Lossy Line Characterization and Modeling for SPICE and IBIS

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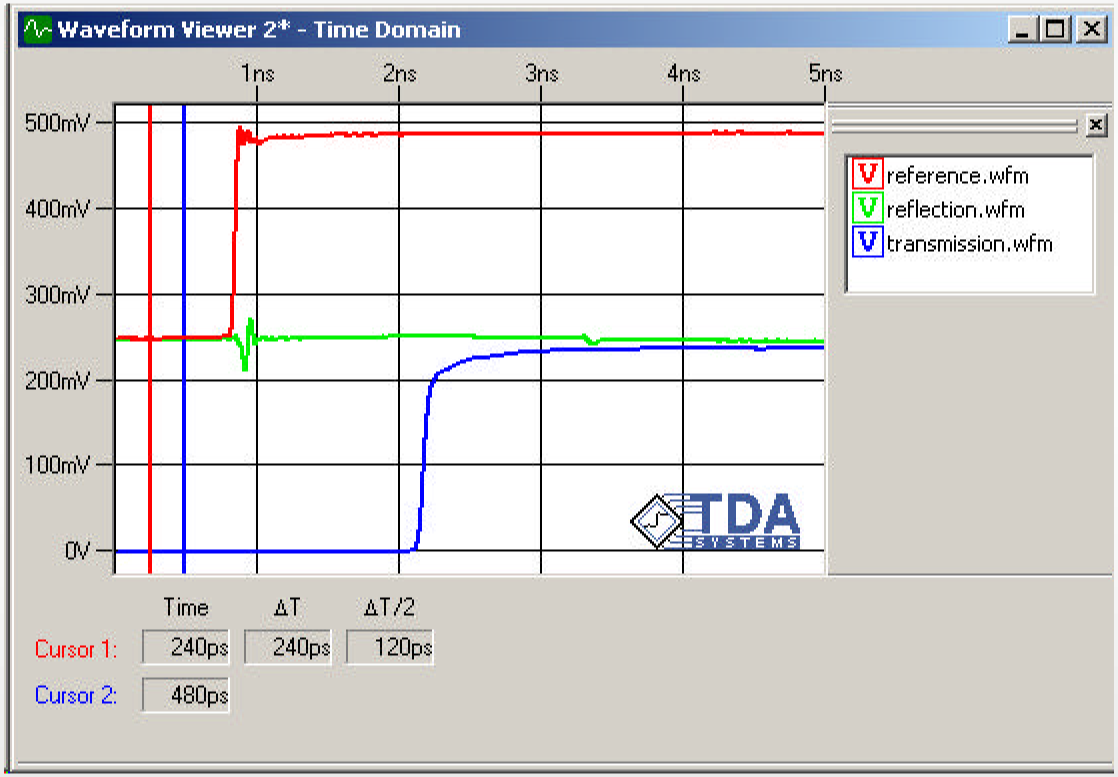
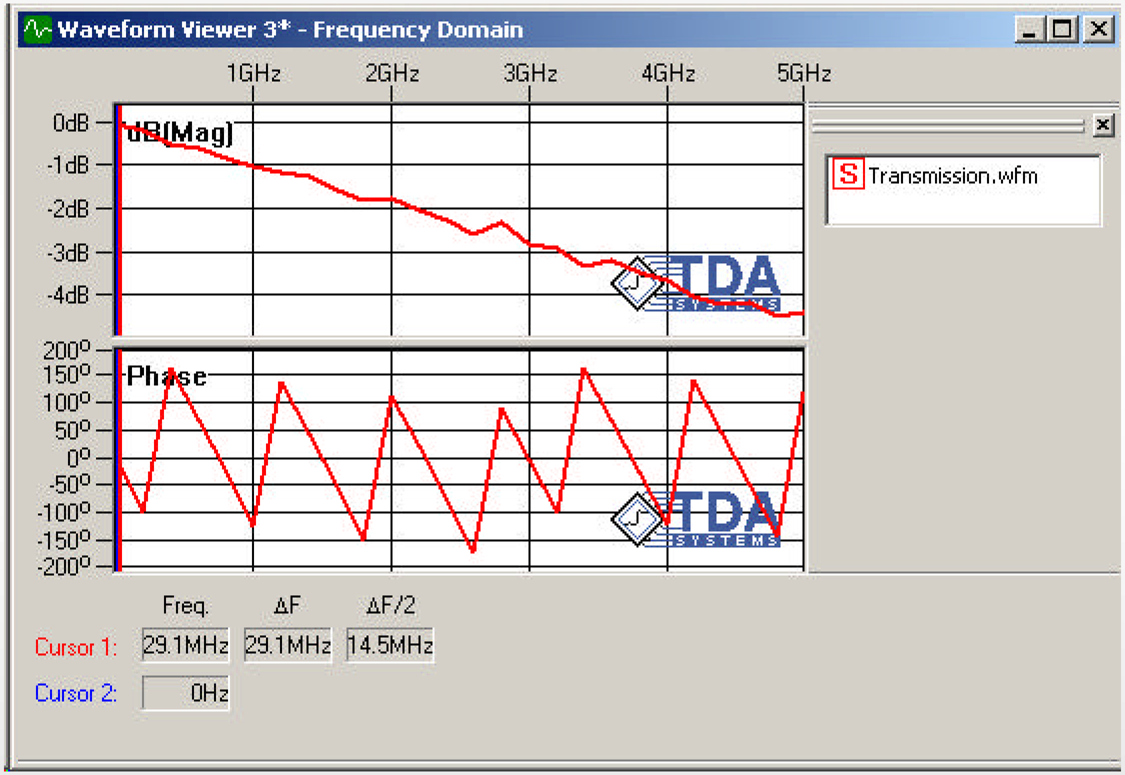
In This Talk...

