MPX

Material Property Extractor

Ching-Chao Huang
huang@ataitec.com

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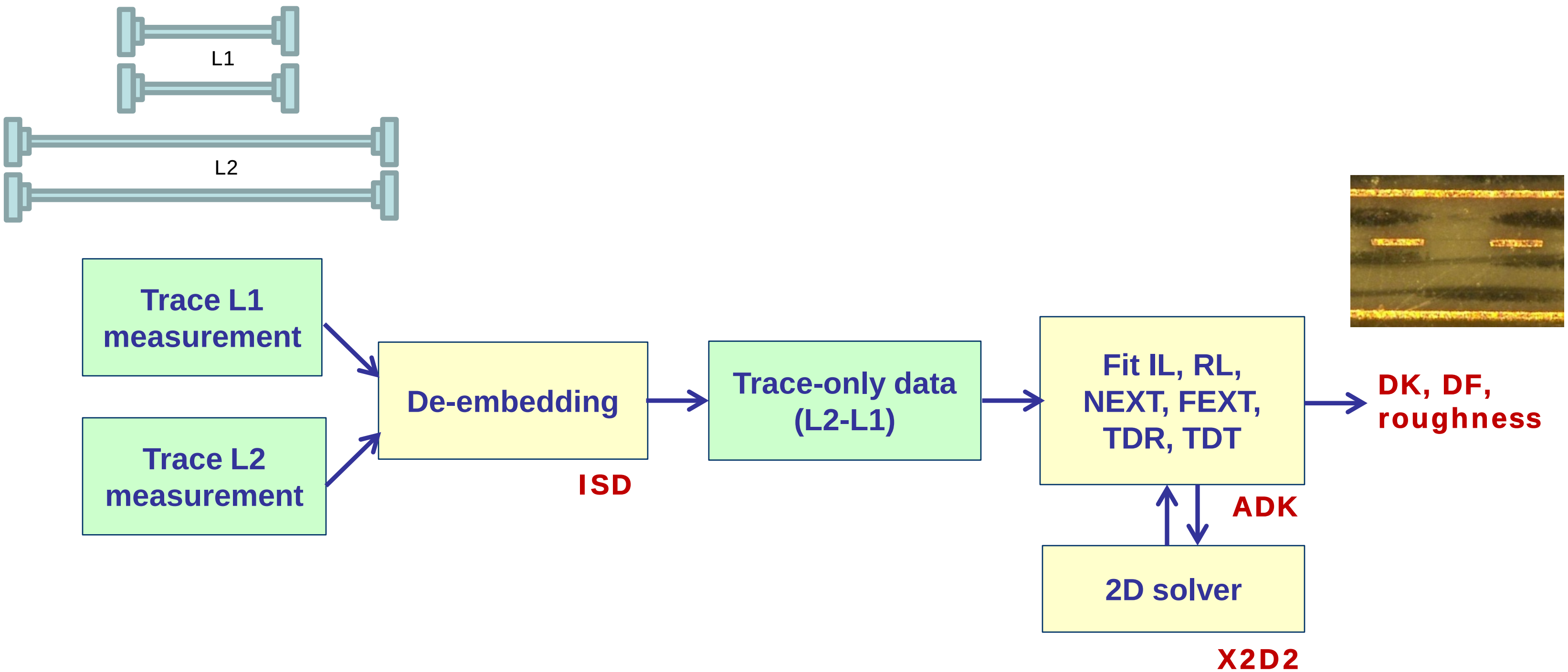
Outline

- What is MPX
- What is ISD
- Causal DK, DF, surface roughness
- Matching IL, RL, NEXT, FEXT, TDR and TDT
- Scalable models
- MPX vs. eigenvalue
- Summary

What is MPX

- A platform to automate PCB material property extraction (DK, DF, roughness).

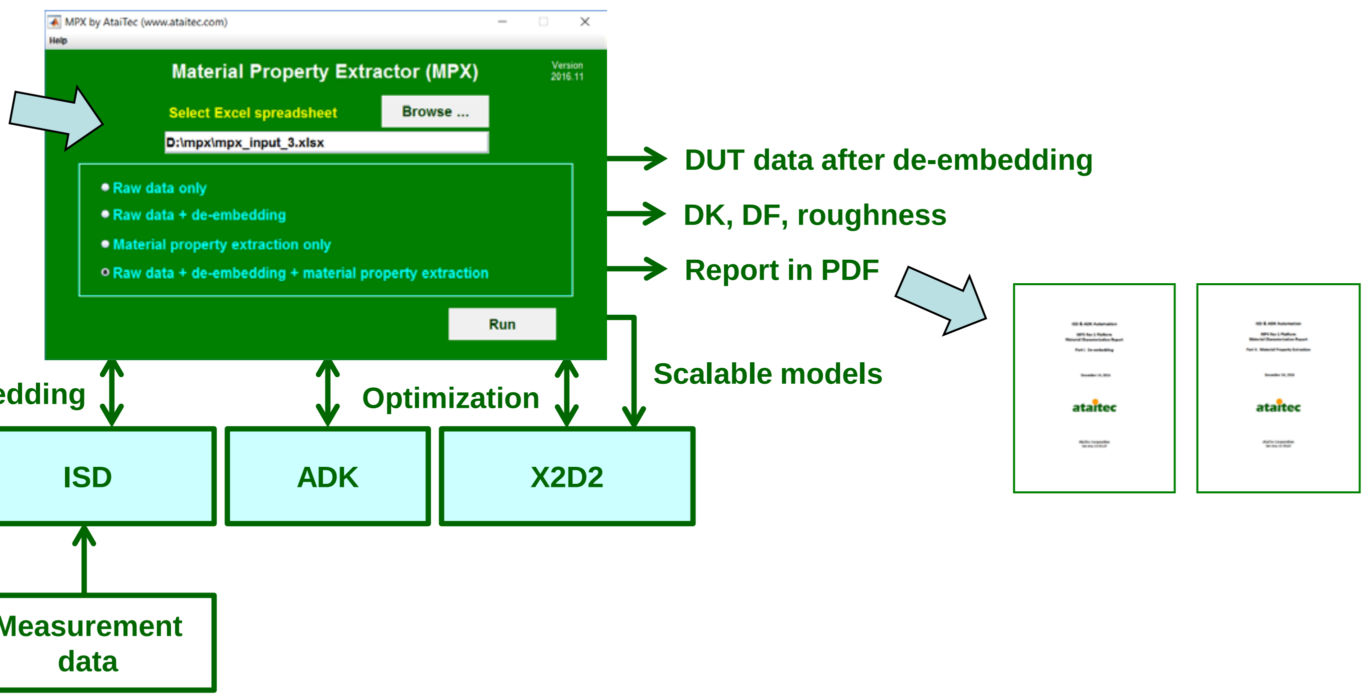


from two 4-port measurements to de-embedding and curvefitting

Model and report generation

- MPX inputs a setup file and outputs a report and length- and frequency-scalable models.

S.No	Parameter	Extraction 1
1	Layer	T5
2	Lines	L5,L7
3	Width/Spacing	WS1
4	Metal top width (mil)	5.61
5	Metal bottom width (mil)	5.91
6	Metal pitch (mil)	14.9
7	Metal thickness (mil)	1.21
8	Bulk conductivity (sigma)	5.80E+07
9	Roughness (um)	0.3
10	Rough surface indices	[1 1 1 1 1]
11	Extraction template	3
12	Dielectric thickness (mil)	4.65 1.19 2.38 3.85
13	DK for bottom dielectric	3.5 1 3.4 30
14	DK for top dielectric	3.6 1 3.5 30
15	DF for bottom dielectric	0.002 1 0.004 10 0.005 30 0.0055 40
16	DF for top dielectric	0.002 1 0.004 10 0.005 30 0.0055 40
17	Tolerance for metal width (%)	15
18	Tolerance for metal pitch (%)	15
19	Tolerance for roughness (%)	15
20	Tolerance for bottom DK (%)	15
21	Tolerance for top DK (%)	15
22	Tolerance for bottoom DF (%)	15
23	Tolerance for top DF (%)	15
24	Frequency range (GHz)	0.01 to 40
25	Number of iterations	300
26	Report template	D:\mpx\X2D_report.dotx
27	Extraction only directory	D:\mpx\reports\04-Dec-2016_4



One click does it all.

