Time Domain Reflectometry (TDR) and S-parameter

"Measurements and Best Practice for Signal Integrity"

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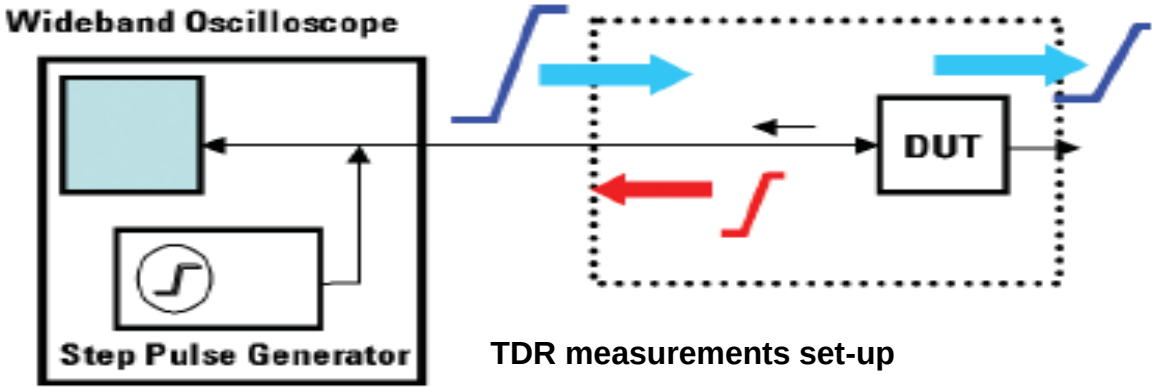
Agenda

- **Time Domain Reflectometry**
  - TDR and TDT measurements
  - True Differential measurements definition
  - Deskew
  - Reference Plane Calibration (SL vs. OSL)
- **S-parameters**
  - Concept and Definition
- **Return Loss and Insertion Loss**
- **Cross-talk interference**
  - NEXT and FEXT concepts
- **Introduction to mixed-mode S-parameters**

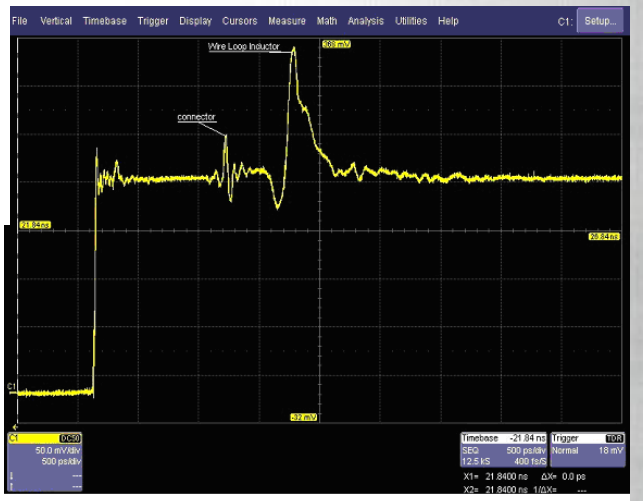
What is TDR ?

TDR - Time Domain Reflectometry (TDR)



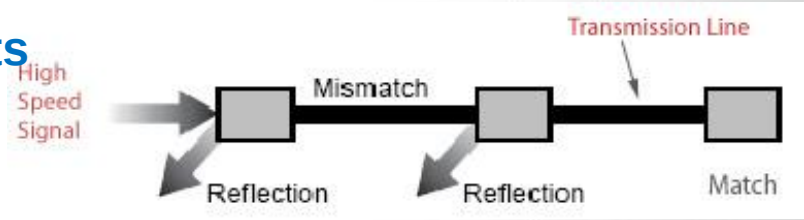
TDR measurements set-up

❖*I t is the measurements of the reflection in the time domain*



- ✓ ***A pulse generator is used to provide an incident step pulse (stimulus)***
- ✓ **Voltage Reflection from the Device Under Test (DUT) is measured by the scope . TDR mismatch**
- ✓ **Shape of the measured Reflection helps determine the type of discontinuity and its location**

❖***TDR measures Discontinuities* that cause reflections and their *Distance***



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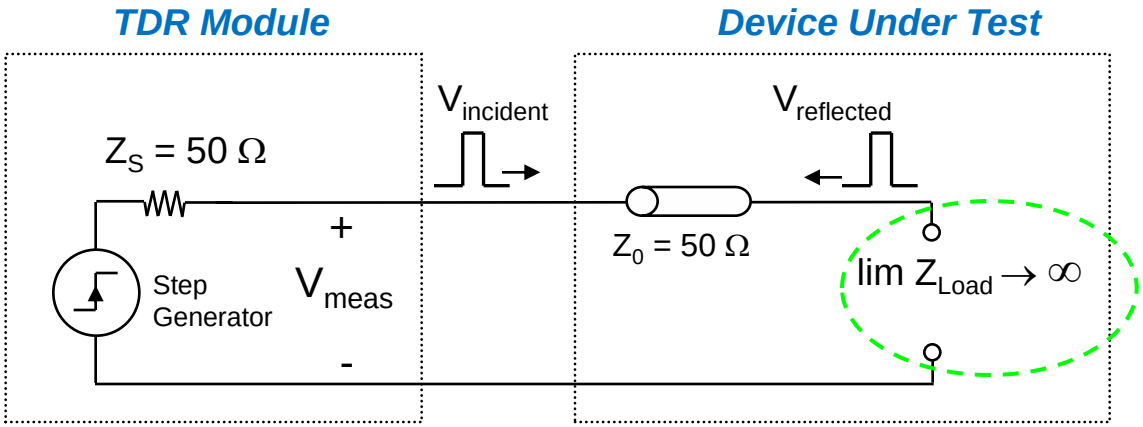
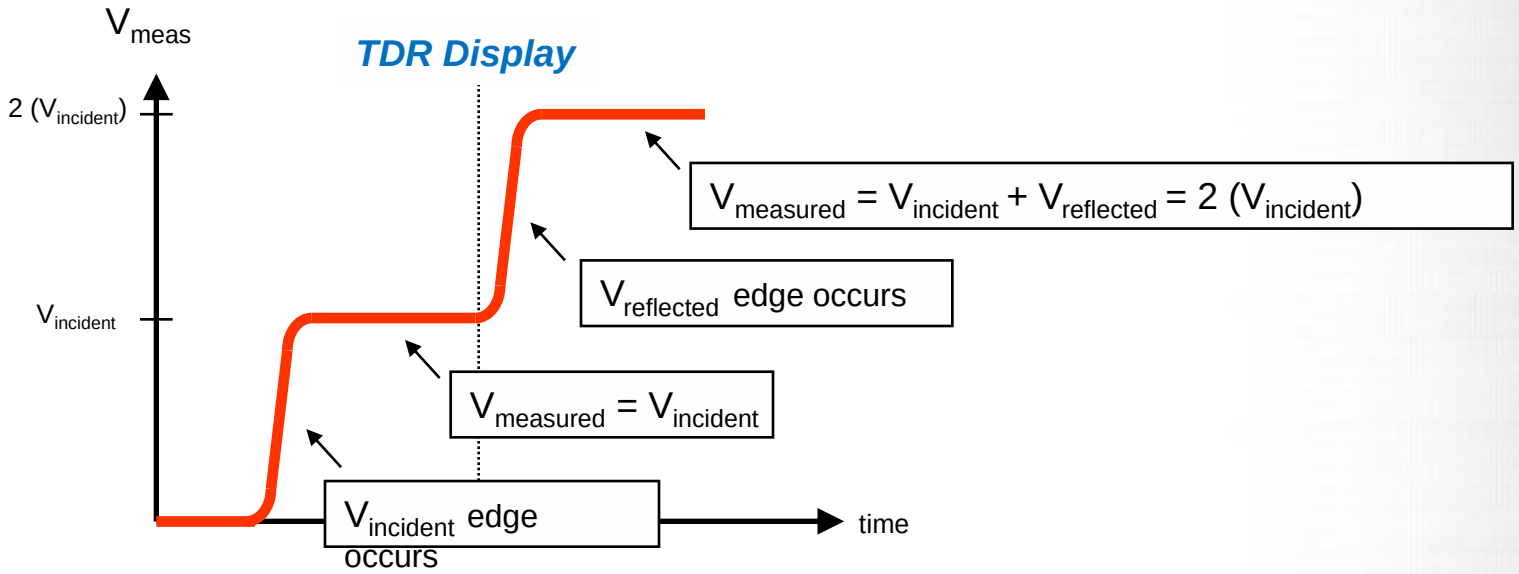
Open Circuit ($Z_{load} \rightarrow \infty$)
TDR example



Solving for $V_{reflected}$:

$$V_{reflected} = V_{incident} \left(\frac{Z_{Load} - Z_0}{Z_{Load} + Z_0} \right)$$

$$\lim Z_{Load} \rightarrow \infty, \quad \therefore V_{reflected} = V_{incident}$$



