

# SI modeling tools that you can use everyday

---

**Ching-Chao Huang**

**AtaiTec Corp.**

***huang@ataitec.com***

***www.ataitec.com***

# Outline

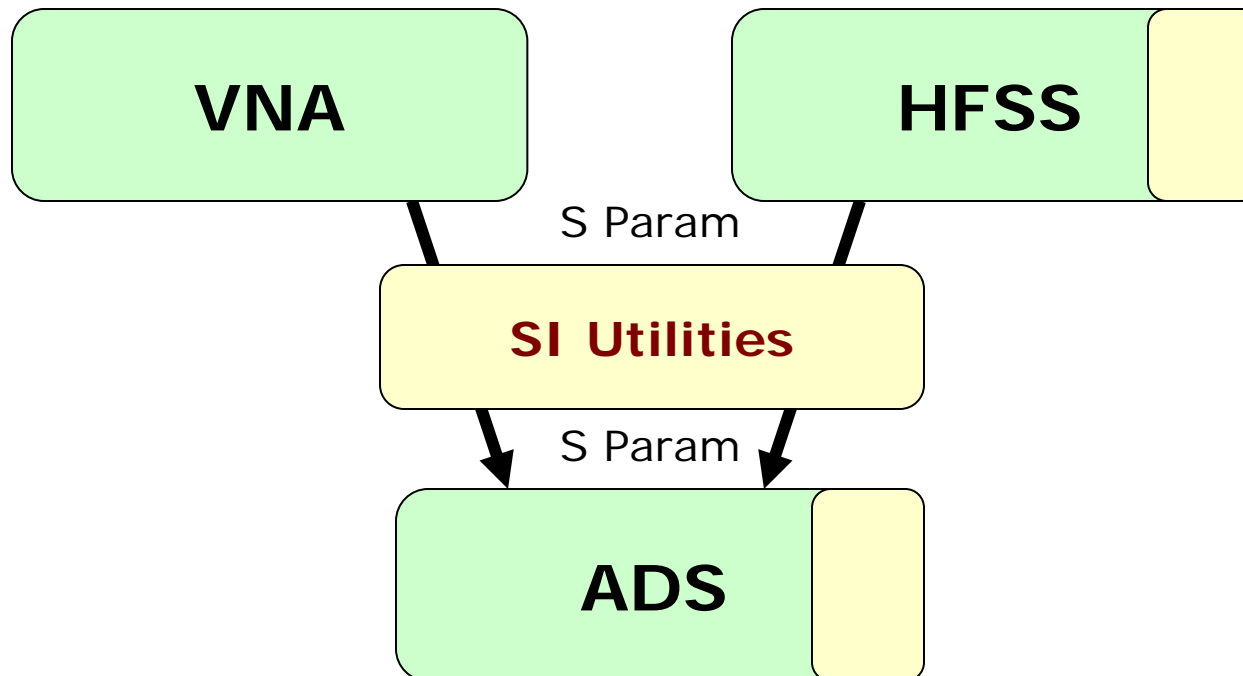
---

- **SI tool box**
  - [S] to [S]
  - [S] to ?
  - ? To [S]
  - 2D solver
- **3D fast solver**