- Examples of loss
- Why loss matters
- Physical basis for loss
- Modeling approaches
- Loss modeling issues
- Our approach
- Results
- Conclusions

Loss Example: Time Domain



Loss Example: Frequency Domain



Why Loss Matters

- Ignoring loss can cause design failures
  - Data rates too high
  - Drivers too weak
- Overestimating loss can result in overly conservative designs
  - Slower than necessary
  - Stronger drive than necessary

Why Loss is a "Recent" Issue

- **Loss is only recently significant in common digital design**
  - **Faster rise times and data rates**
  - **Narrower traces**
  - **Same old materials…**
- **Loss has long been significant in analog design**
  - **Frequency-Domain analysis methods**
  - **Not targeted toward broadband modeling**

Physical Basis for Loss

- Resistance in metal
  - Varying skin depth causes frequency-dependent resistance
  - Magnetic flux internal to metal causes frequency-dependent inductance
- Conductance in dielectric
  - Constant non-zero loss tangent causes frequency-dependent conductance
  - Charges moving within dielectric cause frequency-dependent capacitance

Different TEM Modeling Approaches

- **Lumped**
  - **Defined for all frequencies**
  - **Slow for long lines**
- **Distributed**
  - **Based on parameters (R_{skin}, $G_{dielectric}$)**
    - Defined for all frequencies
    - Not as general
  - **Based on RLGC data**
    - General for quasi-TEM
    - Not defined for all frequencies

Loss Modeling Issues

- **Accuracy of model**
  - **Defined for sufficient range of frequencies**
- **Passivity of model**
  - **Cannot generate energy**
  - **Required for use in a time-domain simulator which handles feedback**
  - **Requires model to be causal**
- **Stability of algorithm**
  - **Unstable algorithms can cause passive models to blow up**

Causality in TEM Models

- **From basic physics, the real and imaginary parts of the dielectric constant are tightly related to ensure causality.**
- **The same is true of the permeability constant,** m
- **In TEM modeling, this means that R and L are related, and G and C are related**
- **Models based on RLGC data should address this issue**