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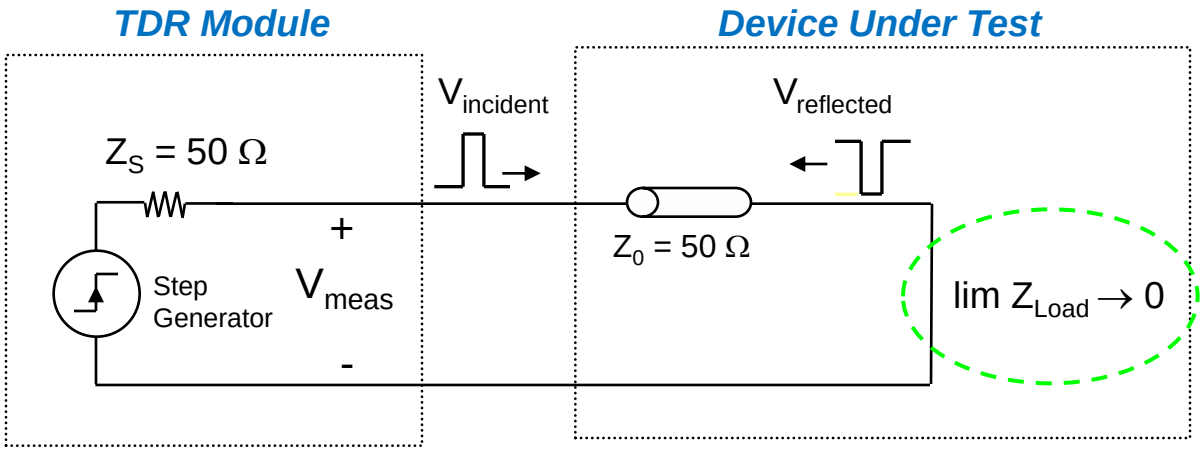
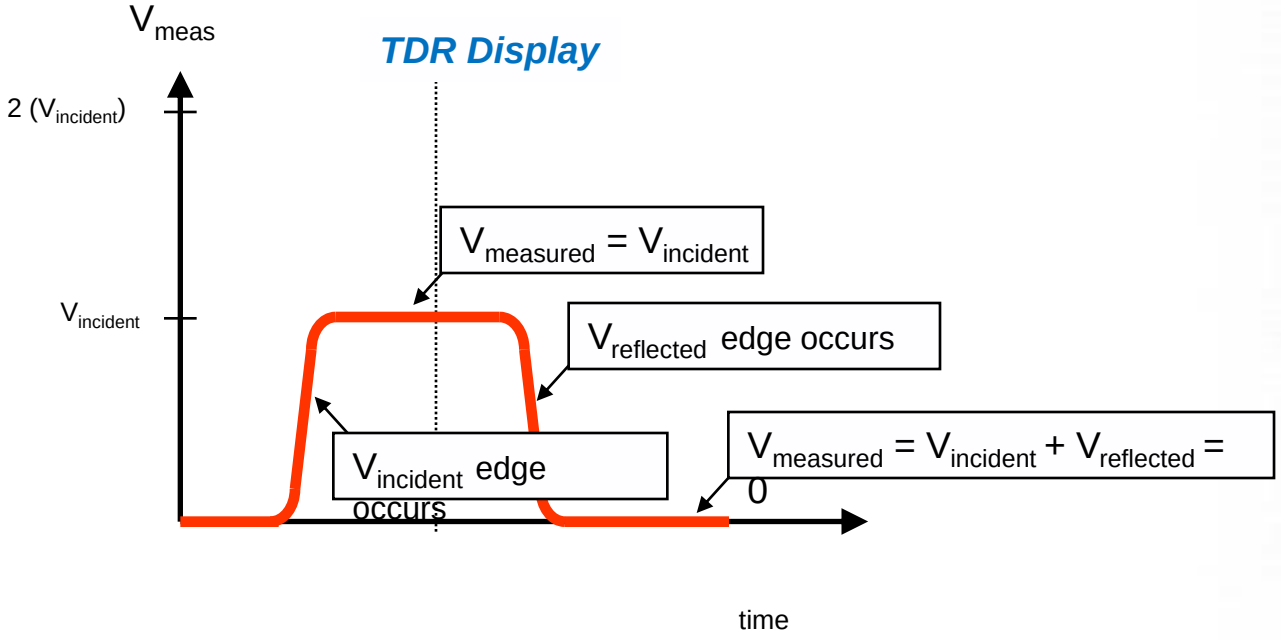
Short Circuit (Z_{load} =0)
TDR example



Solving for $V_{reflected}$:

$$V_{reflected} = V_{incident} \left(\frac{Z_{Load} - Z_0}{Z_{Load} + Z_0} \right)$$

lim $Z_{Load} \rightarrow 0$, $\therefore V_{reflected} = -V_{incident}$



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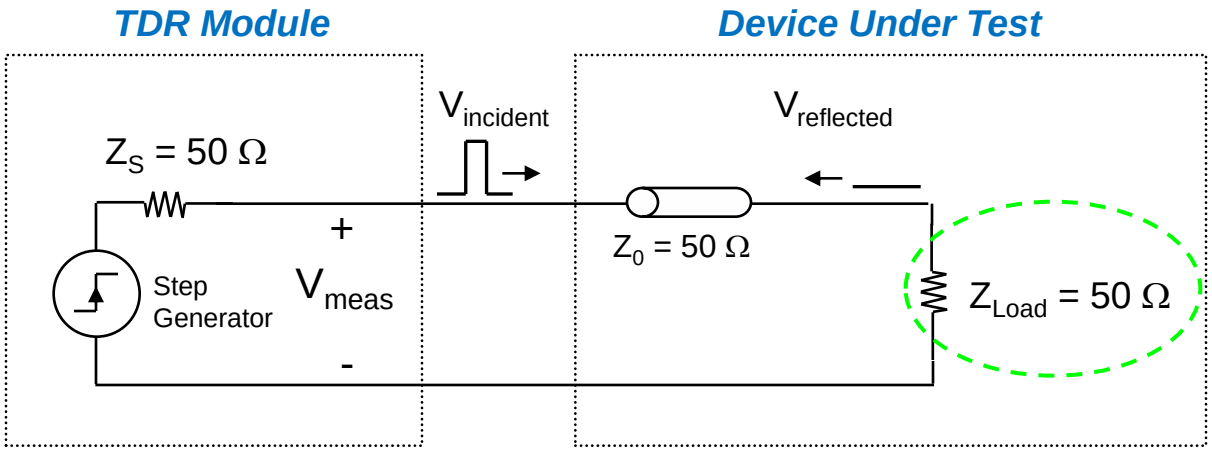
Matched Impedance (Z_{load} =50 Ohm)

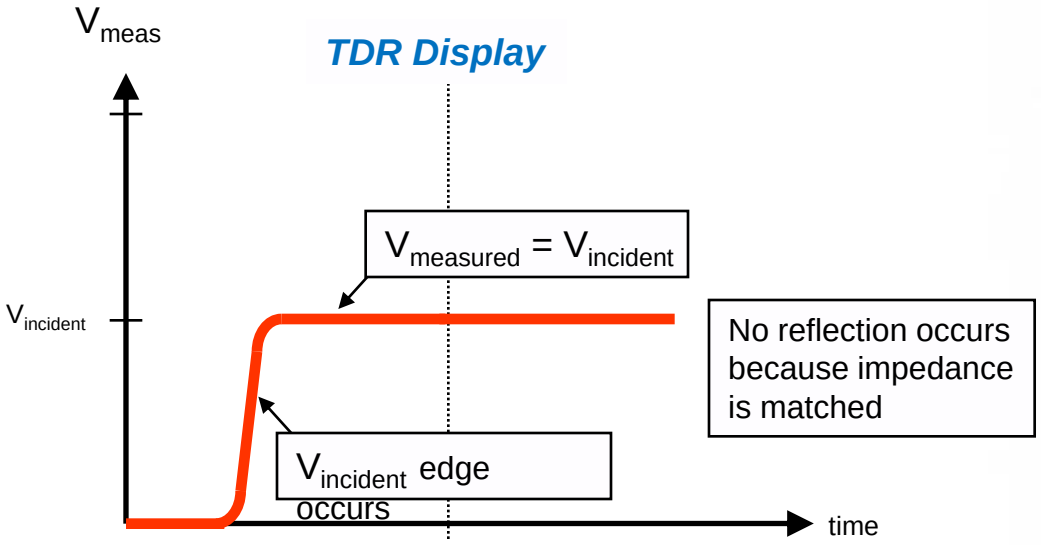
TDR example



Solving for $V_{reflected}$:

$$V_{reflected} = V_{incident}\left(\frac{Z_{Load} - Z_0}{Z_{Load} + Z_0}\right)$$

$Z_{Load} = Z_0, \quad \therefore V_{reflected} = 0$



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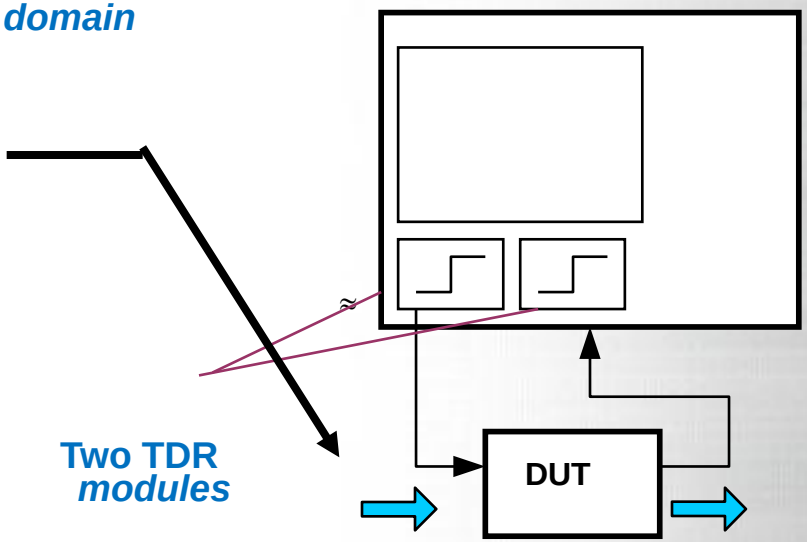
What is TDT?