# SI Modeling & Simulation

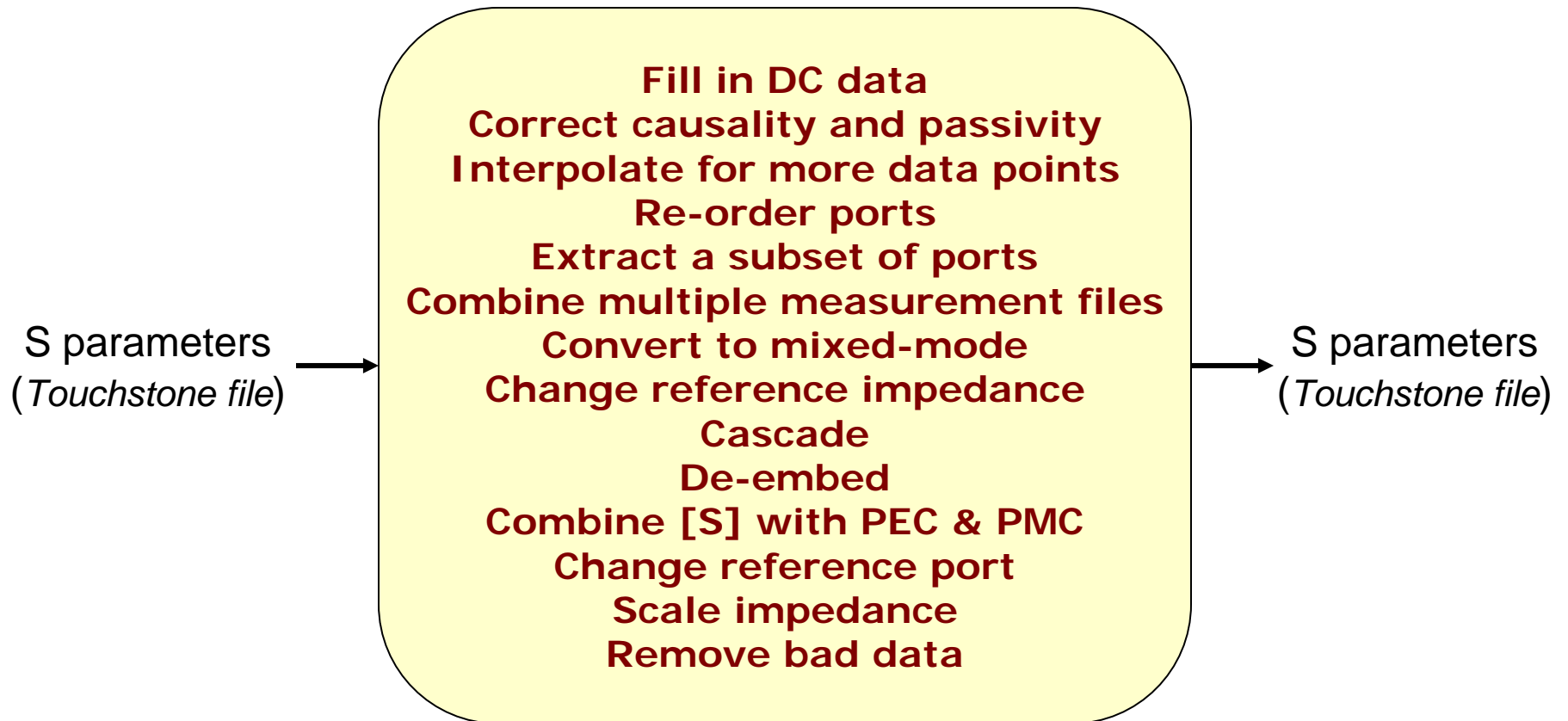
---

- There are more than 20 ways to process S parameters.



