

Advanced SI Design Kit (ADK)

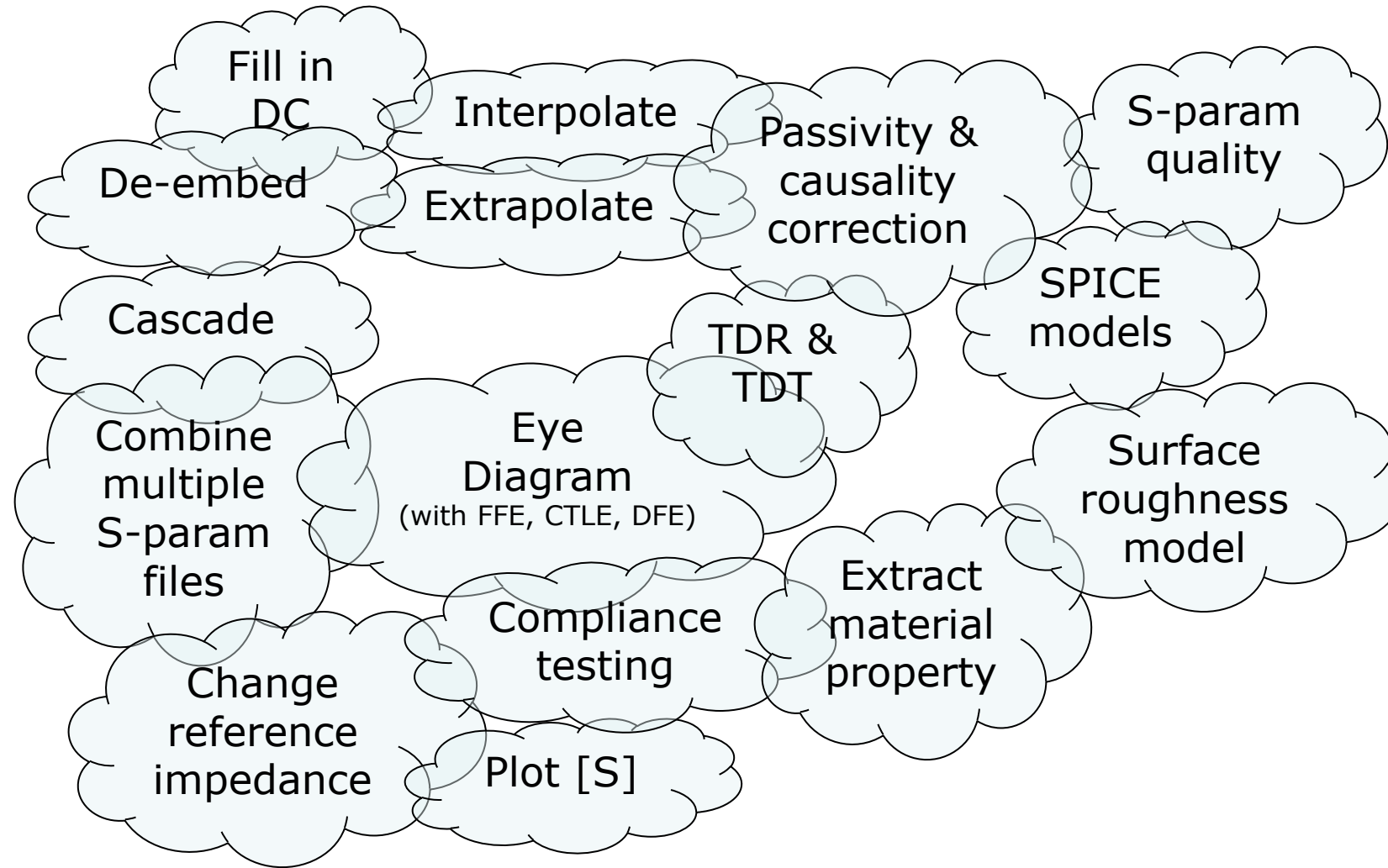
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huang@ataitec.com

July 9, 2022

Outline

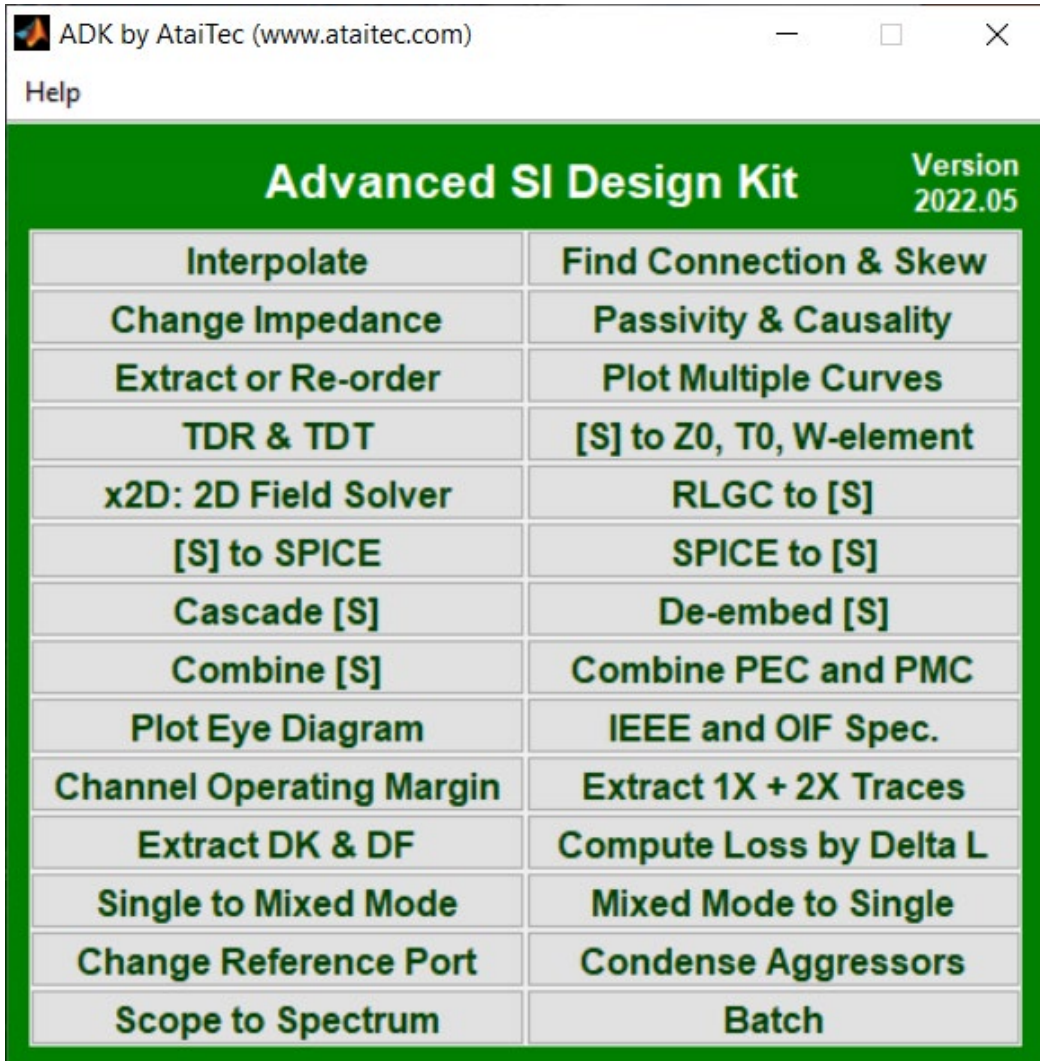
- Can SI tools be made like mobile apps?
- Advanced SI Design Kit (ADK)
 - Many mobile-apps-like SI tools in one place: causality correction, eye diagrams, TDR/TDT, compliance testing, DK/DF extraction, Delta L, Channel Operating Margin (COM), ...
 - Complex SI operations in ~ 3 mouse clicks.
 - Significantly increase productivity.
- Advanced 2D solver (X2D2)
 - Model DK, DF and roughness.