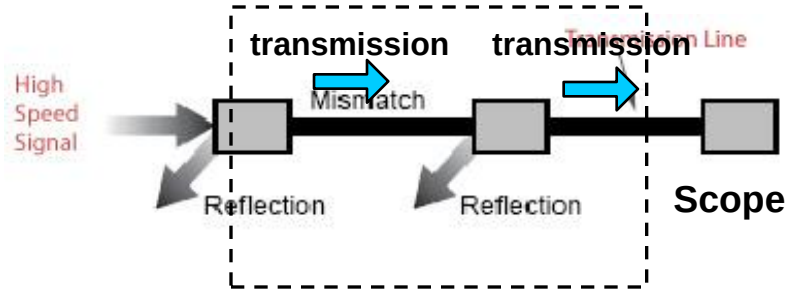
TDT - Time Domain Transmission (TDT)

❖*It is the measurements of the transmission in the time domain*

- ✓ *A pulse generator is used to provide an incident step pulse (stimulus)*
- ✓ *Voltage Transmission from the Device Under Test (DUT) is measured by the scope*
- ✓ *TDT ≈ Insertion (Transmission) Loss*
- ✓ *Requires two TDR modules – one to generate the step and other to sample*



TDT measurements set-up



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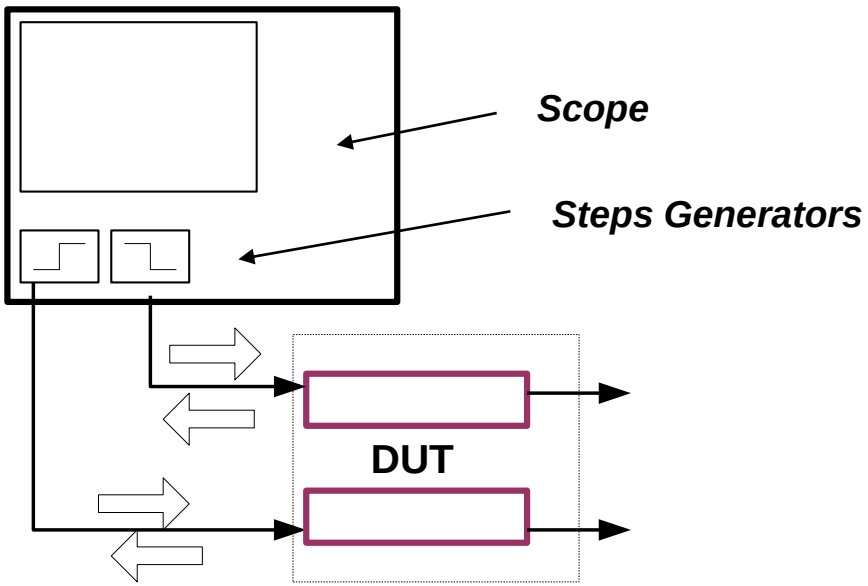
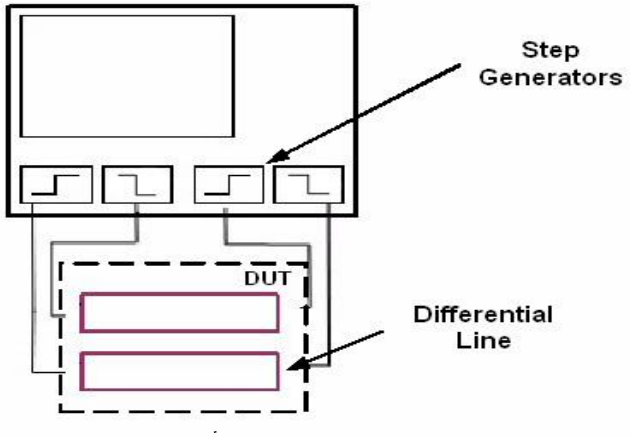
True Differential TDR / TDT

- ✓ *High Speed digital systems are mainly differential*
- ✓ *TDR requires two ST-20 modules to provide the differential signal (stimulus), step pulses, positive and negative (automatically changes polarity when selecting differential)*



Differential TDR measurements set-up

- ✓ *De-skew control aligns the two pulses from each of the two ST-20 modules.*
  - ✓ *HW deskew (±50 ps)*
- ✓ *Requires four TDR modules – two to generate the differential signal and other two to receive the differential signal*



Differential TDT measurements set-up

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Reference Plane Calibration

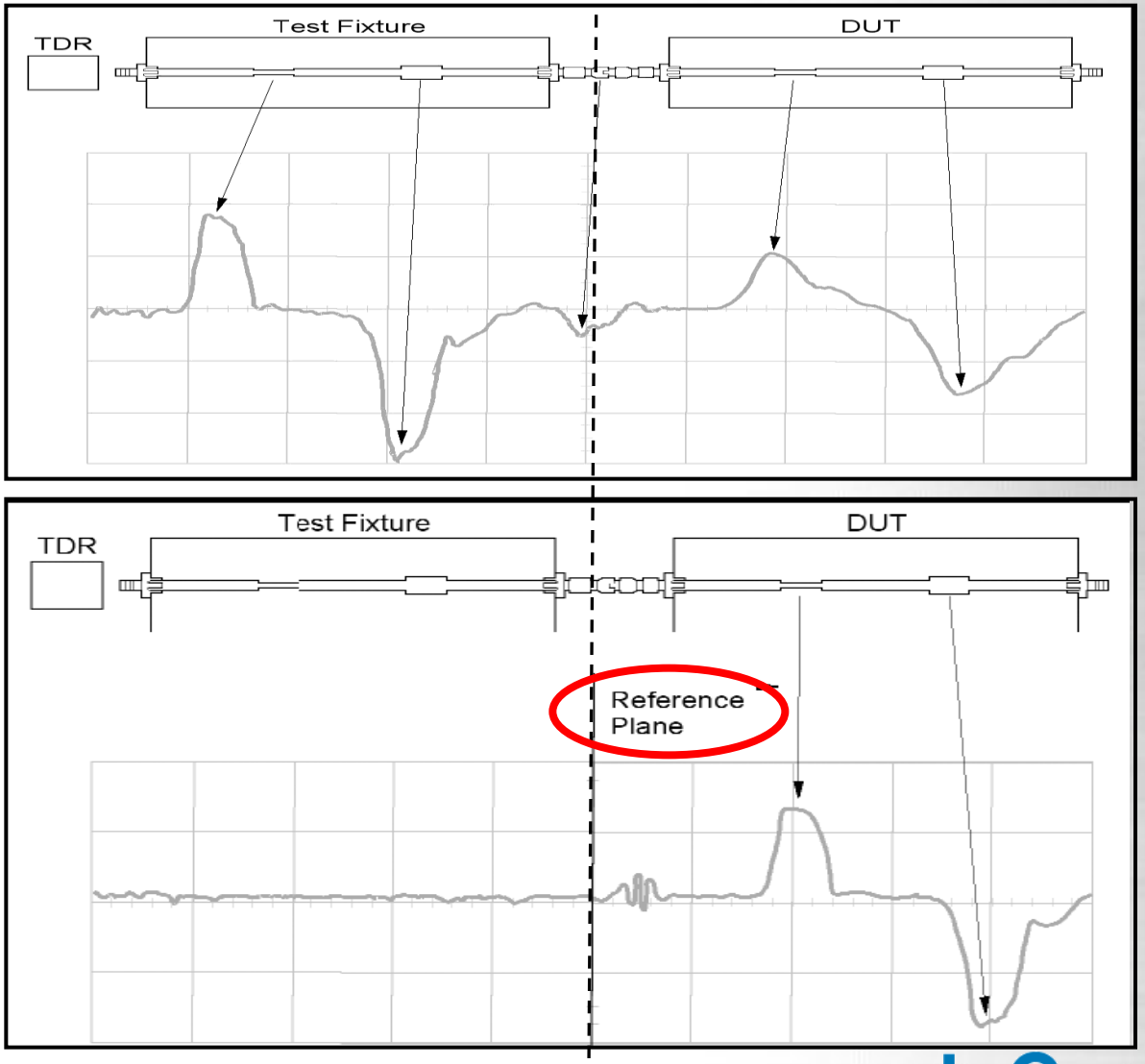
❖*Before calibration – effects of test fixture and connectors are included in the response*

Calibration Methods :

❖***Short Load (SL)***
Uses Two known standards (Short & Load)

