IEEE SW Test Workshop
Semiconductor Wafer Test Workshop

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Probe Card Characterization in Time and Frequency Domain

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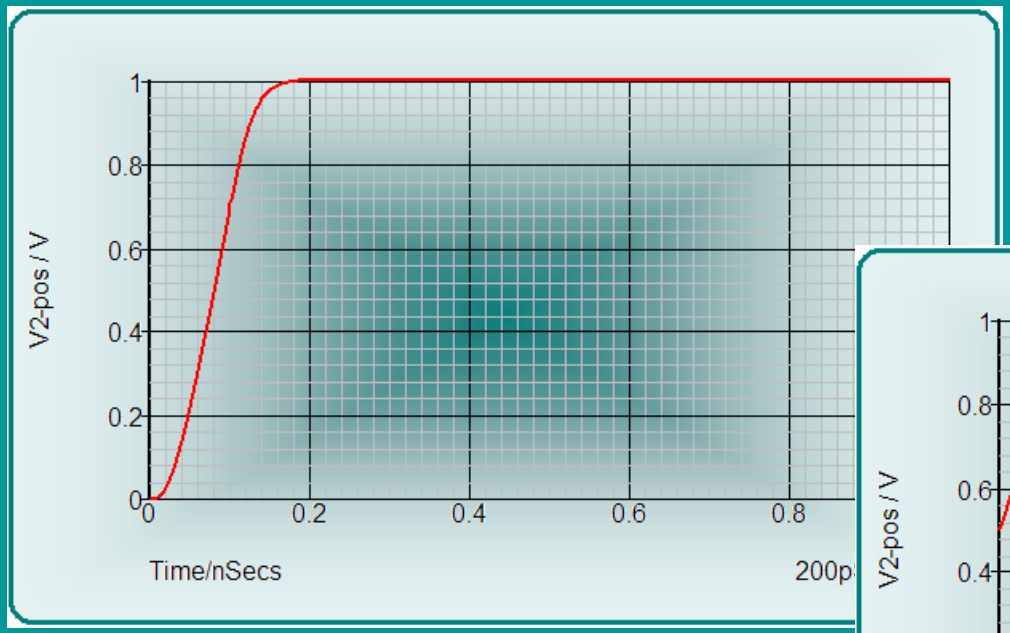
Objectives

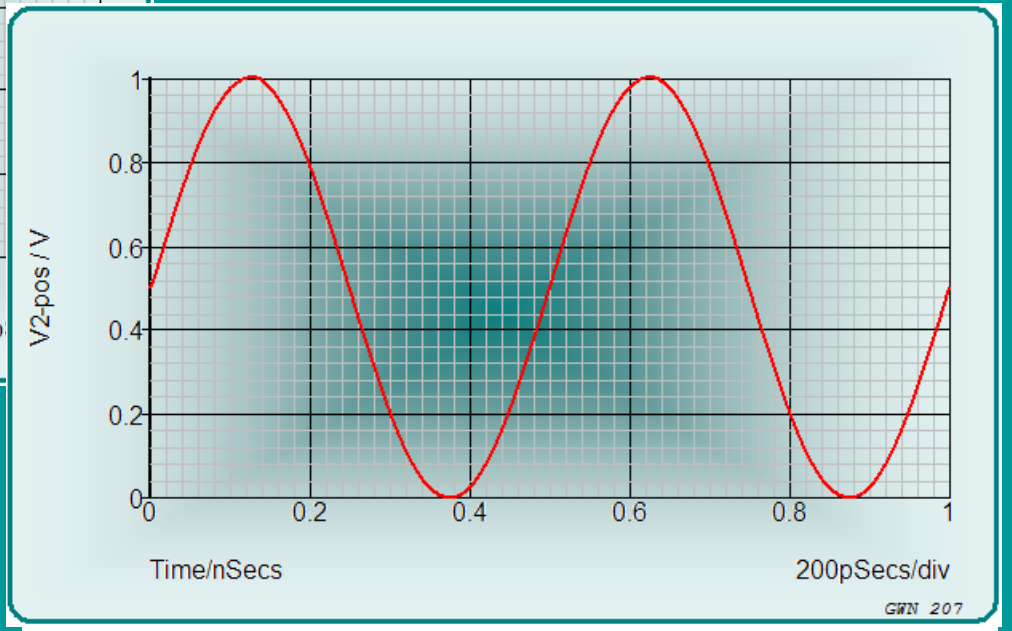
- Illuminate differences between Time Domain (TD) and Frequency Domain (FD) probe card measurements
- Explore thru and reflection measurements
- Identify measurement limitations due to terminations

Time vs. Frequency Domain

- Time domain (TD) instrument records response of the circuit to a step excitation
- Frequency domain (FD) records response of the circuit to a sine wave of changing (swept) frequency
- Time and Frequency domain linked by Fourier transform - many test instruments are capable of operating in both domains