If it takes more than 5 seconds to do any of these, it is too long...



Advanced SI Design Kits (ADK)

Many mobile-apps-like SI tools in one place



- Complex SI operations, from causality correction to eye diagrams, TDR/TDT, compliance testing, DK/DF extraction, Channel Operating Margin, ... in a few mouse clicks.
- Everything you want to do with S parameters in one place.
- Increase productivity.

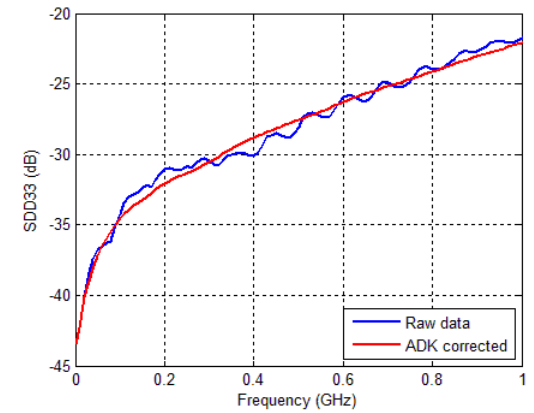
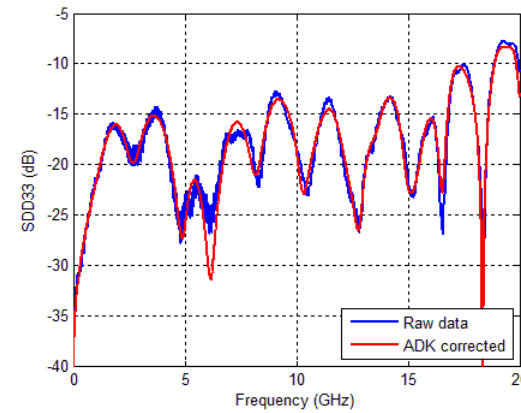
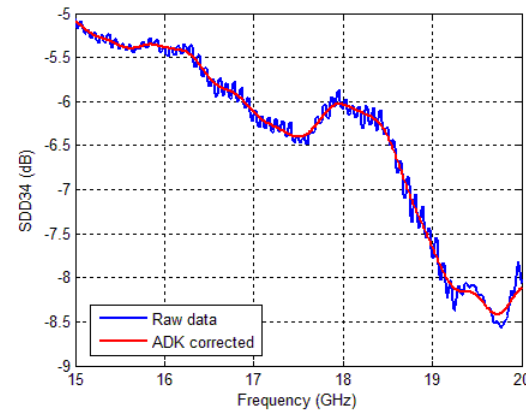
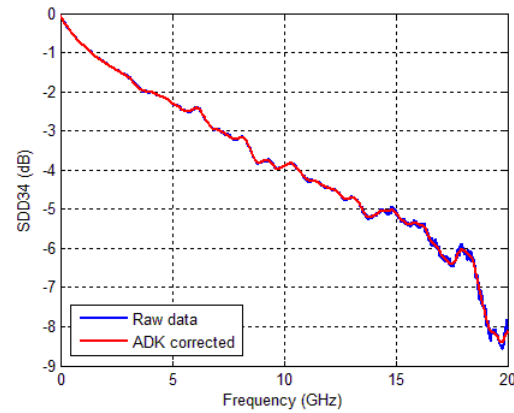
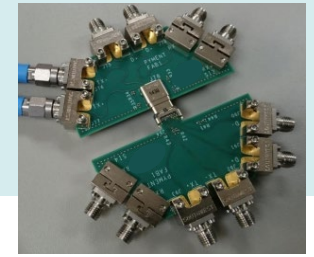
Passivity & causality correction

The only tool that can correct measurement error

The screenshot shows a software window titled 'Correct Passivity & Causality by AtaiTec (www.ataitec.com)'. The interface has a green background with white and yellow text. At the top, it says 'Correct Passivity & Causality'. Below this, there's a section 'Select Input Touchstone File' with a 'Browse ...' button and a text field containing 'D:\USD_Examples\USB_Type_C\total_typeC.s8p'. The main area is divided into several sections: 'Correct [S] at DC' with two radio buttons: 'Set DC resistance for point-to-point net' (selected) and 'Set DC by resistive circuit file'. The first option has input fields for 'Signals: 0.05 Ohm' and 'Ground: 0 Ohm'. The second option has a 'Browse ...' button. Below these are two more radio buttons: 'Extrapolate [S] at DC' and 'Use original value'. To the right of the 'Correct [S] at DC' section are two checkboxes: 'Reciprocal' and 'Passive', both checked. Further right is a 'Causal' section with a dropdown menu set to 'Smoother' and a checked checkbox for 'Kramers-Kronig'. Below these is a 'Port Connection' section with three radio buttons: 'Default' (selected), 'IN: 1, 2, 3, ...; OUT: n+1, n+2, n+3, ...', and 'IN: 1, 3, 5, ...; OUT: 2, 4, 6, ...'. At the bottom left is a 'Reverse polarity' section with a 'Port number' input field. At the bottom right are a checked checkbox for 'Plot figures' and a 'Run' button.

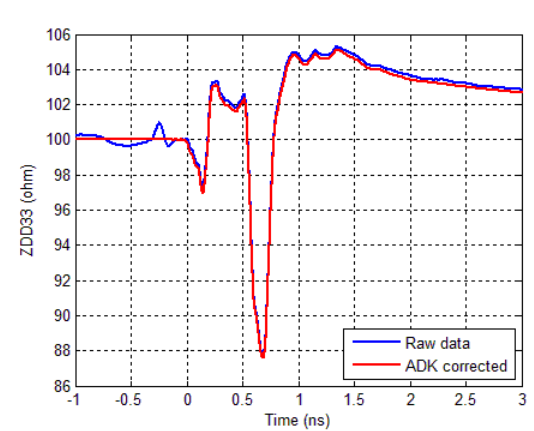
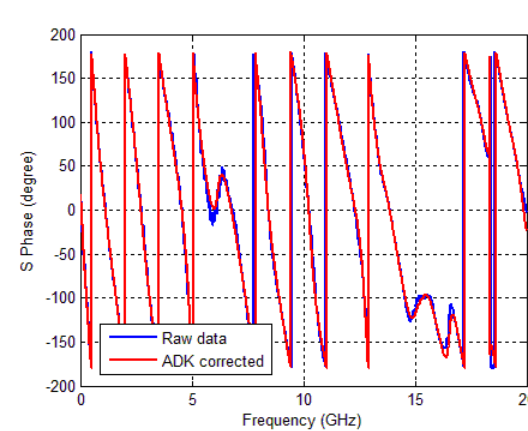
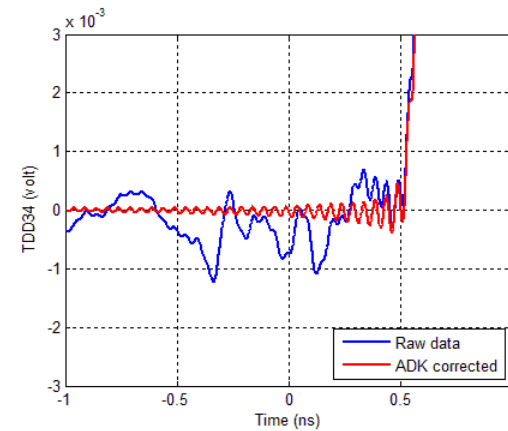
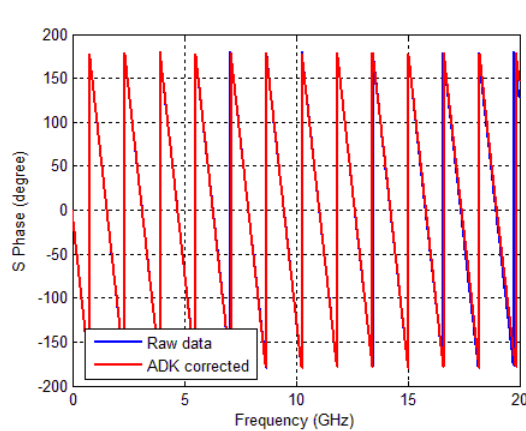
- Proprietary algorithm to smooth S-param magnitude and phase and correct causality error for any noisy data.
- Popular vector-fitting method can only correct small error for simulation data.
- Multiple ways to fill in DC data.