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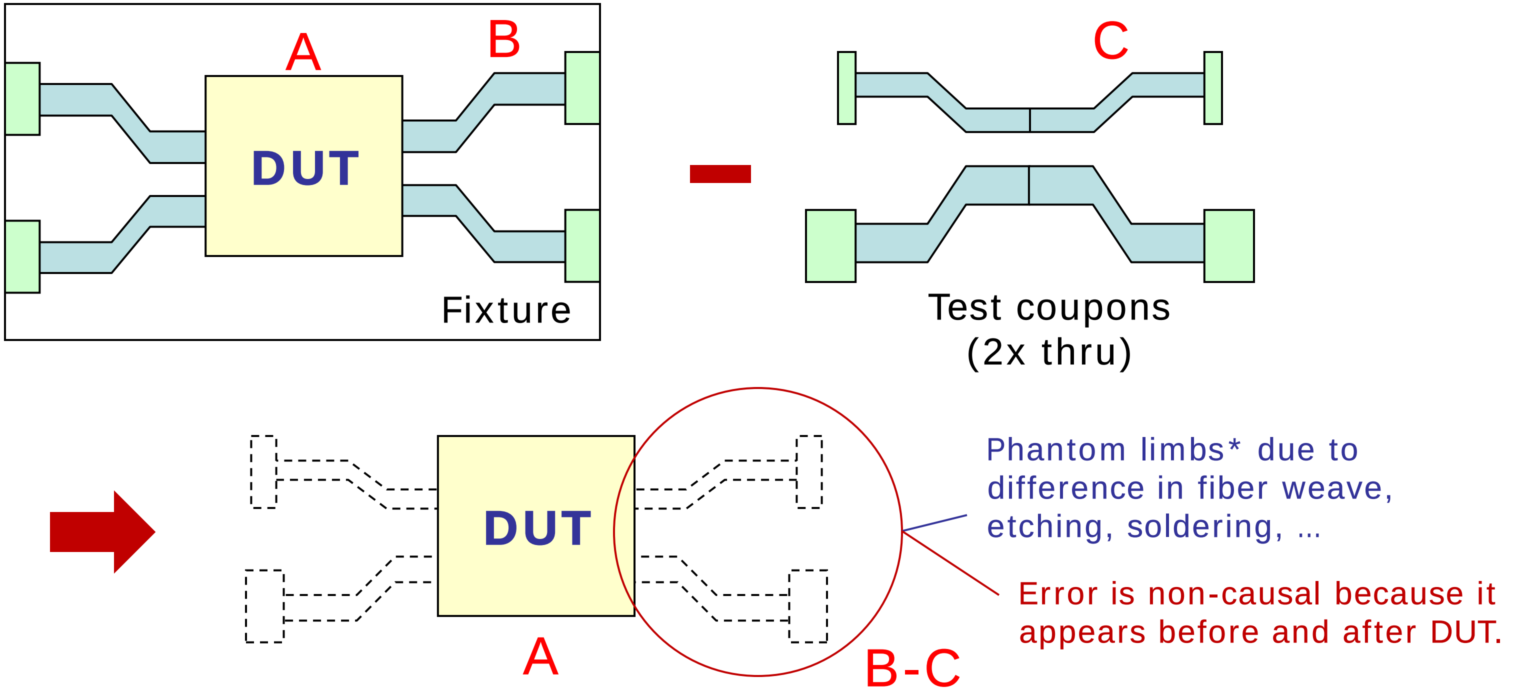
Why do many de-embedding tools have causality error

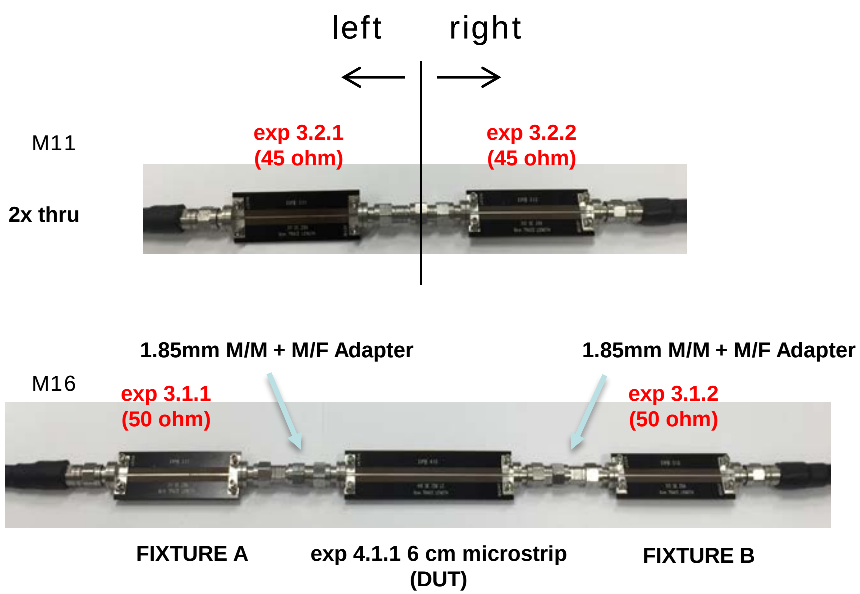
- Many tools use test coupons directly for de-embedding, so difference between actual fixture and test coupons gets piled up into the DUT results.



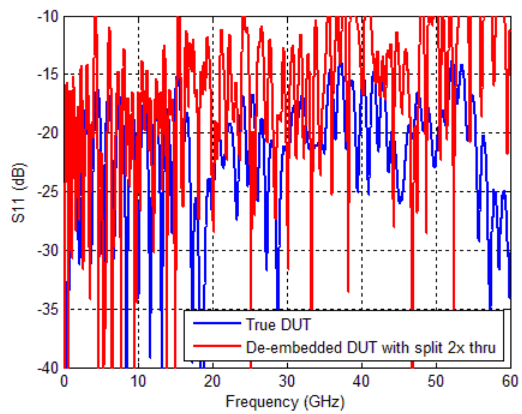
* http://www.edn.com/electronics-blogs/test-voices/4438677/Software-tool-fixes-some-causality-violations by Eric Bogatin

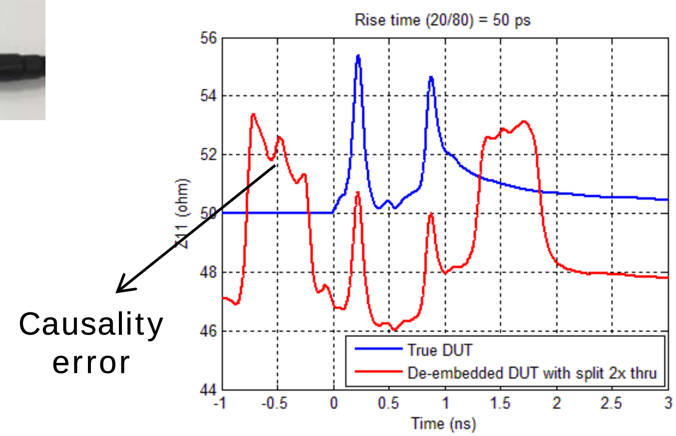
Causality error makes correlation and curvefitting impossible

- Splitting 45 ohm “2x thru” test coupon to de-embed 50 ohm fixture gives large causality error.



IEEE P370 example
(Each component can be measured separately.)





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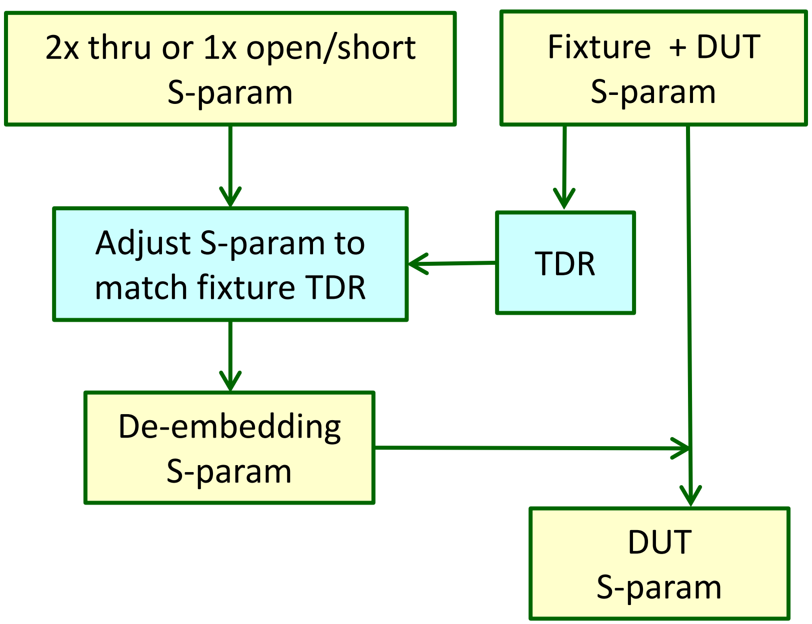
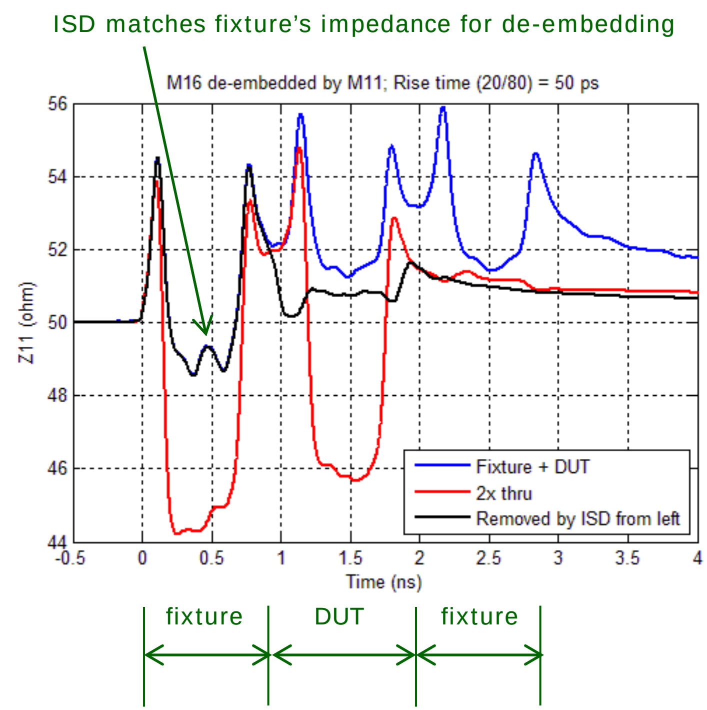
In-Situ De-embedding (ISD)

Introduced to avoid causality error in de-embedding

- Instead of splitting "2x thru" test coupon directly for de-embedding, ISD adjusts 2x thru's IL and RL to match fixture's impedance.