❖***Open Short Load (OSL)***
Uses Three known standards
(Open , Short & Load)

❖*After calibration – effects of test fixture and connectors are removed from response*



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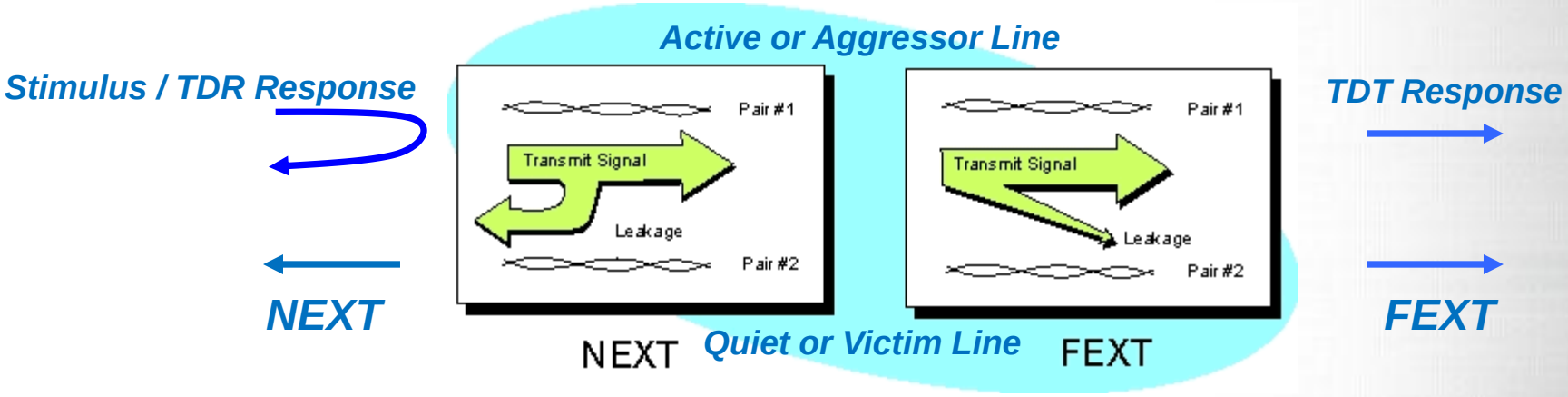
NEXT/FEXT on adjiacent trasmission lines



- ***Near-End Cross Talk (NEXT) is the ratio between the voltage measured on the near end on the quiet line and the stimulus.***
- ***Far-End Cross Talk (FEXT) is the ratio between the voltage measured on the far end on the quiet line and the stimulus.***

- ✓ ***NEXT-FEXT Cross-talk measured the coupling between two adjacent transmission lines***

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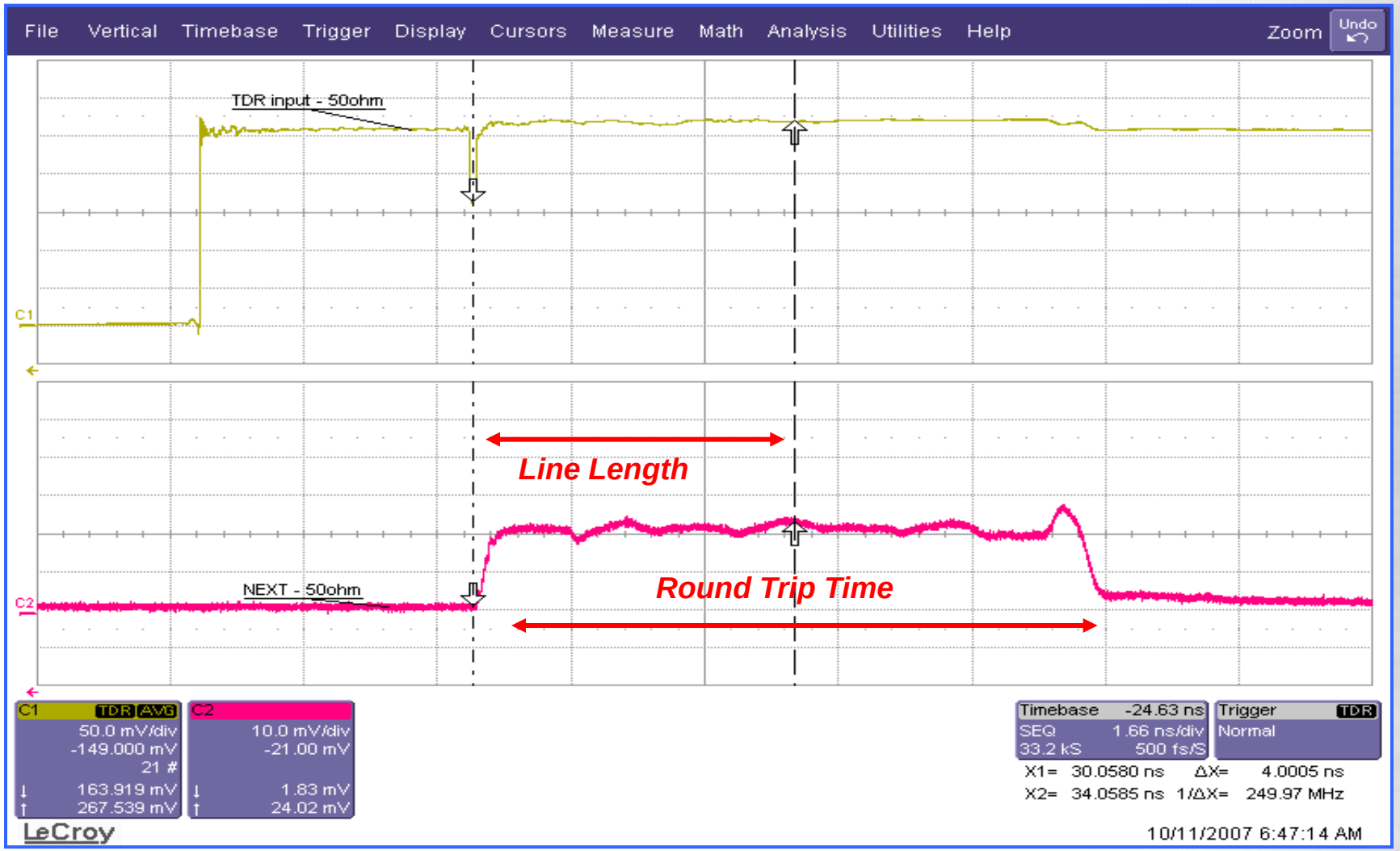
NEXT – Quiet Line @ 50Ω



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Introduction to S-Parameters

✓ *S-parameters (Scattering matrix) are the way we electrically accurately describe how RF energy propagates through a multi-port DUT.*

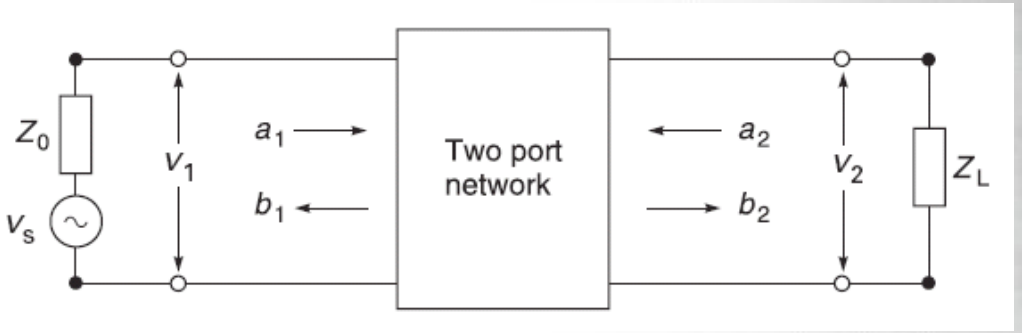
✓ *DUT even if incredibly complicated is considered as simple "black box"*

✓ *The S-parameter matrix for an N-port DUT contains N^2 S-parameters*

✓ *S-parameters are complex numbers (magnitude and phase)*

S11 – Magnitude Reflection

Frequency



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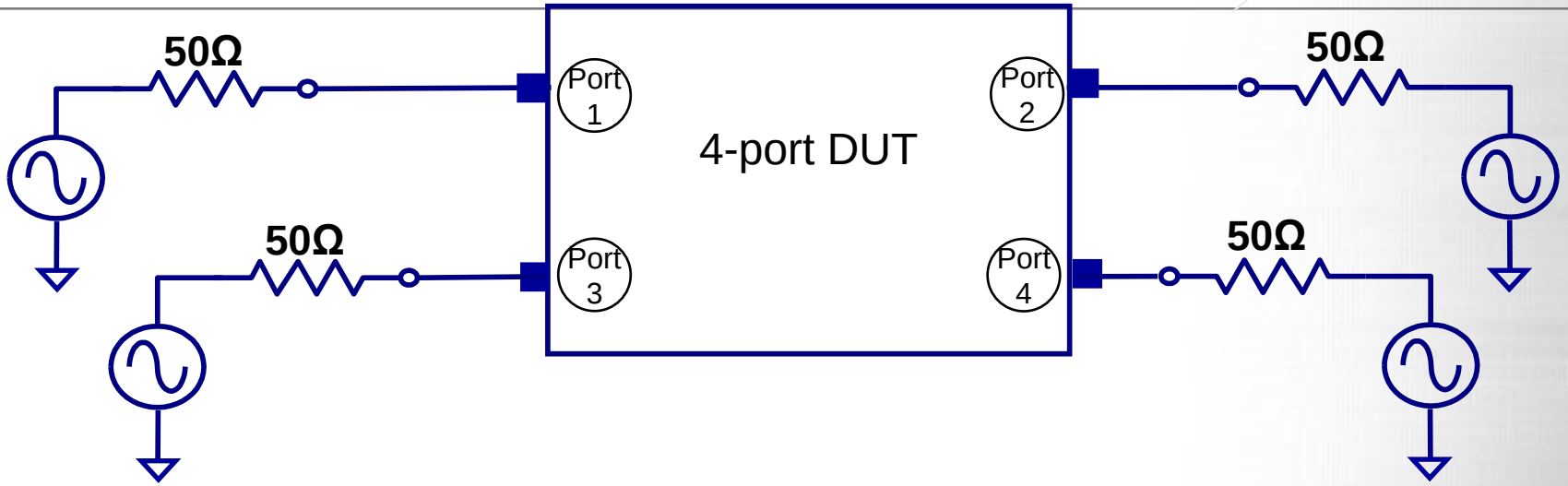
General 4 port Measurement Setup



