DesignCon 2012

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Temperature and Moisture Dependence of PCB and Package Traces and the Impact on Signal Performance

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UBM Electronics

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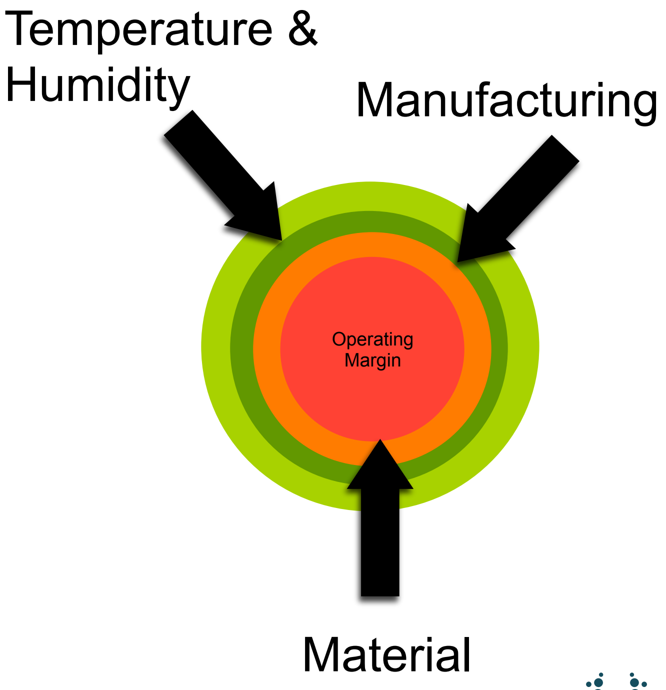
Motivation

- Link speeds increasing, margins decreasing
- Simulation may include variation due to silicon (PVT); variation in passive models is less common
- E.g., impact of temp, moisture, manufacturing and material on board and package electricals
- Here we focus on temp and moisture
- Complex permittivity is usually freq, temp and moisture dependent
- The complex permittivity impacts channel loss, impedance matching, etc., making it critically important to characterize



Agenda

1. Measurement data of package and PCB samples as a function of temperature and moisture content
2. Temperature and moisture modeling
3. Capturing temperature-dependent effects
4. Direct scaling of solved s-parameters
5. Real-world impact of temperature