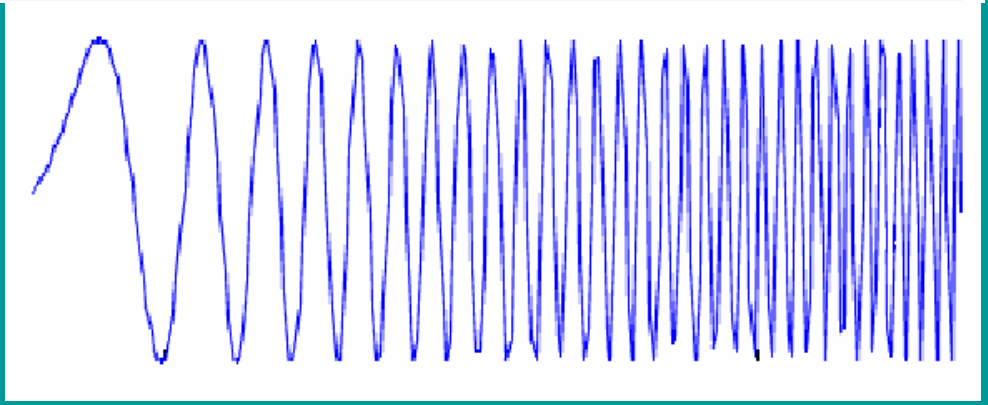
TD vs. FD





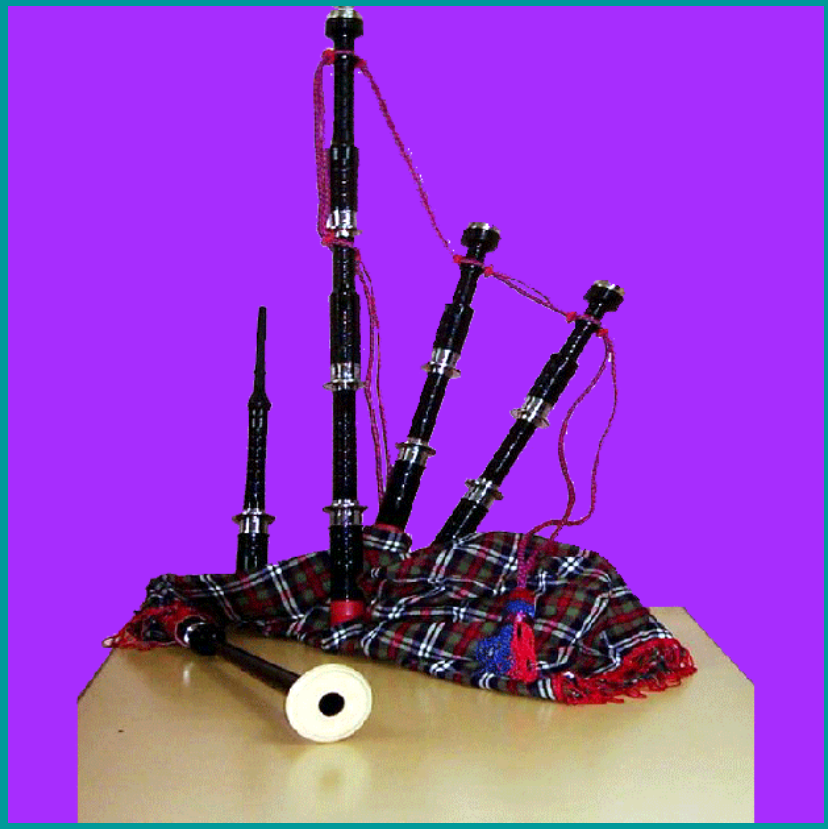
- Time domain:
  One step

- Frequency domain:
  Sine wave with
  swept frequency



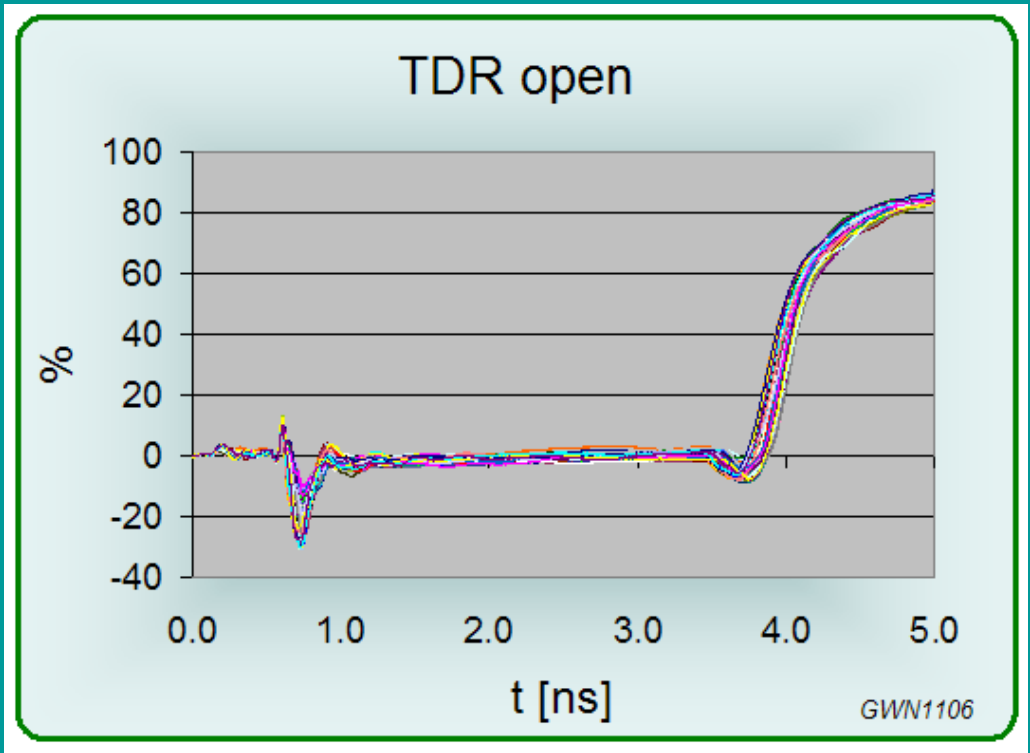
TD vs. FD

- TD explores obstacles



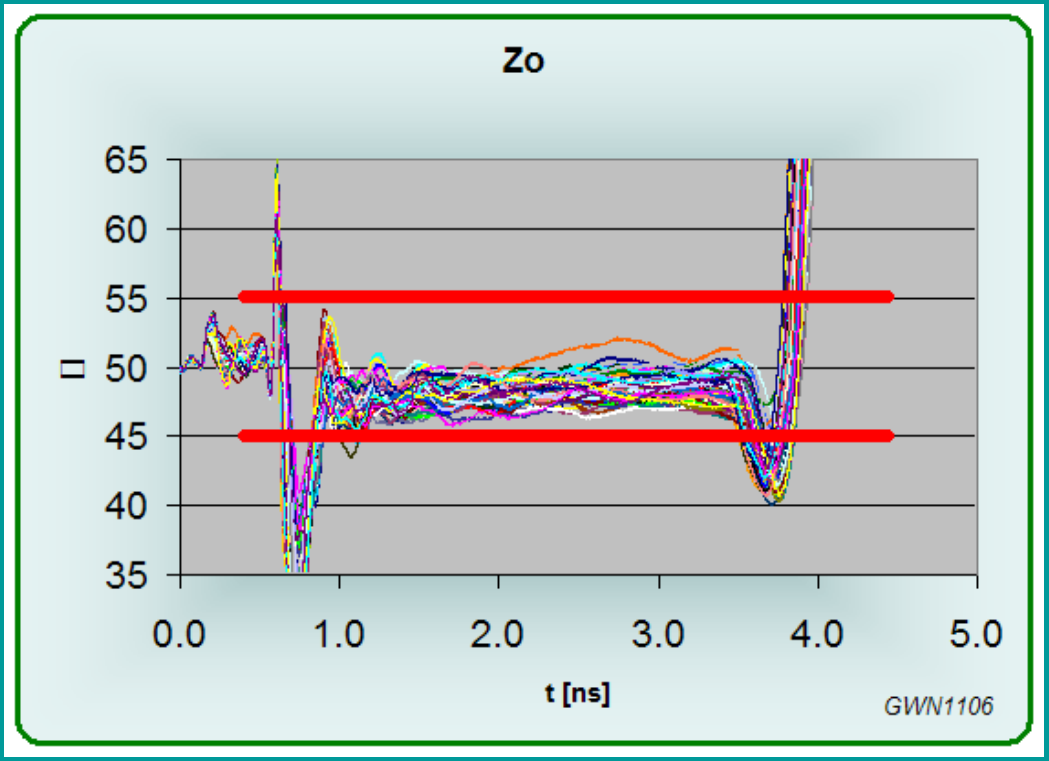
- FD explores individual response ‘components’