Our Model Extraction Approach

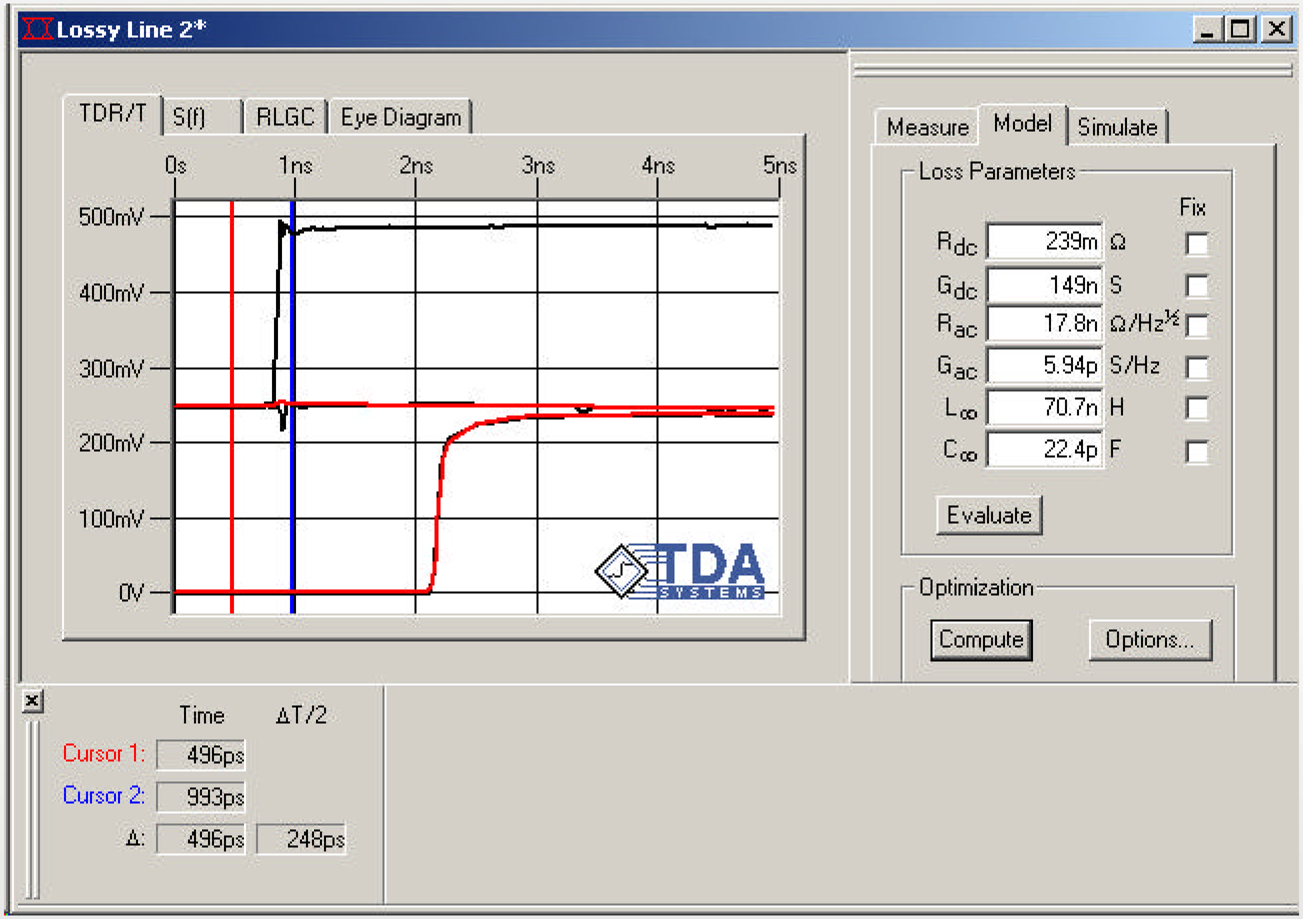
- **Assume equations:**

$$Z \approx R_{dc} + R_{ac}\sqrt{f} + jwL_{\infty}$$

$$Y \approx G_{dc} + G_{ac}\, f + jwC_{\infty}$$

- **Extract/Optimize loss parameters: R_{dc}, R_{ac}, G_{dc}, G_{ac}, $L_{¥}$, $C_{¥}$**
- **Write resulting model in various formats**
  - **Lumped**
  - **Distributed with parameters**
  - **Distributed with RLGC data**