- ✓ ***4-port DUT can be modeled as single-ended or differential***
  - ❖ ***Single ended S-parameter measurements for a 4-port network are straightforward—just like 2-port case, only more S-parameters***

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{21} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{24} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

  - ❖ ***A 4-port DUT can also be modeled as 2-port differential DUT and in this case represented using "Mixed-Mode" S-Parameters***

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Practical Lab

Time Domain Reflectometry (TDR) and S-parameter

"Measurements and Best Practice for Signal Integrity"

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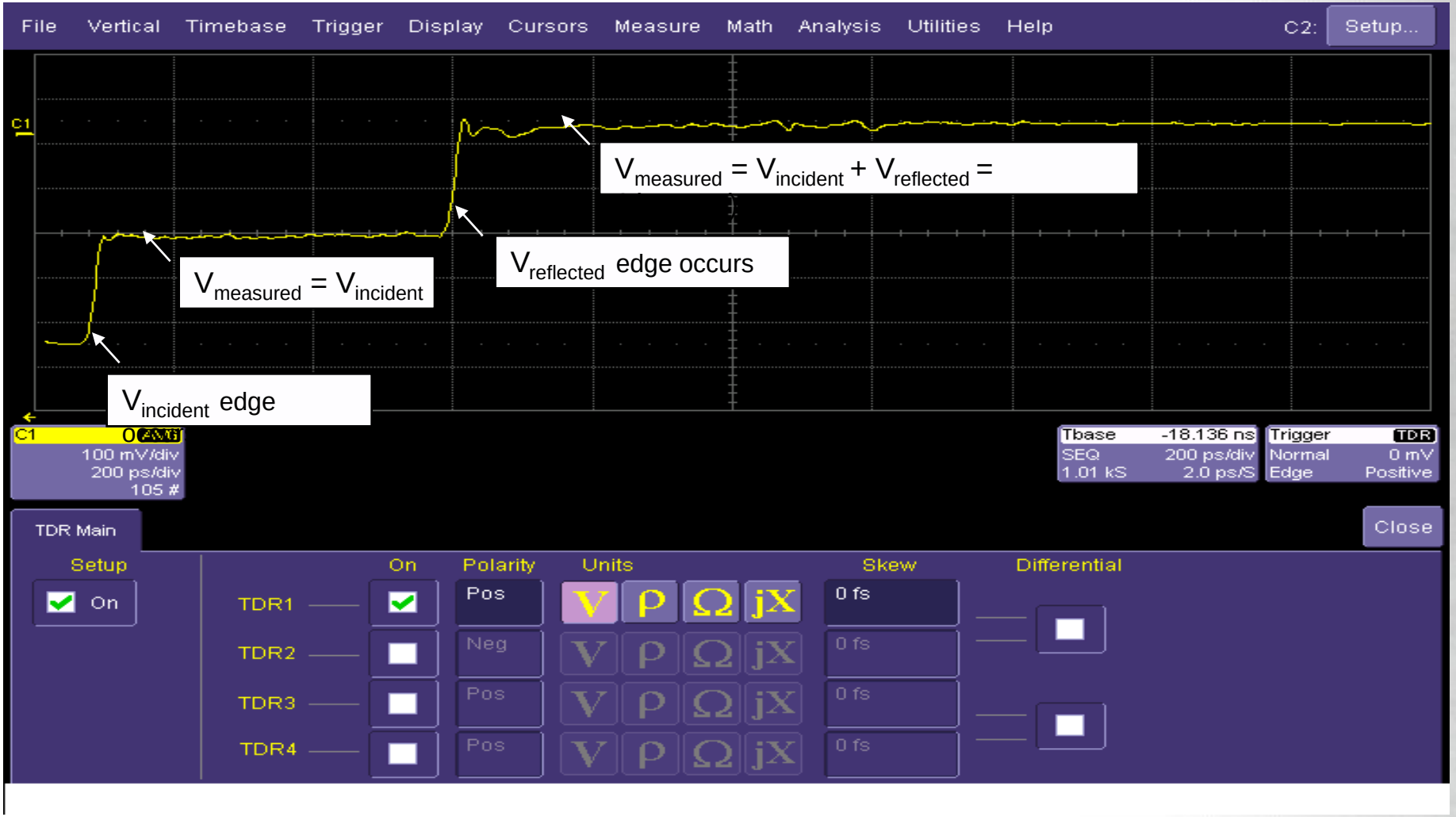
Open in the air
TDR example



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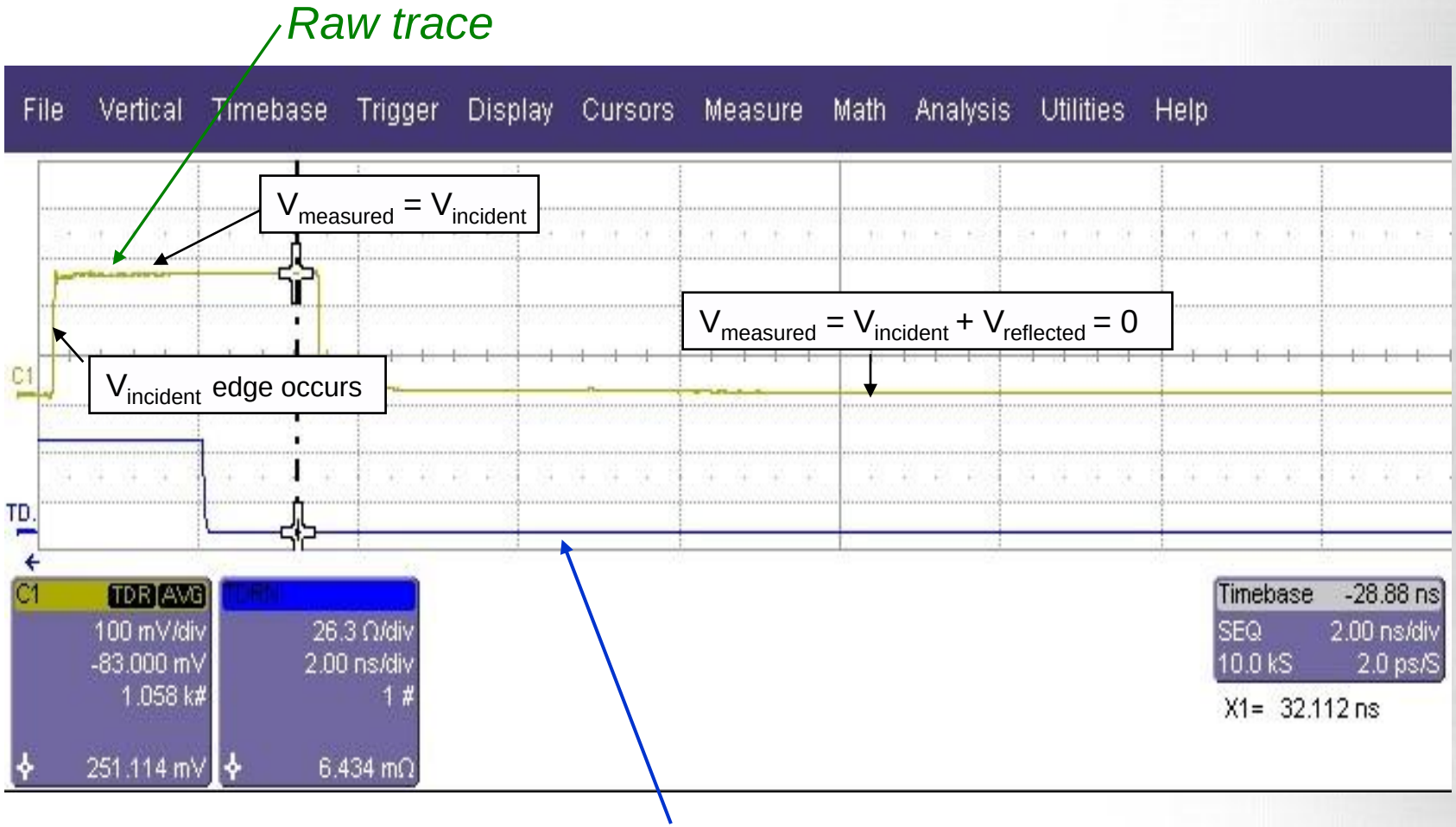
Short terminated (Z_{load} = 0)