USB Type-C raw measurement



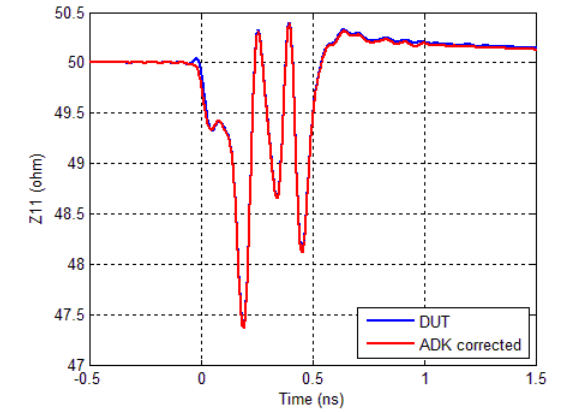
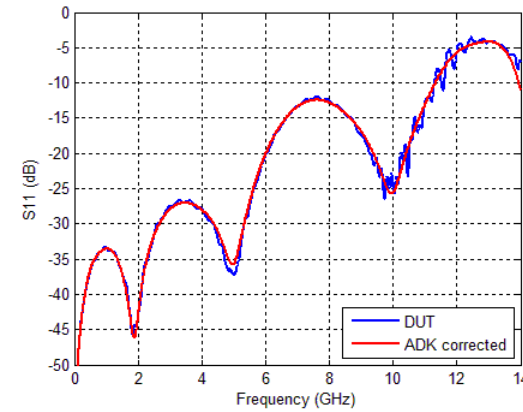
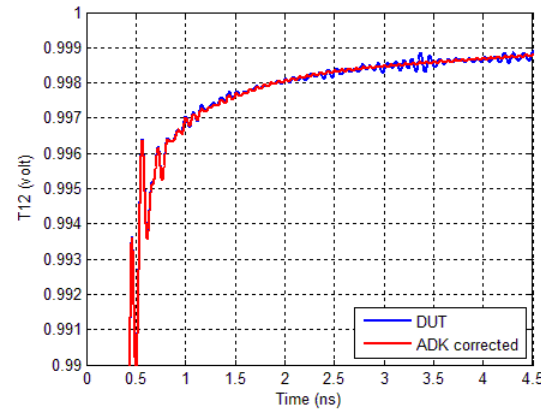
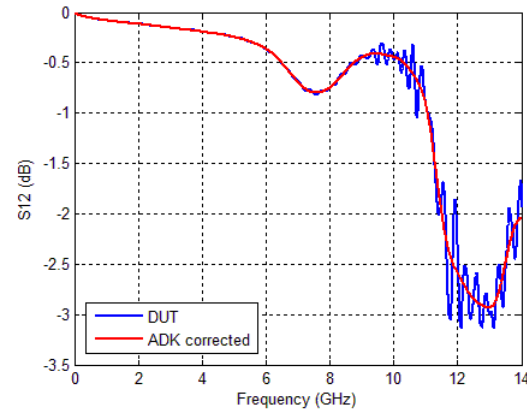
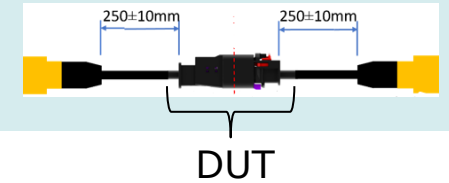
Insertion loss

Return loss



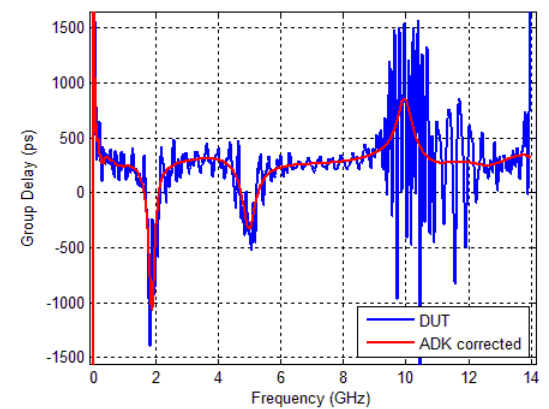
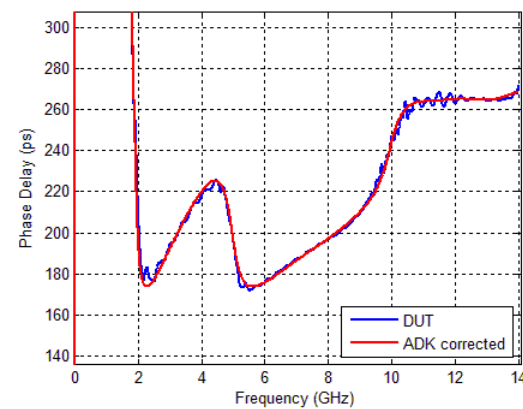
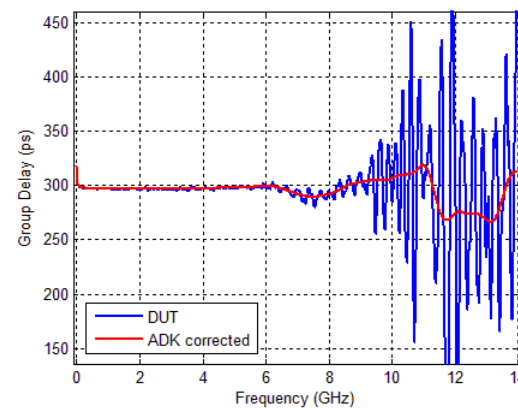
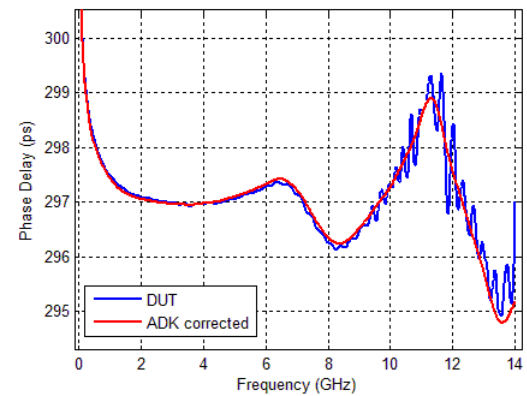
Rise time (20/80) = 50ps