# From [S] to [S]

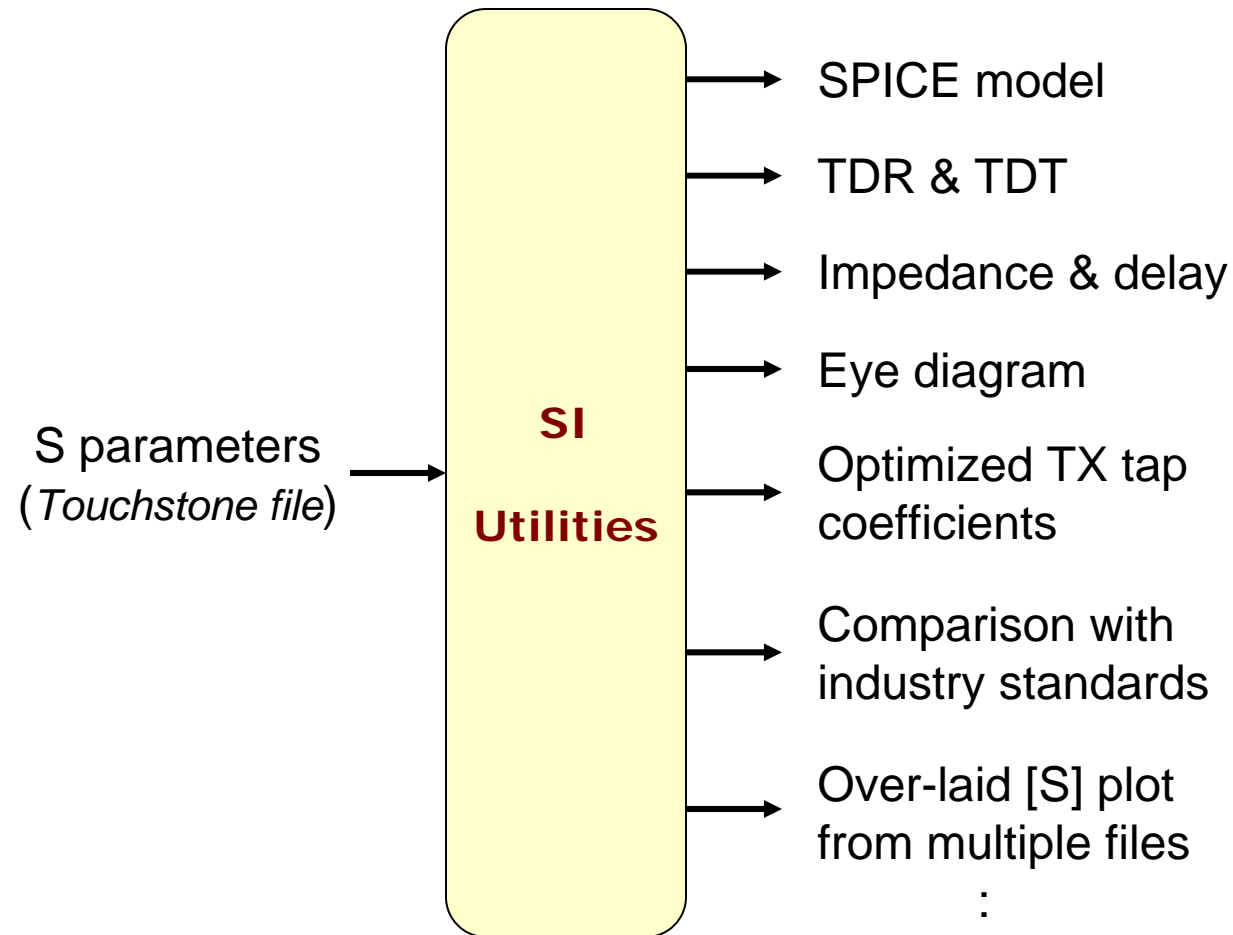
---



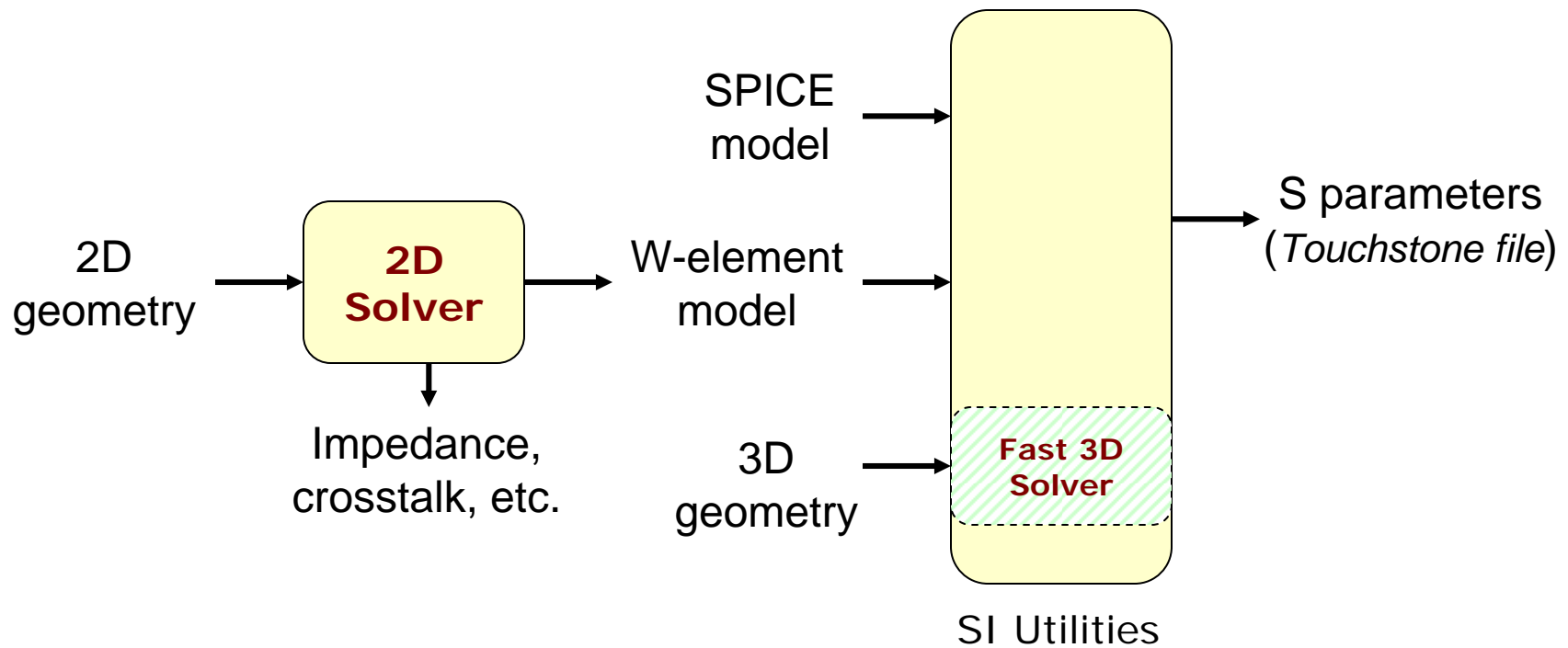
SI Utilities

# From [S] to ?

---

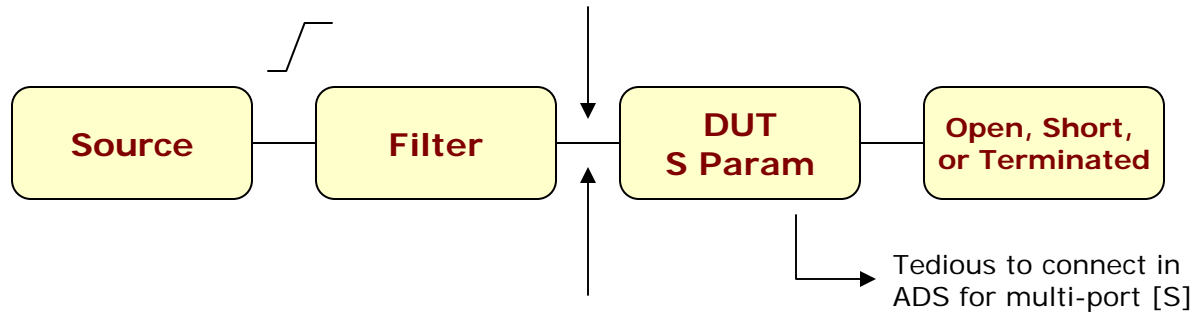


# From ? to [S]

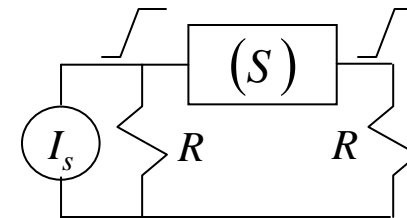


# Convert [S] to TDR & TDT

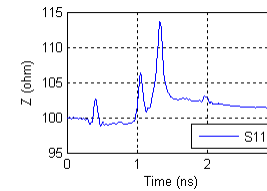
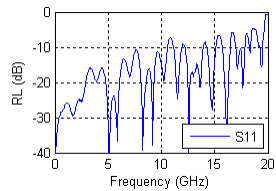
How to set up source and filter to give proper edge rate at the input of DUT?



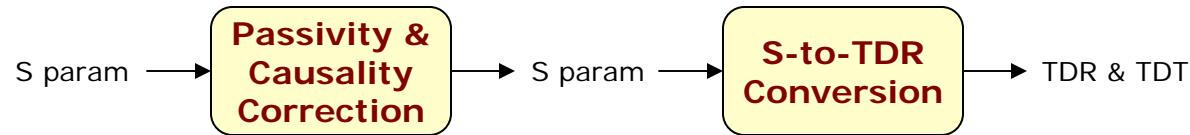
Does simulation correlate with direct TDR & TDT measurements?



