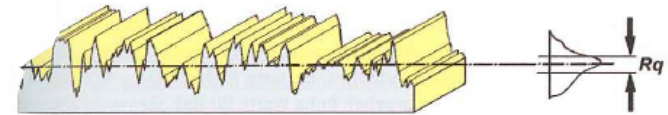
# Surface roughness model

- Effective conductivity (by G. Gold & K. Helmreich at DesignCon 2014) needs only two variables:  $\sigma_{bulk}$ ,  $R_q$

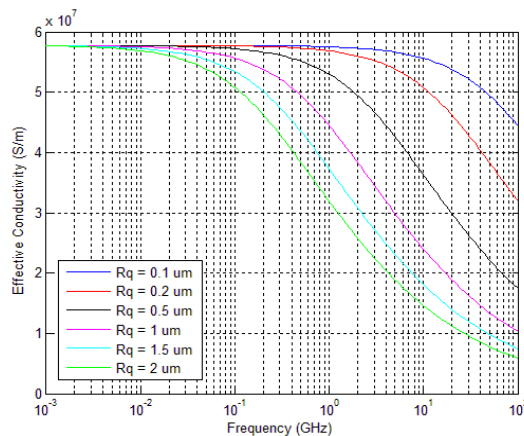
Parameter	Description	Standard
$R_q$	root mean square	DIN EN ISO 4287
$R_a$	arithmetic average	DIN EN ISO 4287, ANSI B 46.1
$R_t$	core roughness depth	DIN EN ISO 13565
$R_z$	average surface roughness	DIN EN ISO 4287

Table 1: Statistical parameters to describe surface roughness

$$\sigma(x) = \sigma_{bulk} \cdot CDF(x) = \sigma_{bulk} \cdot \int_{-\infty}^x PDF(u) du = \sigma_{bulk} \cdot \int_{-\infty}^x e^{-\frac{u^2}{2R_q^2}} du$$



- Numerically solving  $\nabla^2 \bar{B} - j\omega\mu\sigma\bar{B} + \frac{\nabla\sigma}{\sigma} \times (\nabla \times \bar{B}) = 0$  and equating power to that of smooth surface gives  $\sigma_{eff}$