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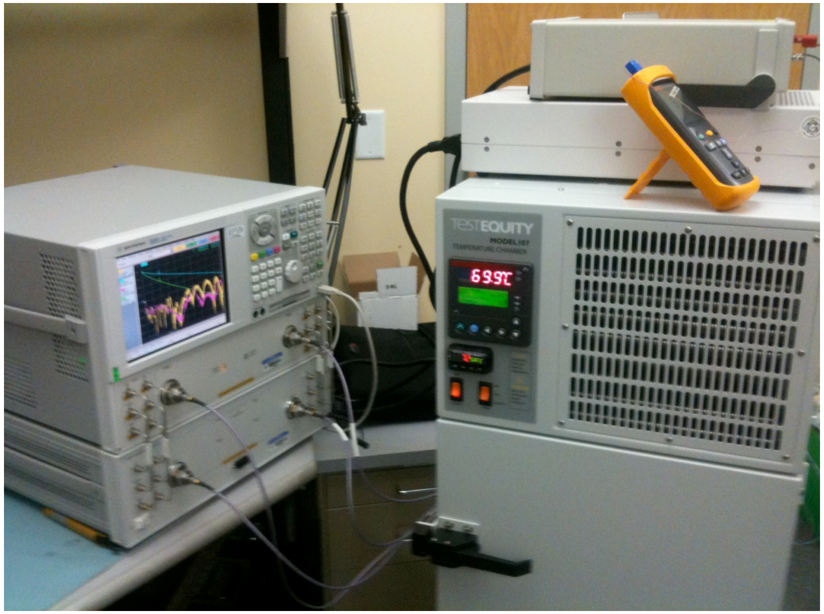
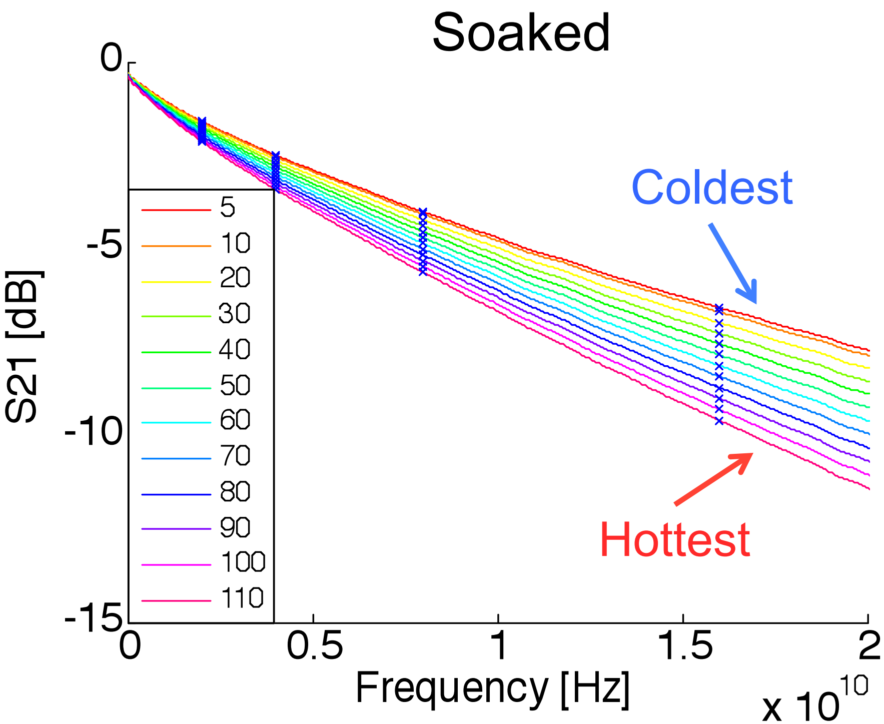
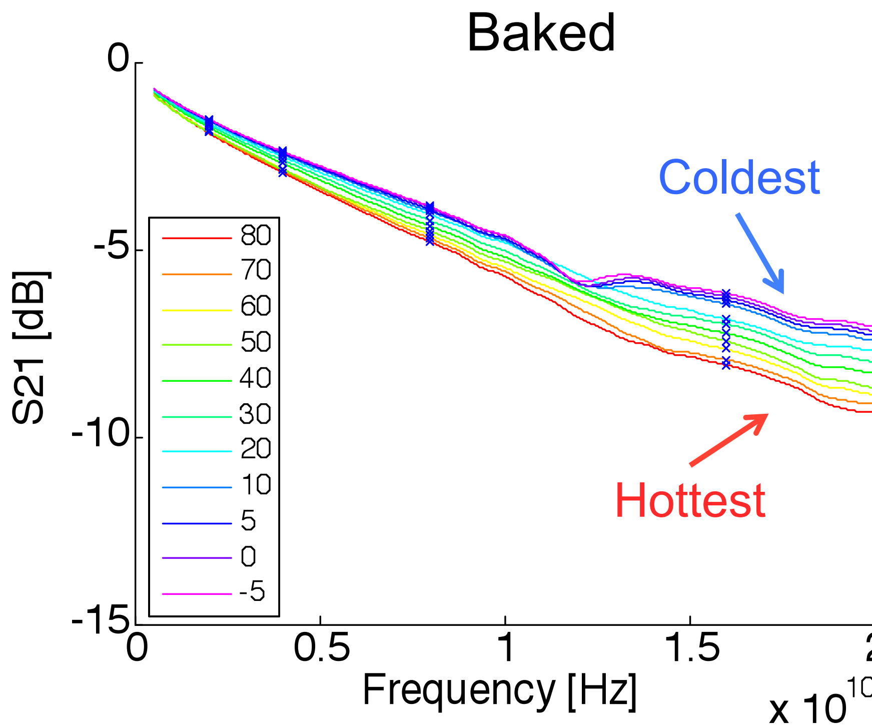
Temperature & Humidity Measurements