Example: Extraction Results



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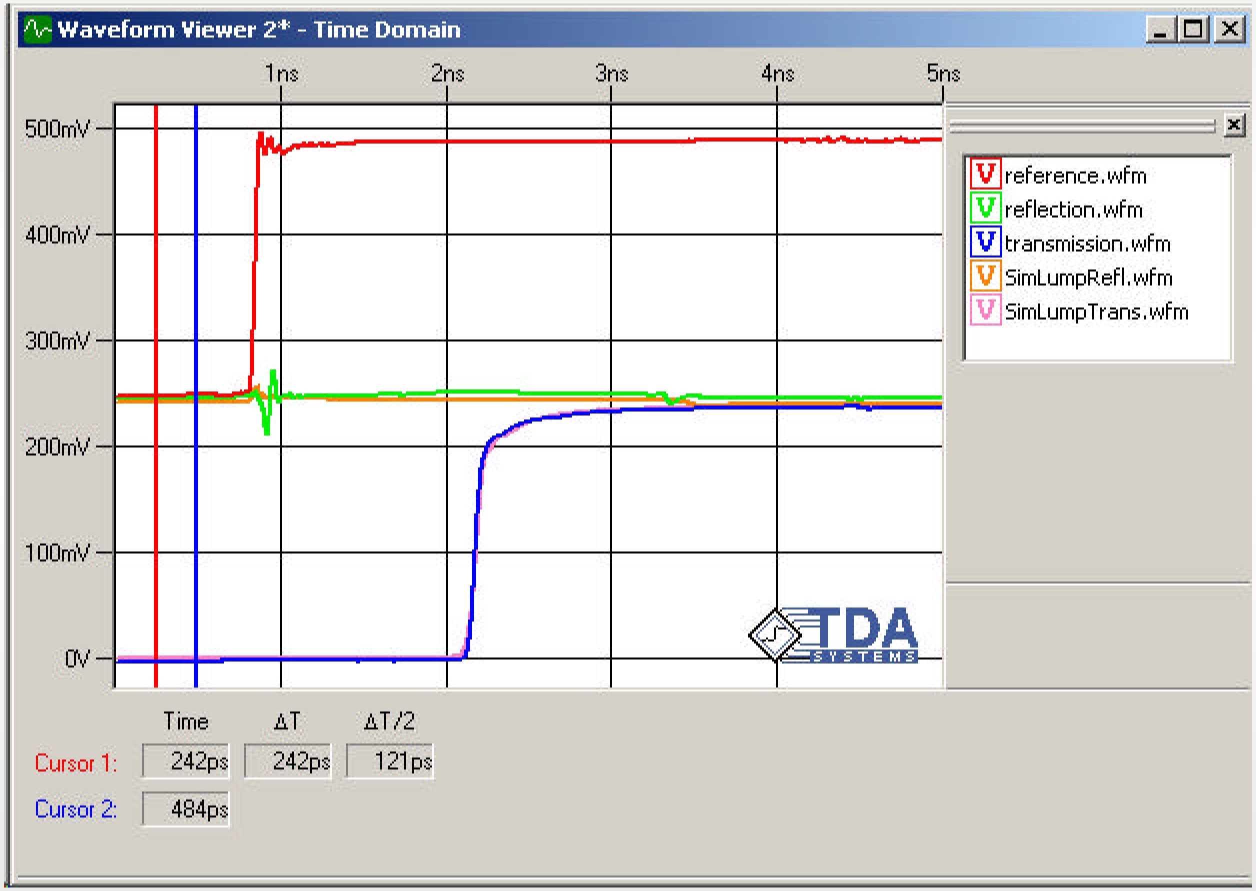
Example: Lumped Simulation Results