Example: Probe Card TDR



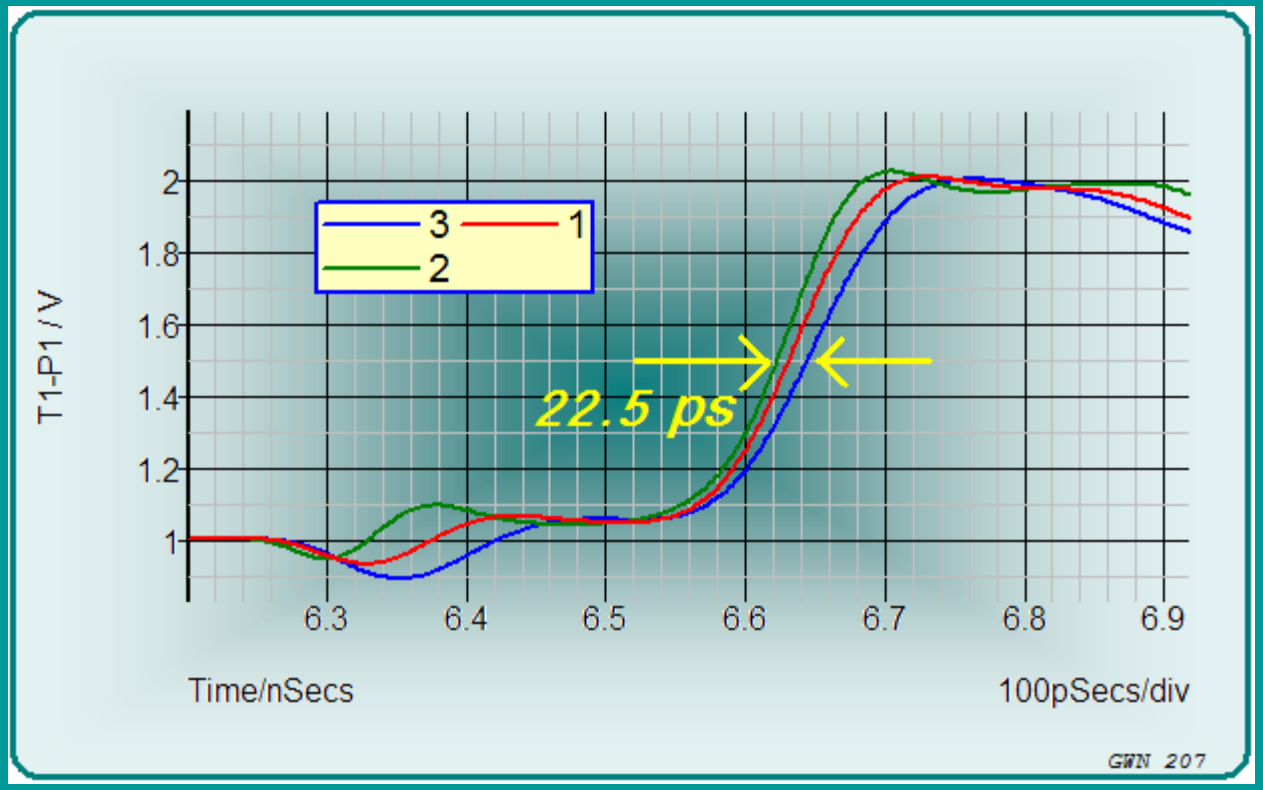
- Performed with an open circuit at the probes- examines impedance levels, discontinuities and timing differences (skew)

Probe Card TDR



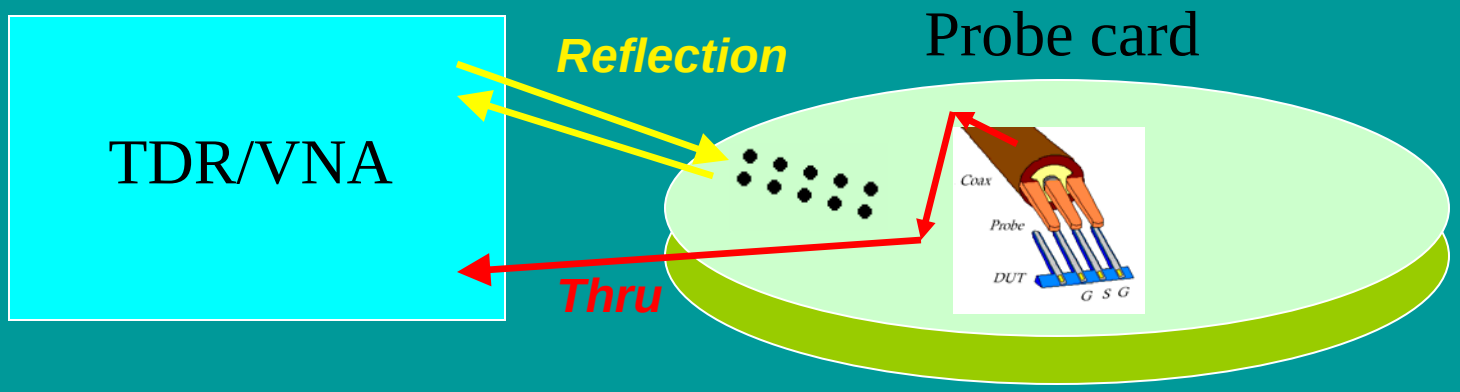
- Impedance graph gives info about the properties of PCB transmission lines

Model results: Skew



- Despite perfectly matched line lengths, different parasitics (1-3) cause different delay times

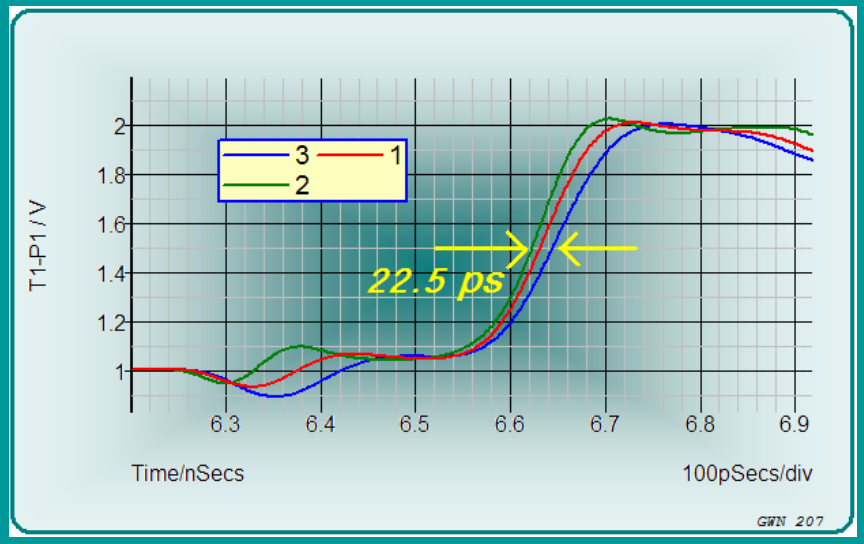
Thru vs. reflection measurement



The complexity of a 'thru' setup far exceeds that for 'reflection'

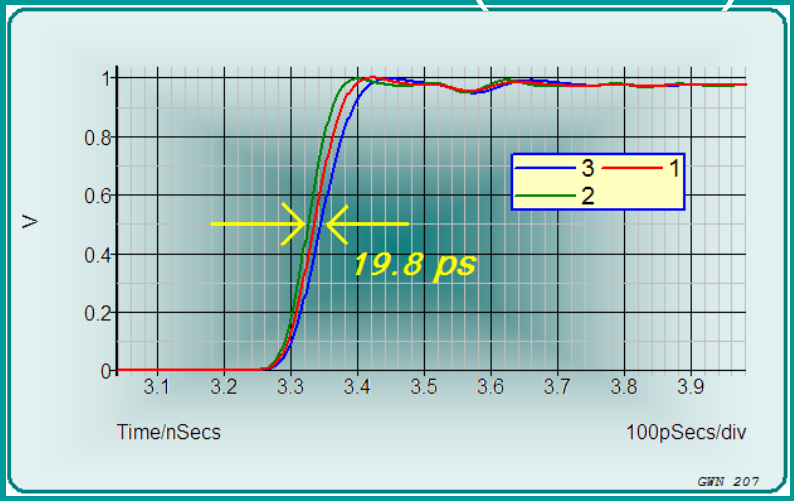
- Thru measurement gives response of signal path from source to load.
- Reflection measurement contains the effects of two signal passes through the signal path.
- Thru measurement is more representative of the effects the signal path will have on the signal.