SAE/USCAR-49 inline connector



Insertion loss

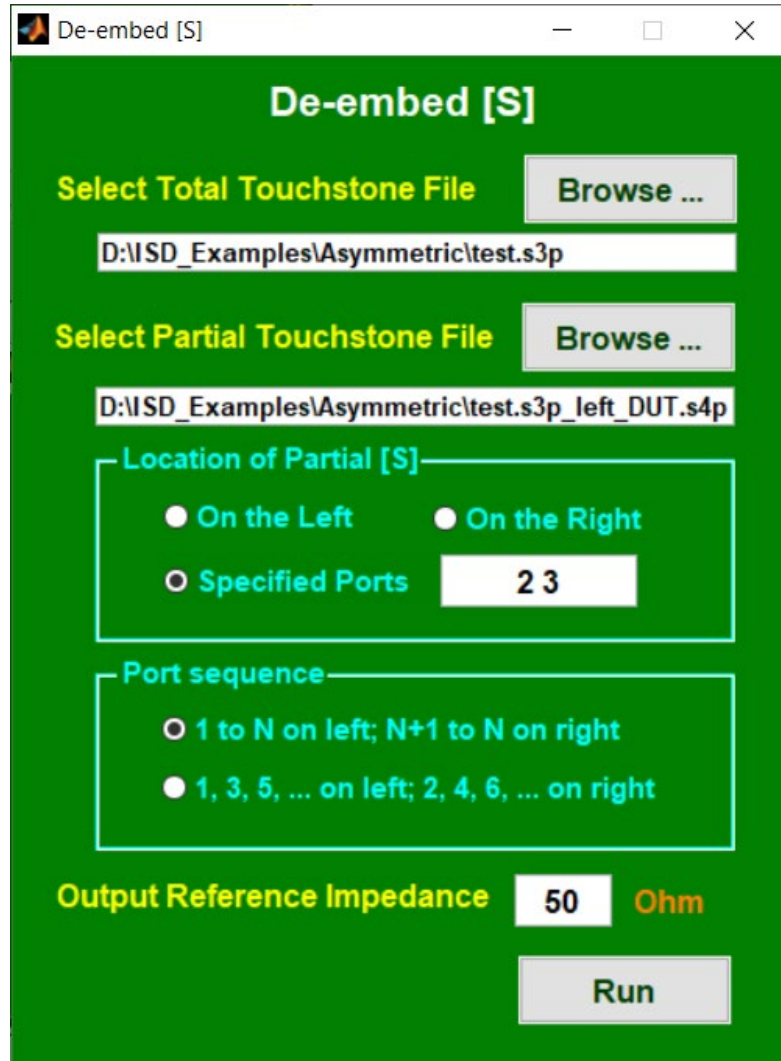
Return loss



Rise time (20/80) = 50ps

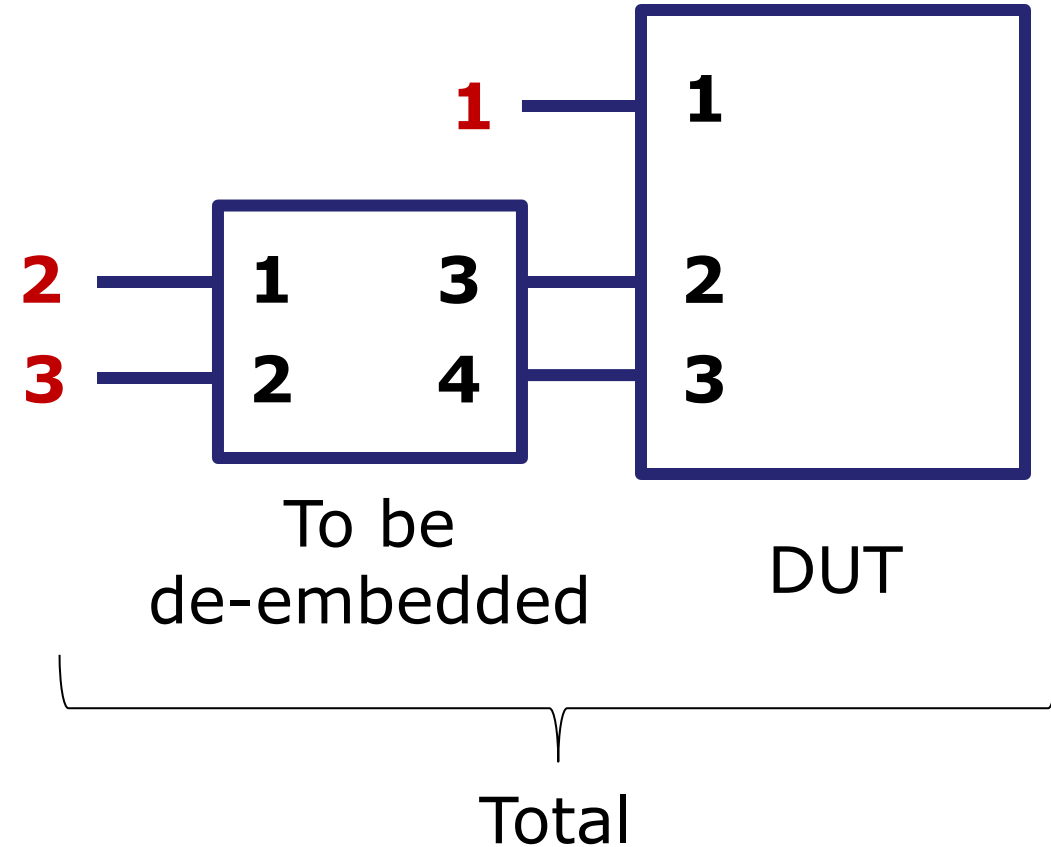
De-embed [S]

The only tool that can de-embed arbitrary N ports from M ports



The screenshot shows the 'De-embed [S]' software window. It has a green background and contains the following fields and controls:

- Select Total Touchstone File:** A text box containing 'D:\ISD_Examples\Asymmetric\test.s3p' and a 'Browse ...' button.
- Select Partial Touchstone File:** A text box containing 'D:\ISD_Examples\Asymmetric\test.s3p_left_DUT.s4p' and a 'Browse ...' button.
- Location of Partial [S]:** A section with three radio buttons: 'On the Left', 'On the Right', and 'Specified Ports'. The 'Specified Ports' option is selected.
- Specified Ports:** A text box containing '2 3'.
- Port sequence:** A section with two radio buttons: '1 to N on left; N+1 to N on right' and '1, 3, 5, ... on left; 2, 4, 6, ... on right'. The second option is selected.
- Output Reference Impedance:** A text box containing '50' and the label 'Ohm'.
- Run:** A button at the bottom right.



