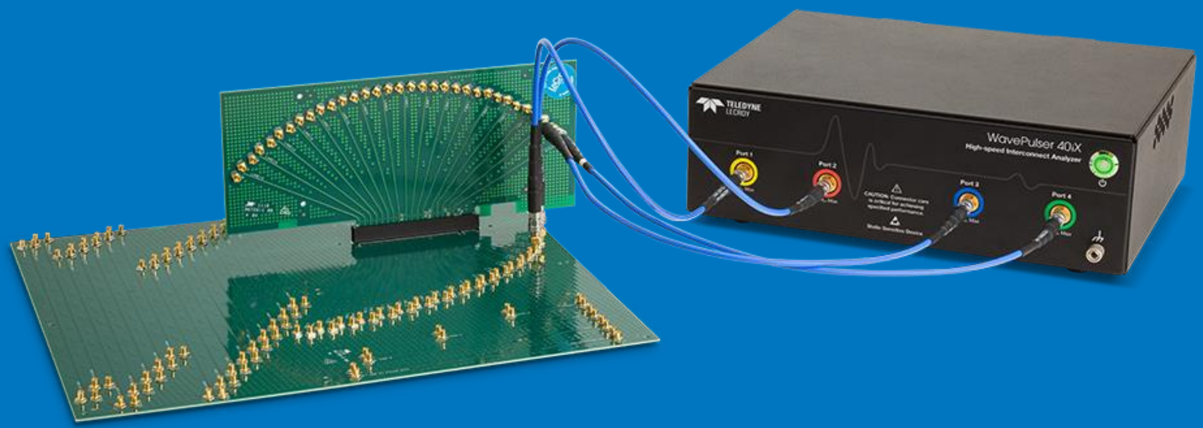
Rise time and Spatial Resolutions for WavePulser 40iX

High Speed Interconnect Analyzer

April-2020



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Everywhereyoulook™

Unmatched Characterization Insight

WavePulser 40iX: Testing in frequency and time domain

Time Domain

TDR

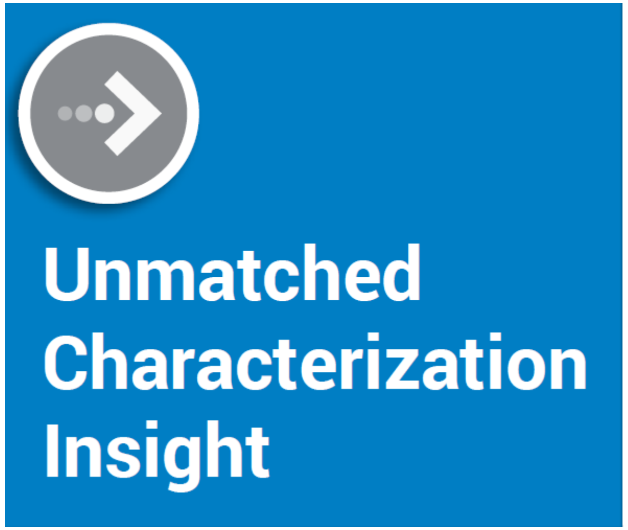
Frequency Domain

VNA

Deep Toolbox

(S-parameter de-embedding, Time Gating, Emulation equalized eye-diagram and jitter analysis)

The combination of S-parameters (frequency domain) and Impedance Profile (time domain) in a single acquisition with a deep toolbox for simulation, emulation, de-embedding and time-gating provides:



WavePulser 40iX in a nutshell

Testing in frequency and time in a single acquisition

DC to 40 GHz
Mixed-mode

S-parameters

Frequency Domain

Spatial Resolution < 1 mm
Differential and Common mode

Step and Impulse response
(rise time < 8.5 ps)
Impedance Profile

Time Domain

De-Embedding
Time Gating

Equalized eye-diagram
Jitter Analysis

Deep Toolbox

WavePulser 40iX
High Speed Interconnect Analyzer

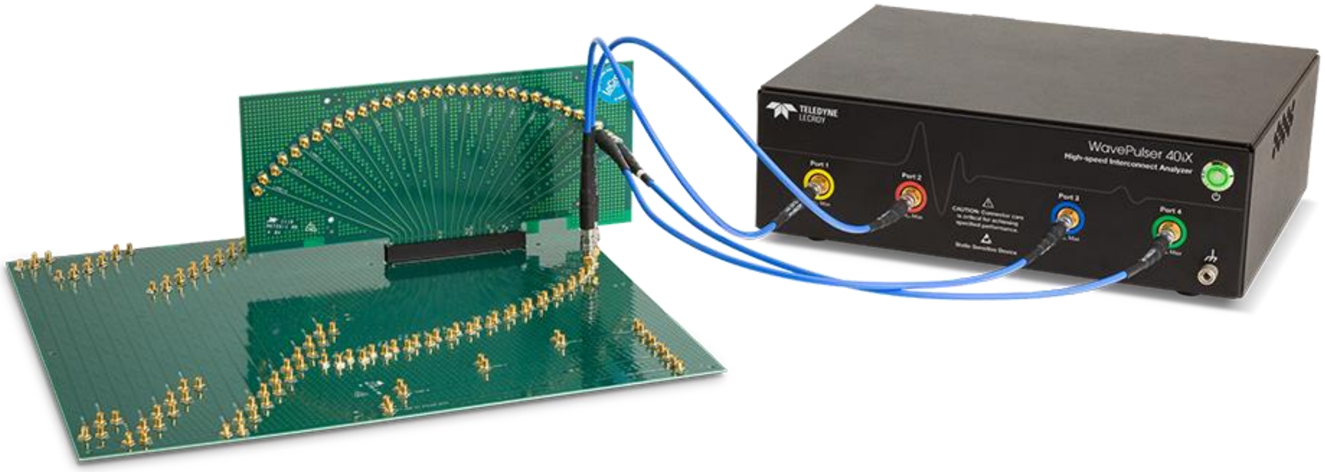
Unmatched Characterization Insight

WavePulser 40iX rise time and spatial resolution

- ❑ The relationship between rise-time and bandwidth in oscilloscopes is explored
- ❑ These concepts extend to time-domain reflectometer (TDR) instruments in the spatial resolution of the impedance profile plot

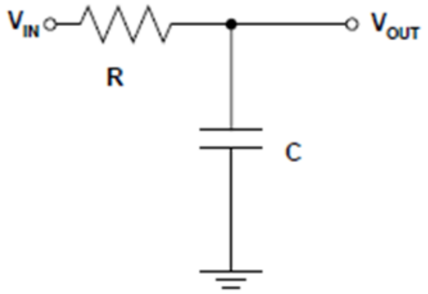
- ❑ WavePulser 40iX computes calibrated impedance profiles from DC to 40 GHz
- ❑ WavePulser 40iX directly measures the DC point, unlike the VNA, which is critical to proper time-domain analysis.
- ❑ WavePulser 40iX resolves impedance in traces with electrical length of 5.575 ps, or approximately 1 mm in length

High-speed Interconnect Analyzer: the ideal single tool for high-speed hardware designers and test engineers



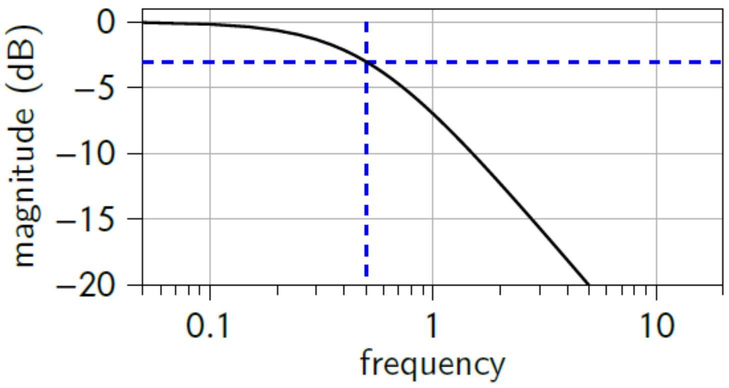
Relationship between rise time and bandwidth in oscilloscopes