Compare: Reflection vs. transmission measurement



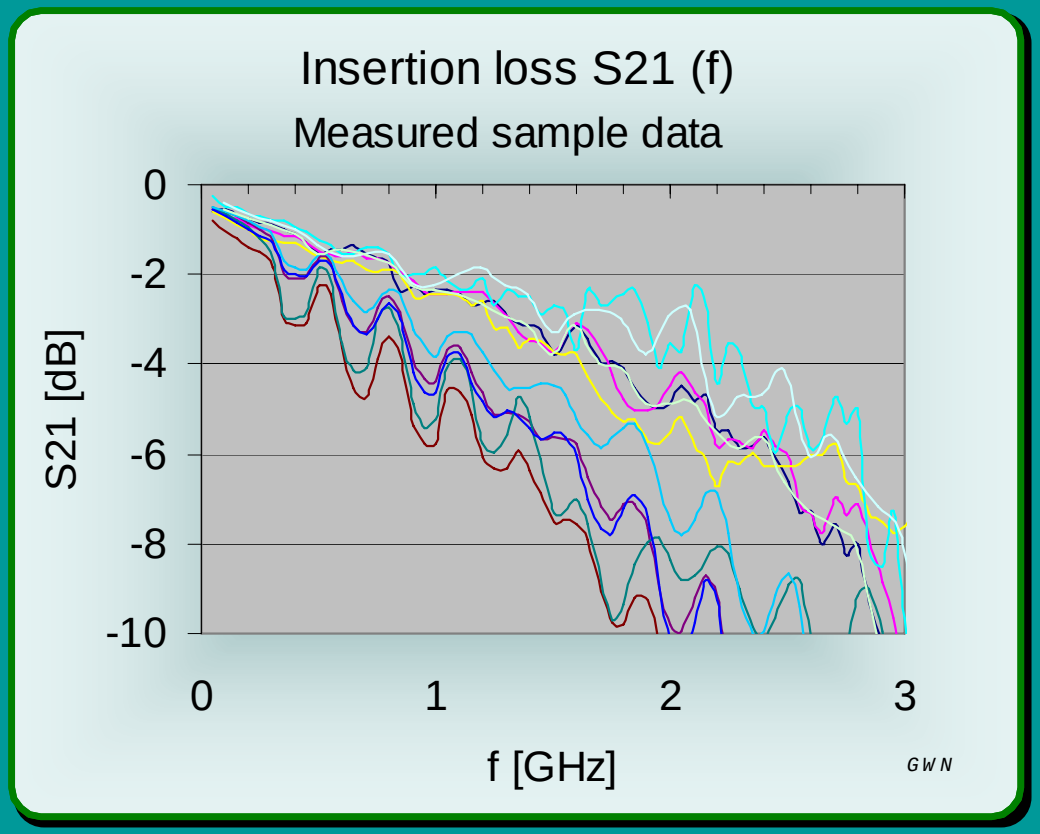
Reflection (skew = 2x actual because of round trip, i.e. skew = 11.25 ps)

Transmission (skew x1)



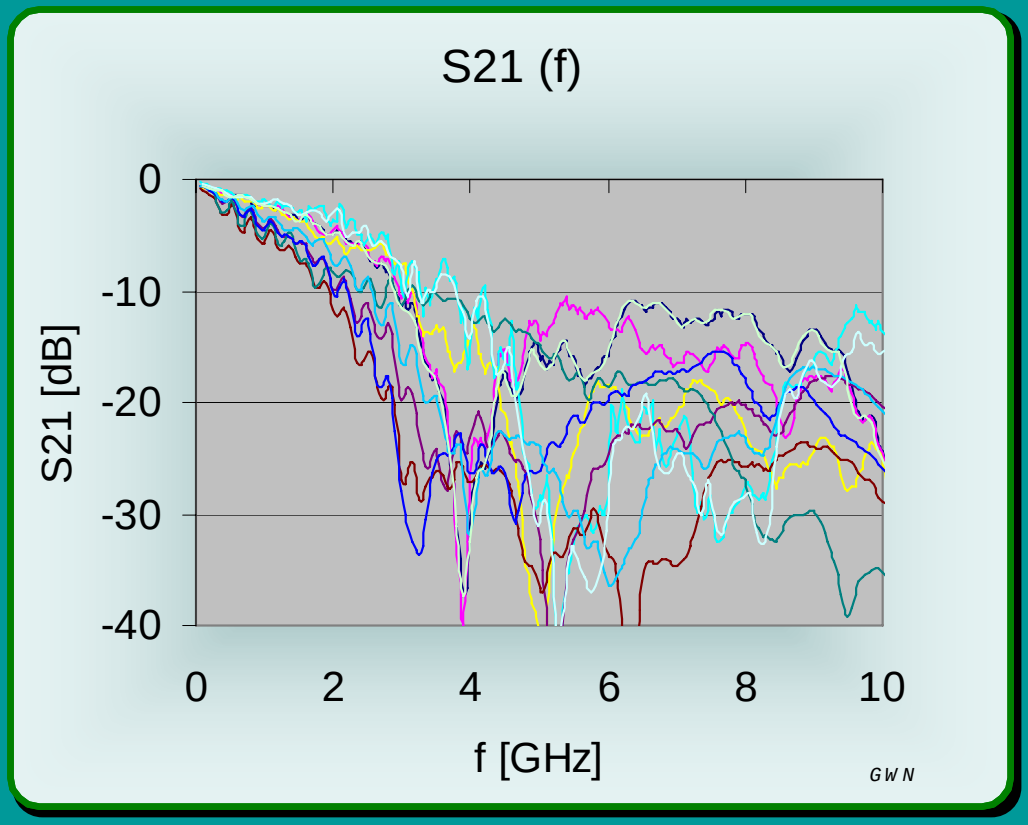
- Parasitics at the probes increase the skew, this is not appropriately captured in a reflection measurement

Measurement results: Insertion loss (S21)



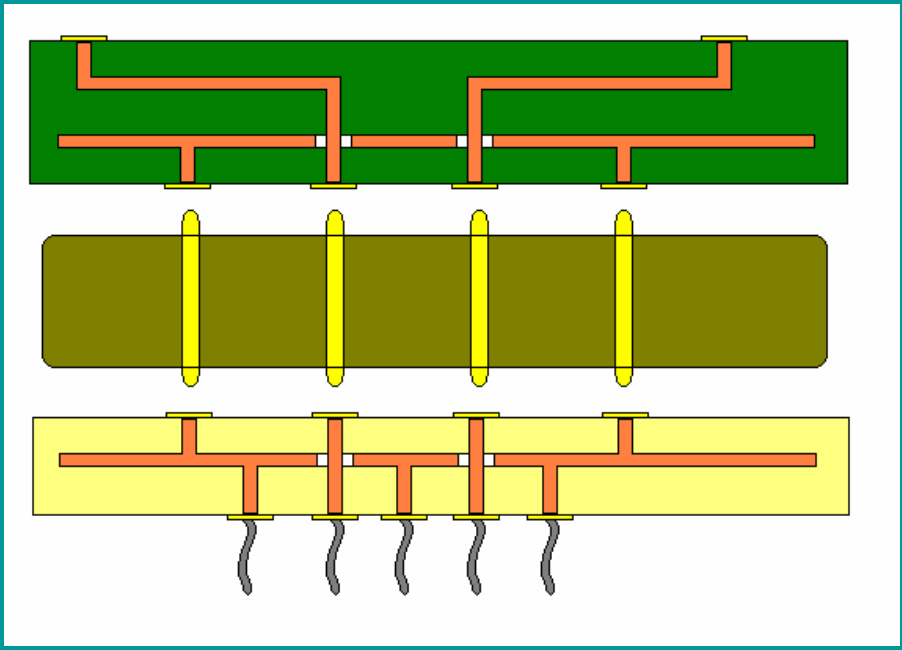
Thru measurement into a 50 Ohm load - apples and oranges selection, but all S21 increase more or less steadily toward 3 GHz