- Samples soaked or baked in humidity chamber (30C/60 & 125C/0)
- 40 GHz VNA measurements in temperature chamber from about 0 to 100 C (not humidity chamber)
- Generalized s-parameters are obtained using two different stripline trace lengths (100mm and 50mm)
- Materials used are commercially available low-loss PCB material and organic packaging material



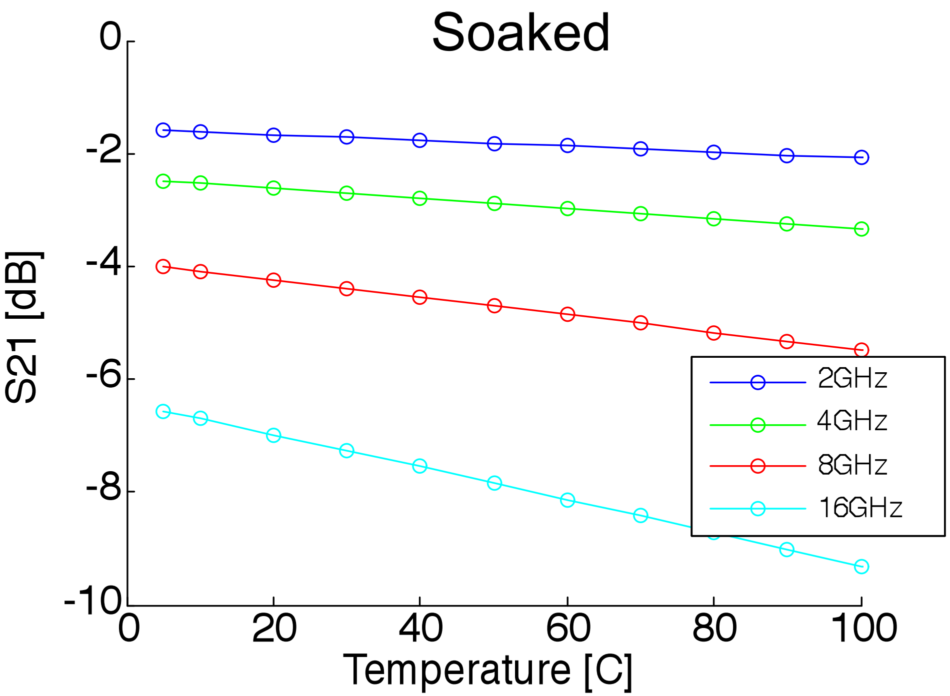
Package Measurements

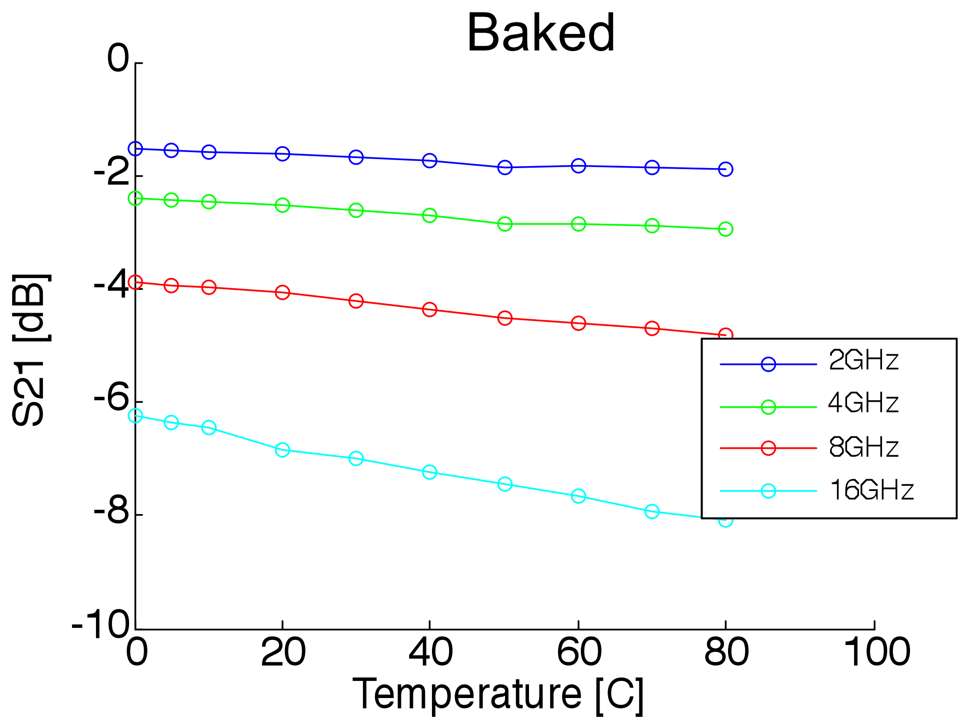




50 mm total length

Package Measurements





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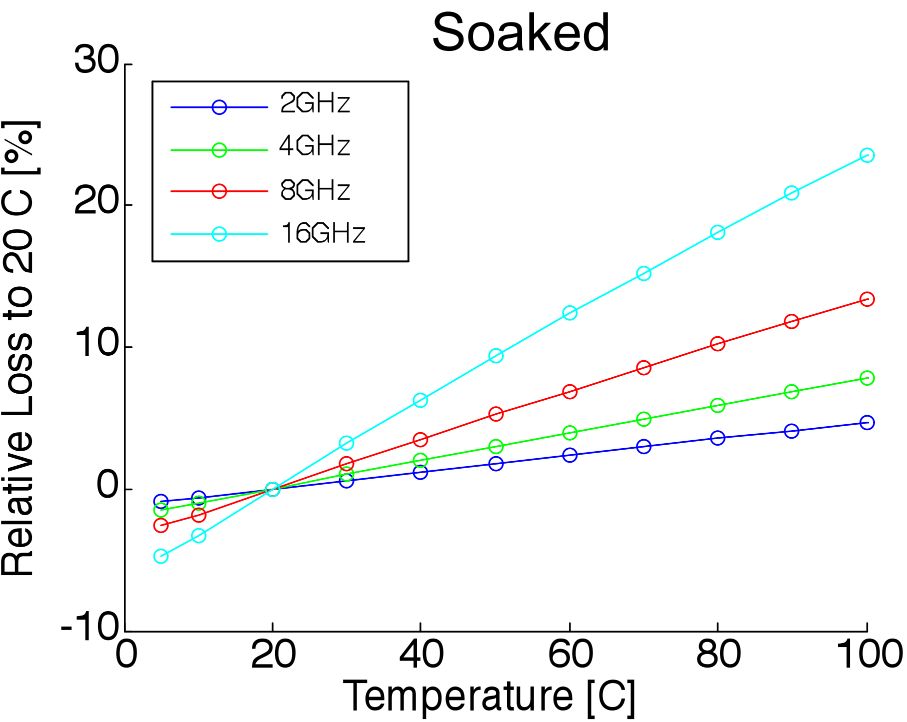