Robust DK/DF/SR extraction

Extract DK, DF and Roughness

Tools

☐ Trace only
☒ Delta L

Touchstone File (Trace only) J:\USD_Examples\DK_DF_Extraction\Stripline_7in.s4p_DUT.s4p

Stripline (Homogeneous)

Length = 2 inch
From 0 to 100 GHz

Cross section (in mil)

td1	4	td2	4.7
tm	0.7	pitch	10.910
wt	4.349	wb	4.349

☐ Fixed
☐ Thickness ☒ Width ☐ All

* Optimized

Roughness (Rq)

Top ground	0	um
Signal	0.3321	0.3 um
Bottom ground	0	um
Sigma	5.8e7	S/m

☐ Fixed Rq

☒ Create new Touchstone file

Length 2 inch
Minimum Frequency 0 GHz
Maximum Frequency 50 GHz
Number of Points 501

☐ Linear ☒ Log

Reference Impedance 50 Ohm

DK & DF at 1 GHz

DK	3.498	DF	0.000132
M1	10.504	M2	13.085

☐ Auto de-skew

☐ Fixed M1, M2

Updated after extraction

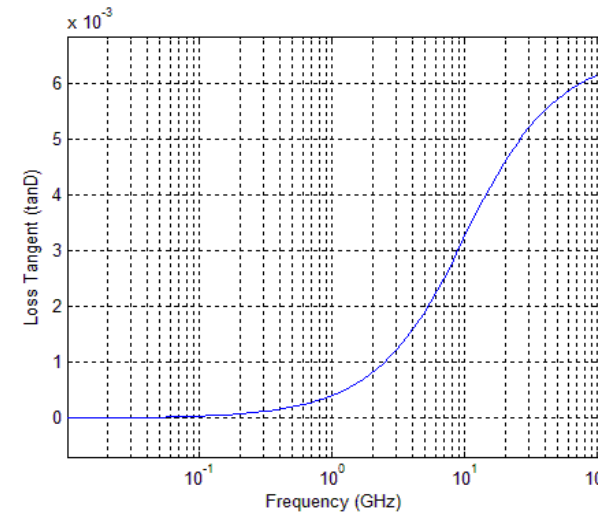
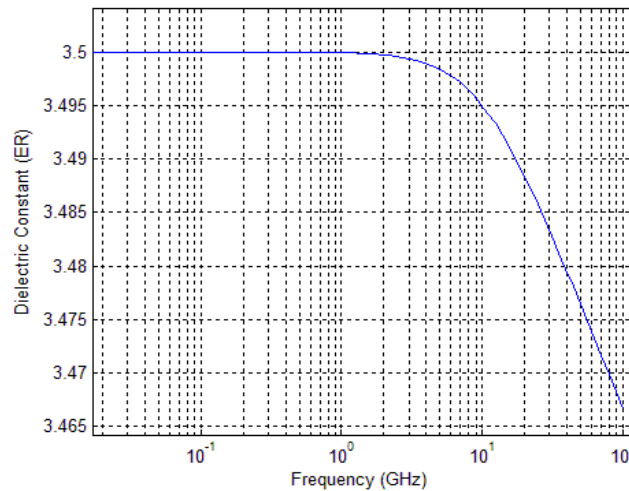
- Interactive GUI
- Multiple templates
- Different roughness for each surface
- Simulate directly
- Huray model conversion
- Compatible HFSS models

Causal dielectric model

- Wideband Debye (or Djordjevic-Sarkar) model

- Need only four variables: ε_∞ , $\Delta\varepsilon$, m_1 , m_2

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



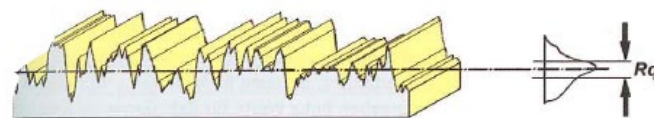
$$\varepsilon_\infty = 3.35 \text{ , } \Delta\varepsilon = 0.15 \text{ , } m_1 = 10 \text{ , } m_2 = 14.5$$

Surface roughness model

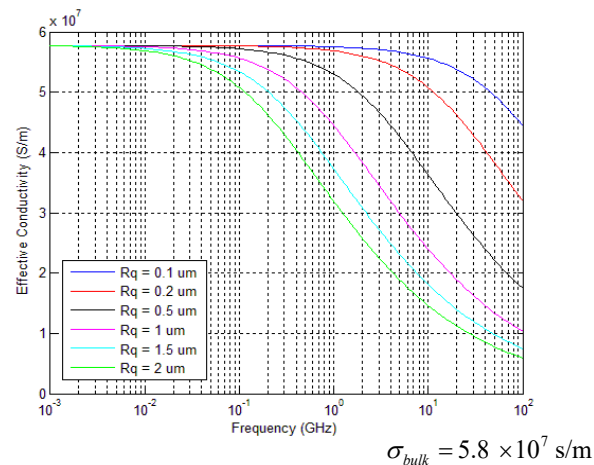
- Effective conductivity (by G. Gold & K. Helmreich at DesignCon 2014) needs only two variables: σ_{bulk} , R_q

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_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 σ_{eff}



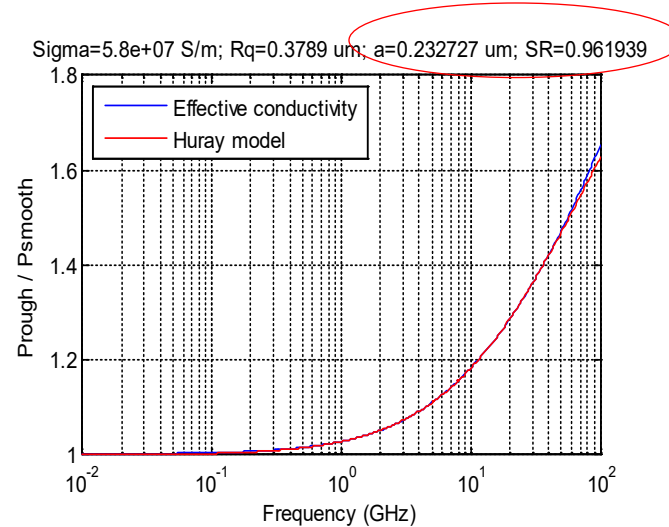
- ❖ Simple
- ❖ Work well with field solver
- ❖ Give effect of roughness on all IL, RL, NEXT and FEXT

Convert effective conductivity to Huray model

- Huray model

$$\frac{P_{rough}}{P_{smooth}} \approx 1 + \frac{3}{2} \cdot SR \cdot \left(\frac{1}{1 + \frac{\delta(f)}{a} + \frac{1}{2} \left(\frac{\delta(f)}{a} \right)^2} \right)$$
$$\delta(f) = \sqrt{\frac{1}{\pi f \mu \sigma}} \quad ; \quad a = \text{radius} \quad ; \quad SR = \text{surface ratio}$$

- Curvefit Prough / Psmooth to convert σ_{bulk} , R_q to a , SR



Compute loss by Delta L

Compute Loss by Delta L

Touchstone Files

Select number of files: 4

	File Name	Length (in)
L1	Browse ... Examples\Delta_L\PCB_2in.s4p	2
L2	Browse ... Examples\Delta_L\PCB_3in.s4p	3
L3	Browse ... Examples\Delta_L\PCB_5in.s4p	5
L4	Browse ... Examples\Delta_L\PCB_7in.s4p	7

Figure Property (Optional)

Xmin	Xmax	Ymin	Ymax
		0	2
Xsize (in)	Ysize (in)	X label	Y label

Legend (sep'd by ;)