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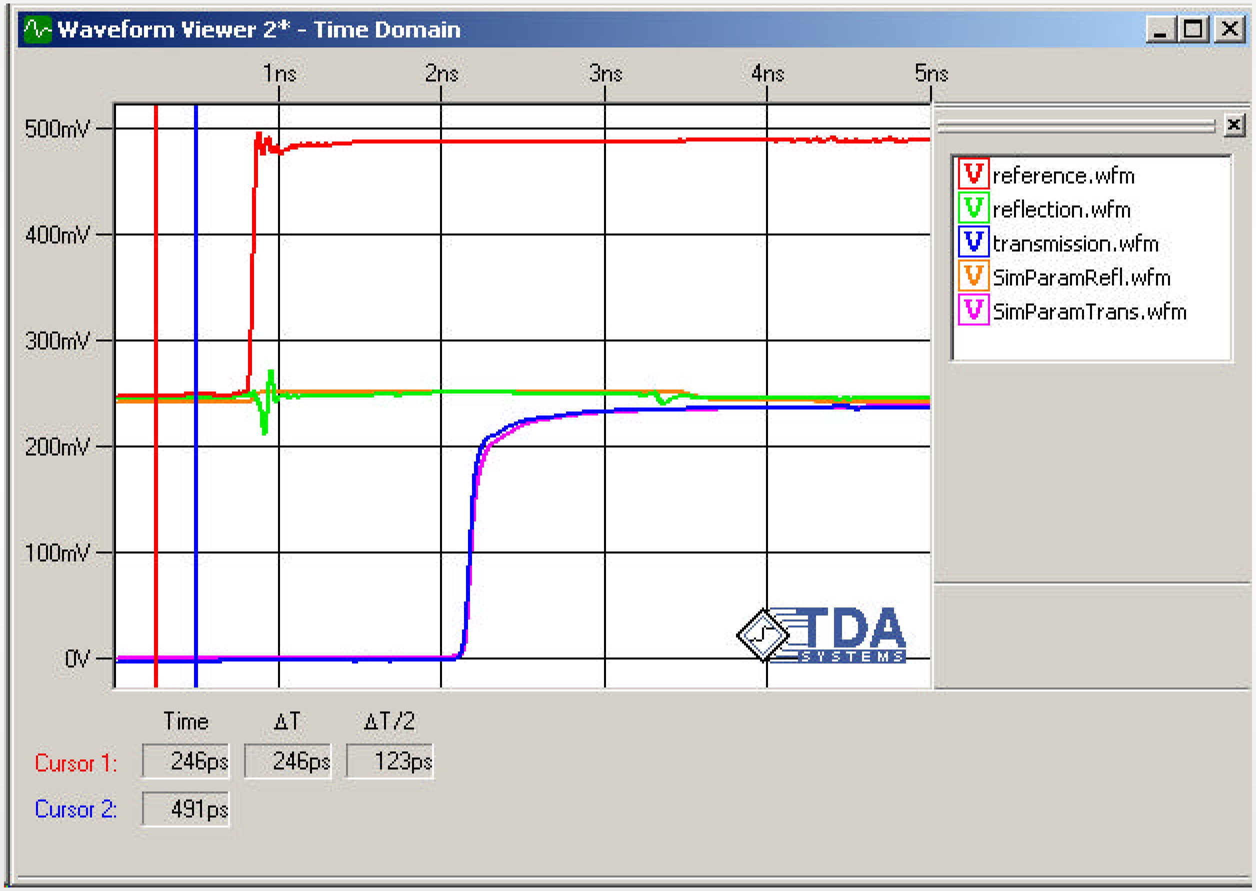
Example: Parameterized Simulation Results