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IEEE P370 example: Microstrip
ISD vs. Split 2x thru

- ISD results correlate well with true DUT when 2x thru and fixture have different impedance.

M11

2x thru

exp 3.2.1
(45 ohm)

exp 3.2.2
(45 ohm)

1.85mm M/M + M/F Adapter

1.85mm M/M + M/F Adapter

M16

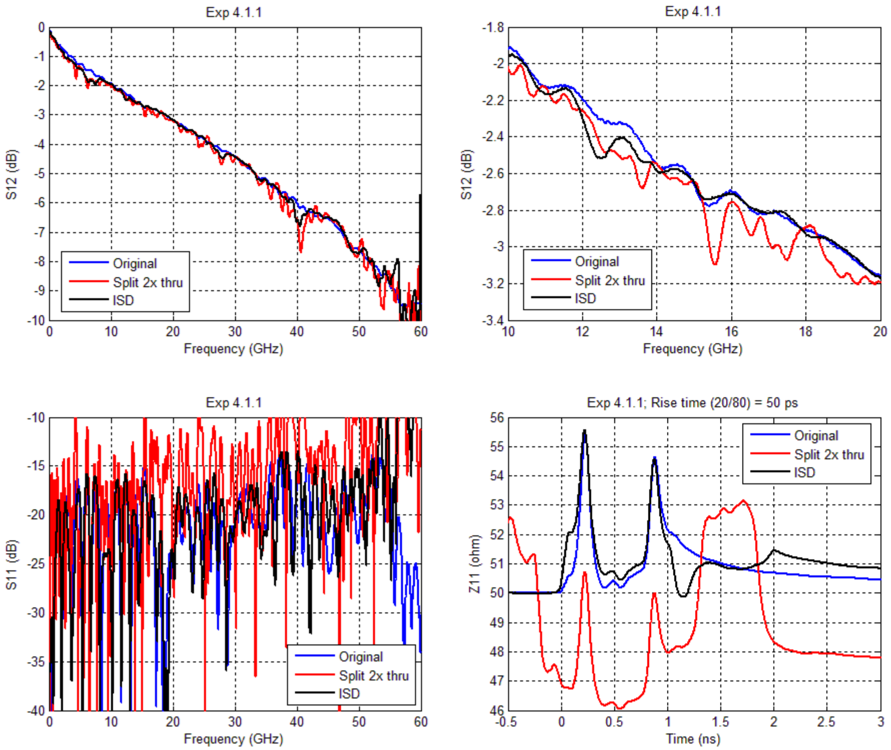
exp 3.1.1
(50 ohm)

exp 3.1.2
(50 ohm)

FIXTURE A

exp 4.1.1 6 cm microstrip
(DUT)

FIXTURE B



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IEEE P370 example: Beatty standard

ISD vs. Split 2x thru

- ISD results correlate well with true DUT when 2x thru and fixture have different impedance.

M11

exp 3.2.1 (45 ohm)

exp 3.2.2 (45 ohm)

2x thru

M18

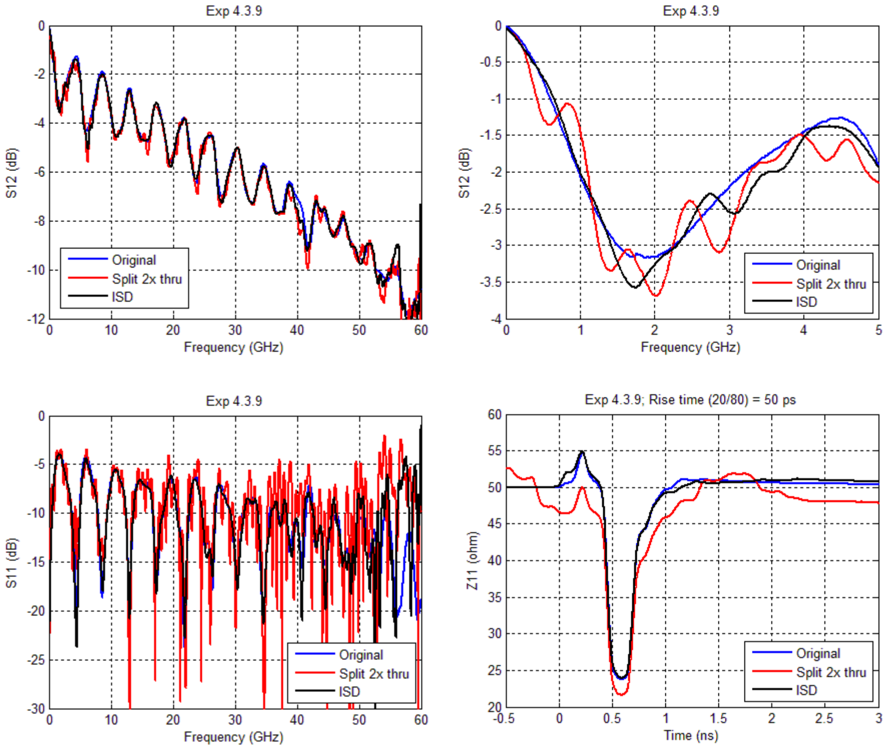
exp 3.1.1 (50 ohm)

exp 3.1.2 (50 ohm)

FIXTURE A

exp 4.3.9 Beatty standard (DUT)

FIXTURE B



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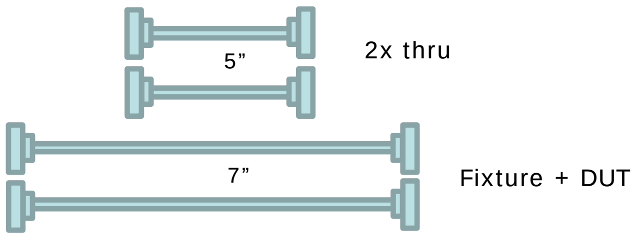
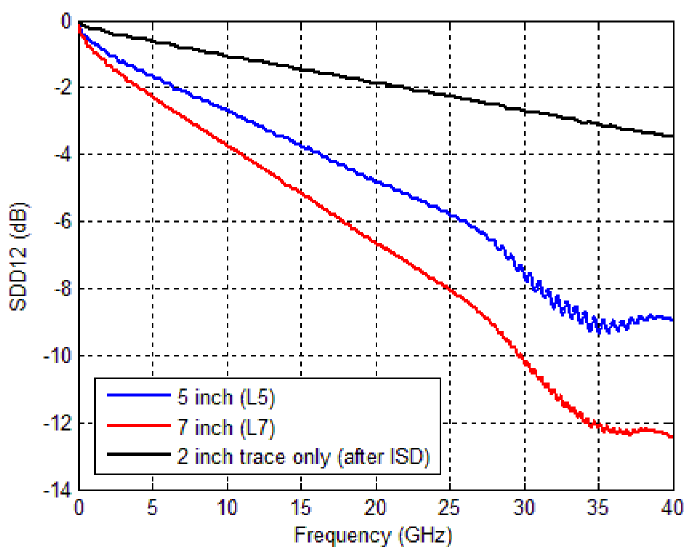
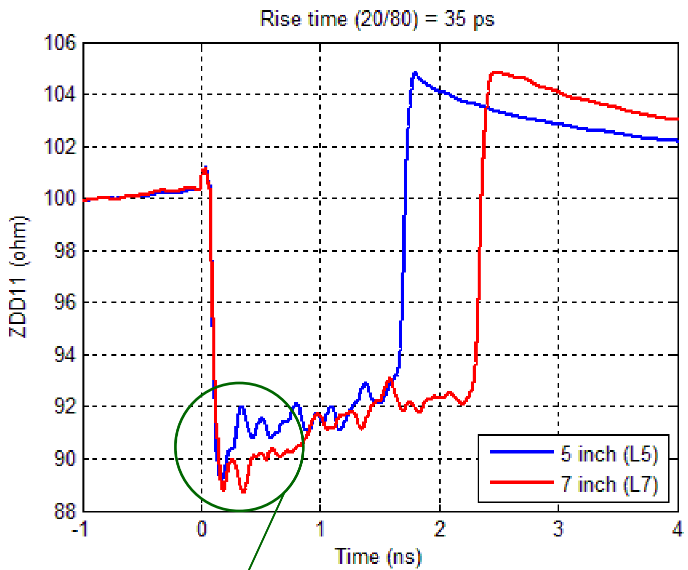
Extracting material property from ISD de-embedded results

- The shorter trace is used as 2x thru. The DUT results (trace only after ISD) will be matched by 2D solver.







2x thru and fixture have different impedance.