TDR example



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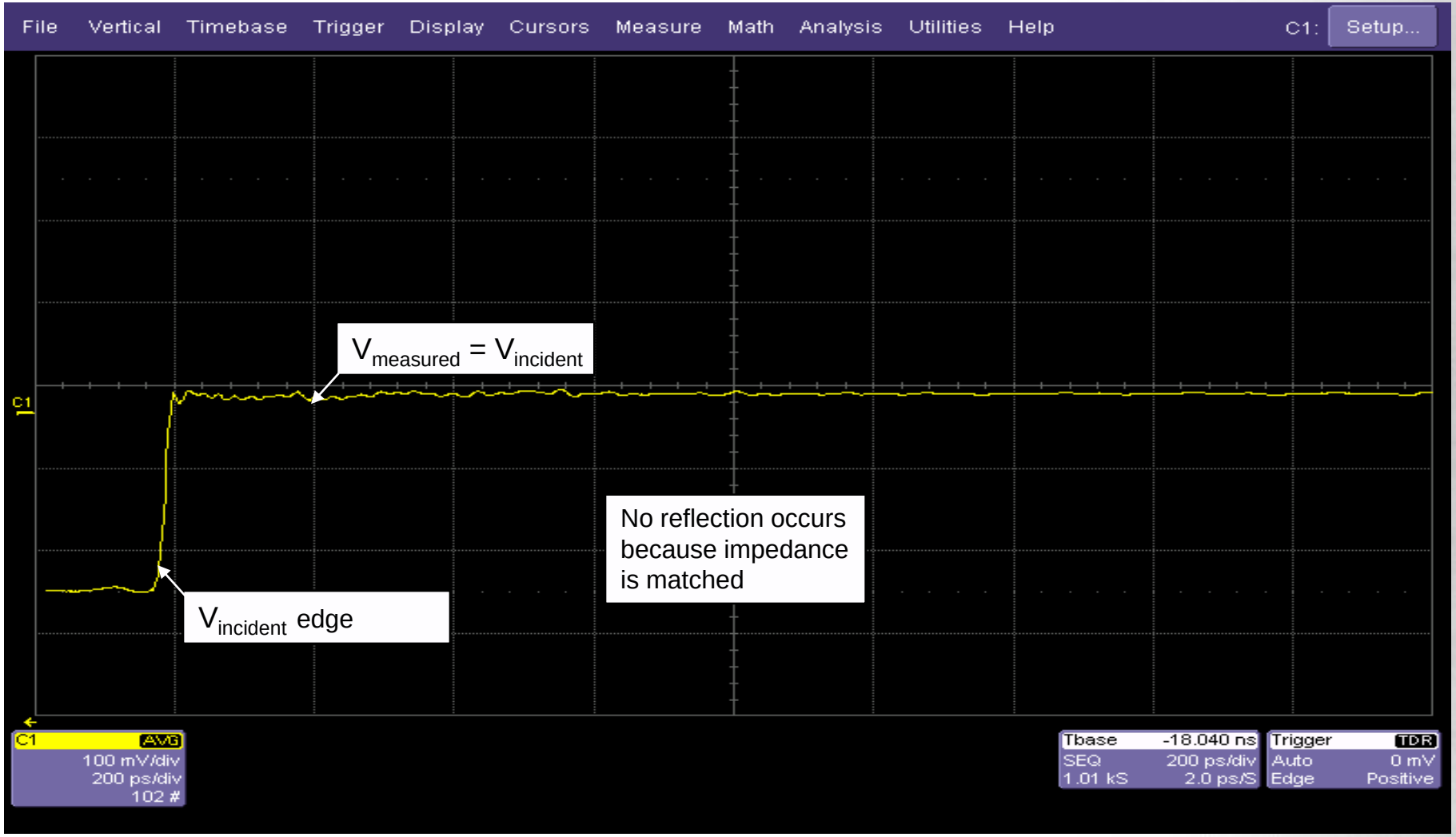
Matched Impedance
TDR example



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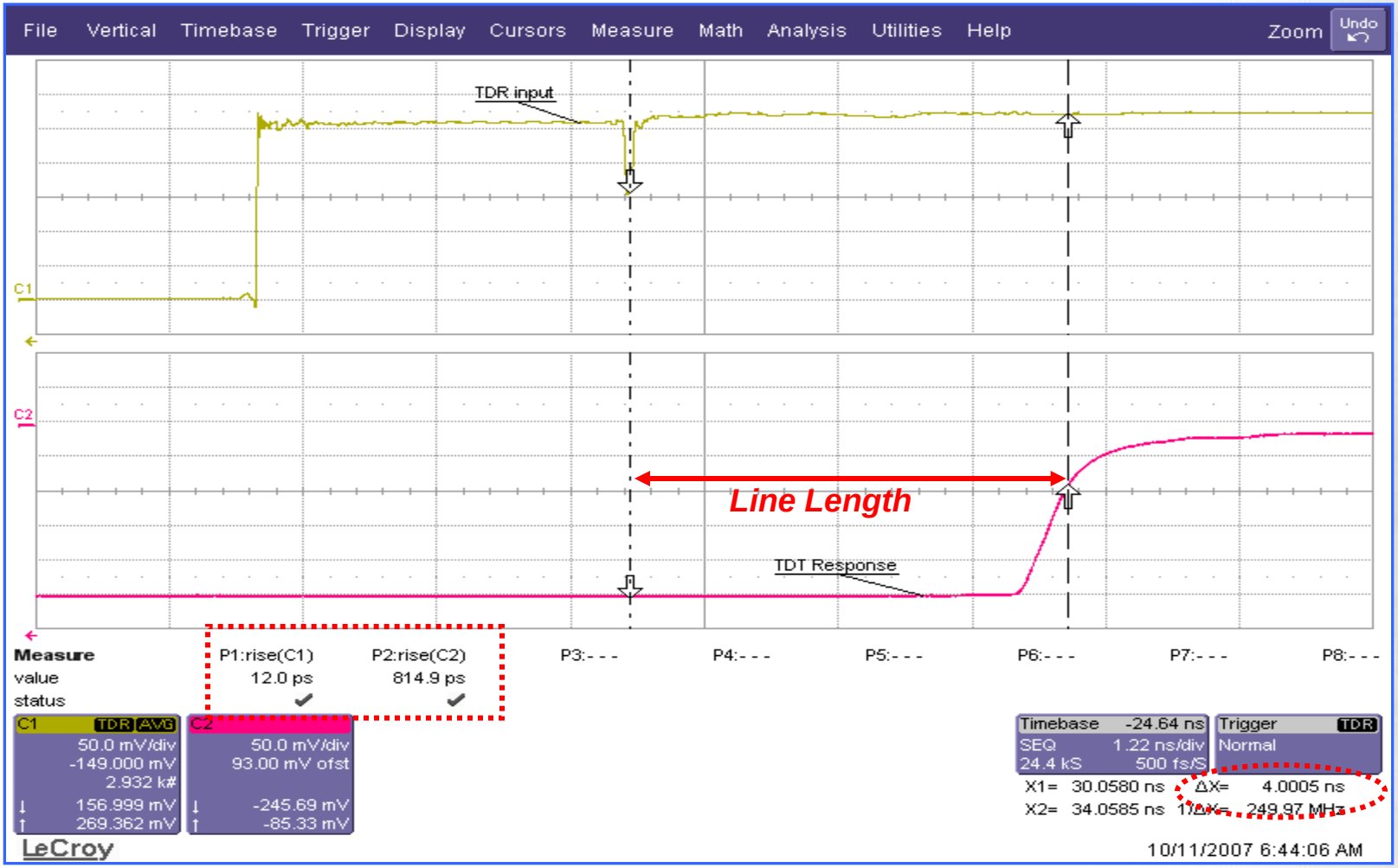
Rise-time Degradation on a 24” Line