Figure title

Line color: brkmcg Font size: 10

Line width: 2

Cutoff frequency: ☐ Auto select ☒ 100 GHz

Put marker at: 4 8 12.89 16 GHz

Fit curve: Bottom

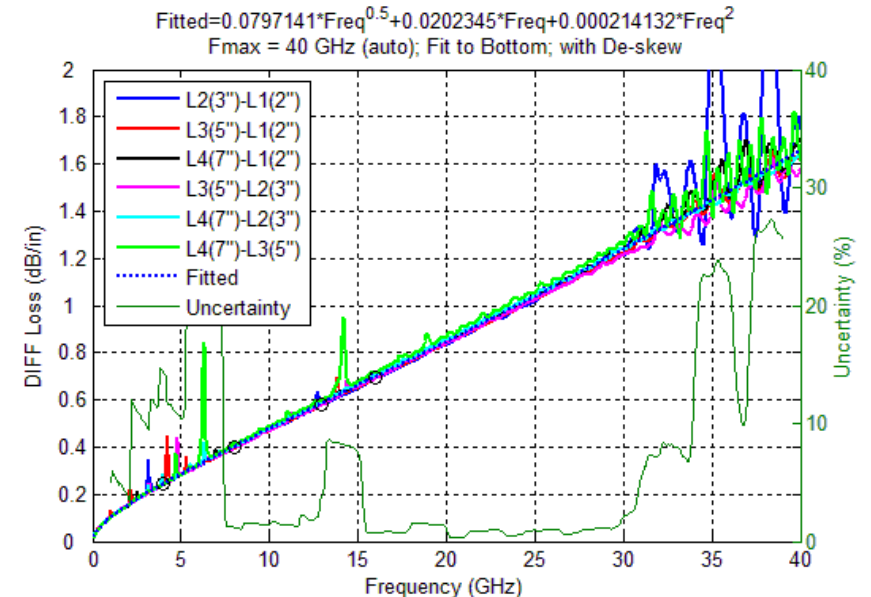
☒ Plot uncertainty

☒ Raw ☒ After ISD

☒ Auto De-skew

Run

- Curvefitted equation for loss per inch with uncertainty
- Auto de-skew
- Fit data to bottom, middle or top



[S] to TDR & TDT

Convert [S] into TDR & TDT

Find min/max

Select Input Touchstone File

D:\USD_Examples\USB_Type_C\total_typeC.s8p

Select curves

☐ All
☒ Port indices

Single-ended
☐ Differential mode
☐ Common mode

Port sequence

☐ 1, 2 to N+1, N+2
☐ 1, 3, ... to 2, 4, ...
☐ Default

Input Waveform before Filter

☐ Step ☐ Single-bit ☐ Impulse

Rise Time (20% to 80%) 41.4448 ps
Total Time 5 ns
Resolution 2 ps
Delay 0 ns

Filter

Bandwidth 6.3337 GHz

☐ Butterworth filter
Roll-off at -20 dB/dec
☐ Brickwall filter

Desired Outputs

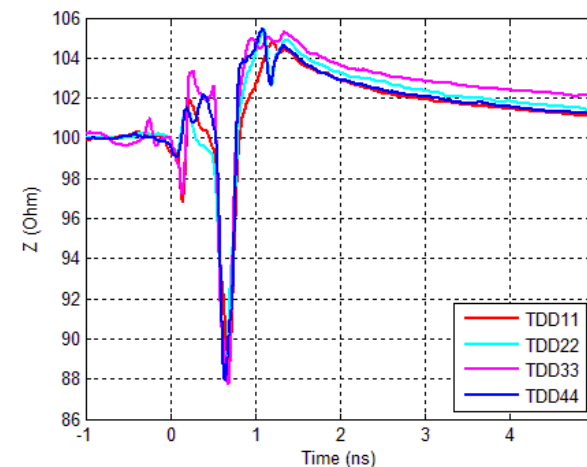
☐ Impedance Profile
☐ TDR with Open Termination
☐ TDR & TDT with Matched Termination

After filter:

Rise time (20/80) = 50 ps
Rise time (10/90) = 72.7041 ps

☒ Plot figures

- Built-in filter & IFFT.
- Single-ended, differential or common mode.
- Step, single-bit or impulse response.
- Correlated with TDR equipment.



Robust S-param and TDR/TDT viewer

- Add math expression, spec curves, figure title/legend.
- Display delay or DK, VSWR, Smith Chart.
- Reset impedance.
- Flexible port index.

Plot Multiple [S] Curves

Touchstone or TDR Input Files

Select number of curves to plot: 2

File Name	[S] Indices
or\TRL_DUT_mezz_conn.s4p.out	1 1
tal_mezz_conn.s4p_DUT.s4p.out	1 1

Figure Property (Optional)

Xmin	Xmax	Ymin	Ymax
-1	2		

Xsize (in)	Ysize (in)	X label	Y label
		Time (ns)	ID11 (ohm)

Math expression:

Spec curve (in x1 y1 x2 y2 ...):

Legend (sep'd by ;):

Figure title:

Line color: Font size:

Line width:

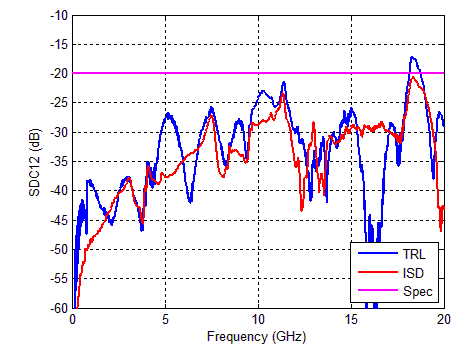
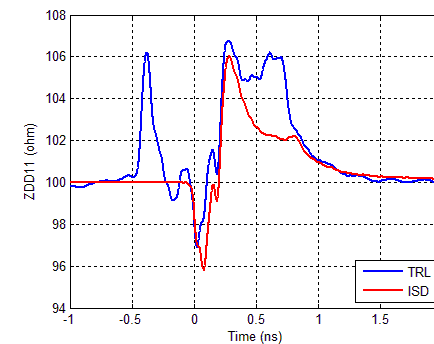
Plot

☐ S ☐ Z ☐ Y ☐ L ☐ vswr ☐ Smith

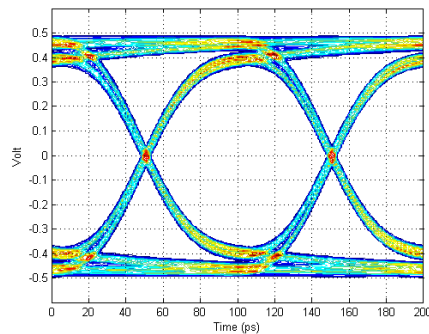
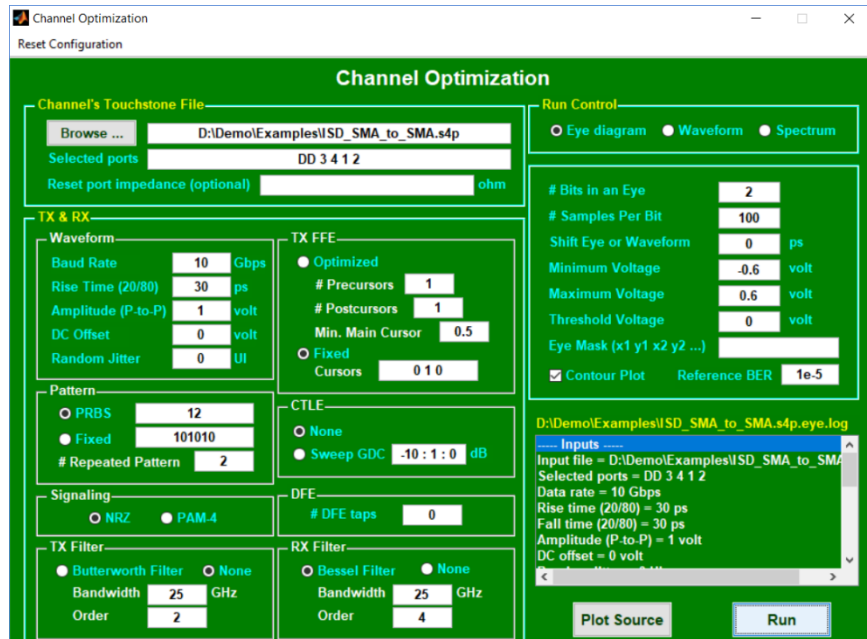
☐ Phase angle ☐ Log(f)