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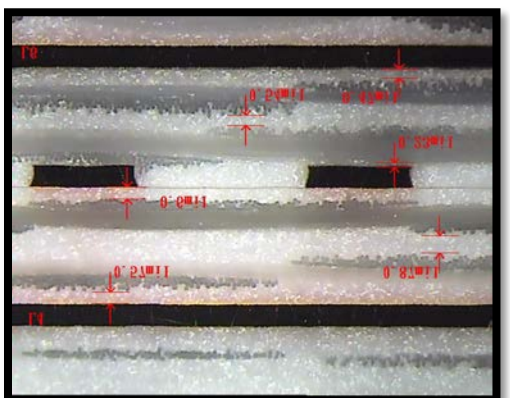
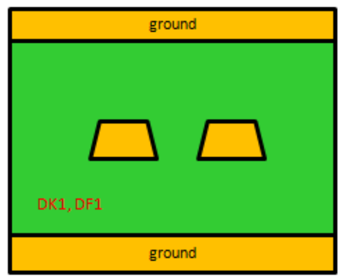
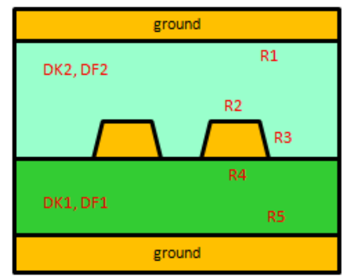
Cross-sectional models for 2D solver

Optimized variables:
DK1, DF1, DK2, DF2
R1, R2, R3, R4, R5 (roughness, on/off)
Metal width and spacing

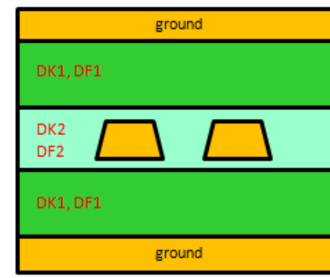




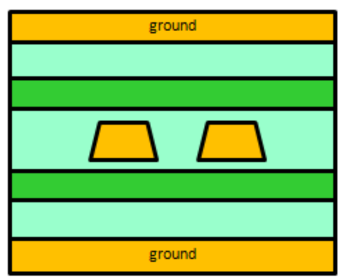
Model 1



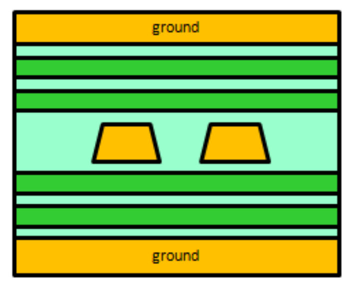
Model 2



Model 3



Model 4



Model 5

More models
can be added.

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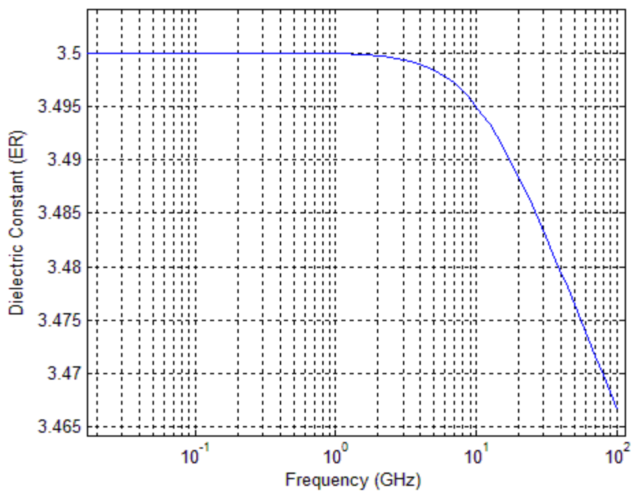
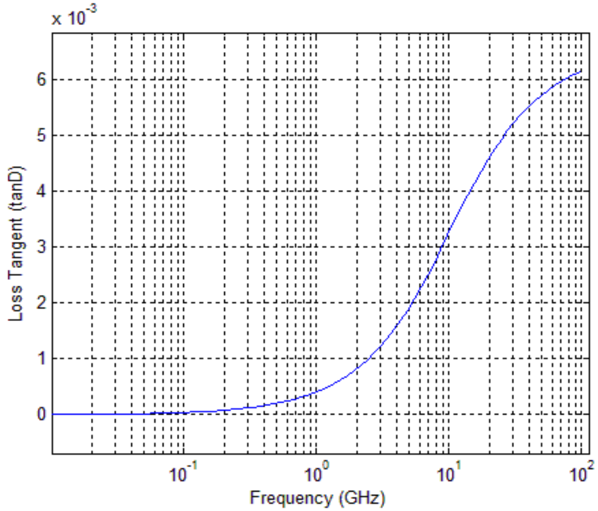
Causal dielectric model

- Wideband Debye (or Djordjevic-Sarkar) model
  - Need only four variables: ε_∞ , $\Delta\varepsilon$, m_1 , m_2

$$\varepsilon = \varepsilon_\infty + \Delta\varepsilon \cdot \frac{1}{m_2 - m_1} \cdot \log_{10}\left(\frac{10^{m_2} + i \cdot f}{10^{m_1} + i \cdot f}\right)$$
$$= \varepsilon_r \cdot (1 - i \cdot \tan\delta)$$





$$\varepsilon_\infty = 3.35 \ , \ \Delta\varepsilon = 0.15 \ , \ m_1 = 10 \ , \ m_2 = 14.5$$

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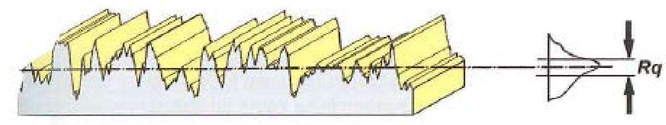
Surface roughness model

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

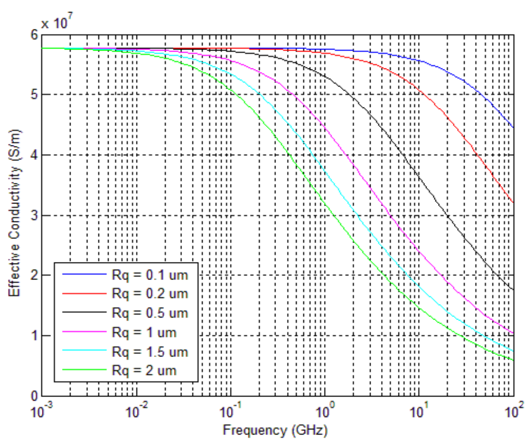
Parameter	Description	Standard
R_q	root mean square	DIN EN ISO 4287
R_a	arithmetic average	DIN EN ISO 4287, ANSI B 46.1
R_k	core roughness depth	DIN EN ISO 13565
R_z	average surface roughness	DIN EN ISO 4287