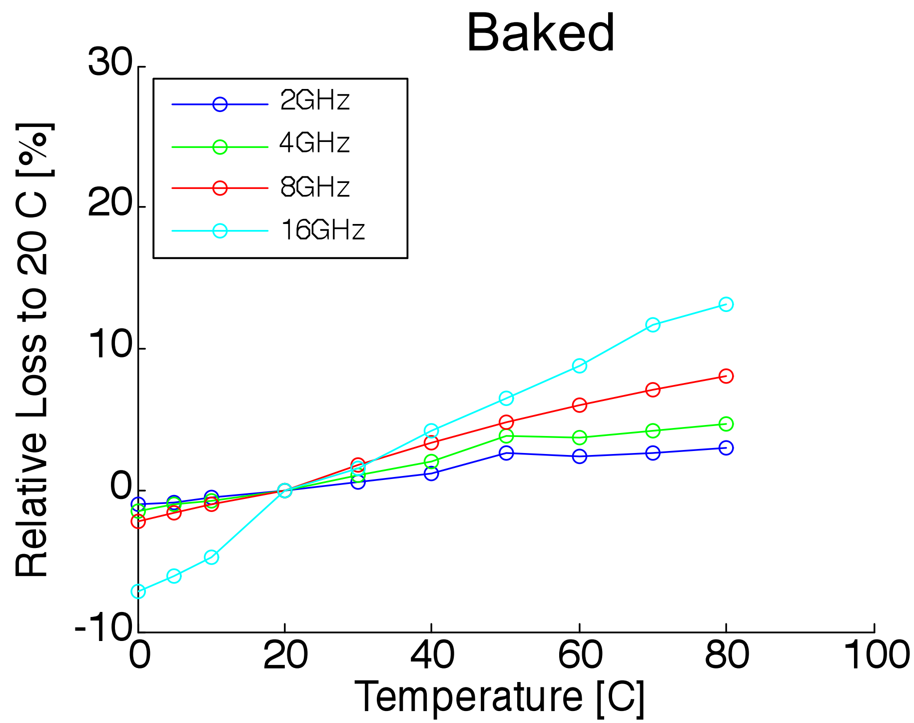

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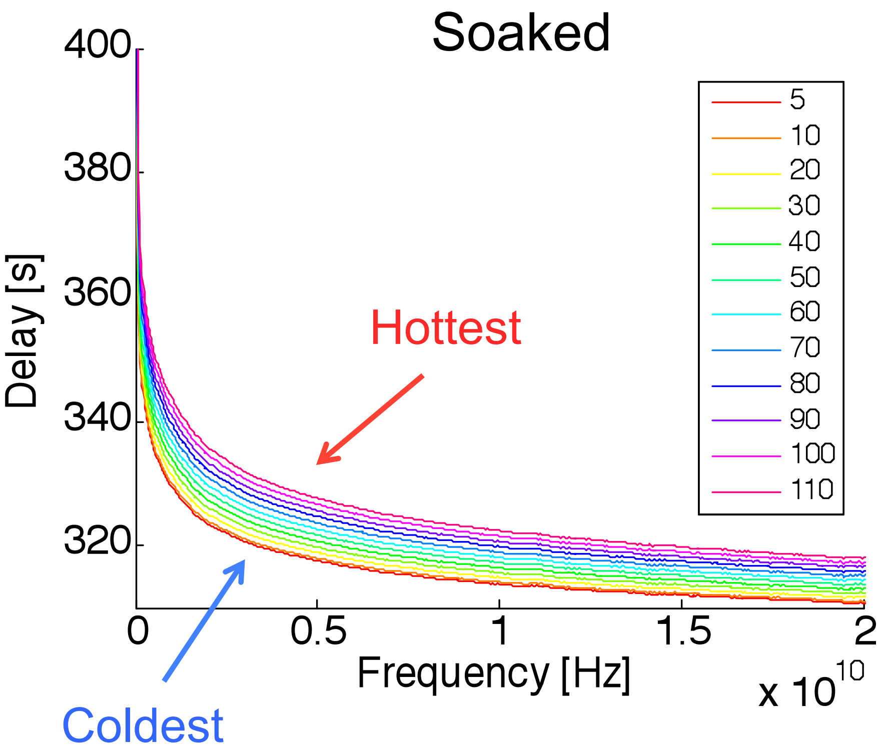