Expanded frequency range



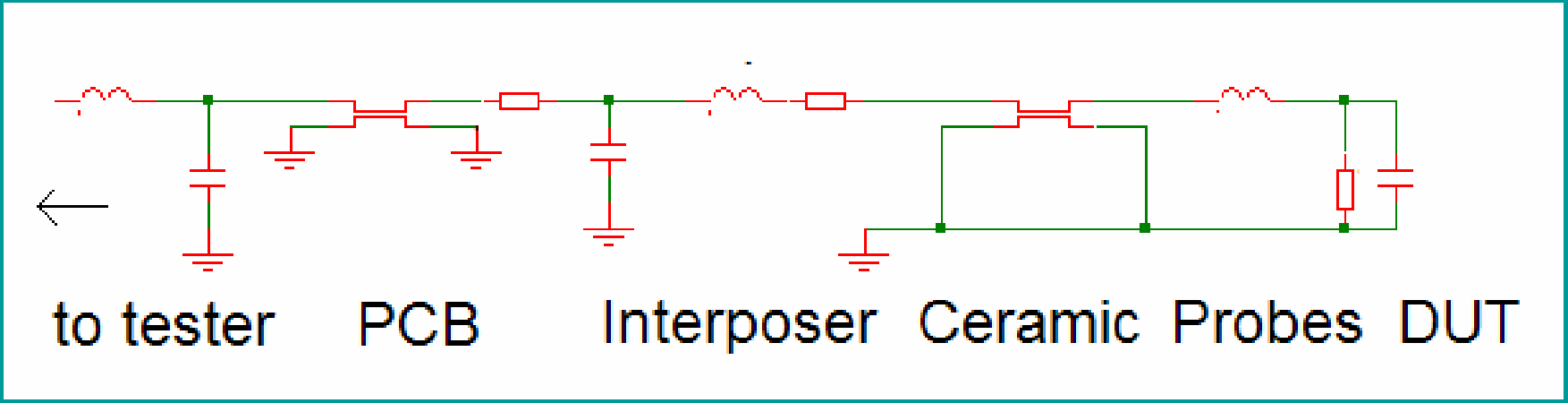
- Resonances become apparent; an examination of causes can be made via SPICE model

Probe card components



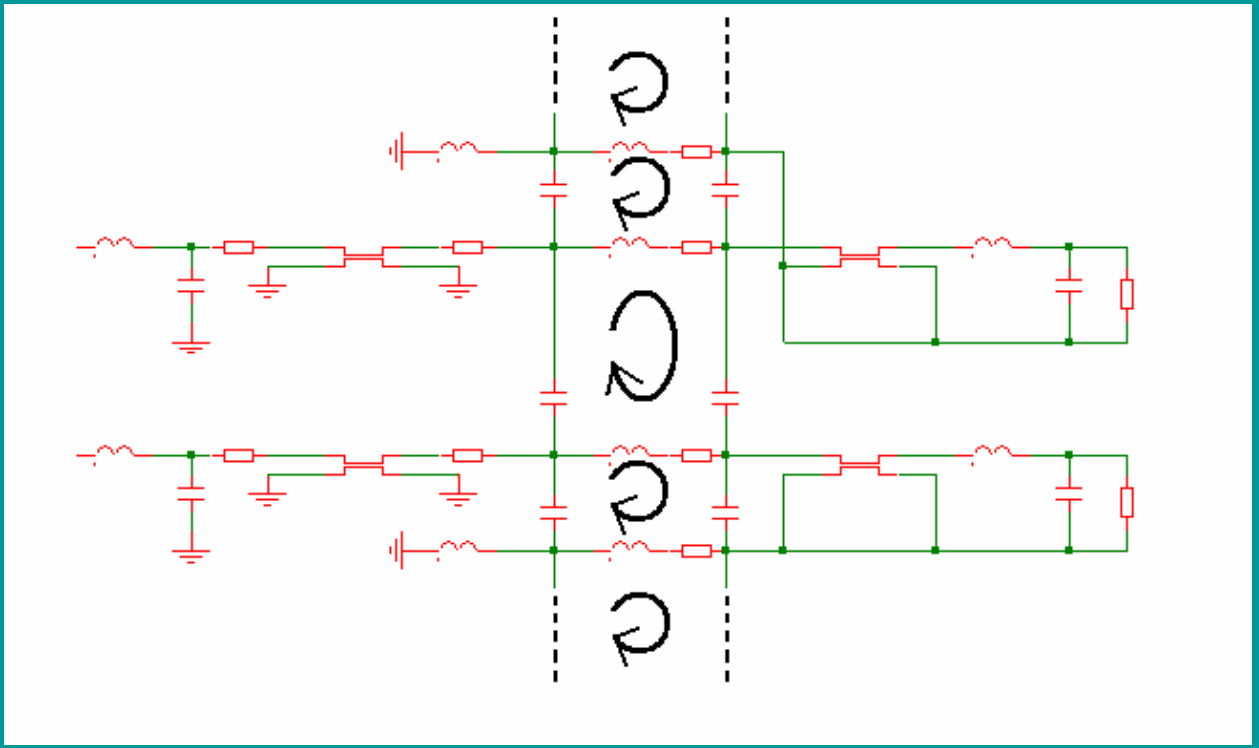
- PCB
- Interposer
- Ceramic
- Contactors

A simple equivalent circuit



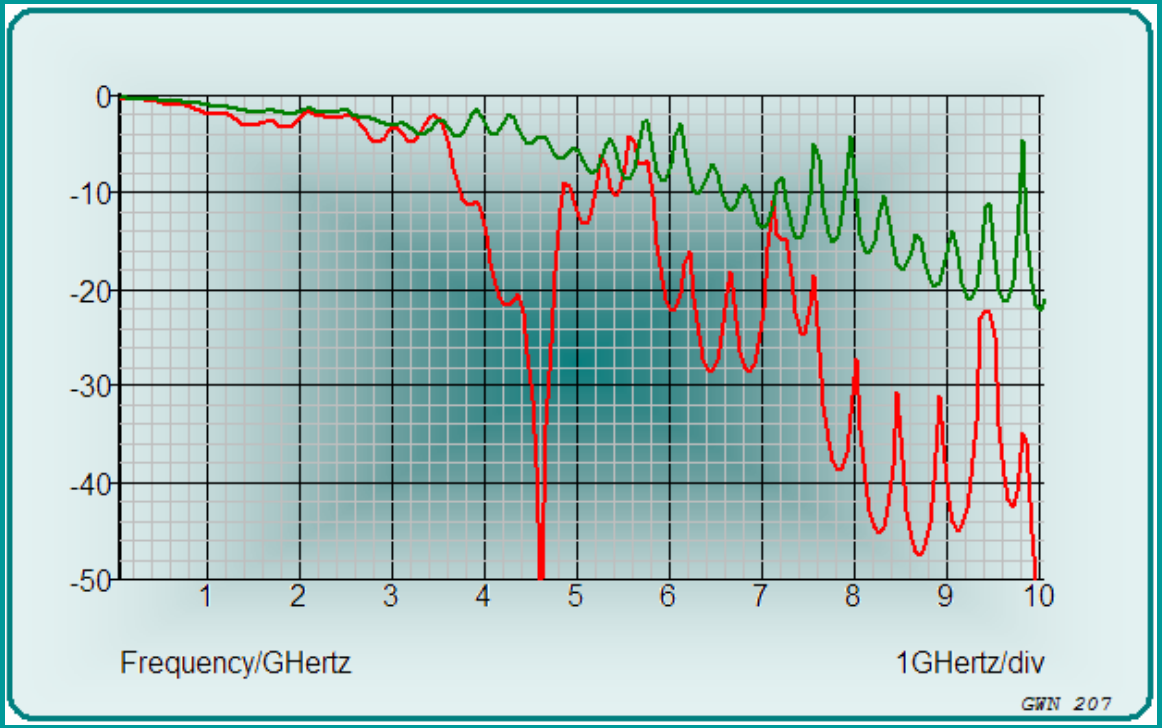
- Tester connector and PCB to ceramic interposer are modeled as lumped inductors
- Via parasitics are modeled as lumped capacitances
- PCB and ceramic are modeled as lossy transmission lines

Expanded interposer model



The simple model of the interposer can be expanded to include interactions with adjacent connections. The interposer has many contacts that are electrically coupled with each other.