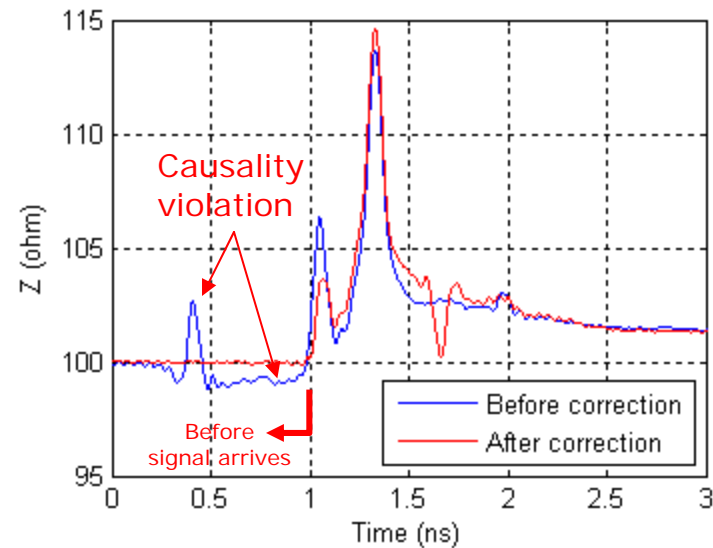
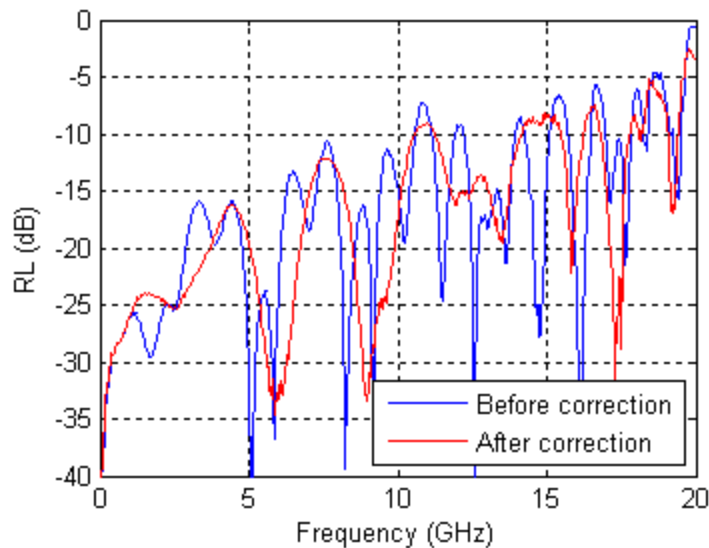
Simplified to



# Passivity & Causality Correction

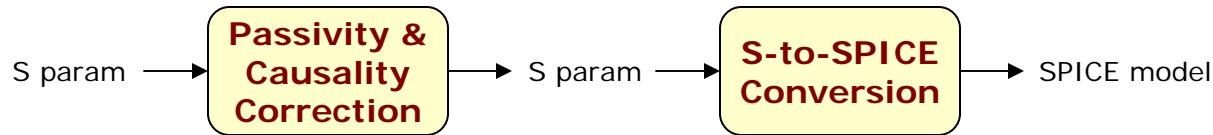


- (Mild) causality error in time domain can mean huge difference in S param.

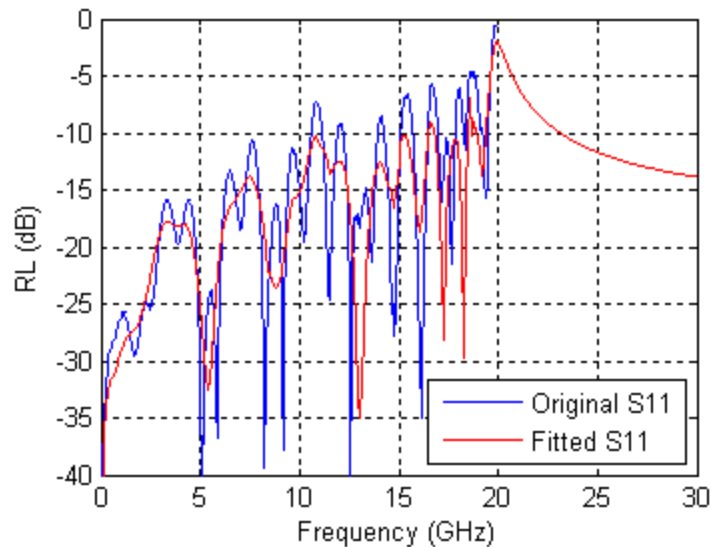


TDR @50 ps (20/80), shifted by 1ns

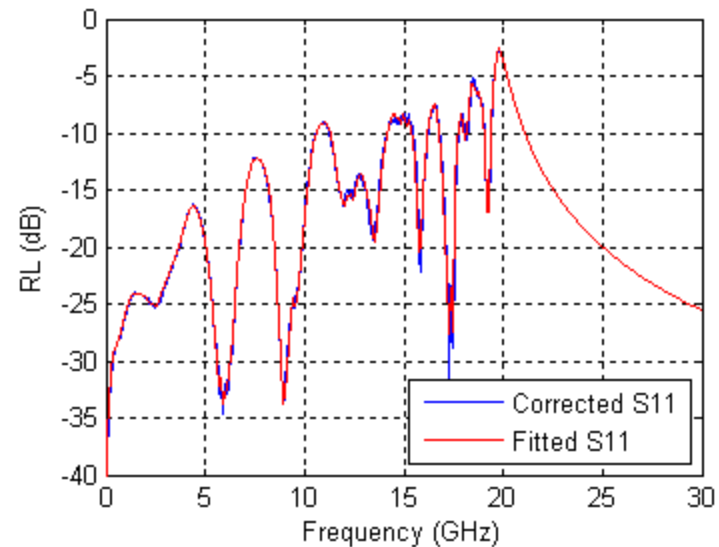
# Convert [S] into SPICE Model



- **Curvefitting SPICE models can be difficult without causality correction.**

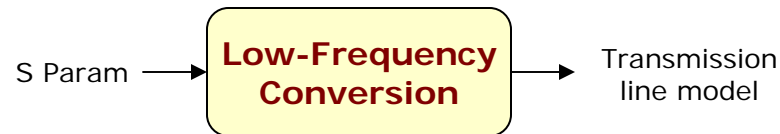


w/o causality correction



with causality correction

# Convert [S] into Transmission Line



- Any structure can be approximated by a transmission line (or even lumped circuit) at low frequencies.