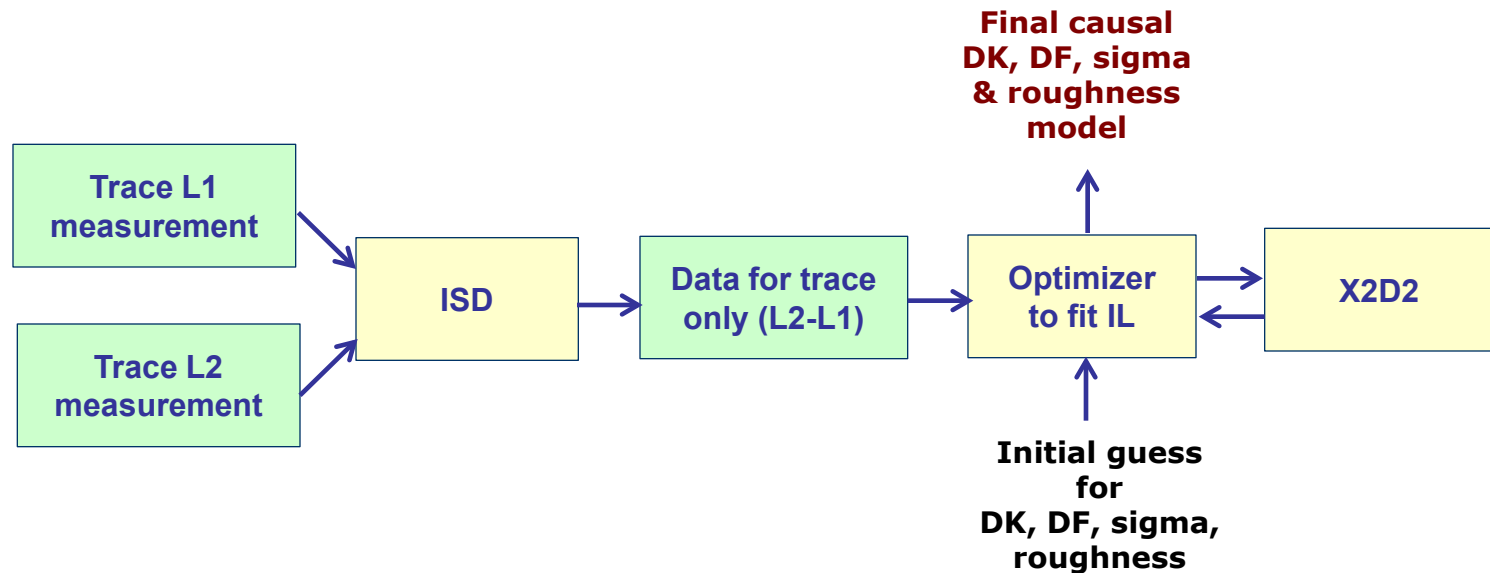


$$\sigma_{bulk} = 5.8 \times 10^7 \text{ s/m}$$

- ❖ Simple
- ❖ Work well with field solver
- ❖ Give effect of roughness on all IL, RL, NEXT and FEXT

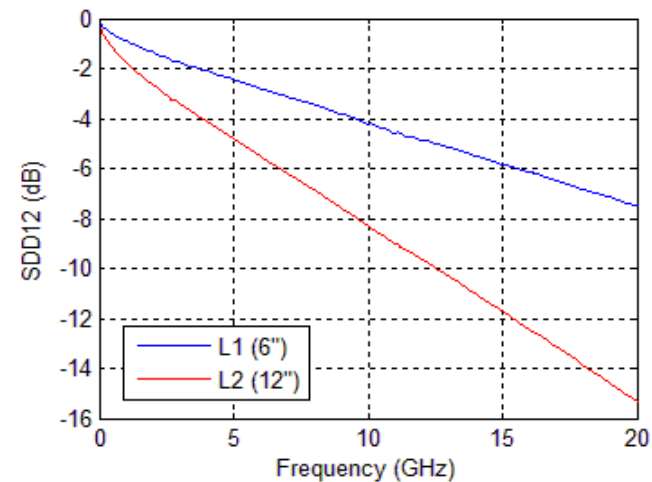
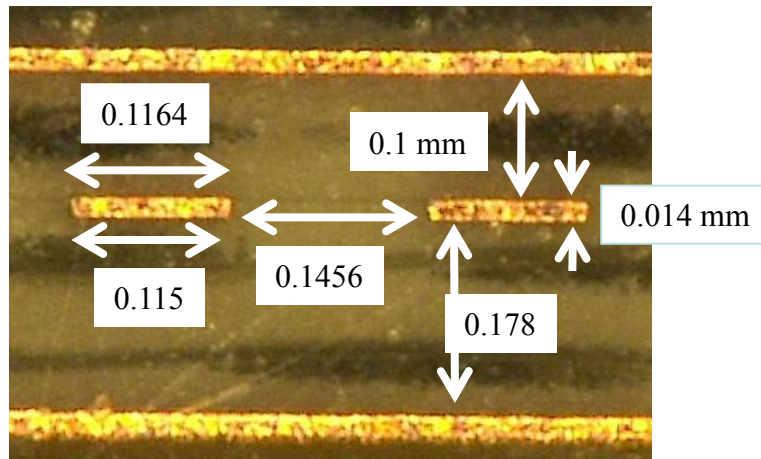
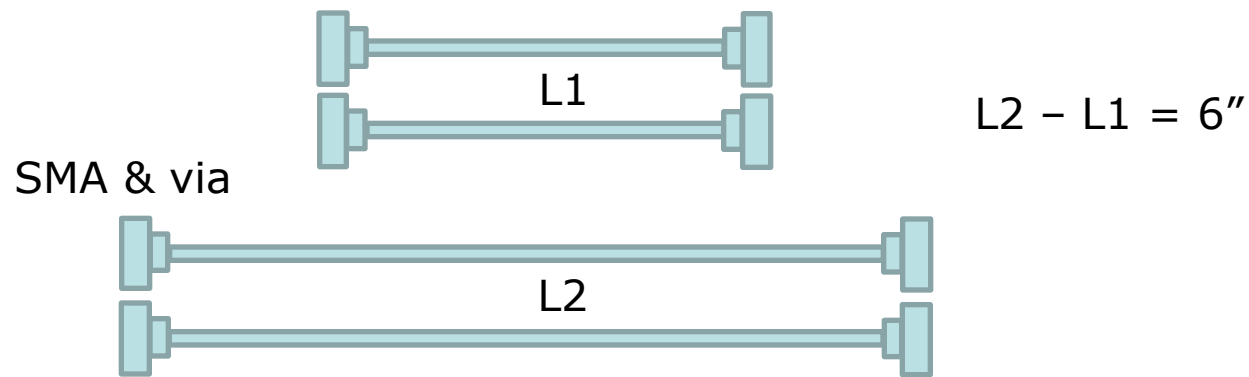
# PCB extraction and modeling methodology

- Measure two traces of different length (L1 & L2).
- Use ISD to extract trace-only data.
- Extract causal DK, DF and surface roughness model by running multiple X2D2 to fit IL in both magnitude and phase.



