Time Domain Reflectometry (TDR) measurements for Signal Integrity.

Roy Ediss, November 2005.

At high speeds circuit interconnects become transmission lines.

If line delay (td) > 20% of driver rise time, we are therefore creating transmission lines on digital PCB layouts and need to verify their parameters.

What transmission line parameters can be determined with TDR?

Impedance
Propagation Time delay
Relative Dielectric Constant
Excess Capacitance and Inductance

Time Domain Reflectometry (TDR) & Time Domain Transmission (TDT),

compared to

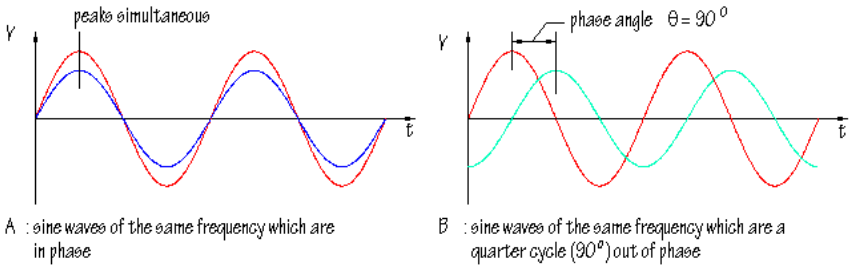
Vector Network Analysis (VNA)

VNA.

VNA measures voltage versus frequency - analysis is in the Frequency Domain.

Instrument has a 50 Ohm system impedance.

Sine wave output.



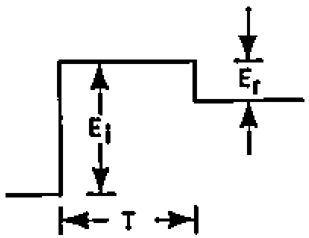
Circuit reflection and transmission parameters are determined by comparison of the amplitude and phase difference of input and reflected\transmitted signal.

TDR\T

TDR\T measures voltage versus time. - analysis is in the Time Domain.

Instrument has a 50 Ohm system source impedance, against which load impedance may be determined.

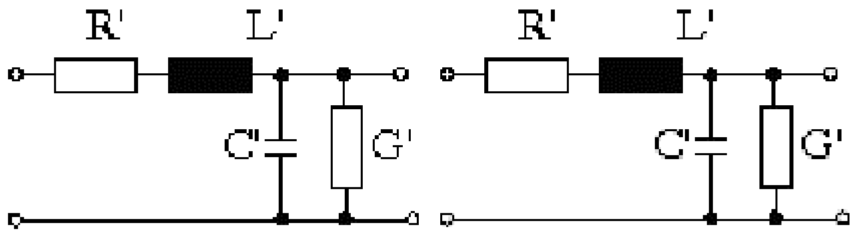
Standard instrument 35pS risetime output pulse.
(Picosecond Pulse Labs. bolt-on produces 7pS risetime).



Important capability to “look through” and isolate distributed circuit parameters in time domain.

<u>TDR measurements</u>. **<u>Impedance.</u>**

Impedance of a transmission line is created from the distributed resistance, inductance and capacitance.



Lumped element unit-per-length equivalent circuit of a two-conductor transmission line for TEM mode of propagation.
Where the per-unit-length parameters are:
R = Resistance m^{-1} L = Inductance m^{-1} C = Capacitance m^{-1} G = Conductance m^{-1}

Characteristic Impedance

$$Z_0 \quad \sqrt{\frac{j\omega L' - R}{j\omega C' + G'}} \qquad [\Omega]$$

losses can generally be neglected to give:

$$Z_C = \sqrt{\frac{L'}{C'}} \qquad [\Omega]$$

Measurement of impedance from Reflection Coefficient.

Impedance can be defined in terms of how waveforms interact with a circuit.