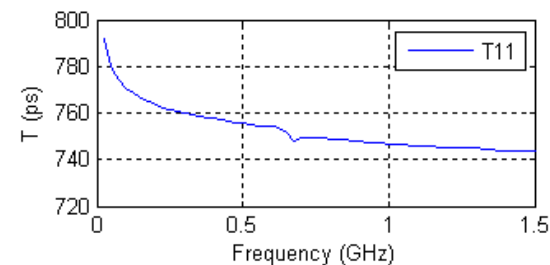
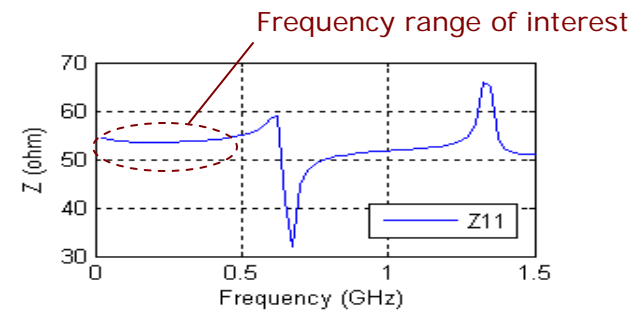
$$(Y) \approx \begin{pmatrix} Y_0 \coth \Gamma & -Y_0 \operatorname{csch} \Gamma \\ -Y_0 \operatorname{csch} \Gamma & Y_0 \coth \Gamma \end{pmatrix}$$

$$Z_0 = Y_0^{-1} \quad \text{Characteristic impedance}$$

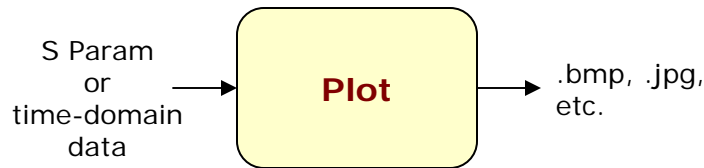
$$T = \frac{\Gamma}{j\omega} \quad \text{Characteristic delay}$$

$$R + j\omega L = Y_0^{-1} \Gamma$$

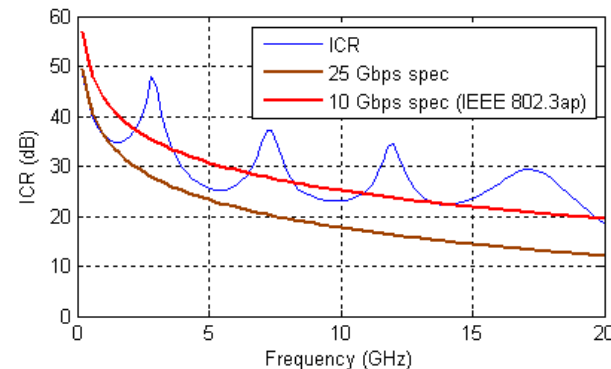
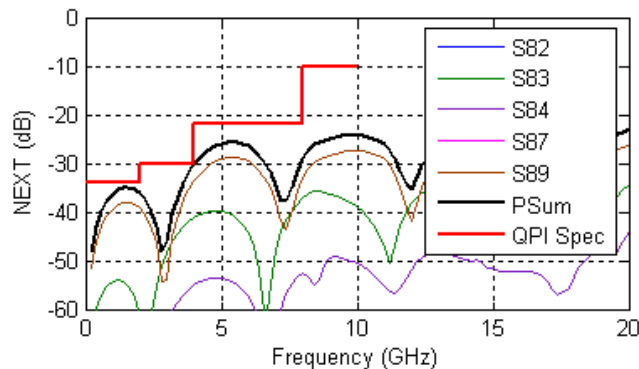
$$G + j\omega C = Y_0 \Gamma$$



# Plot Multiple [S] Curves

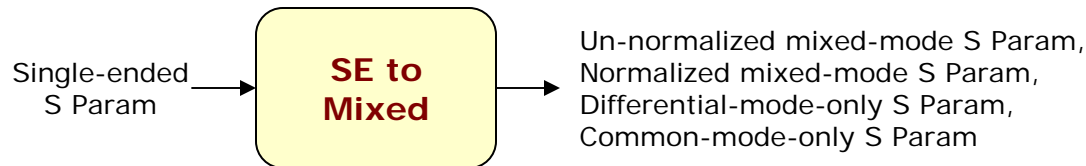


- Plot S param curves from different files
- Plot time-domain curves from different files
- Save to .bmp, .jpg, ... for reports
- Change line color & style, legend and label
- Compare with industry standard spec.



# Convert Single-Ended [S] into Mixed-Mode [S]

---

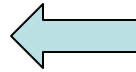


- **Un-normalized vs. normalized mixed-mode [S]**
  - Touchstone version 1.0 uses only one reference impedance
  - Un-normalized mixed-mode (or odd-and-even mode) referenced to 50 ohm gives the same [S] as differential-and-common mode reference to 100 and 25 ohm, respectively.
  - Normalized mixed-mode referenced to xx ohm gives correct differential- and common-mode impedance.
  - It is sometimes more convenient to have differential-mode-only Touchstone files referenced to 100 ohm or common-mode-only Touchstone files referenced to 25 ohm.