☐ Phase delay ☐ Reset Zref to

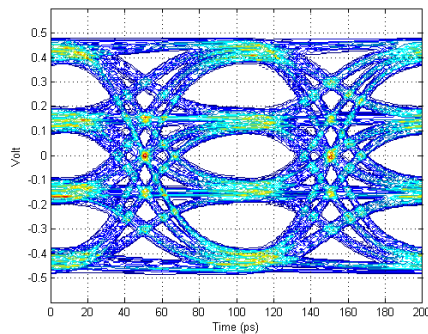
☐ Group delay



Plot eye diagram



NRZ



PAM4

- [S] to eye diagram, waveform or spectrum.
- Single-ended, differential or mixed-mode.
- With or without NEXT and FEXT.
- With or without TX FFE, RX CTLE and DFE.
- Fixed or PRBS patterns.
- NRZ or PAM4

IEEE, OIF and PCIe Spec.

- Compare IL, RL, crosstalk, ICR, ICN, ccICN with various compliance spec.

IEEE and OIF Spec.

Reset Configuration

Select Input Touchstone File

D:\ISD_Examples\PCle5.0\allTest_DUT_Z42p5.s28p

☒ Convert to Differential Signals

Number of Crosstalk Curves

[S] Indices for crosstalk

Curve 1	3 2
Curve 2	3 6
Curve 3	3 8

Select a standard

PCle 5.0

Baud Rate Gsym/s

Rise Time ps

ccICN

☒ kxa from dB to dB

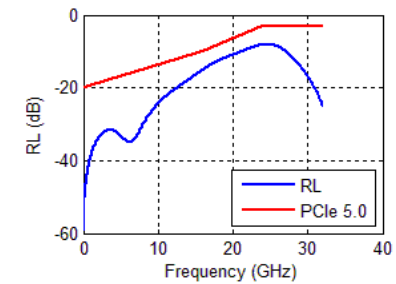
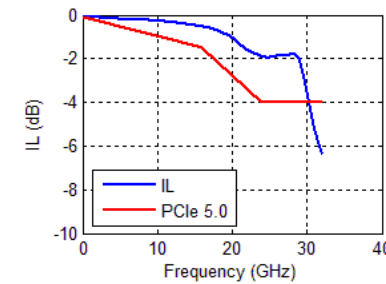
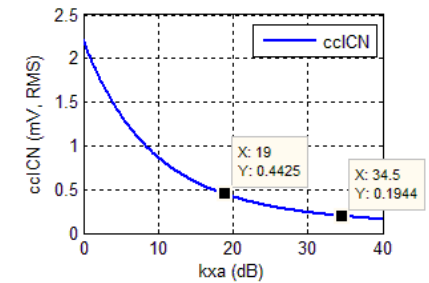
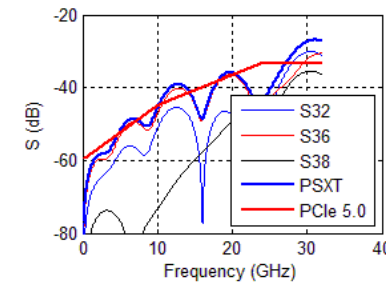
Place marker at kxa = dB

App = mV fmin0 = MHz

fmax0 = GHz

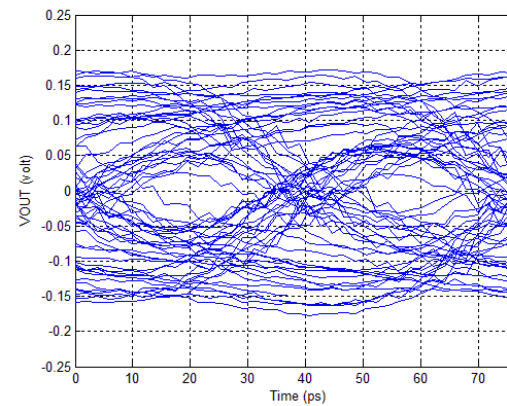
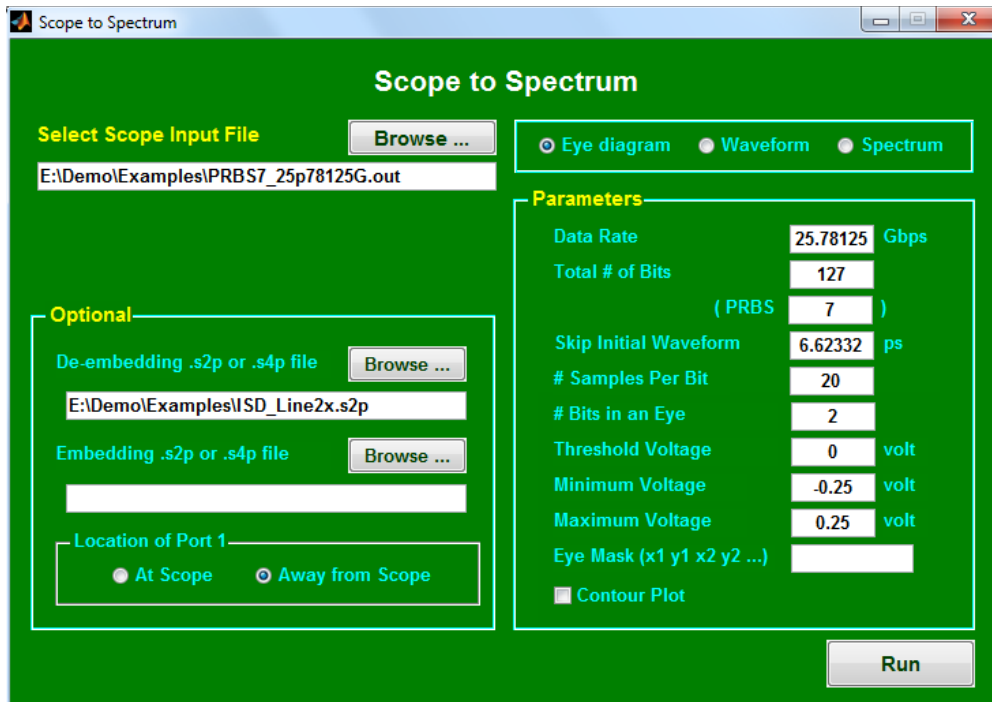
Insertion loss index

Return loss index

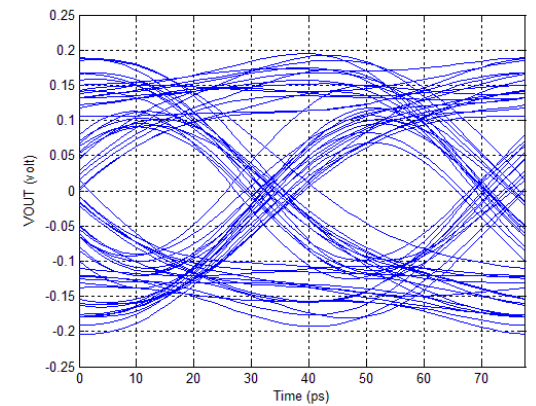


Scope embedding & de-embedding

- Plot scope data in waveform, eye diagram or spectrum.
- Embed and/or de-embed [S] from scope data.