- Resistance-capacitance network



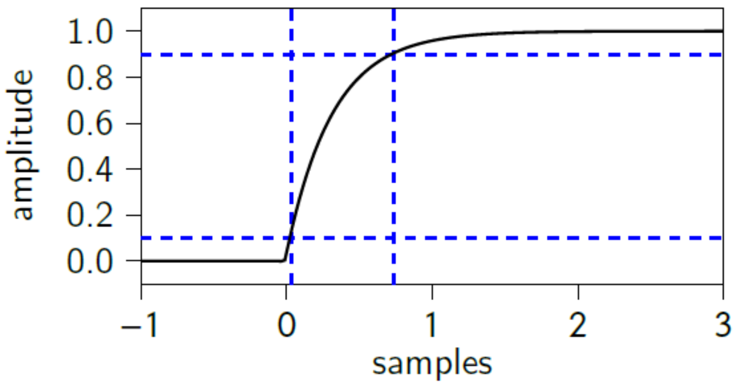
- Single-pole network with time constant $\tau = R \times C$
- Phase response is *minimum phase*

- Frequency response



- BW is considered the point where magnitude drops to -3 dB (f_{3dB})

- Rise time



- Rise-time is specified as the time the signal takes to traverse thresholds, i.e 10%-90% or 20%-80% ($rt_{10\text{-}90}$ and $rt_{20\text{-}80}$)

- *risetime* x *bandwidth* = *m*

$$rt_{10\text{-}90} \times f_{3dB} = 0.35$$

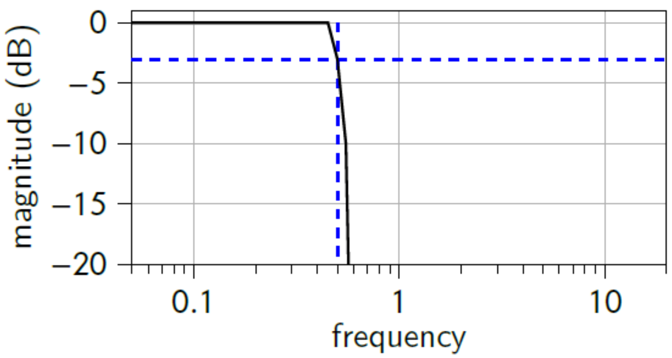
(commonly stated equation)

$$rt_{20\text{-}80} \times f_{3dB} = 0.221$$

Relationship between rise time and bandwidth in brick-wall system

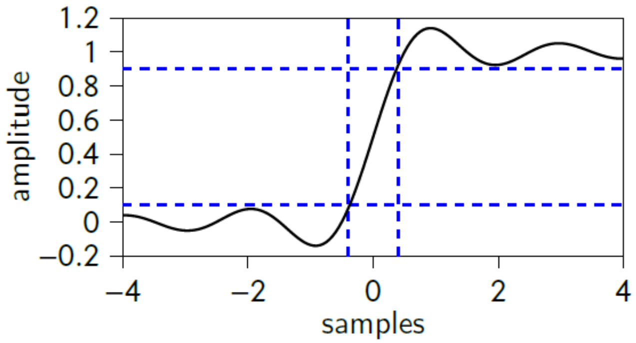
- A brick-wall system is one that passes frequency content with unity gain up to the a given frequency and no content after that frequency
- When considering S-parameters, the end frequency (F_e) defines an effective sample rate for the time-domain waveform. F_s= 2 x F_e and the sample period is T_s=1/F_s
- If F_e=40 GHz F_s=80 GHz and T_s=12.5 ps
- Step response generated from S-parameter file can be resampled to an higher effective rate using a sin(x)/x interpolation. Frequency response and step response of this system are shown in this slides
- Phase response is *linear phase*

- Frequency response



- BW is considered the point where magnitude drops to -3 dB (f_{3dB})

- Rise time



- Rise-time is specified as the time the signal takes to traverse thresholds, i.e 10%-90% or 20%-80% ($rt_{10\text{-}90}$ and $rt_{20\text{-}80}$)