# From [S] to [Y]

Single-ended:

$$\begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} I_1 \\ I_2 \end{pmatrix}$$



Odd-and-even:

$$\begin{pmatrix} Y_{oo} & Y_{oe} \\ Y_{eo} & Y_{ee} \end{pmatrix} \begin{pmatrix} V_1 - V_2 \\ V_1 + V_2 \end{pmatrix} = \begin{pmatrix} I_1 - I_2 \\ I_1 + I_2 \end{pmatrix}$$



Differential-and-common:

$$\begin{pmatrix} \frac{Y_{oo}}{2} & Y_{oe} \\ Y_{eo} & 2 \cdot Y_{ee} \end{pmatrix} \begin{pmatrix} \frac{V_1 - V_2}{2} \\ \frac{V_1 + V_2}{2} \end{pmatrix} = \begin{pmatrix} \frac{I_1 - I_2}{2} \\ I_1 + I_2 \end{pmatrix}$$

$$\begin{pmatrix} Y_{dd} & Y_{dc} \\ Y_{cd} & Y_{cc} \end{pmatrix} \begin{pmatrix} \frac{V_1 - V_2}{2} \\ \frac{V_1 + V_2}{2} \end{pmatrix} = \begin{pmatrix} \frac{I_1 - I_2}{2} \\ I_1 + I_2 \end{pmatrix}$$

$$Y_{dd} = \frac{Y_{oo}}{2}; Y_{cc} = 2 \cdot Y_{ee}$$

$$\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} V_1^+ \\ V_2^+ \end{pmatrix} = \begin{pmatrix} V_1^- \\ V_2^- \end{pmatrix}$$

50 ohm ref.

$$\frac{1}{2} MSM^T$$



$$\begin{pmatrix} S_{oo} & S_{oe} \\ S_{eo} & S_{ee} \end{pmatrix} \begin{pmatrix} V_1^+ - V_2^+ \\ V_1^+ + V_2^+ \end{pmatrix} = \begin{pmatrix} V_1^- - V_2^- \\ V_1^- + V_2^- \end{pmatrix}$$

50 ohm ref.

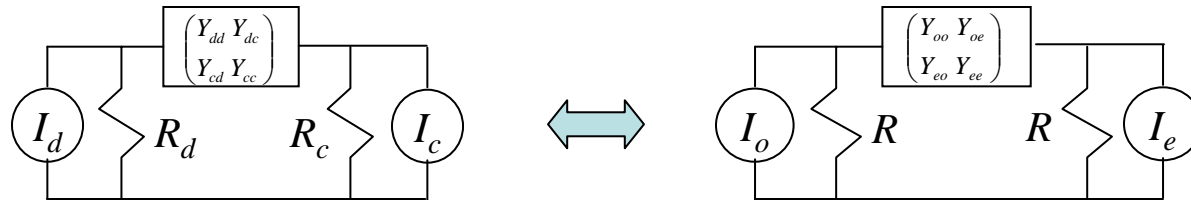
$$\begin{pmatrix} S_{dd} & S_{dc} \\ S_{cd} & S_{cc} \end{pmatrix} \begin{pmatrix} \frac{V_1^+ - V_2^+}{2} \\ \frac{V_1^+ + V_2^+}{2} \end{pmatrix} = \begin{pmatrix} \frac{V_1^- - V_2^-}{2} \\ \frac{V_1^- + V_2^-}{2} \end{pmatrix}$$

100 & 25  
ohm ref.

# Differential/Common vs. Odd/Even

Ref. to 100 / 25 ohm

Ref. to 50 ohm



$$\begin{pmatrix} Y_{dd} + \frac{1}{R_d} & Y_{dc} \\ Y_{cd} & Y_{cc} + \frac{1}{R_c} \end{pmatrix} \begin{pmatrix} V_d \\ V_c \end{pmatrix} = \begin{pmatrix} I_d \\ I_c \end{pmatrix}$$

$$\begin{pmatrix} Y_{oo} + \frac{1}{R} & Y_{oe} \\ Y_{eo} & Y_{ee} + \frac{1}{R} \end{pmatrix} \begin{pmatrix} V_o \\ V_e \end{pmatrix} = \begin{pmatrix} I_o \\ I_e \end{pmatrix}$$

$$\begin{pmatrix} V_d \\ V_c \end{pmatrix} = \frac{1}{\Delta_{dc}} \begin{pmatrix} Y_{cc} + \frac{1}{R_c} & -Y_{dc} \\ -Y_{cd} & Y_{dd} + \frac{1}{R_d} \end{pmatrix} \begin{pmatrix} I_d \\ I_c \end{pmatrix}$$

$$\begin{pmatrix} V_o \\ V_e \end{pmatrix} = \frac{1}{\Delta_{oe}} \begin{pmatrix} Y_{ee} + \frac{1}{R} & -Y_{oe} \\ -Y_{eo} & Y_{oo} + \frac{1}{R} \end{pmatrix} \begin{pmatrix} I_o \\ I_e \end{pmatrix}$$

$$\Delta_{dc} = \left( Y_{cc} + \frac{1}{R_c} \right) \left( Y_{dd} + \frac{1}{R_d} \right) - Y_{dc} Y_{cd} = \left( 2Y_{ee} + \frac{2}{R} \right) \left( \frac{Y_{oo}}{2} + \frac{1}{2R} \right) - Y_{oe} Y_{eo} = \left( Y_{ee} + \frac{1}{R} \right) \left( Y_{oo} + \frac{1}{R} \right) - Y_{oe} Y_{eo} = \Delta_{oe}$$