Table 1: *Statistical parameters to describe surface roughness*

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



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



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

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

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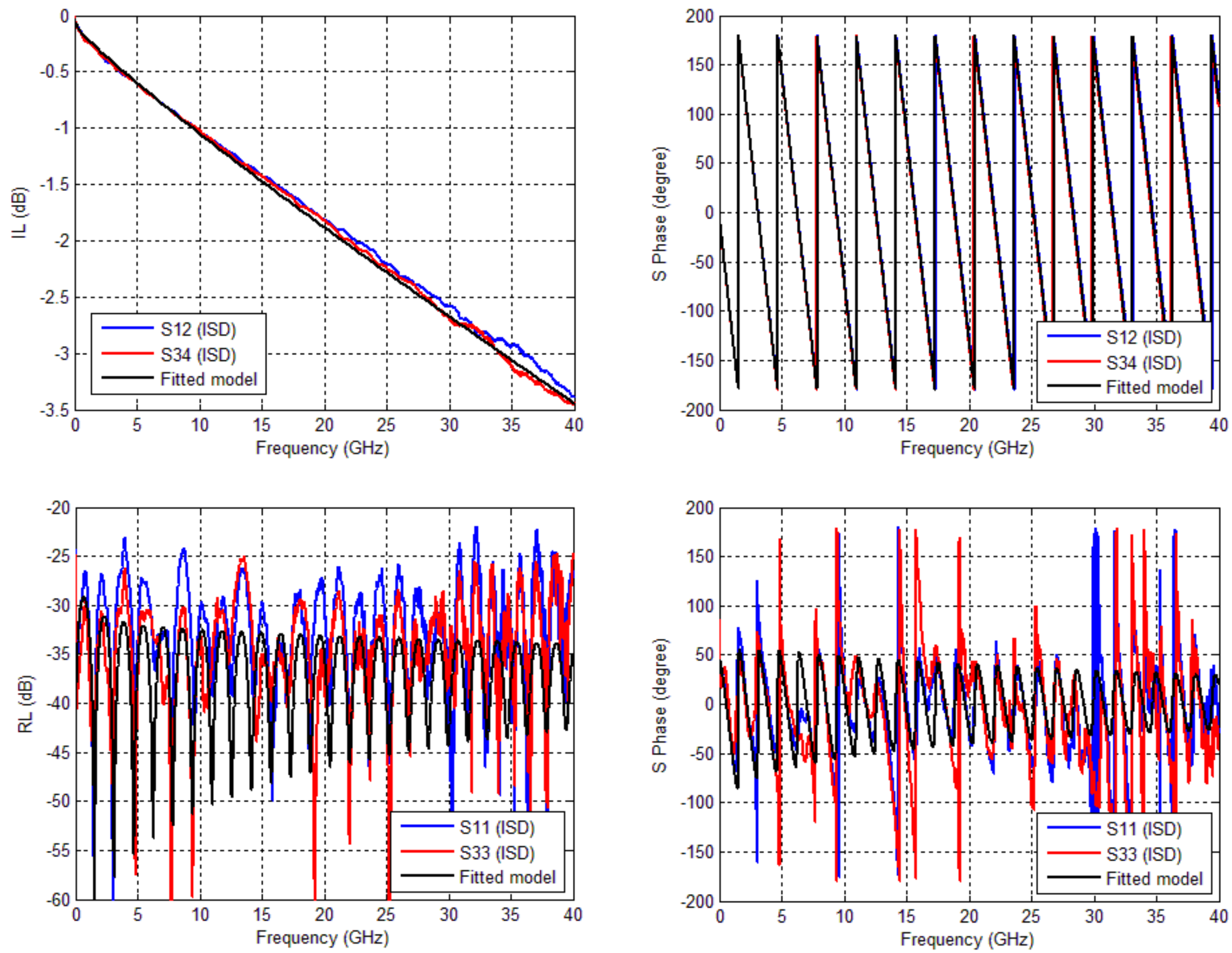
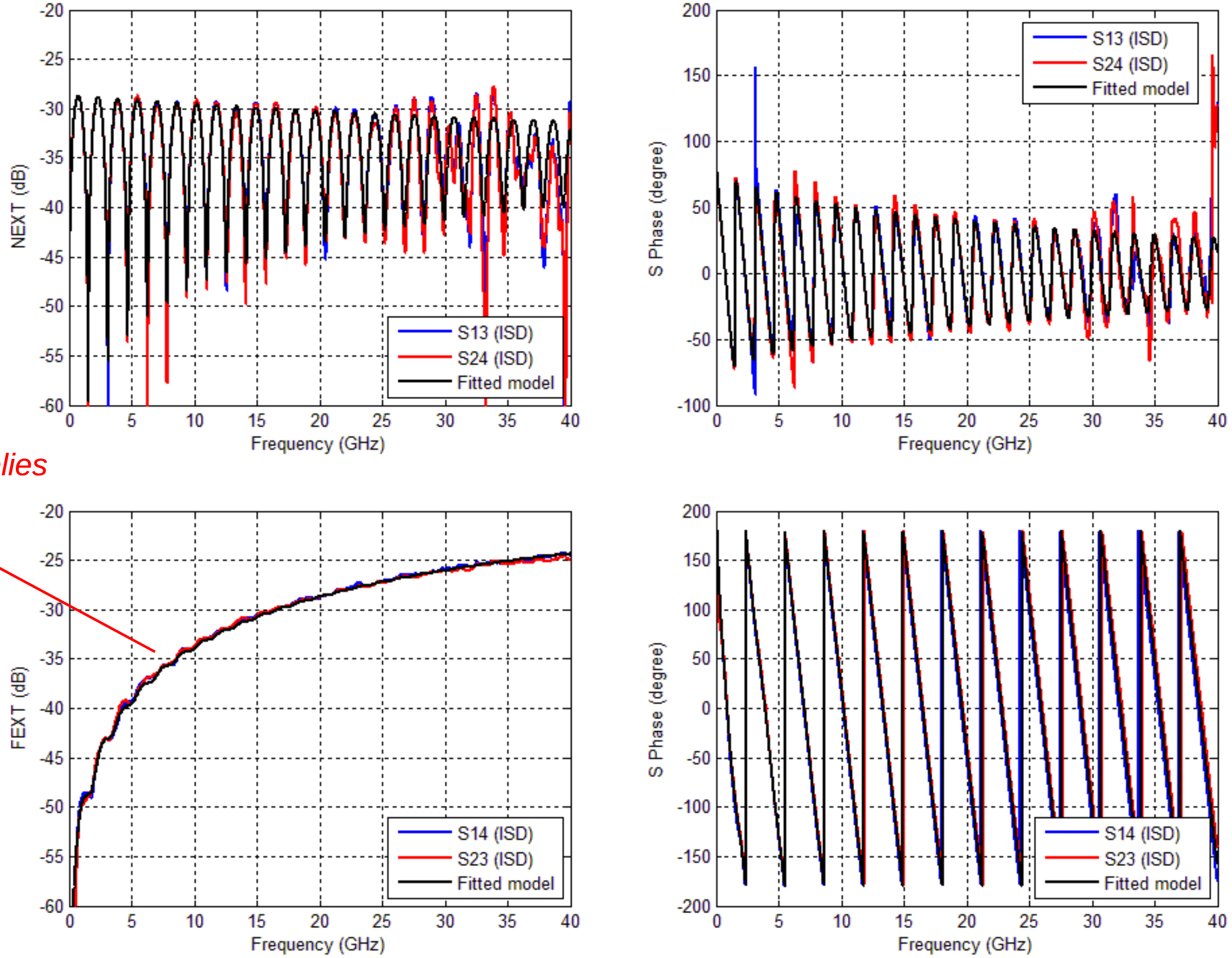
Matching IL and RL