- *risetime* x *bandwidth* = *m*

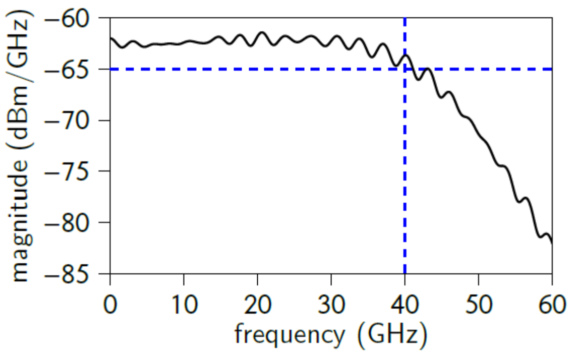
$$rt_{10\text{-}90} \times f_{3dB} = 0.446$$ (it was 0.35 for single-pole systems)

$$rt_{20\text{-}80} \times f_{3dB} = 0.317$$ (it was 0.221 for single-pole systems)

WavePulser 40iX Risetime

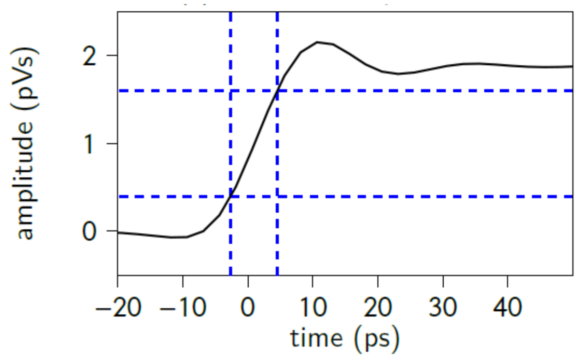
- WavePulser 40iX utilizes an impulse stimulus
- WavePulser 20-80 rise-time measurement of 7.23 ps
- WavePulser 40iX risetime is higher than for the single-pole system because the response characteristic drops more sharply than a single-pole response
  - The time-domains plots are generated from calibrated s-parameter measurements

- Frequency response



- Product of the pulser frequency content and the frequency response of the sampler
- Flat content of -62 dBm/GHz up to 40 GHz (f_{3dB} = 40 GHz)

- Rise-time



- Marker are placed at the 20% point and at the 80% point for a 20-80 risetime measurement of 7.23 ps ($rt_{20\text{-}80}$ = 7.23 ps)

WavePulser 40iX risetime is somewhere in between the single-pole system and brick-wall system

- *risetime* x *bandwidth = m*

$$rt_{20\text{-}80} \times f_{3dB} = 0.289$$

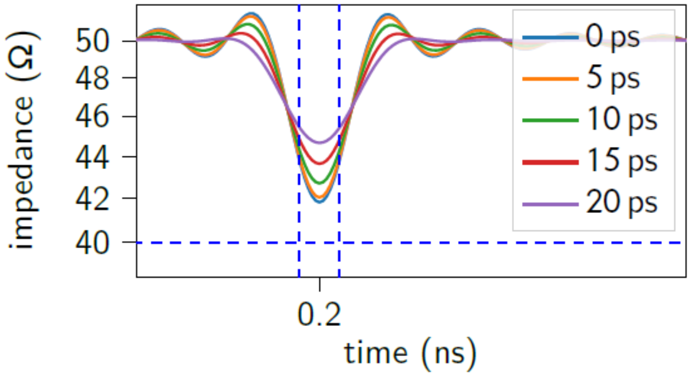
$$m_{brick\text{-}wall} < m_{WavePulser\ 40iX} < m_{single\text{-}pole}$$