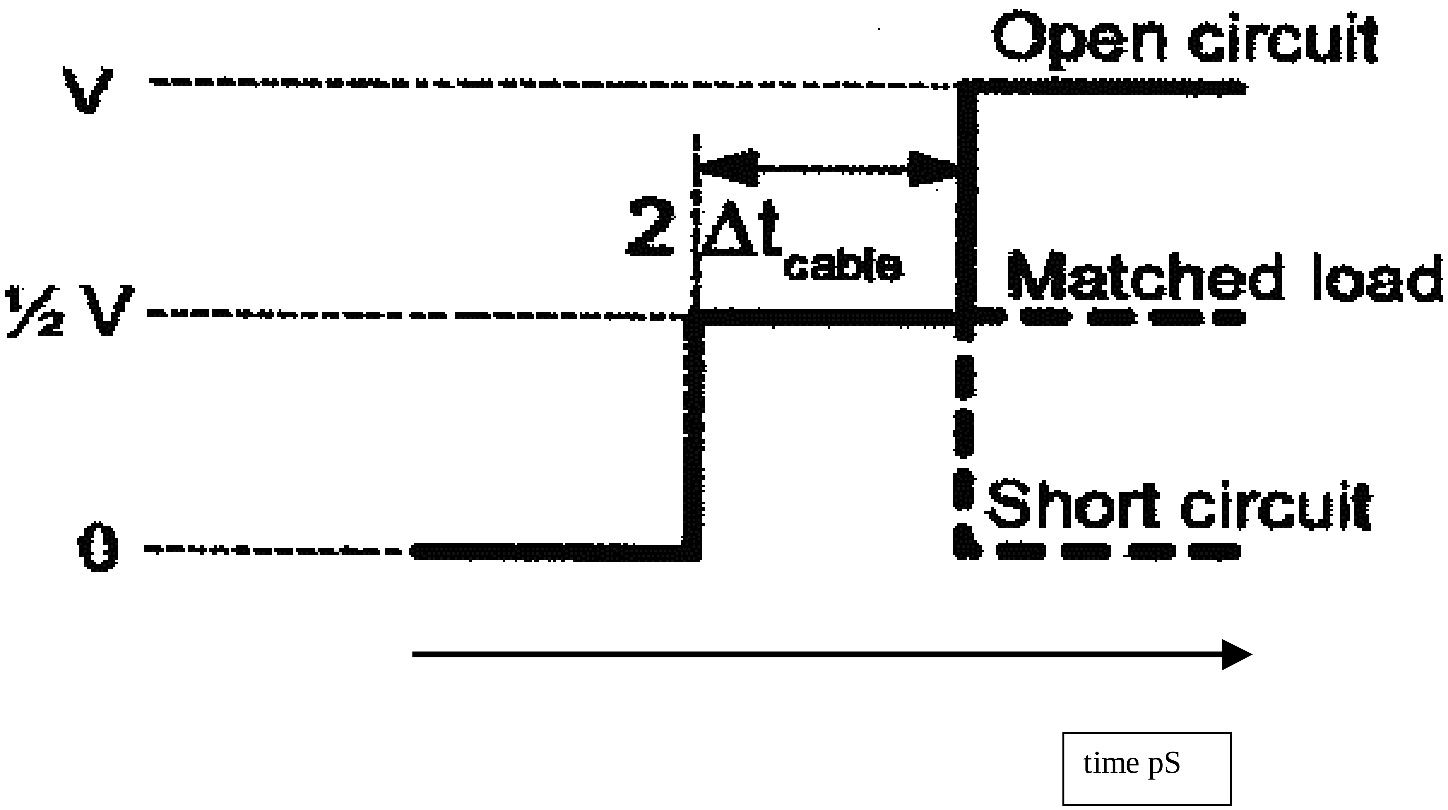
If an incident wave propagates from a circuit region with impedance Z_L and hits another region with Zo it can be reflected, and the Reflection Coefficient is related to the two impedances by:

$$\rho = \frac{V_{reflected}}{V_{incident}} = \frac{(Z_L - Z_0)}{(Z_L + Z_0)}$$

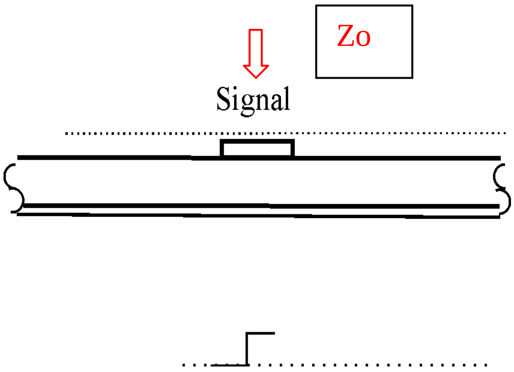
The Reflection Coefficient may be determined if Vreflected is measured and Vincident is known (instrument property).
And Z_L is known (instrument property i.e. 50 Ohms),
So then Zo can be determined from:

$$Z_0 = Z_L * \frac{(1+\rho)}{(1-\rho)}$$

Measurement of impedance from Reflection Coefficient.



Characteristic Impedance of single ended, microstrip, stripline, and coplanar transmission line.