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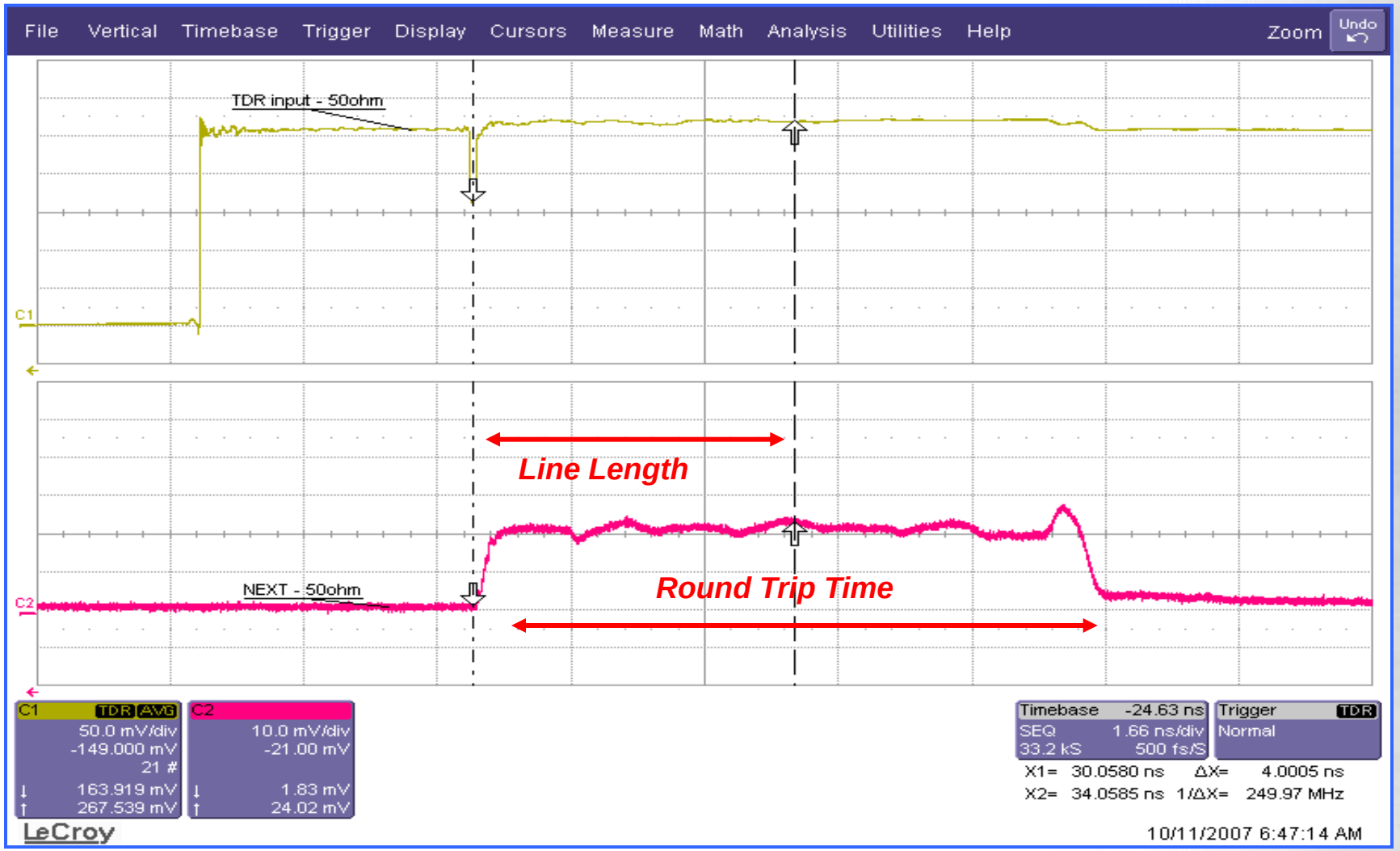
NEXT – Quiet Line @ 50Ω



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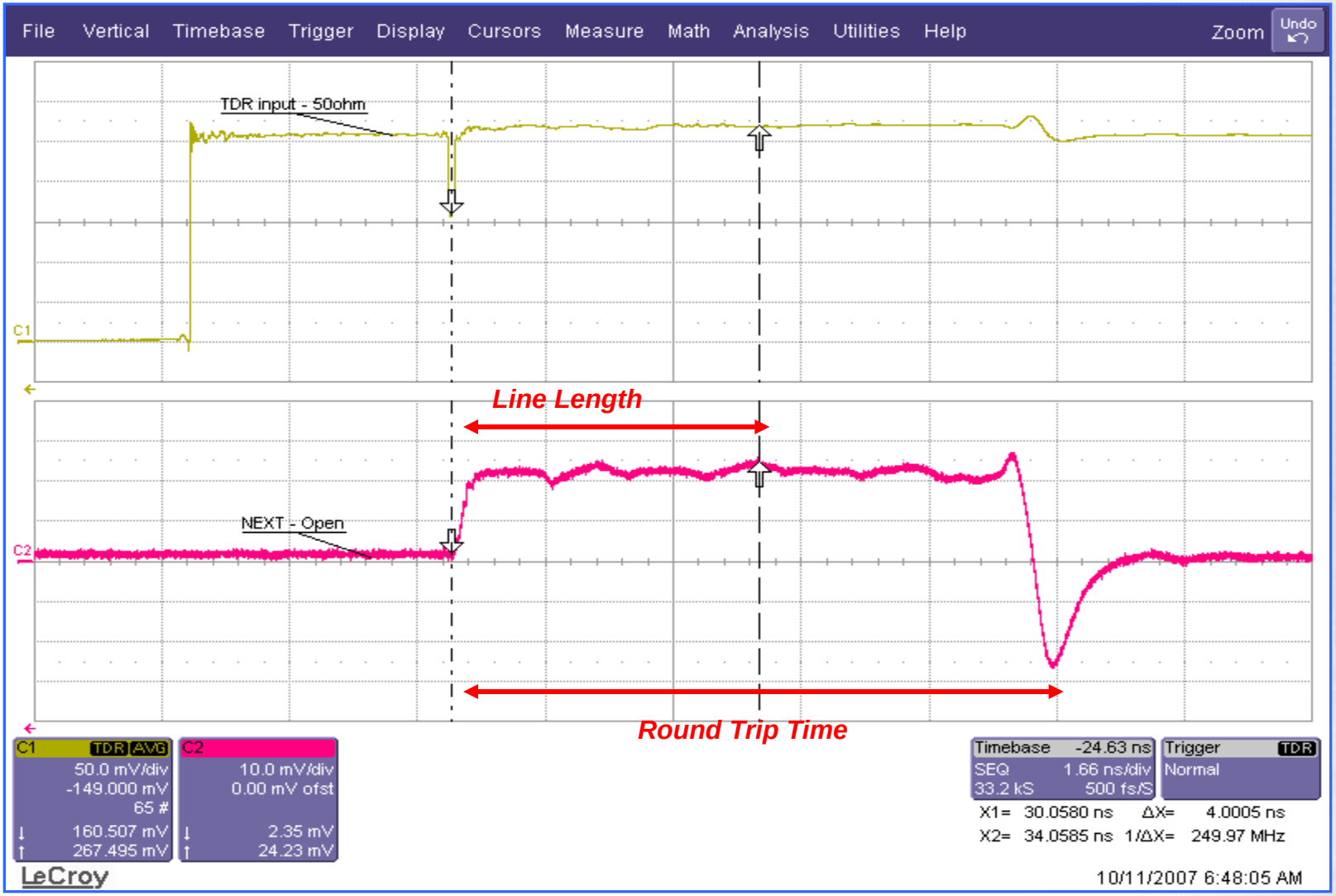
NEXT – Quiet Line Open Terminated



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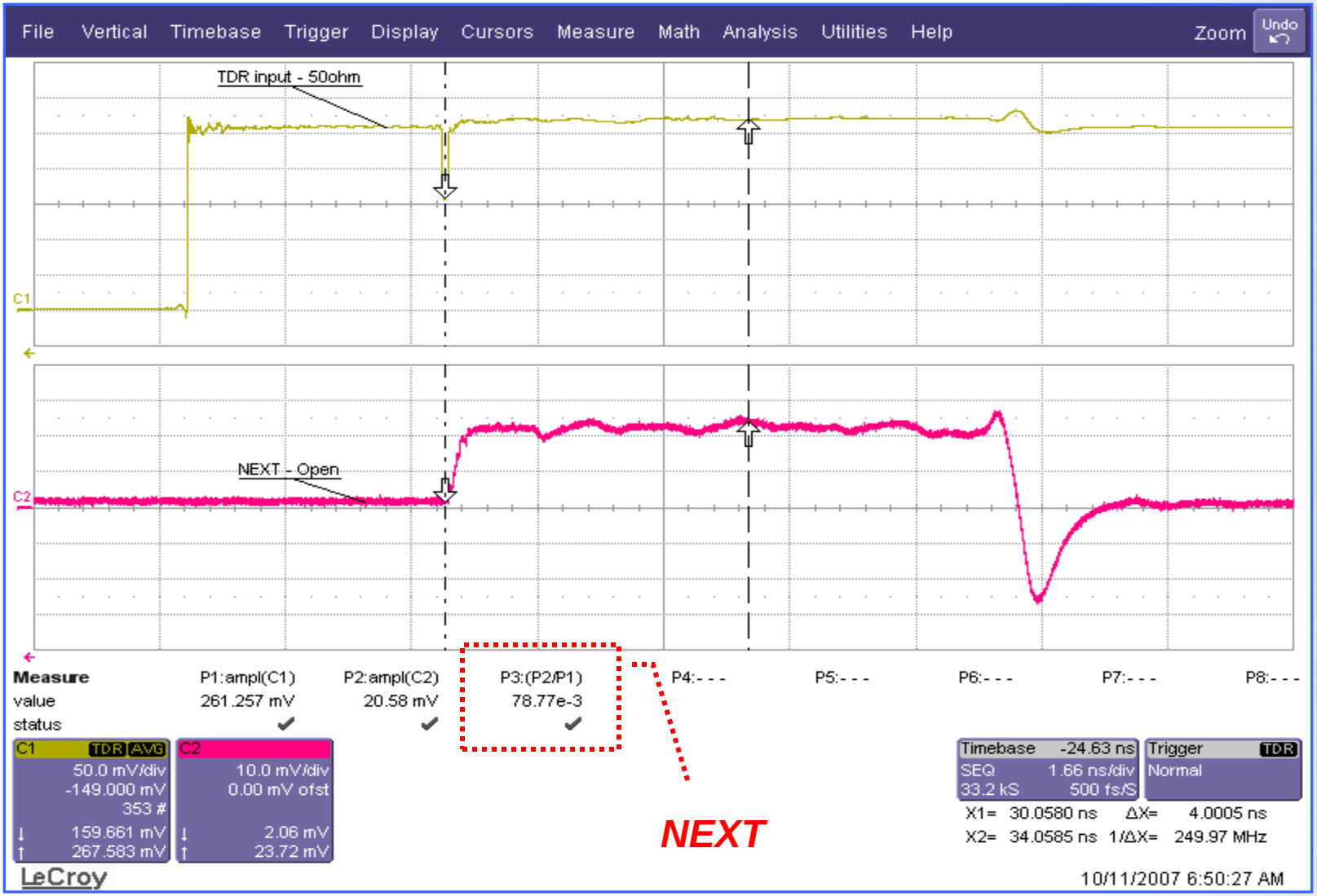
NEXT – Quiet Line Open Terminated readout