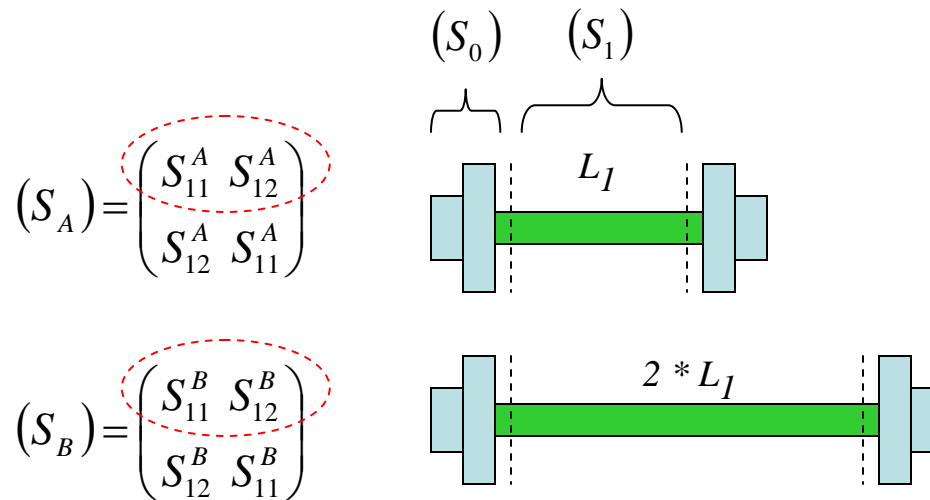
$$S_{cd} = \frac{2V_c}{I_d \sqrt{R_c R_d}} = \frac{-2Y_{cd}}{\sqrt{\frac{R}{2}} \cdot 2R \cdot \Delta_{dc}} = \frac{-2Y_{eo}}{R \cdot \Delta_{oe}} = \frac{2V_e}{I_o R} = S_{eo} \quad (\text{Let } I_d=1, I_c=0; I_o=1, I_e=0)$$

$$S_{dd} = \frac{2V_d}{I_d R_d} - 1 = \frac{2 \left( Y_{cc} + \frac{1}{R_c} \right)}{2R \cdot \Delta_{dc}} - 1 = \frac{2 \left( 2Y_{ee} + \frac{2}{R} \right)}{2R \cdot \Delta_{dc}} - 1 = \frac{2 \left( Y_{ee} + \frac{1}{R} \right)}{R \cdot \Delta_{oe}} - 1 = \frac{2V_o}{I_o R} - 1 = S_{oo}$$

# Extract [S] from Measurements



- Assuming symmetry, we can extract S param for SMA (or probe pad) and trace from two measurements.

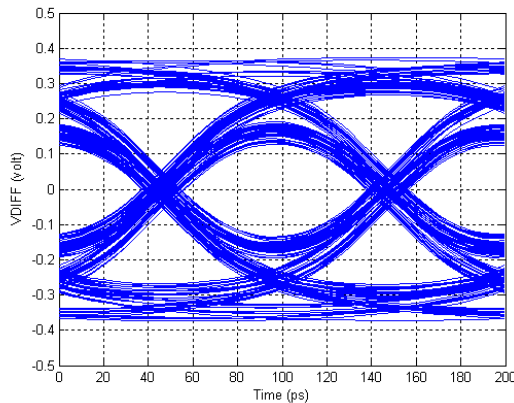


$$\begin{array}{c} S_A \\ S_B \end{array} \Rightarrow \begin{array}{l} T_A = T_0 T_1 T_0 \\ T_B = T_0 T_1 T_1 T_0 \end{array} \Rightarrow \begin{array}{l} T_0^2 = T_A T_B^{-1} T_A \\ T_1 = T_0^{-1} T_A T_0^{-1} \end{array} \Rightarrow \begin{array}{c} S_0 \\ S_1 \end{array}$$

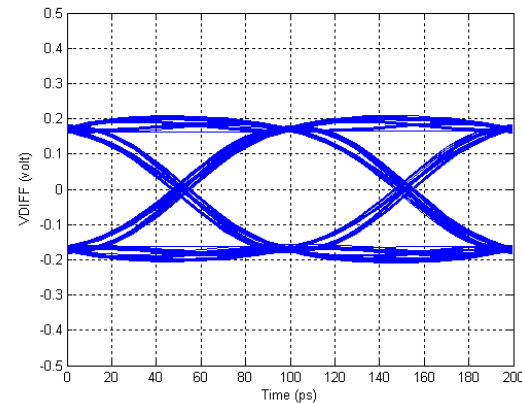
# Channel Optimization



- Fixed cursors vs. optimized TX tap coefficients
- Fixed vs. random data patterns
- 8B10B encoding



w/o TX equalization

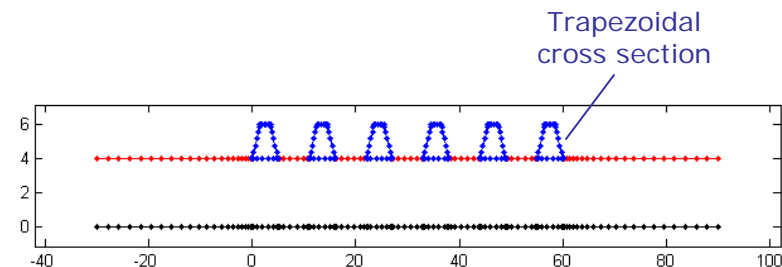
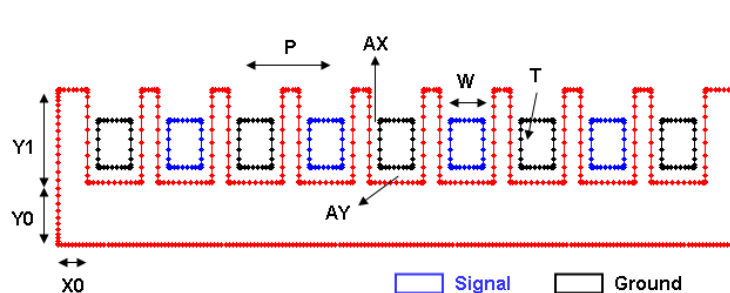


with TX equalization

# 2D Field Solver

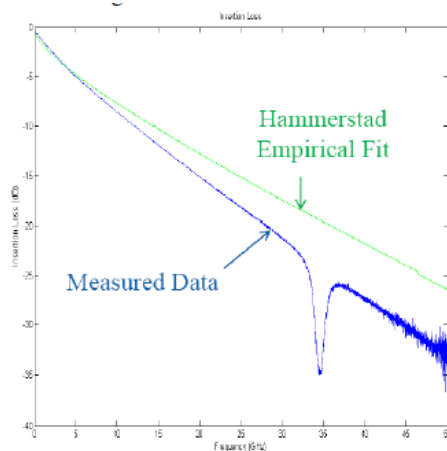


- Templates for common structures
- User-defined files for arbitrary cross sections
- Ground or float conductors
- Output impedance & RLGC W-element model