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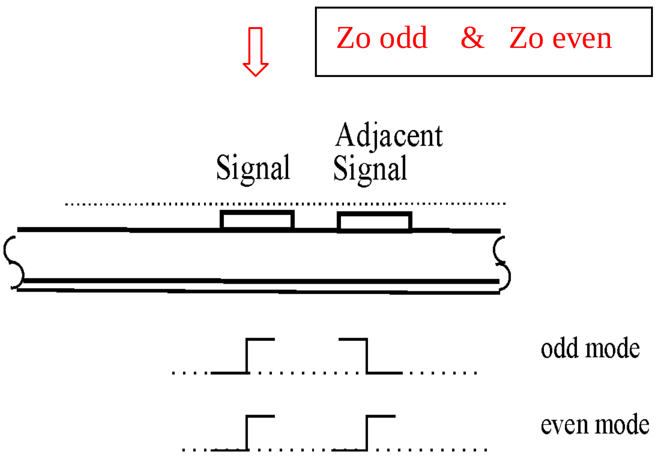
Characteristic Odd Mode & Even Mode Impedance of coupled single ended transmission line.

Note: Zo odd, decreases and Zo even increases compared to uncoupled Zo value when adjacent track is driven.



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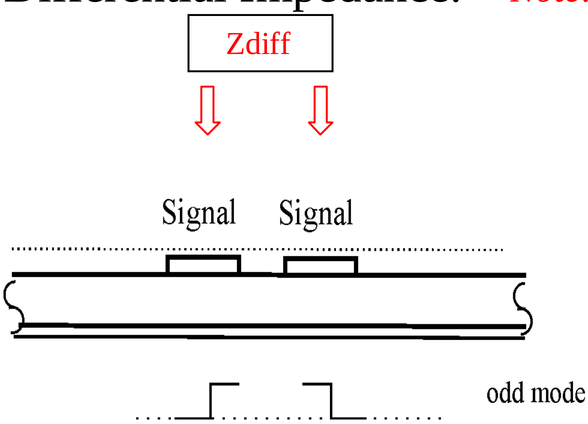
Differential Impedance. *Note: Z diff is twice Zo odd.*



TDR measurements.

Propagation Time delay.

Relative Dielectric Constant or Relative Permittivity

Propagation time, t_d can be measured.
Note: that the transit time T from physical circuit point 1 to point 2 on the TDR screen is: $T = t_d * 2$

And if the distance d, between two physical points is known then after measuring t_d, the actual signal velocity in the dielectric can then be determined from:

$$v = \frac{d}{t_d}$$

If the velocity of propagation in a dielectric is given by:

$$v = \frac{1}{\sqrt{\varepsilon_r}} \times v_c$$

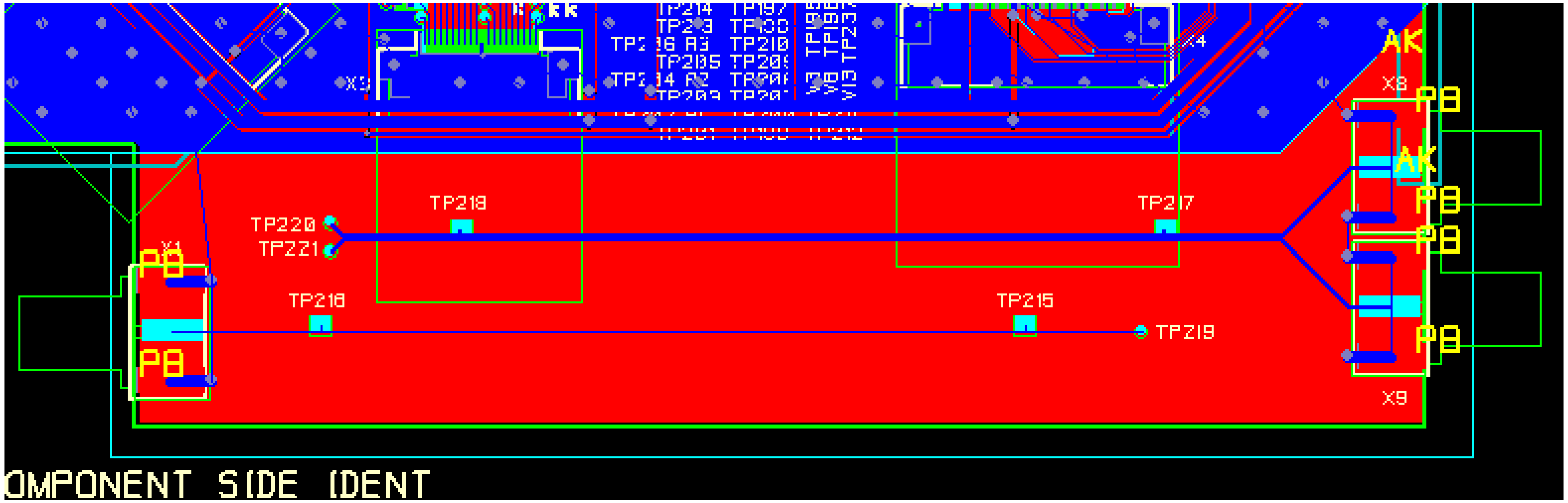
Where v_c is constant speed of light $300*10^6$ ms^{-1}