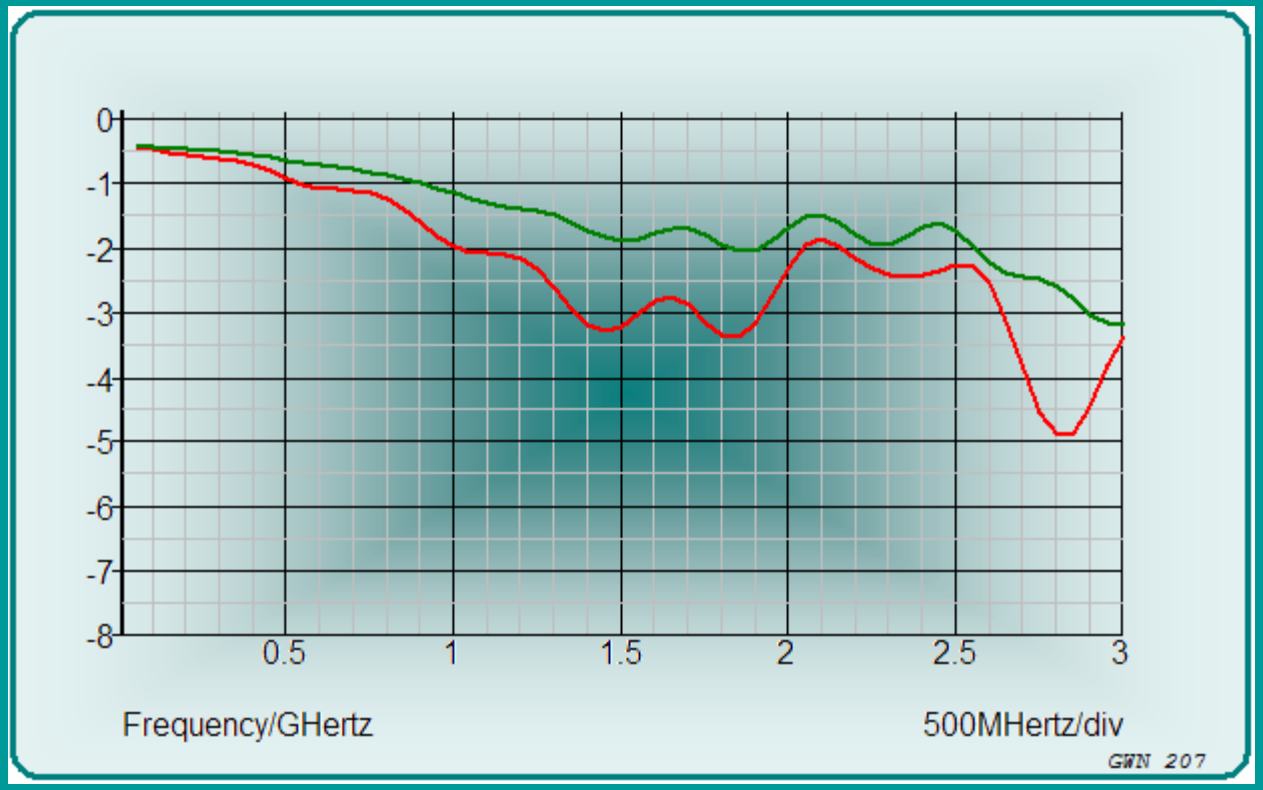
Model results: S21



- Thru model: Simple (green), expanded (red)

  Strong resonance dips appear at elevated frequencies for the expanded interposer model

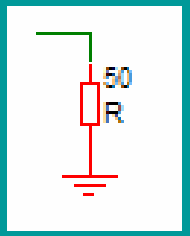
Lower frequency detail



Components with resonances can adversely affect the performance at lower frequencies (red curve)

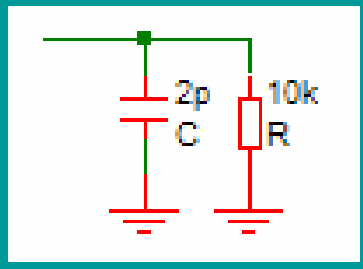
Effect of terminations

- Thru measurements generally require a 50 Ohm termination at the receiver end.

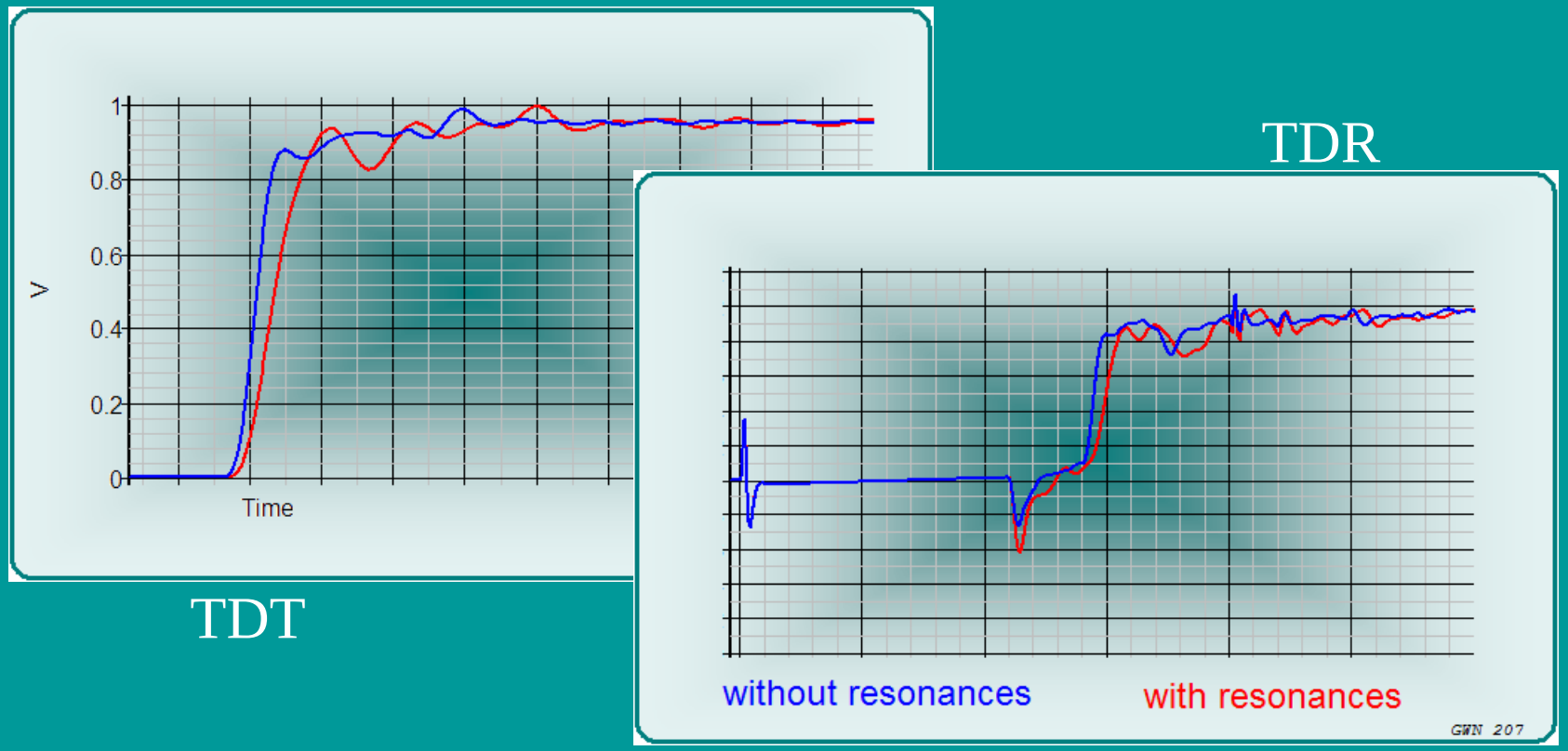


- The actual device being tested does not necessarily present a load of 50 Ohms.