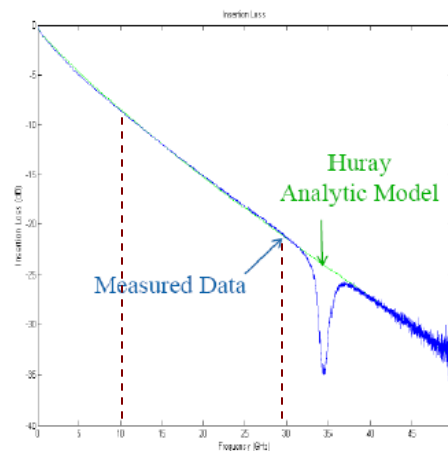


# Surface Roughness

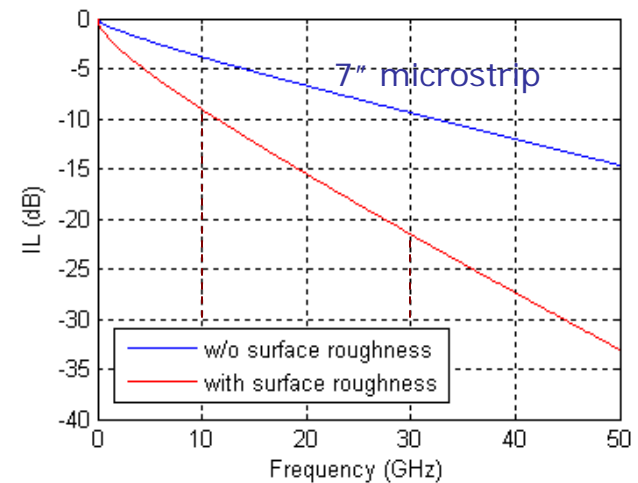
- Hammerstad and Huray models rely on RMS surface deviation and equivalent “snowball” radius, respectively, to curvefit measurement data.
- Given IL at two frequencies, we can adjust  $R_s$  and  $G_d$  terms in W-element models to curvefit measurement data and mimic the effect of surface roughness.



Hammerstad



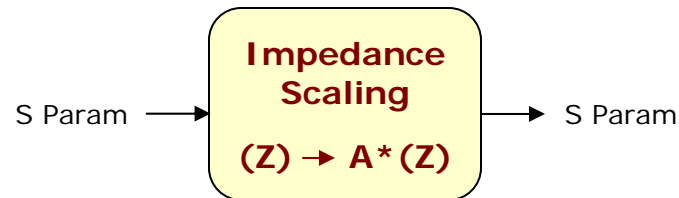
Huray



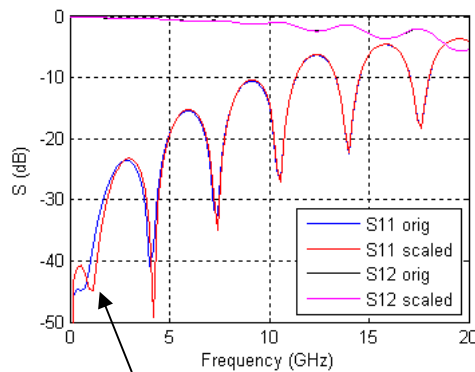
ADK



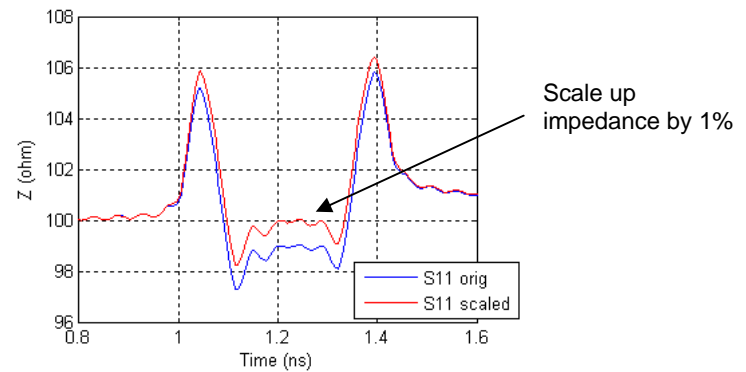
# Scale [S] Impedance



- Traditional 3D solvers tend to be less accurate in computing trace impedance.
- Scaling [S] impedance helps correlation (and generation of corner models).



Impedance scaling has more effect at low frequencies!



**We can scale [S] delay, too!**

# Summary

---

- **We have presented many SI tools beyond HFSS and ADS.**
  - **S-to-S: causality correction, single-ended to mixed-mode, combine S with PEC and PMC, extract S from measurement, graphics tool, ...**
  - **S-to-?: TDR & TDT, SPICE model, transmission line model, eye diagram, channel optimization, ...**
  - **?-to-S: fast 2D & 3D solver, ...**
- **A tool is “useful” if it is used very often.**
  - **CPU or labor-intensive simulations are left for HFSS and ADS.**
- **Advanced SI Design Kits (ADK) collects most-often used SI tools in one place.**
  - **By definition, ADK is intended to be used daily to perform more than 80% of SI tasks.**
  - **ADK enhances productivity and is a good training tool to guide new engineers to go through check list.**