Then the Relative Dielectric constant can be determined from:

$$\varepsilon_r = \left(\frac{v_c}{v}\right)^2$$

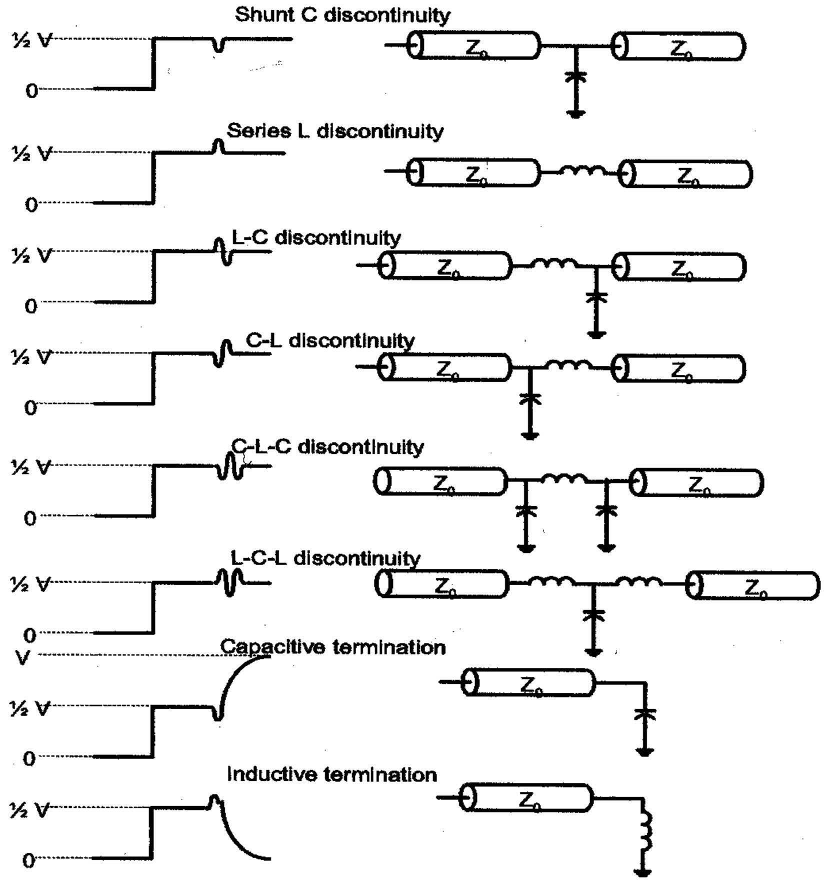
TDR measurements.
Test coupons and structures.

PCB single ended microstrip and differential transmission line test piece, with d = 60mm between marker flags.



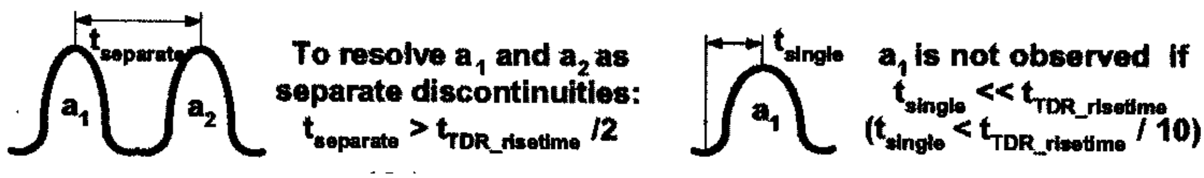
Note that this will provide an effective dielectric constant because some field is in air.
A buried stripline would be required to determine actual dielectric constant.

TDR\TDT measurements.
Excess Capacitance and Inductance



Visual waveform effects from discontinuities and lumped element analysis.

Faster pulse risetime = better resolution
TDR resolution rules of thumb.