Example:

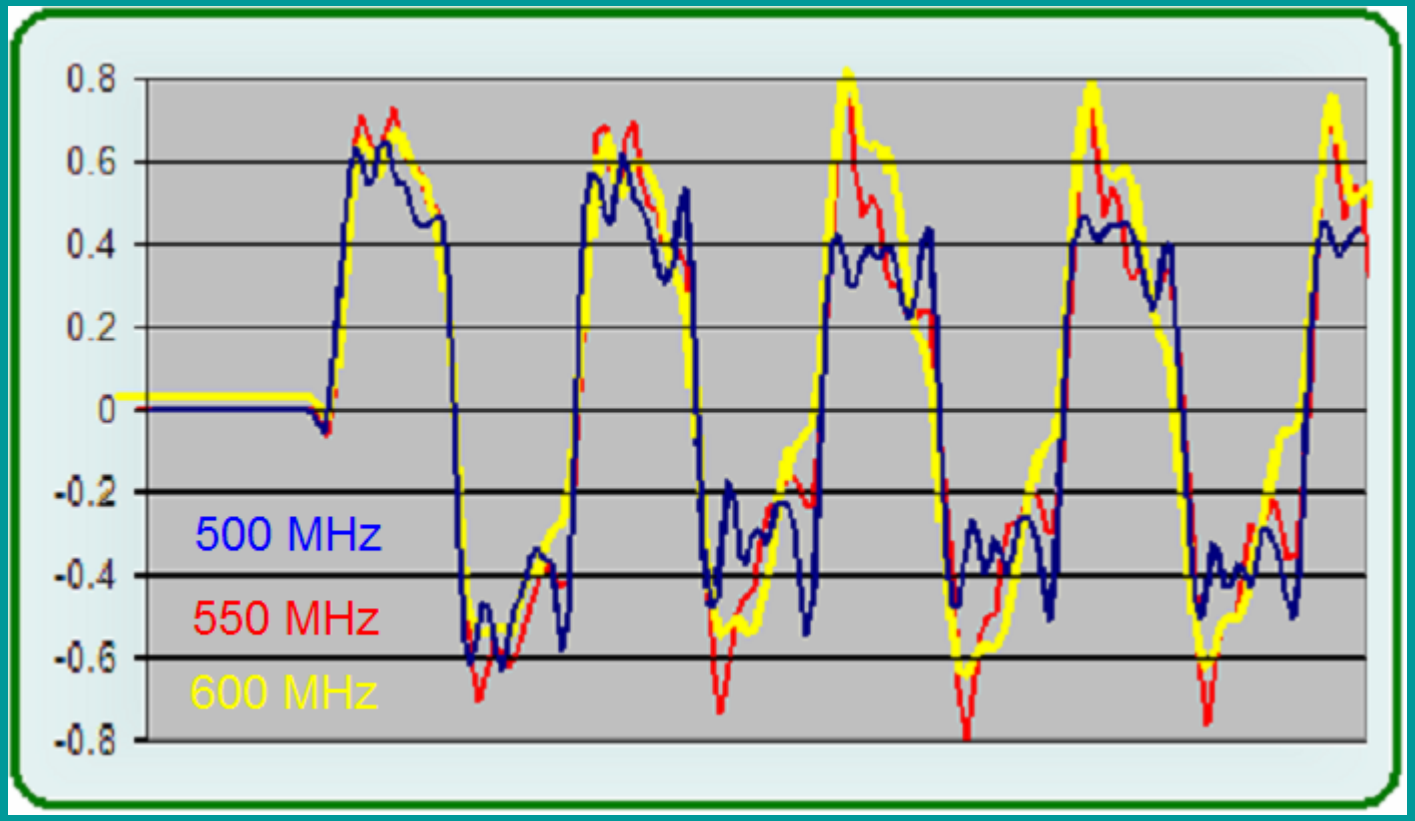


Model results: Time domain



- Model for a single step excitation with and without resonances: Only a modest resonance signature is apparent

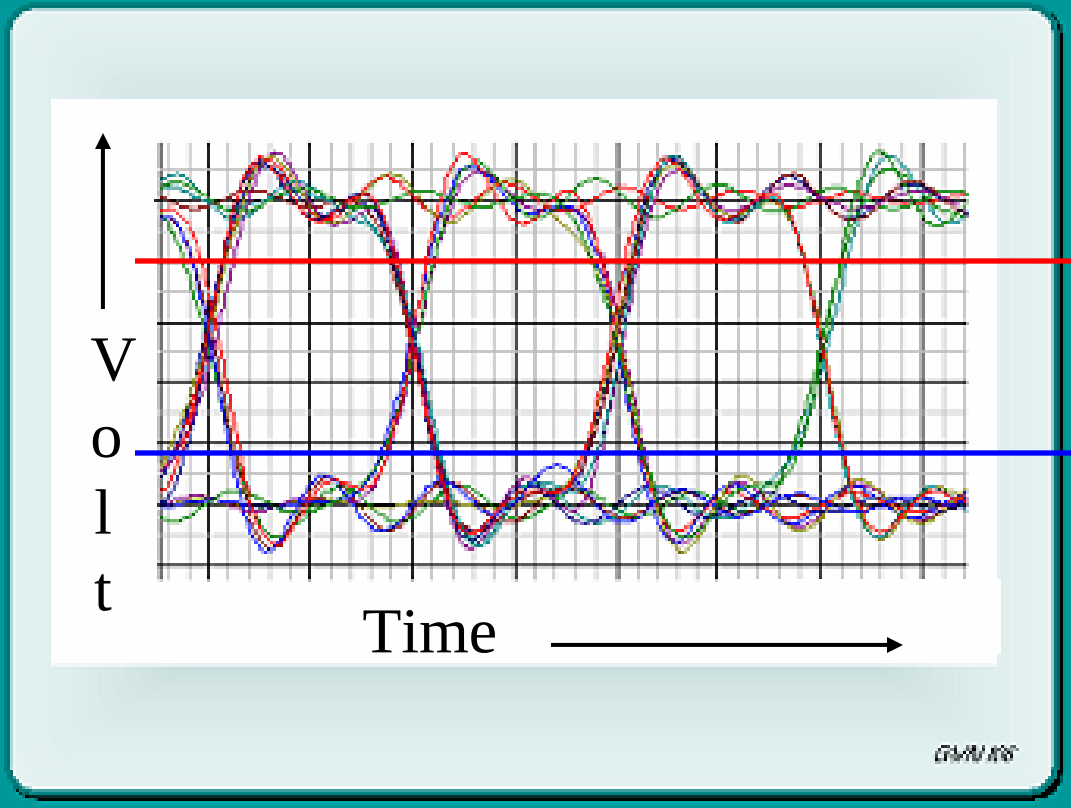
Model results: Time domain



Thru response simulation for a 5 kOhm/1pF load at different clock frequencies of 500, 550, 600 MHz