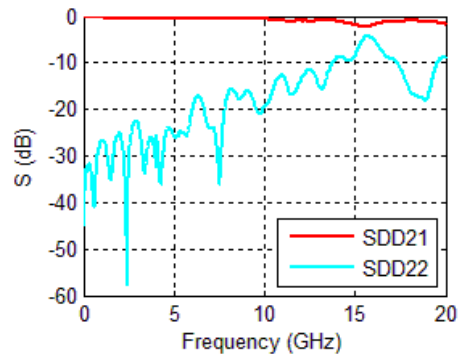
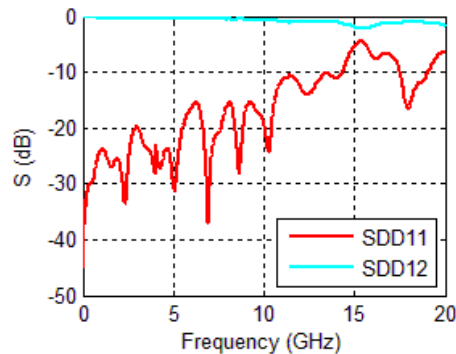
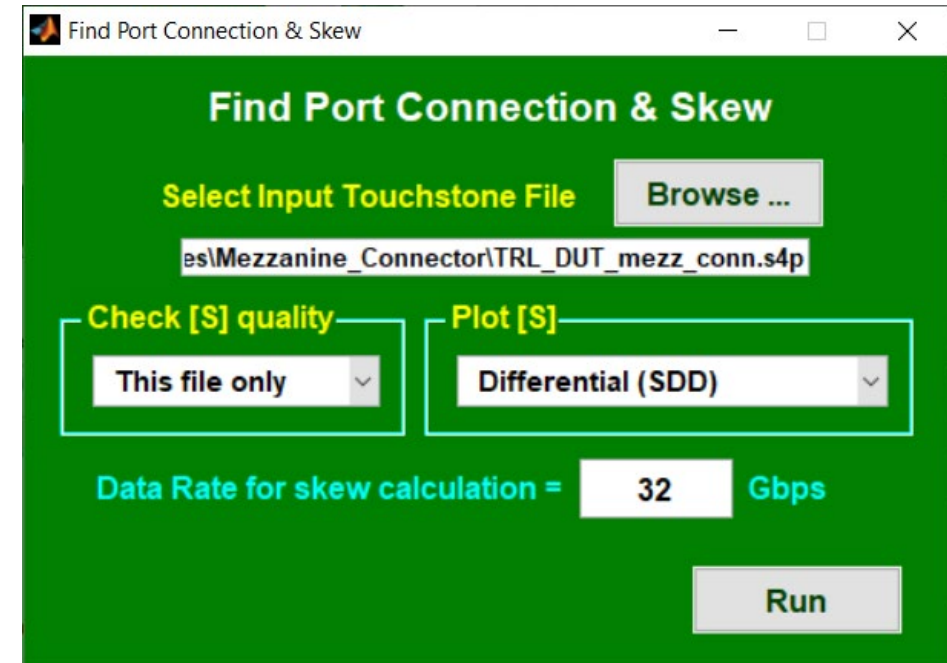


Original



After de-embedding

Find connection

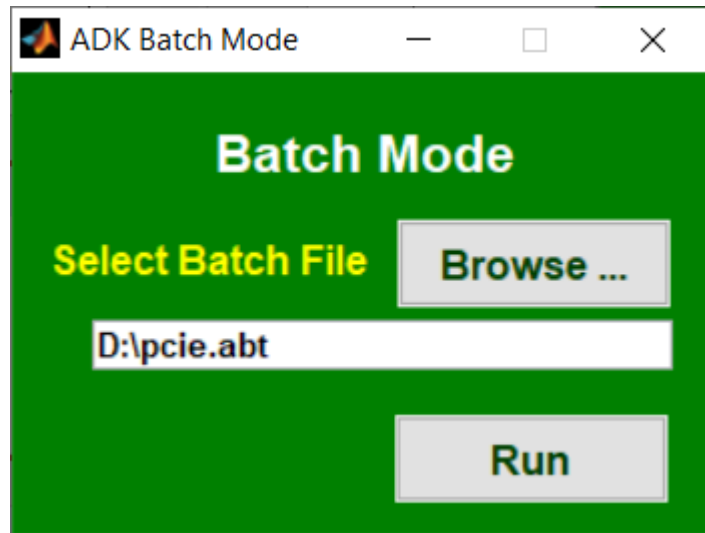


- Quickly examine [S].
- Identify from-to connection.
- Compute quality metrics.
- Compute delay and skew.

```
File name: D:\ISD_Examples\Mezzanine_Connector\TRL_DUT_mezz_conn.s4p
Total 800 points from 0.025 GHz to 20 GHz with 50 ohm Zref.
Reciprocity metric = 99.04 %
Passivity metric = 92.90 %
Causality metric = 62.48 %
Causality metric for each S(i,j):
67.44 84.47 64.01 89.27
86.39 73.68 89.13 62.48
63.05 88.40 67.03 92.20
89.08 66.11 92.36 70.97
From-To Connections:
Port 1 -> 3
Port 2 -> 4
Data rate set to 32 Gbps --
L1: Median phase delay (1 to 3) = 132.159 ps
L2: Median phase delay (2 to 4) = 131.107 ps
Median skew (L1-L2) = 0.974904 ps
Effective Intra-pair skew (EIPS: L1-L2) = 0.9157 ps
```

Batch mode

- Run multiple jobs through batch file in GUI or command line.
- Most ADK functions are available through batch file.



"C:\Program Files (x86)\AtaiTec\ADK\adk2.exe" adkc D:\pcie.abt

```
# standard
infile D:\PCIECEM5\allTest.s28p_Z42p5.s28p_DUT.s28p
spec_no 7
differential 1
ccicn 1
il 3 4
rl 3 3
xtalk 3 2
xtalk 3 6
xtalk 3 8
figure_tag ccICN_FEXT
csv_tag ccICN_FEXT

# passive
infile D:\Demo\examples\ISD_SMA_to_SMA.s4p
symmetric 0
causal 0
plot 0
dc_method 1
resistance 0.05

# s2mix
infile D:\Demo\examples\ISD_SMA_to_SMA.s4p_pass.s4p
mixed 1
order 0
```

X2D2

Advanced 2D solver for surface roughness modeling

- Accurate 2D BEM field solver with causal dielectric and effective-conductivity surface roughness models.
- Compute impedance, RLGC matrices and S parameters.
- Create Touchstone file and tabular W-element model

The screenshot displays the X2D2 software interface, titled "X2D2: The 2D Field Solver with Surface Roughness". The interface is divided into several panels, each with a red box and a label:

- Material property**: A table for Dielectric Property with columns Mat ID, Er, tanD, and Sigma (S/m).

Mat ID	Er	tanD	Sigma (S/m)
1	1	0	0
2	3.49	3.51	0
3	3.51	0.001	0
- Stackup**: A panel for Dielectric properties with fields for Number of Layers (1), Thickness (0.178), Layer 1 Mat ID (31), and Top (0.114, 31).
- Conductor**: A panel for Conductor properties with a table for # Conductors, Thickness, Top Width, Bottom Width, Spacing, x Offset, and Mat ID.

# Conductors	Thickness	Top Width	Bottom Width	Spacing	x Offset	Mat ID
Bottom Ground	0.7					54
Metal 1	2	0.014	0.1164	0.115	0.1456	0
						54

Other visible panels include Metal Property, Causal Dielectric Property, Run Control, and Unit settings.