With standard TDR:
($t_{separation.}$ > ½ TDR risetime = 17.5pS) (1/10 TDR risetime = 3.5pS)

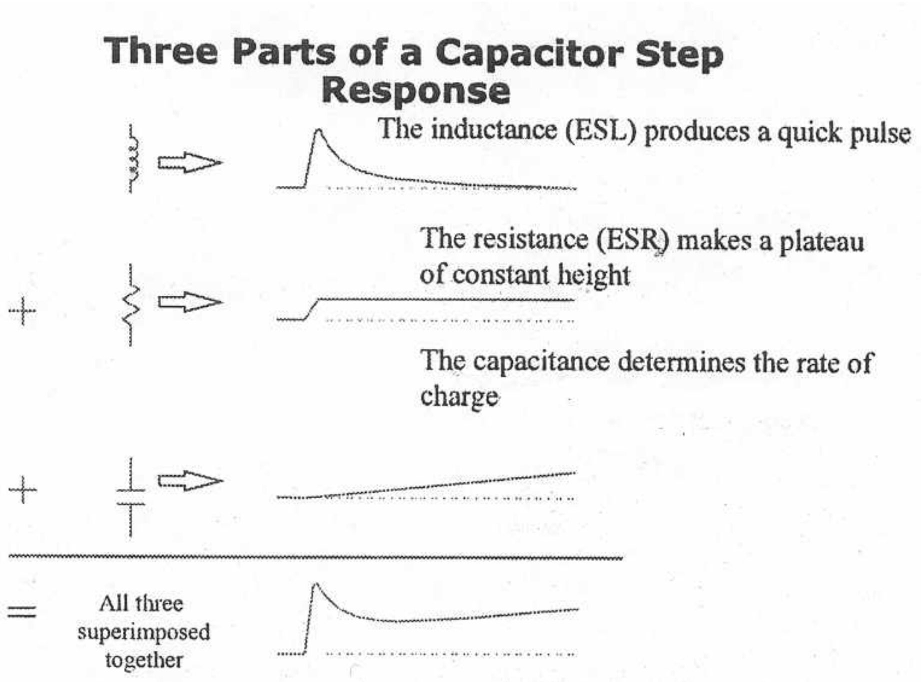
TDR\TDT measurements.

Using excess capacitance and inductance instrument feature.

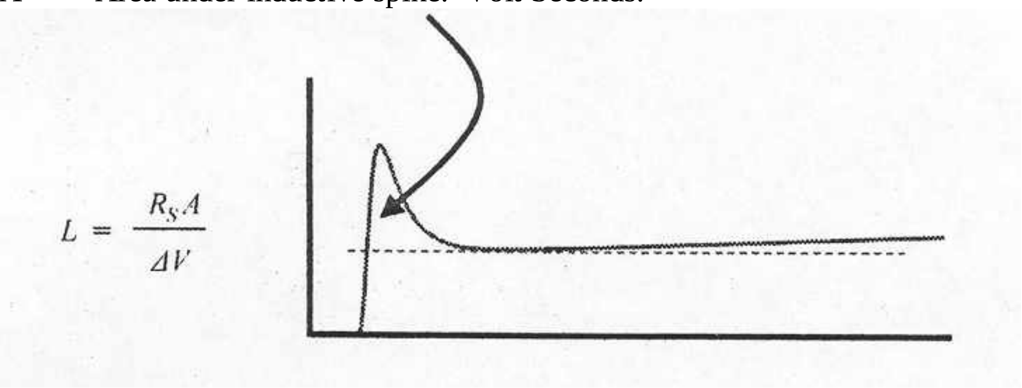
Evaluating the inductance associated with bypass capacitors using Time Domain Reflectometry (TDR) and Time Domain Transmission (TDT).

There is an interest in measuring the often very small value of inductance associated with a capacitor, without the reliance on the careful normalization that is required with a Network/Component Analyzer. If the component is mounted in a shunt arrangement across a test fixture, the capacitance may be determined from the TDR response. Additionally from the TDT response, the value of the components inductance may be determined from the area under the initial pulse observed. The measurement instruments Excess Reactance feature can calculate this area and hence inductance value.

Composition and determination of inductance from area under TDT response.