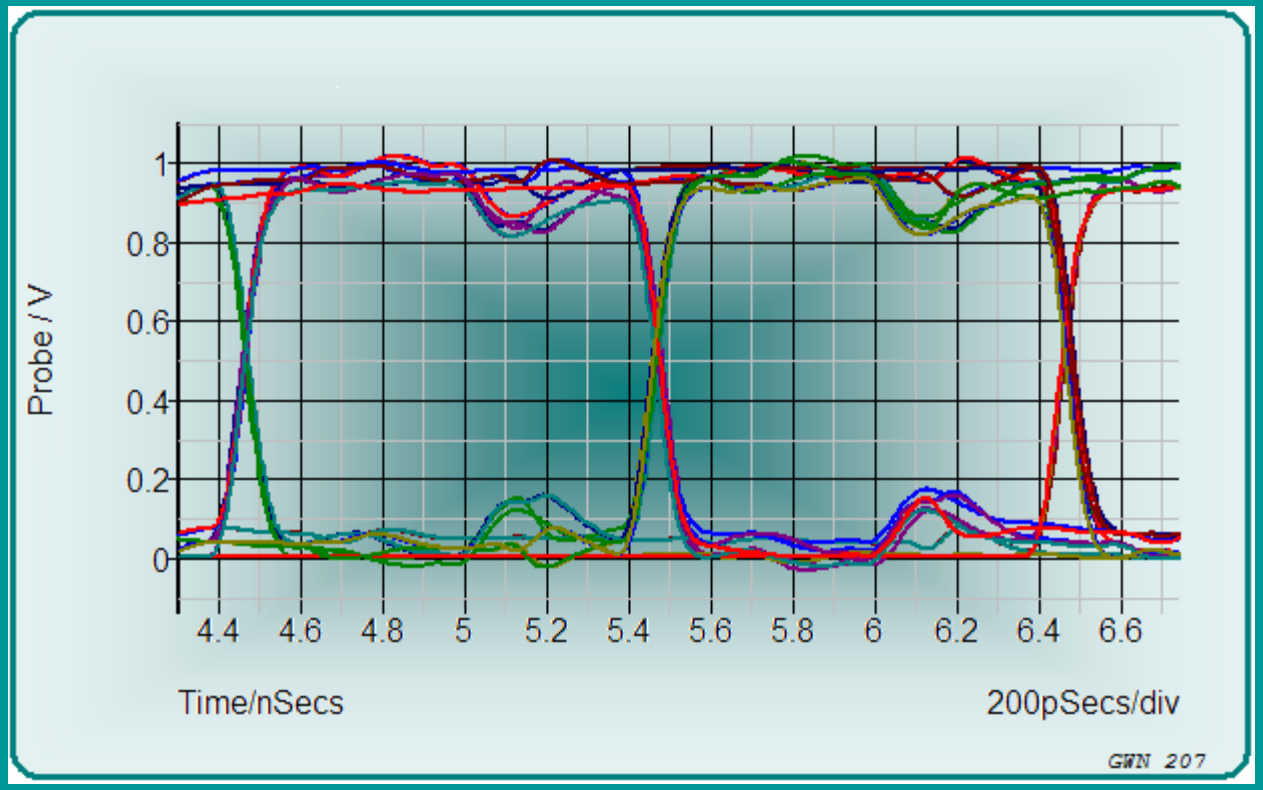
(the graphical periods are altered for easy comparison)

TD thru method: Eye diagram



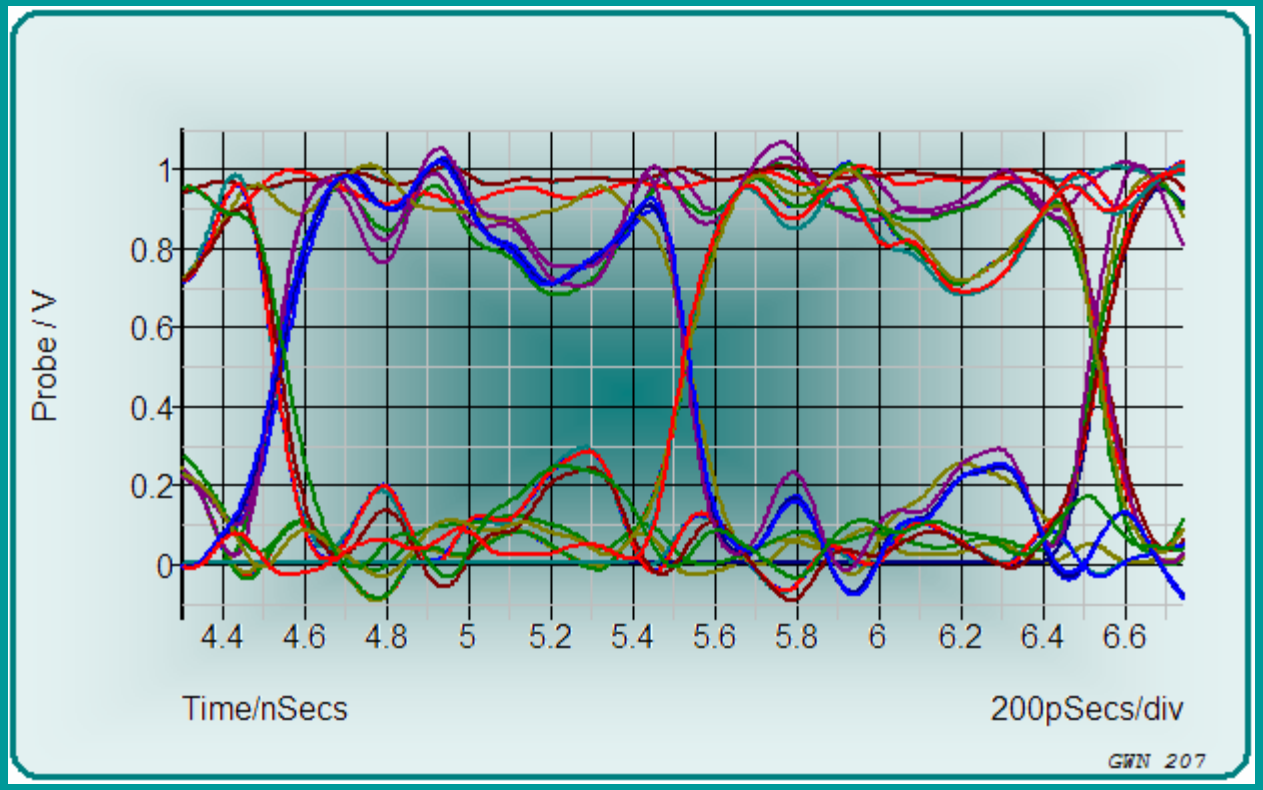
Eye diagrams are the result of a superposition of a number of pseudo-random pulses. They give a visual representation of operating margins

Model results: Eye diagram



- Thru model into a 50 Ohm load, resonances minimized

Model results: Eye diagram



- Thru model into a non-50 Ohm load (DUT=10kΩ, 2pF)

Conclusion

- Time domain techniques are generally applied for reflection measurements.
- Frequency domain thru measurements can reveal resonances in components.
- Skew differs for reflection vs. transmission measurements.
- Time domain measurements may miss some detail.
- Resonances at elevated frequencies can contribute to reduced eye height, especially for non-50 Ohm DUT terminations.

Thank you.