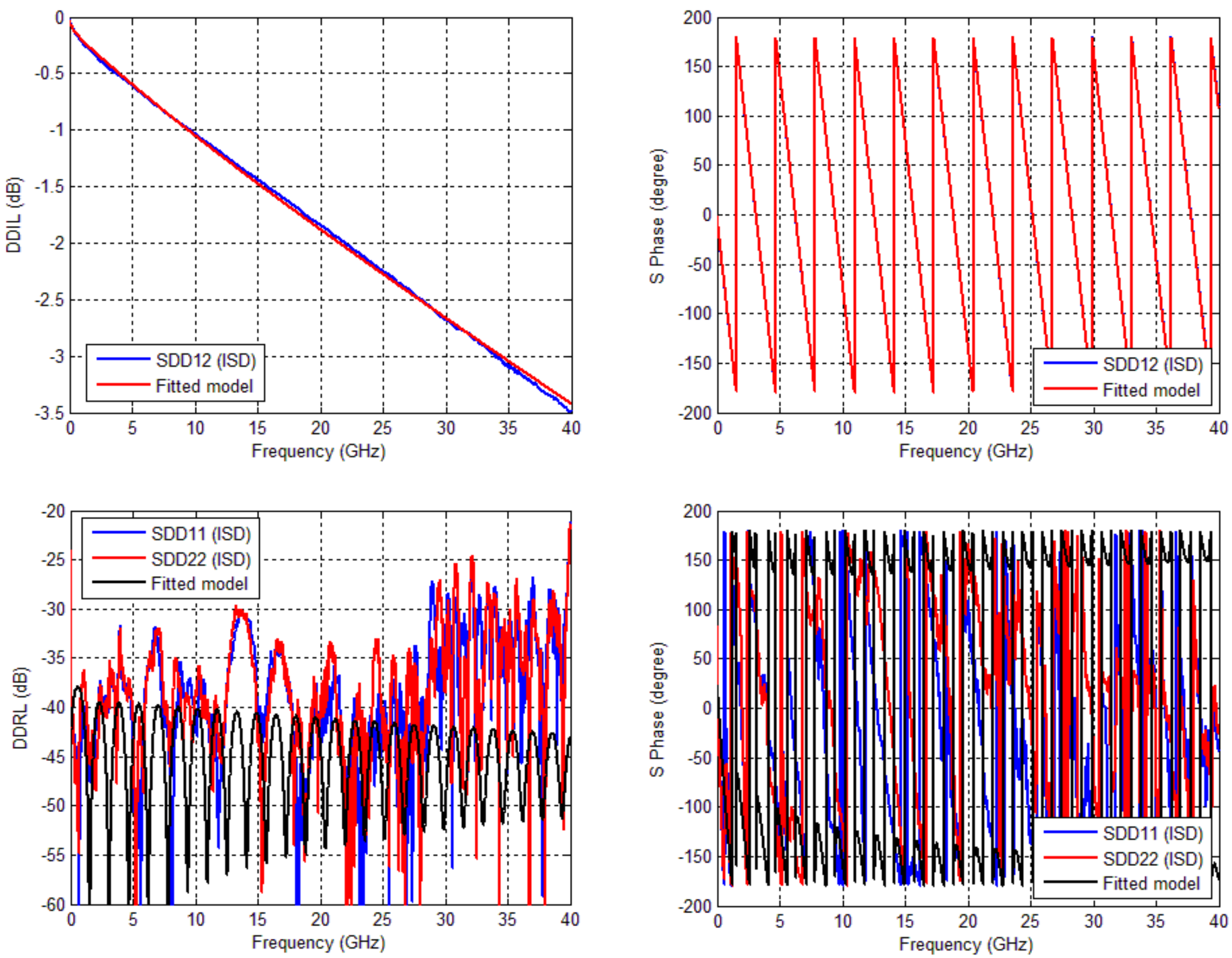


Matching NEXT and FEXT



Large FEXT implies inhomogeneous dielectric

Matching DDIL and DDRL



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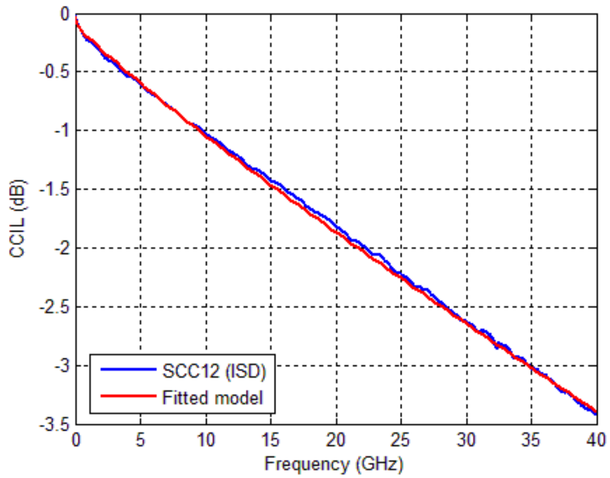
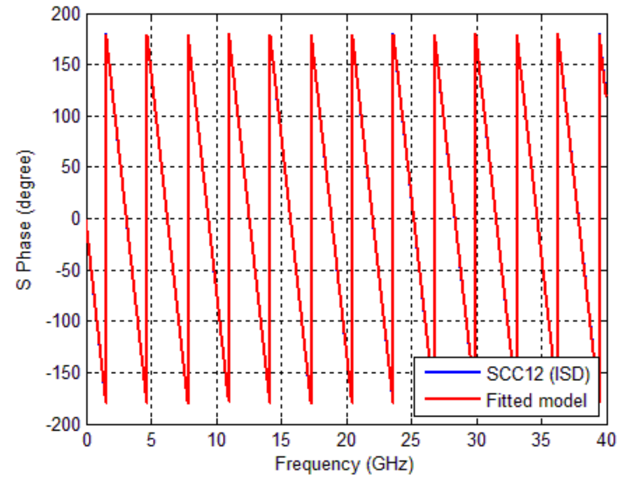
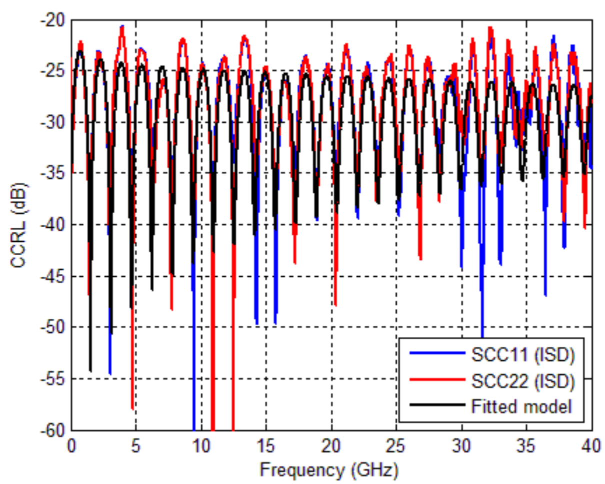
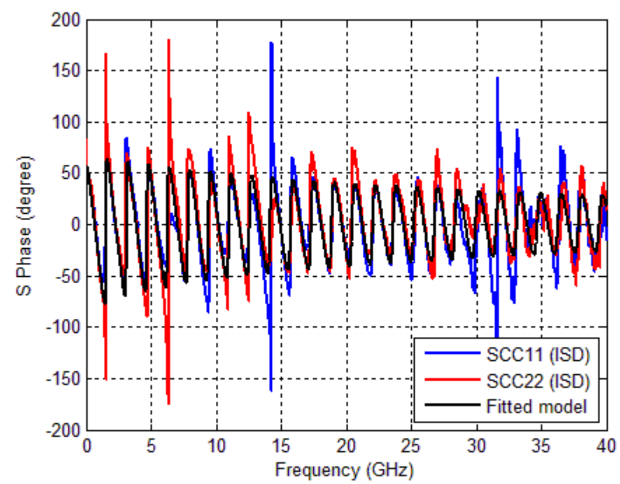
Matching CCIL and CCRL









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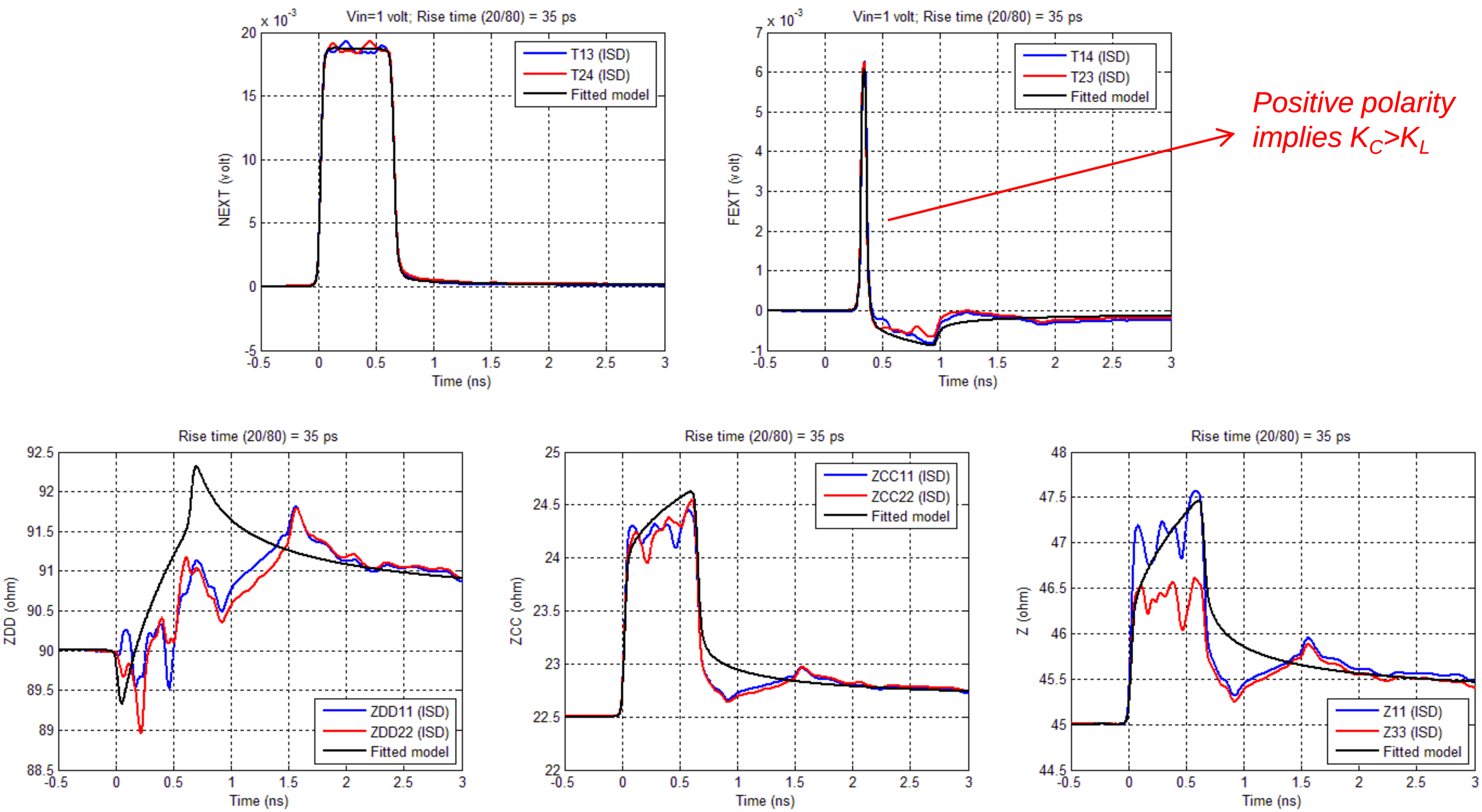
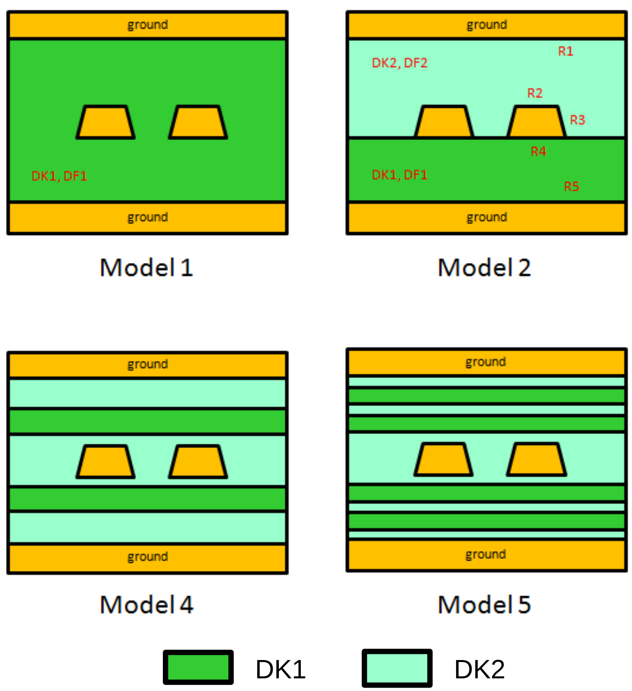
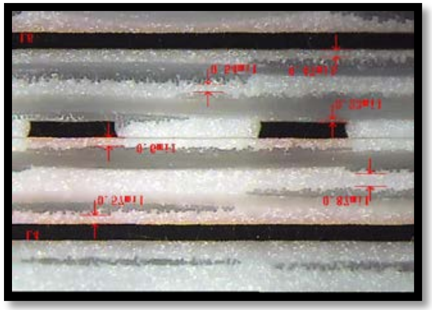
Matching TDT and TDR



Comparison of Models 1 to 5

- Model 1 cannot match FEXT. Models 2 to 5 can match all IL, RL, NEXT, FEXT and TDR/TDT very well.