$$0.317_{20\text{-}80} < 0.289_{20\text{-}80} < 0.221_{20\text{-}80}$$

Relationship between TDR risetime and spatial resolution

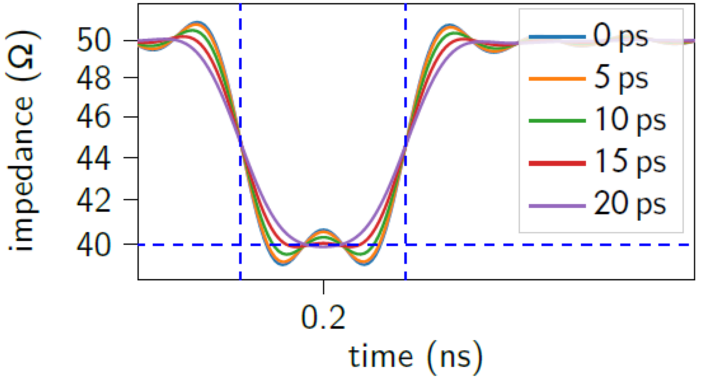
- TDR risetime and spatial resolution is recommended by the IPC for measuring the characteristic of lines on PCB
- Spatial resolution is defined as half the 10-90 risetime of the TDR instruments
- TDR risetime is the combination of the risetime of the pulser and the risetime inherent to the s-parameters, so risetime applied in the simulations do not by themselves determine any spatial resolution.
- The risetime of the applied step in the simulation adds in quadrature with the risetime inherent to the s-parameters.

- Spatial Resolution x1



- Spatial Resolution X1 shows what is resolvable

- Spatial Resolution x4



- Spatial resolution X4 is recommended to precisely measure an impedance

- To convert Spatial Resolution to physical length the propagation velocity must be known

$$L_{TL} = \frac{1}{2} \cdot rt_{10-90} \cdot v_p,$$

WavePulser 40iX Spatial Resolution (physical length)

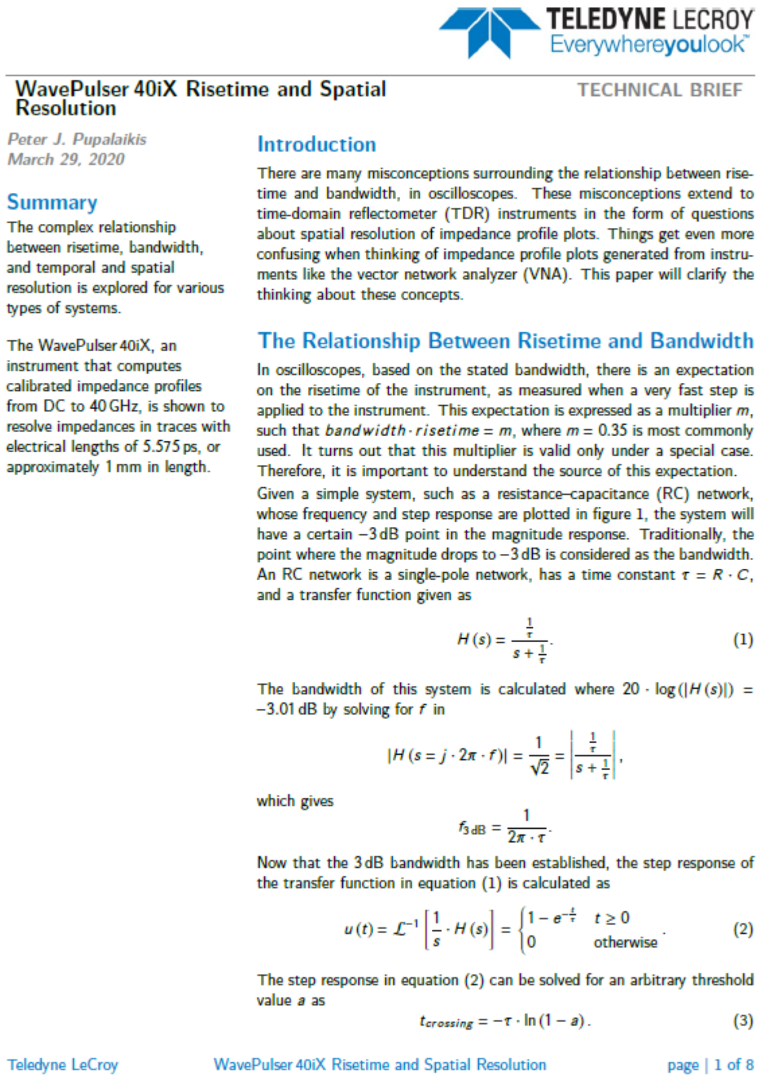
Trace Construction & Material	Dielectric Constant	WavePulser 40iX Spatial Resolution 1x	WavePulser 40iX Spatial Resolution 4x
air	1	1.672 mm	6.688 mm
microstrip (air,FR4)	2.25	1.115 mm	4.460 mm
stripline (FR4)	4.2	0.814 mm	3.256 mm
stripline (advance laminate)	3.7	0.870 mm	3.479 mm
Cable (PTFE)	2.1	1.154 mm	4.616 mm
Cable (PE)	2.3	1.103 mm	4.412 mm