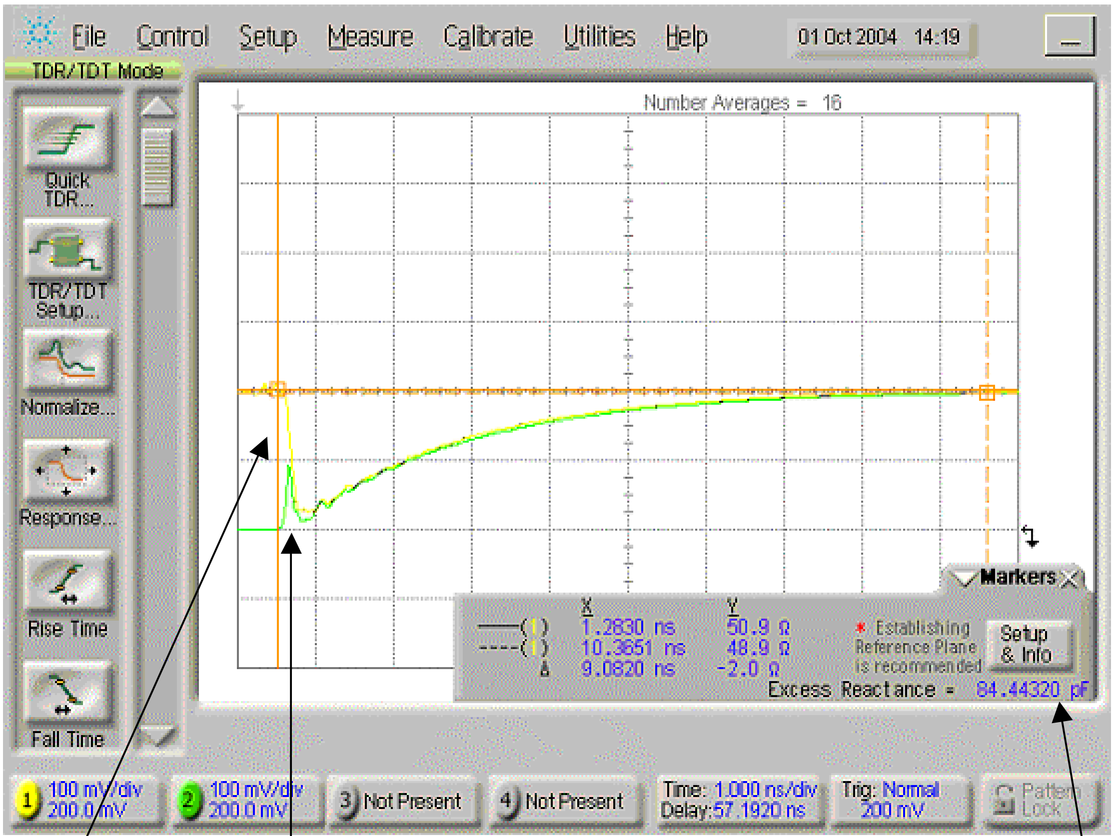


Rs	Source impedance (resistance) of measurement system and test jig. Ohms
V	Open circuit step voltage of test jig. Volts.
L	Inductance. Henries.
A	Area under inductive spike. Volt Seconds.



TDR\TDT measurements.

Using excess capacitance and inductance instrument feature.