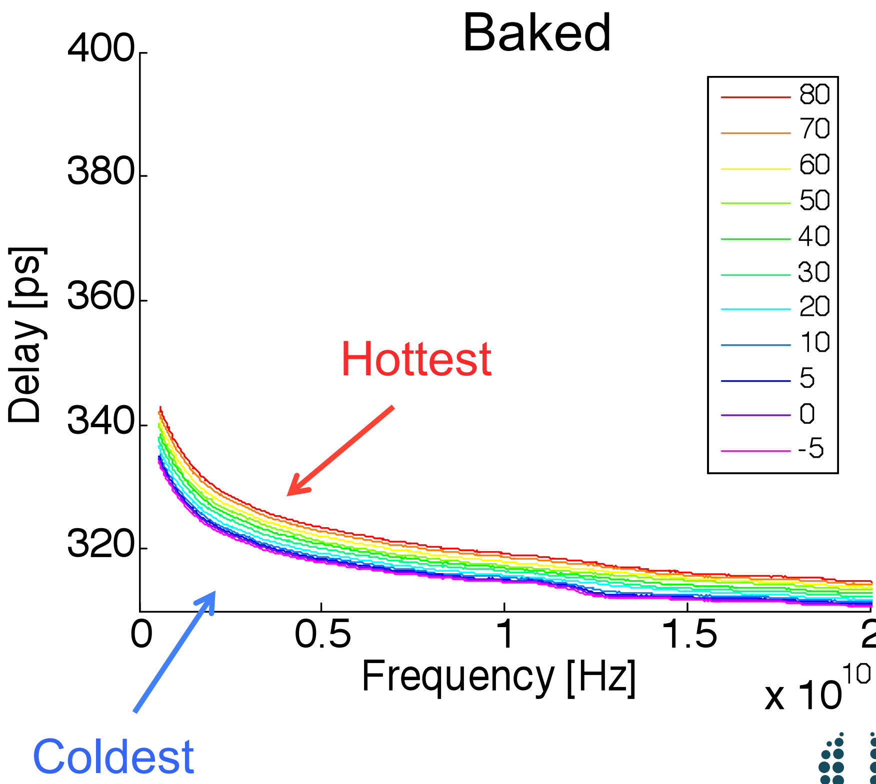

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