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FEXT – Quiet Line Open Terminated

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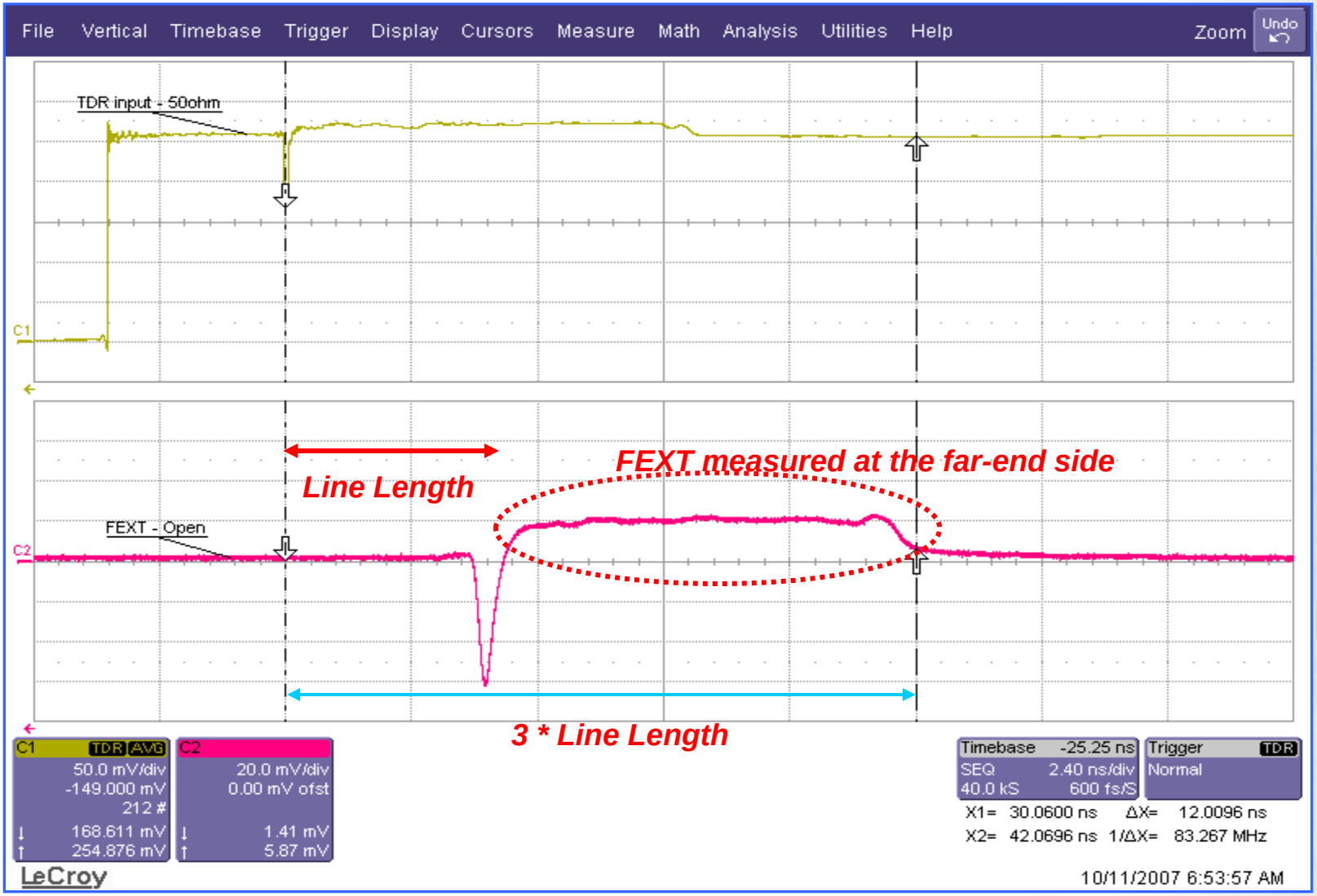
FEXT – Quiet Line Open Terminated (cont.)



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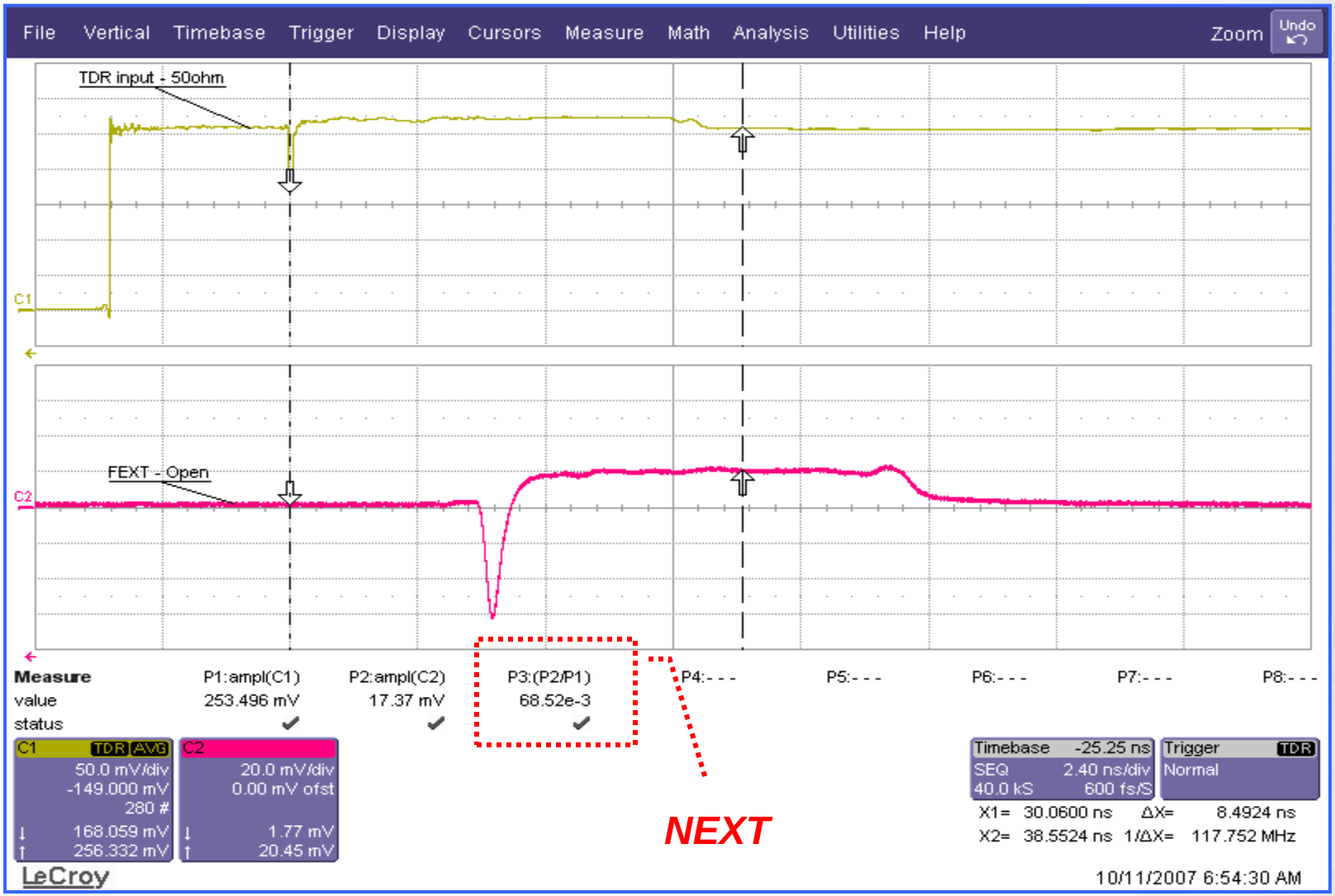
FEXT – Quiet Line Open Terminated readout



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