Model	DK1	DK2
1	3.510	-
2	2.444	4.294
3	3.413	3.623
4	3.863	3.360
5	3.115	3.975

At 10 GHz

DK2>DK1 because of positive-polarity FEXT

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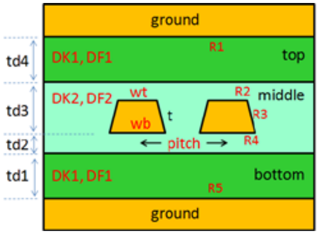
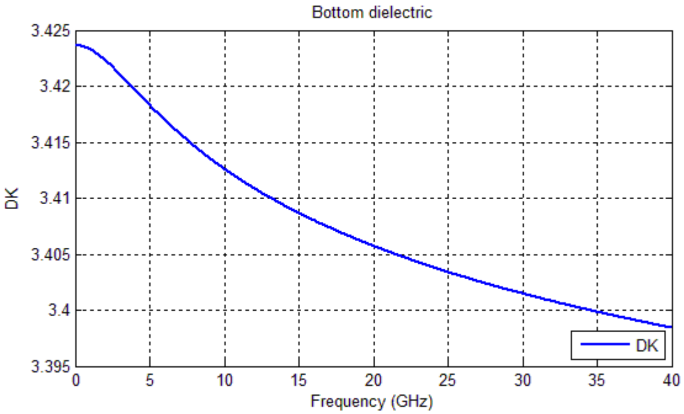
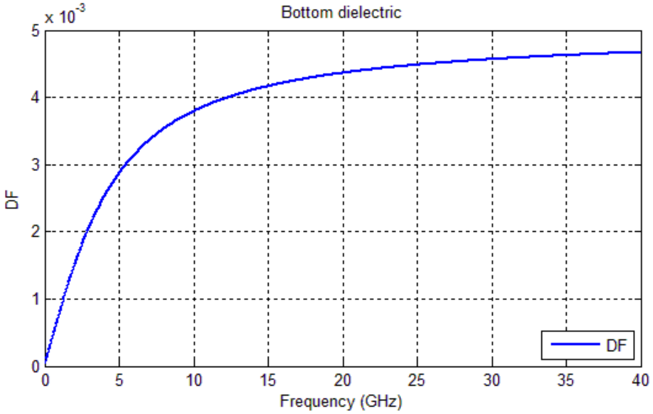
Extracted DK1 and DF1
Model 3



$$\varepsilon_\infty = 3.27929$$
$$\Delta\varepsilon = 0.144348$$
$$m1 = 9.58619$$
$$m2 = 15.4109$$

$$\varepsilon = \varepsilon_\infty + \Delta\varepsilon \cdot \frac{1}{m_2 - m_1} \cdot \log_{10}\left(\frac{10^{m_2} + i \cdot f}{10^{m_1} + i \cdot f}\right)$$
$$= \varepsilon_r \cdot (1 - i \cdot \tan\delta)$$





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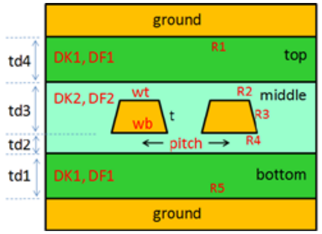
Extracted DK2 and DF2

Model 3



$$\varepsilon_\infty = 3.46724$$

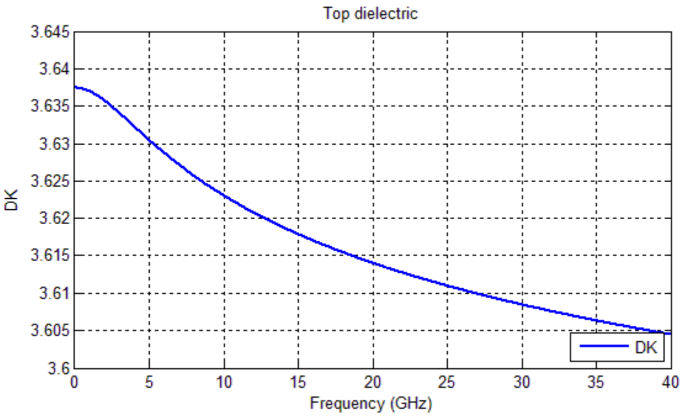
$$\Delta\varepsilon = 0.170196$$

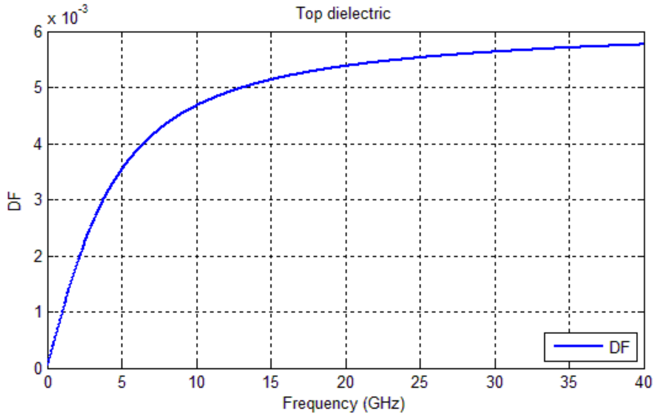
$$m1 = 9.58715$$

$$m2 = 14.8352$$

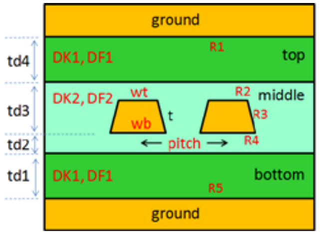
$$\varepsilon = \varepsilon_\infty + \Delta\varepsilon \cdot \frac{1}{m_2 - m_1} \cdot \log_{10}\left(\frac{10^{m_2} + i \cdot f}{10^{m_1} + i \cdot f}\right)$$