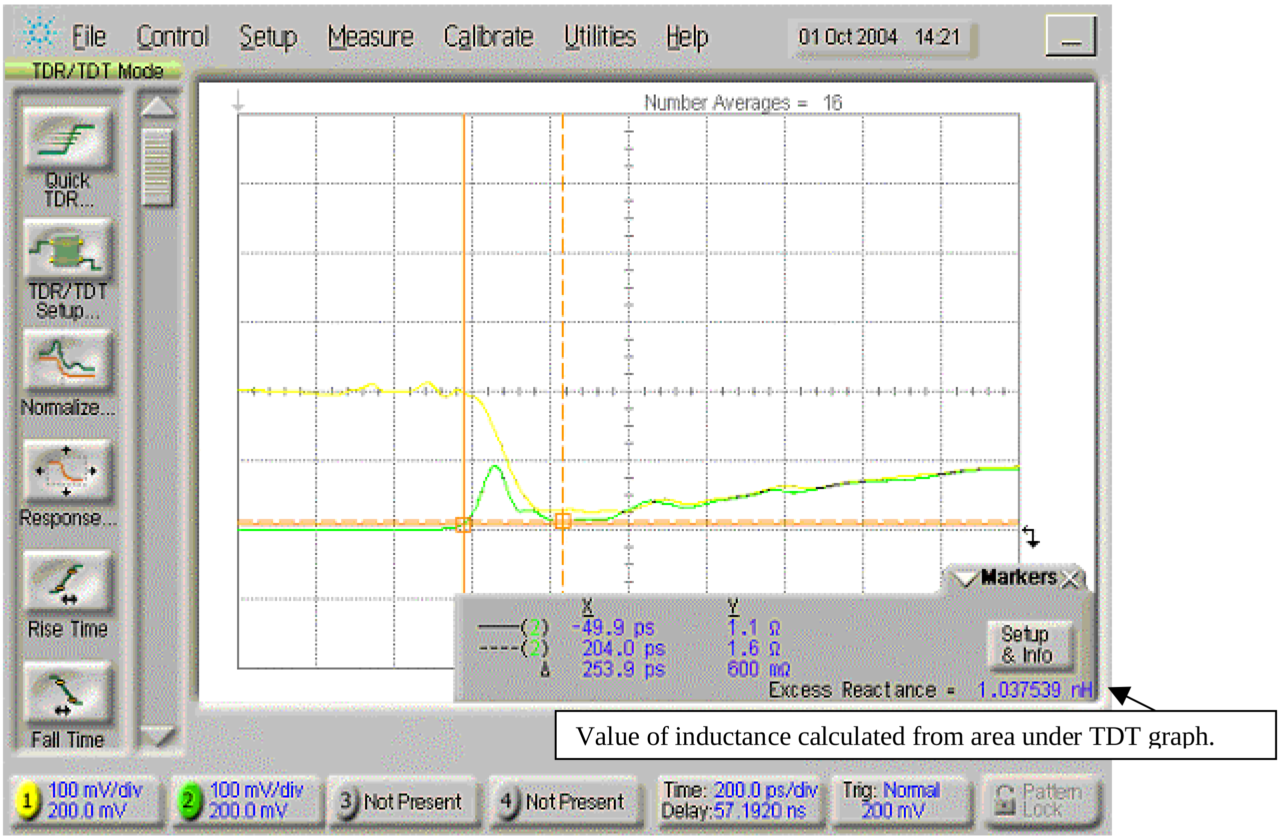


Value of capacitance determined from area under TDR

TDR (yellow) and TDT (green) initial pulse response of capacitor (82pF) across 50 Ohm transmission line. Measurement cursers on TDR response.

TDR\TDT measurements.

Using excess capacitance and inductance instrument feature.