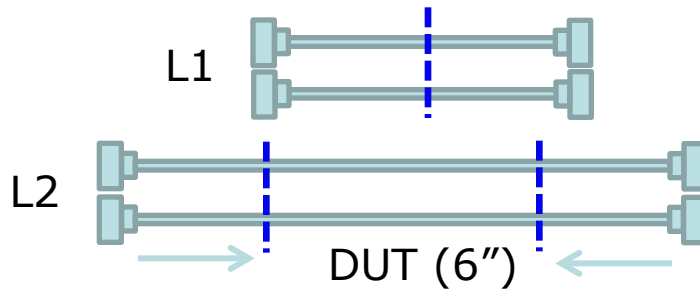
# Example

- Two differential stripline traces of different length (L1 & L2) are measured.



# In-situ de-embedding (ISD) is used to extract trace-only data

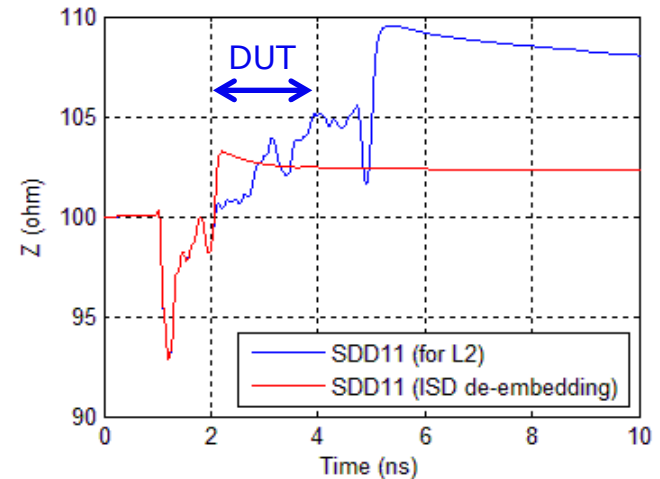
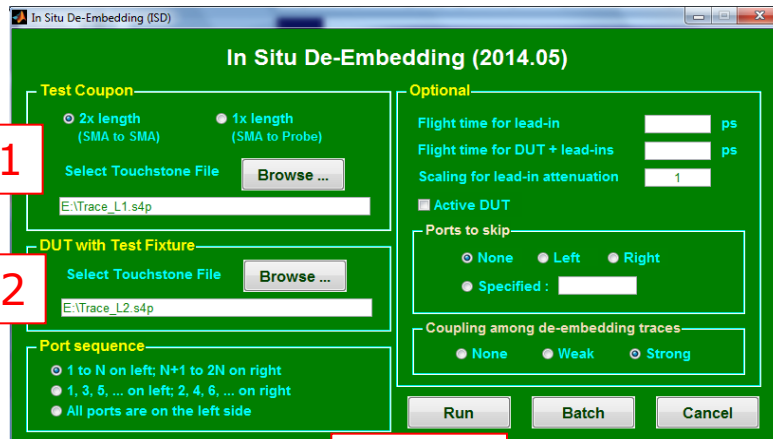
- ISD uses L1 as 2x thru and matches L2 impedance to extract DUT (6" trace).



Step 1

Step 2

Step 3

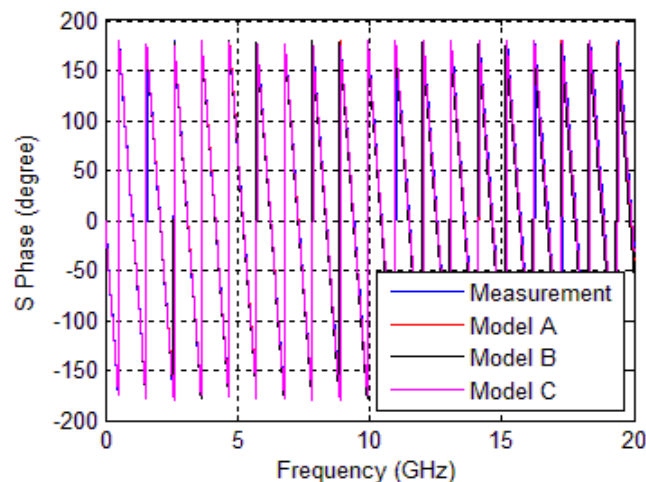
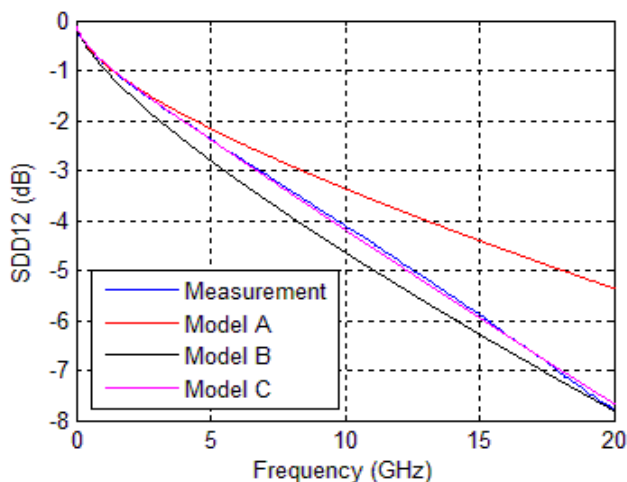