$$= \varepsilon_r \cdot (1 - i \cdot \tan\delta)$$



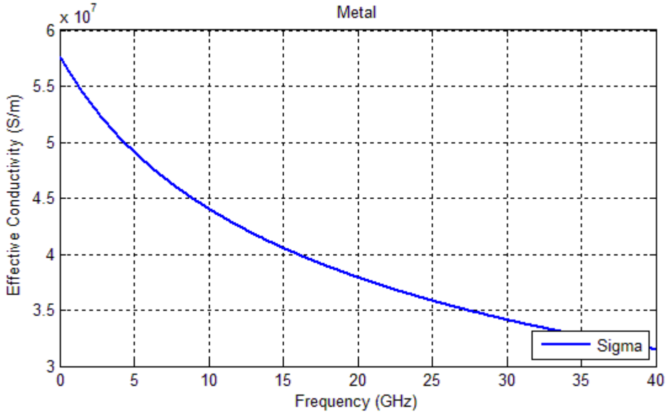


Extracted effective conductivity
Model 3

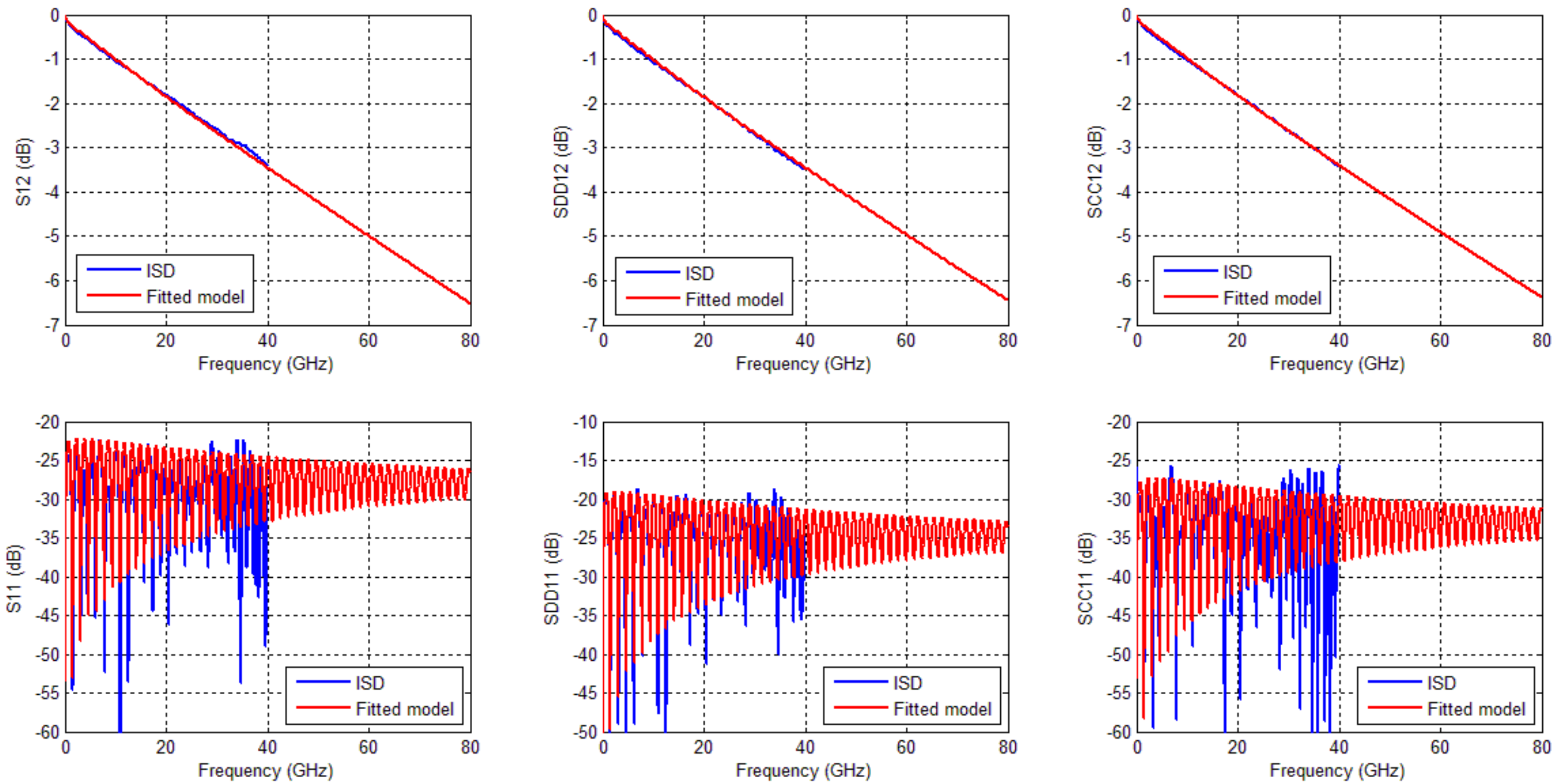


$$\sigma = 5.8\times10^{7}\ \text{S/m}$$

$$R_q = 0.324321\,\mu\text{m}$$



Length- and frequency-scalable models can now be created.



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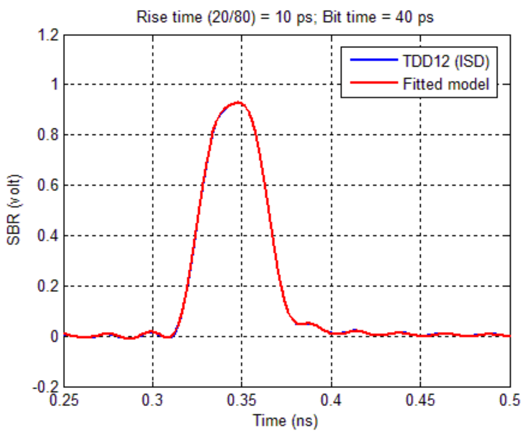
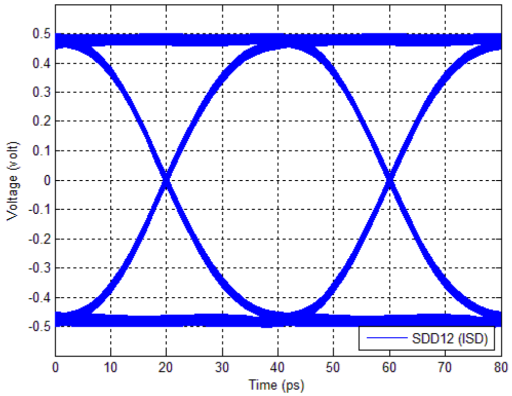
Scalable models are valuable for channel simulation and what-if analysis.

25Gbps, PRBS12

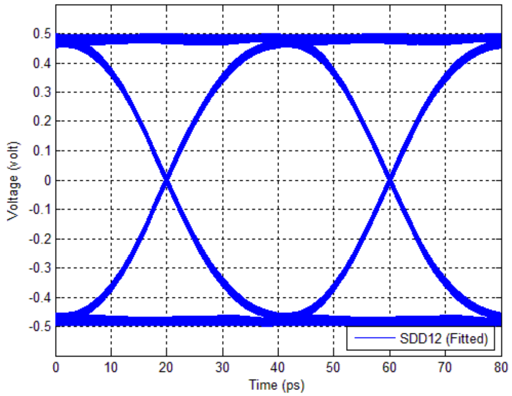


Single-bit response



Measured

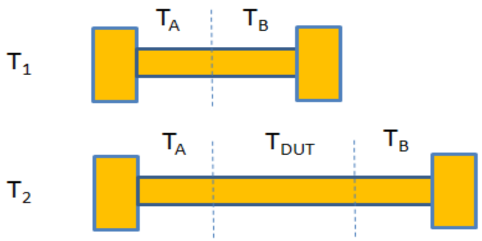
EH=0.904578 volt
EW=39.0764ps



Fitted model

EH=0.91192 volt
EW=39.202 ps

Alternate approach extracts trace-only attenuation from eigenvalue.



$$T_1 = T_A \cdot T_B$$

$$T_2 = T_A \cdot T_{DUT} \cdot T_B$$

$$\Rightarrow \quad T_2 \cdot T_1^{-1} = T_A \cdot T_{DUT} \cdot T_A^{-1}$$

For uniform transmission line:

$$T_{DUT} = P \cdot \begin{pmatrix} e^{-\gamma l} & 0 \\ 0 & e^{+\gamma l} \end{pmatrix} \cdot P^{-1}$$

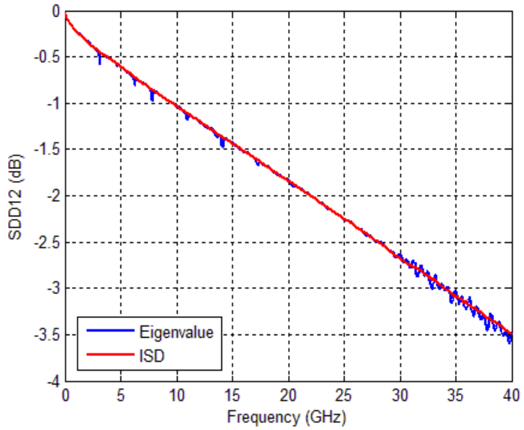
Let $T_2 \cdot T_1^{-1} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$

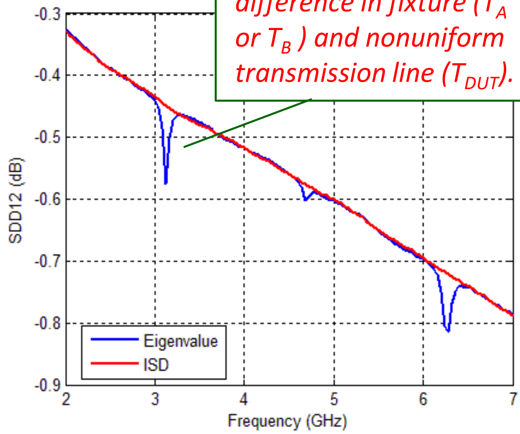
$$\Rightarrow \quad e^{-\gamma l} = \frac{(a+d) \pm \sqrt{(a-d)^2 + 4bc}}{2}$$

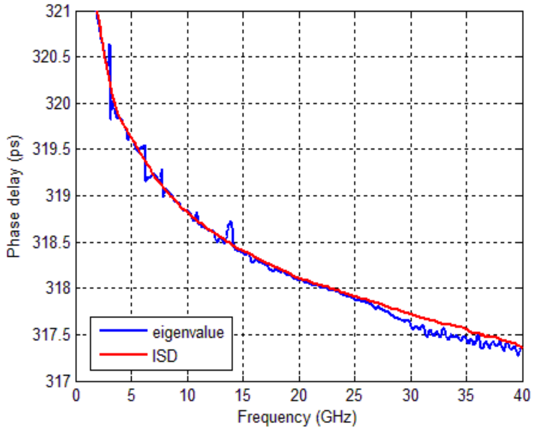
eigenvalue

modal propagation constant

Spikes are due to difference in fixture (T_A or T_B) and nonuniform transmission line (T_{DUT}).







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MPX vs. eigenvalue

- Alternate approach matches eigenvalue with 2D solver for material property extraction.

	MPX	eigenvalue
De-embedding	True de-embedding (with ISD)	Not de-embedding
	IL, RL, NEXT, FEXT are extracted	No RL or NEXT
	Fixtures can be different	Assume fixtures are identical; Extracted data are prone to glitches
	DUT can be arbitrary	Assume trace is uniform
Generated models	Match all IL, RL, NEXT, FEXT, DDIL, DDRL, CCIL, CCRL, TDR, TDT	Match propagation constant only
	Self consistent	Necessary but not sufficient condition
	Models match original data	Models may not match original data
	Two lines can be asymmetric	Two lines must be symmetric

No RL

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Summary

- Material Property Extractor (MPX) automates PCB material property extraction (DK, DF, roughness) into one mouse click.
- Accurate de-embedding is crucial.
- In-Situ De-embedding (ISD) avoids causality error when 2x thru coupon and fixture have different impedance.
- MPX creates self-consistent models by matching all IL, RL, NEXT, FEXT, TDR and TDT.
- MPX creates scalable models that are valuable for channel simulation and what-if analysis.