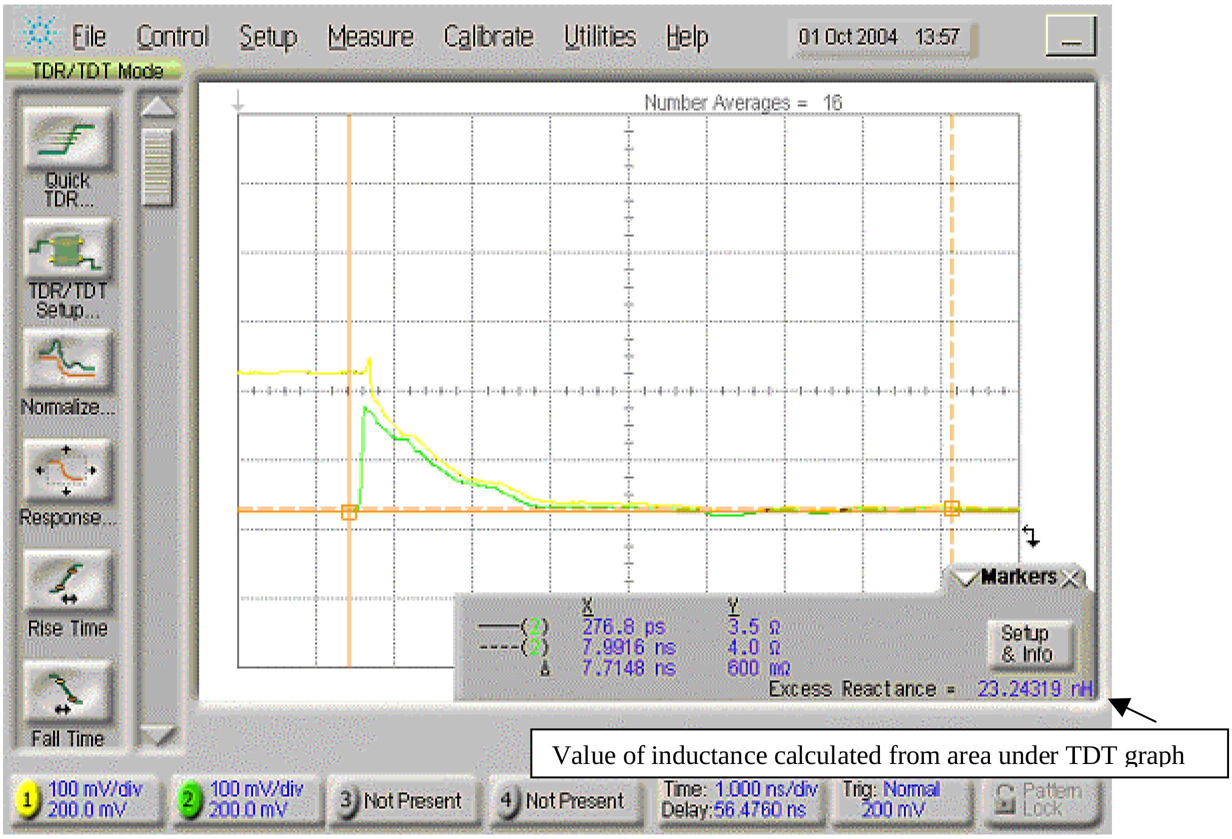


TDR and TDT (green) response of capacitor (82pF) across 50 Ohm transmission line, (with expanded horizontal time scale). Measurement cursers on TDT response.

TDR\TDT measurements.

Using excess capacitance and inductance instrument feature.

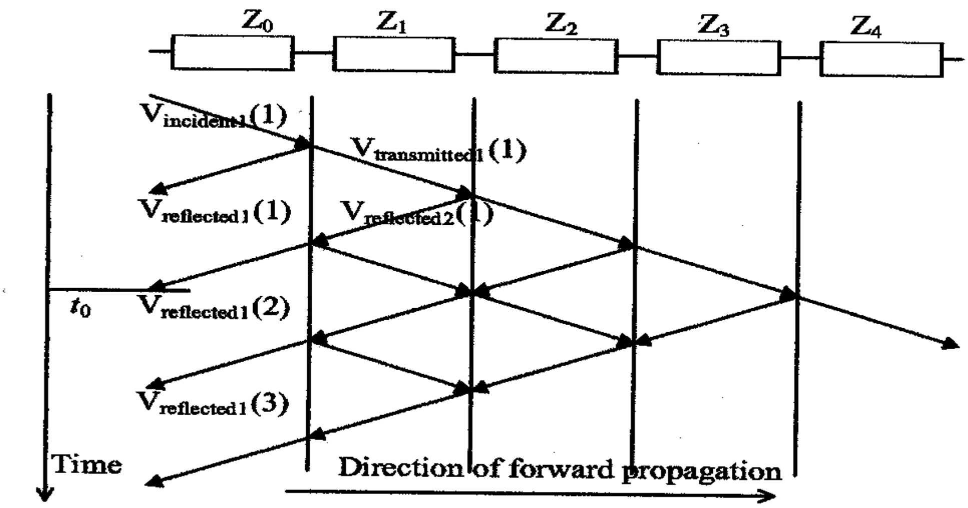
The value of inductance associated with a bypass capacitor component is fairly small compared to the value of its mounting position inductance on a PCB. The total component and mounting inductance value, can be determined by probing at the IC supply pins and assessing the TDT response.



TDR (yellow) and TDT (green) response at the PCB IC DC supply pins with bypass capacitor (100nF) in position. Measurement cursers on TDT response.

Parameter and model generation using IConnect software from Tektronix.

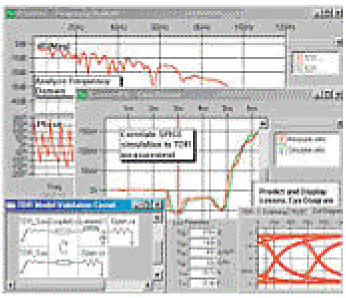
Software that analyzes the TDR\TDT waveform, considers multiple reflections along a circuit and generates a SPICE or IBIS model.



Multiple reflections which result in incorrect readout of impedance in multi-segment circuits.

IConnect FEATURES & BENEFITS

- Easily Analyze Source of Interconnect Jitter, Losses, Crosstalk, Reflections, and Ringing
- Efficiently Model PCBs, Flexboards, Connectors, Cables, Packages, and Sockets
- Analyze Interconnects Concurrently, in Time and Frequency Domains
- Perform Cost-Effective Eye Mask Test, Insertion, and Return Loss Specification Compliance Testing
- Obtain More Accurate Impedance Measurements
- Quickly Locate Interconnect Failures



See:
http://www.tek.com/products/oscilloscopes/sampling/interconnect_analysis/index.html