Rise time (20/80) = 50 ps



# X2D2 is used to compare different models

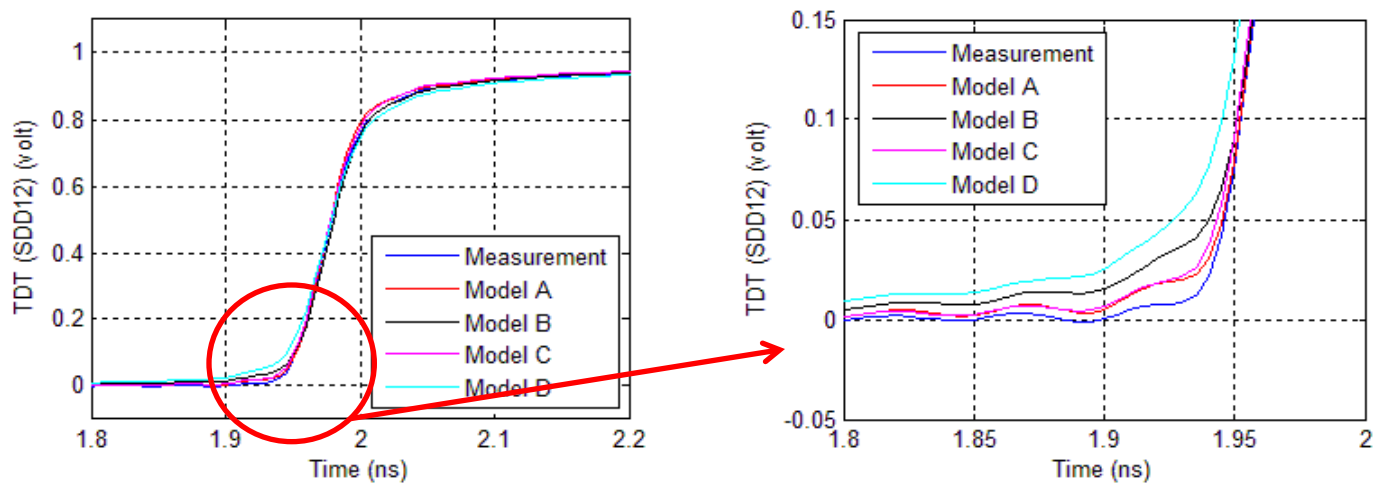
- Model A (manufacturer's) –  $DK=3.51$ ,  $DF=0.004$ ,  
 $\sigma_{bulk} = 5.8 \times 10^7$  s/m,  $R_q = 0$
- Model B (intermediate) –  $DK=3.51$ ,  $DF=0.004$ ,  
 $\sigma_{bulk} = 5.8 \times 10^7$  s/m,  $R_q = 1 \mu\text{m}$
- Model C (optimized) –  $\epsilon_\infty = 3.35$ ,  $\Delta\epsilon = 0.15$ ,  $m_2 = 10$ ,  $m_1 = 14.5$   
 $\sigma_{bulk} = 5.8 \times 10^7$  s/m,  $R_q = 0.8 \mu\text{m}$