Spatial Resolution 4x is the minimum recommended trace length for accurate impedance measurements when using the impedance profile

Rise time and spatial resolution for WavePulser 40iX

- Bandwidth and risetime are related in a manner that depends on the thresholds used to measure the risetime and in the shape of the magnitude and phase response of the system.
- Spatial resolution of TDR instruments depend on the risetime.
- WavePuser 40iX measures from true DC to 40 GHz.
- WavePulser 40iX has the ability to resolve impedance that are 5.575 ps in electrical length, which is approximately 1 mm of resolution for microstrip on FR4, and < 1mm in more common situations.

To know more go to:
https://teledynelecroy.com/doc/rise-time-and-spatial-resolution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WavePulser 40iX Risetime and Spatial Resolution — TECHNICAL BRIEF

Peter J. Pupalaikis
March 29, 2020

Summary

The complex relationship between risetime, bandwidth, and temporal and spatial resolution is explored for various types of systems.

The WavePulser 40iX, an instrument that computes calibrated impedance profiles from DC to 40 GHz, is shown to resolve impedances in traces with electrical lengths of 5.575 ps, or approximately 1 mm in length.

Introduction

There are many misconceptions surrounding the relationship between risetime and bandwidth, in oscilloscopes. These misconceptions extend to time-domain reflectometer (TDR) instruments in the form of questions about spatial resolution of impedance profile plots. Things get even more confusing when thinking of impedance profile plots generated from instruments like the vector network analyzer (VNA). This paper will clarify the thinking about these concepts.

The Relationship Between Risetime and Bandwidth

In oscilloscopes, based on the stated bandwidth, there is an expectation on the risetime of the instrument, as measured when a very fast step is applied to the instrument. This expectation is expressed as a multiplier m, such that $bandwidth \cdot risetime = m$, where $m = 0.35$ is most commonly used. It turns out that this multiplier is valid only under a special case. Therefore, it is important to understand the source of this expectation.

Given a simple system, such as a resistance–capacitance (RC) network, whose frequency and step response are plotted in figure 1, the system will have a certain −3 dB point in the magnitude response. Traditionally, the point where the magnitude drops to −3 dB is considered as the bandwidth. An RC network is a single-pole network, has a time constant $\tau = R \cdot C$, and a transfer function given as

$$H(s) = \frac{\frac{1}{\tau}}{s + \frac{1}{\tau}}. \qquad (1)$$

The bandwidth of this system is calculated where $20 \cdot \log(|H(s)|) = -3.01$ dB by solving for f in

$$|H(s = j \cdot 2\pi \cdot f)| = \frac{1}{\sqrt{2}} = \left|\frac{\frac{1}{\tau}}{s + \frac{1}{\tau}}\right|,$$

which gives

$$f_{3\,dB} = \frac{1}{2\pi \cdot \tau}.$$

Now that the 3 dB bandwidth has been established, the step response of the transfer function in equation (1) is calculated as

$$u(t) = \mathcal{L}^{-1}\left[\frac{1}{s} \cdot H(s)\right] = \begin{cases} 1 - e^{-\frac{t}{\tau}} & t \geq 0 \\ 0 & \text{otherwise} \end{cases}. \qquad (2)$$

The step response in equation (2) can be solved for an arbitrary threshold value a as

$$t_{crossing} = -\tau \cdot \ln(1 - a). \qquad (3)$$

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