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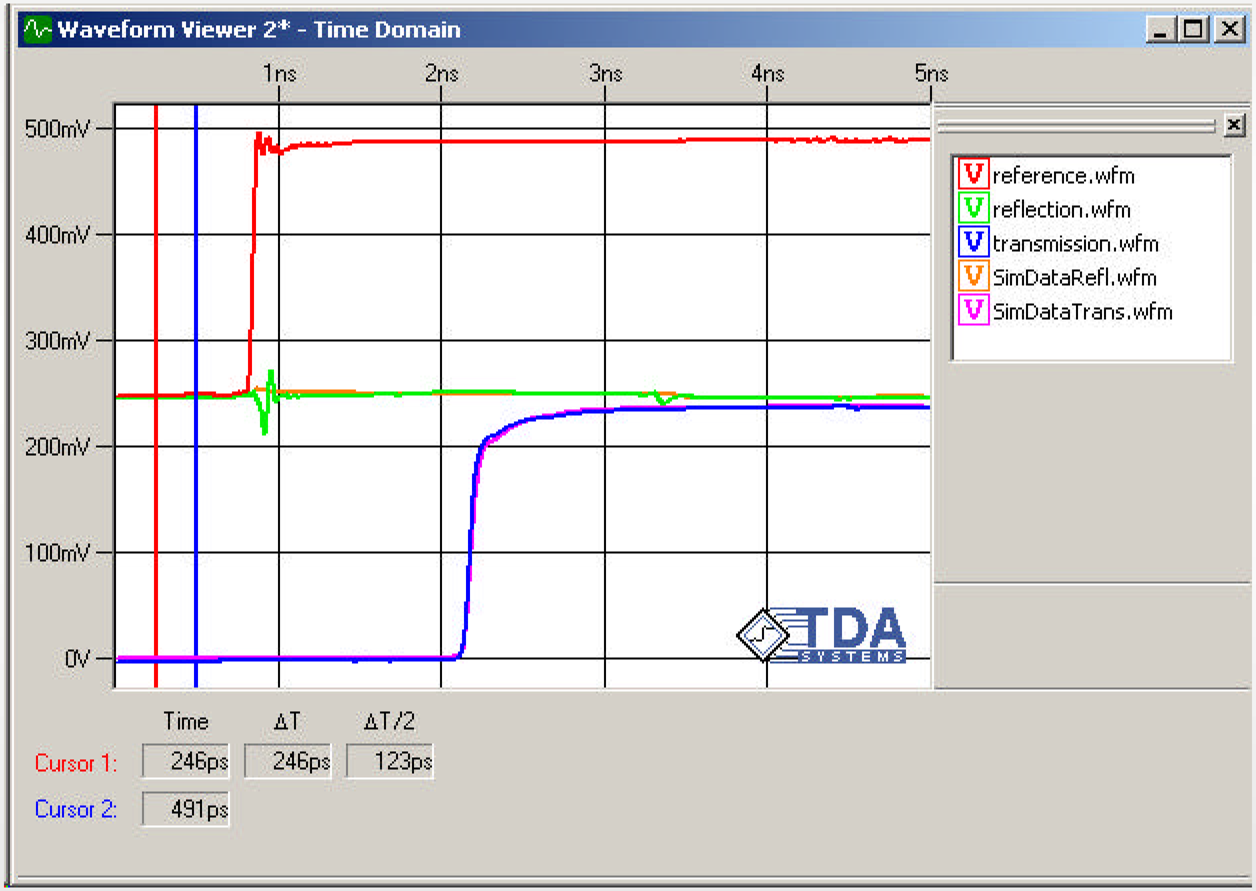
Example: RLGC Data Simulation Results



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Conclusions

- Industry needs lossy line models for board-level simulation
- The capability exists for accurate modeling
  - Lumped elements, parameters, RLGC data
  - Our modeling approach is based on TDR measurements
- Care is required to ensure that models are physical and algorithms are stable