*Fitting differential IL in both magnitude and phase*

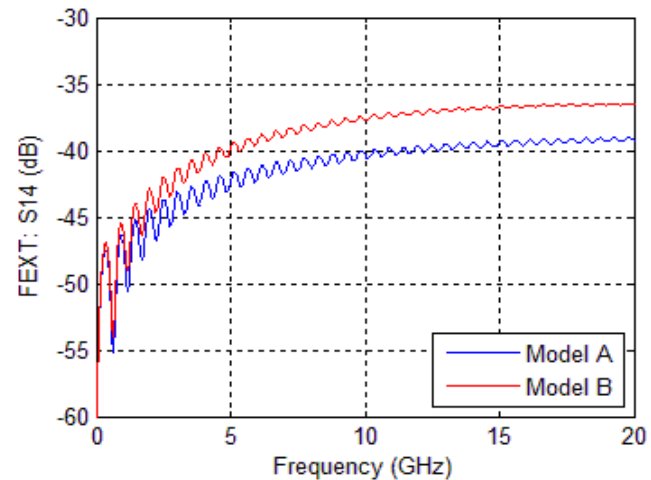
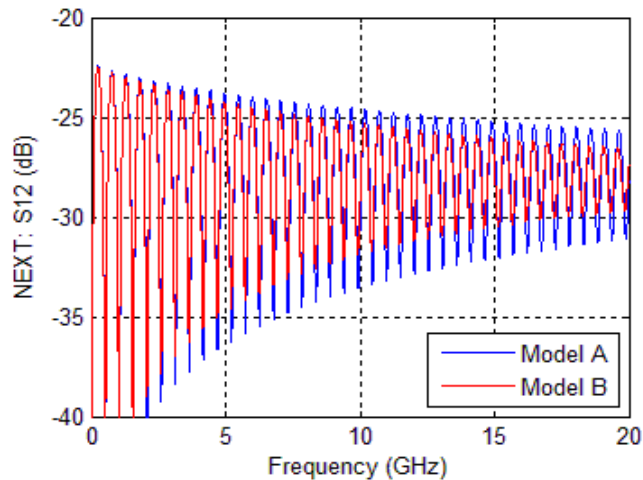
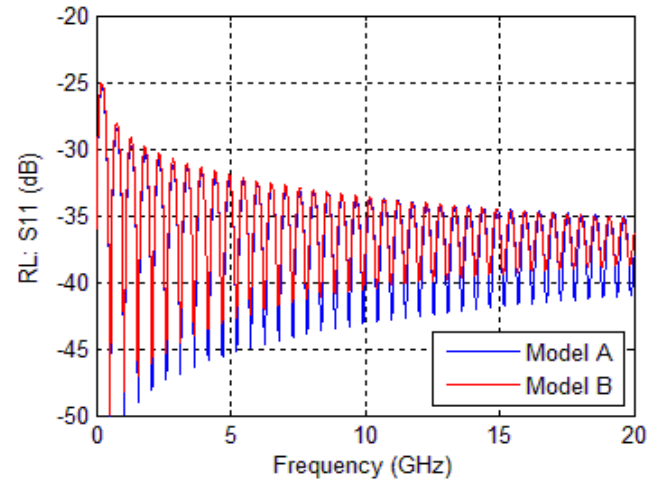
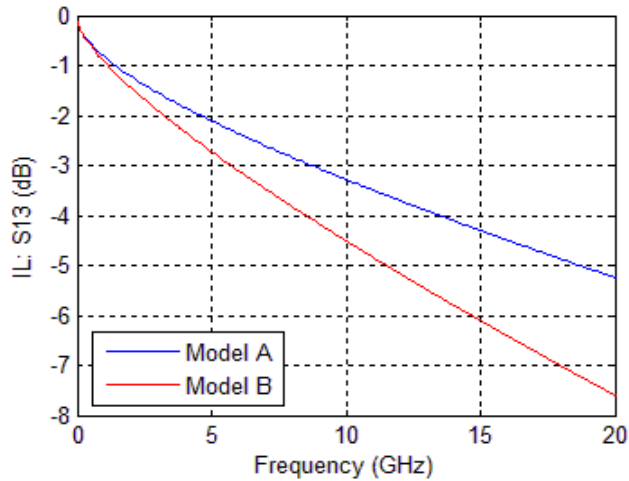
# Causality

- Model A appears okay due to low loss (DF=0.004).
- Model D changes Model A's DF to 0.014 and it gives more non-causal response.
- Model C looks good with wideband dielectric model and surface roughness included.



Rise time (20/80) = 25 ps

# X2D2 gives surface roughness effect on all IL, RL, NEXT and FEXT



# Summary

- Causal dielectric model is made simple through wideband Debye model.
- Surface roughness model is made simple through effective conductivity.
- Extraction of causal dielectric and surface roughness models is made simple through AtaiTec's ISD and X2D2.
- The proposed methodology constructs causal and correlated PCB trace models that help predict 50+ Gbps system performance more precisely.