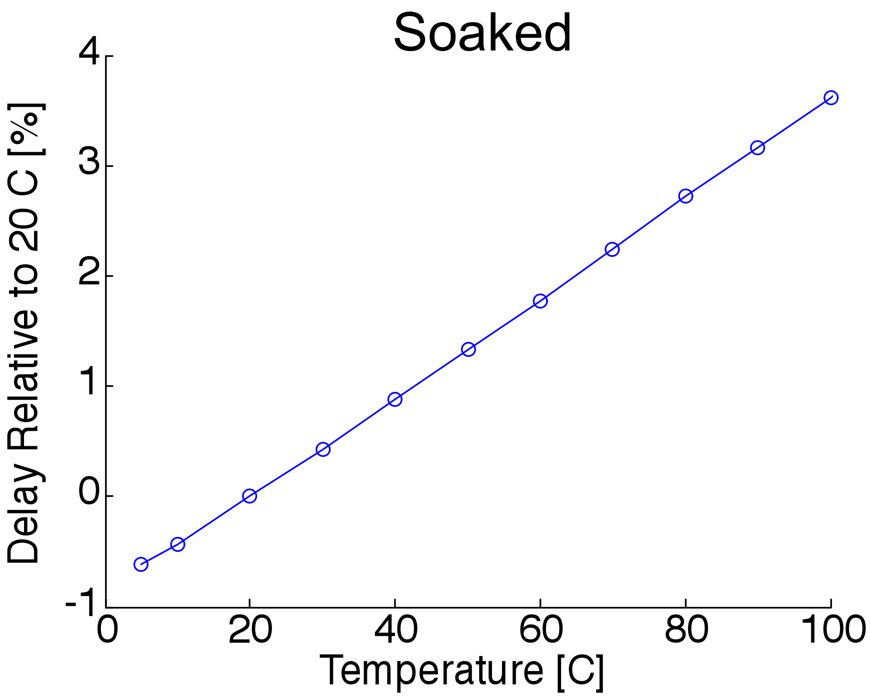
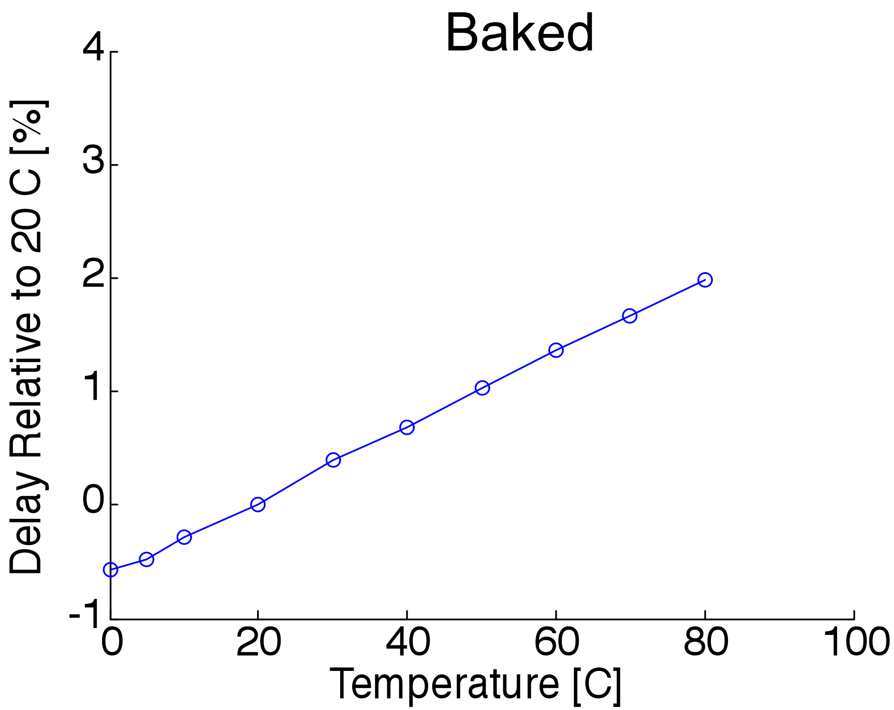
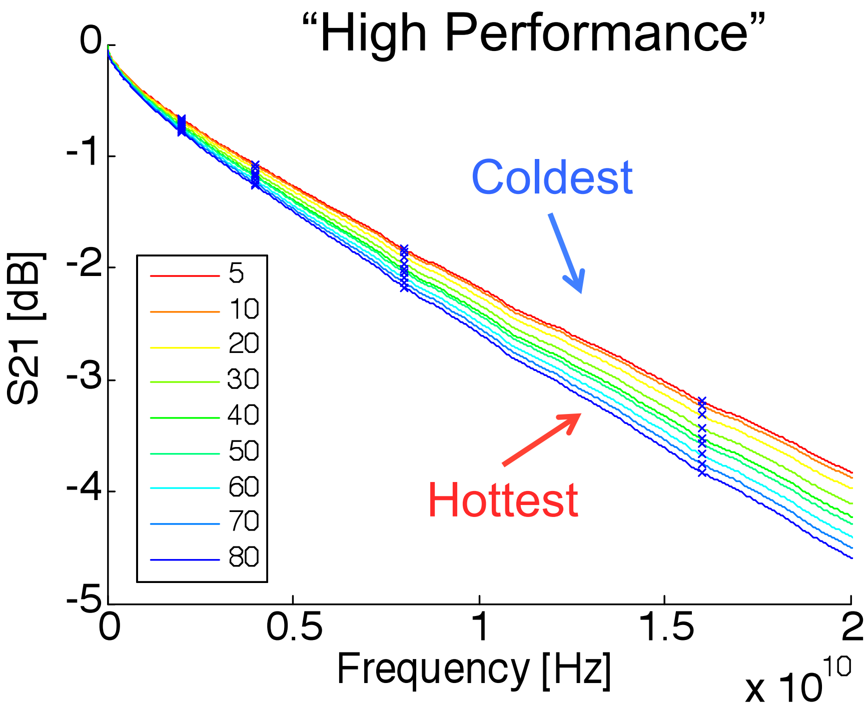
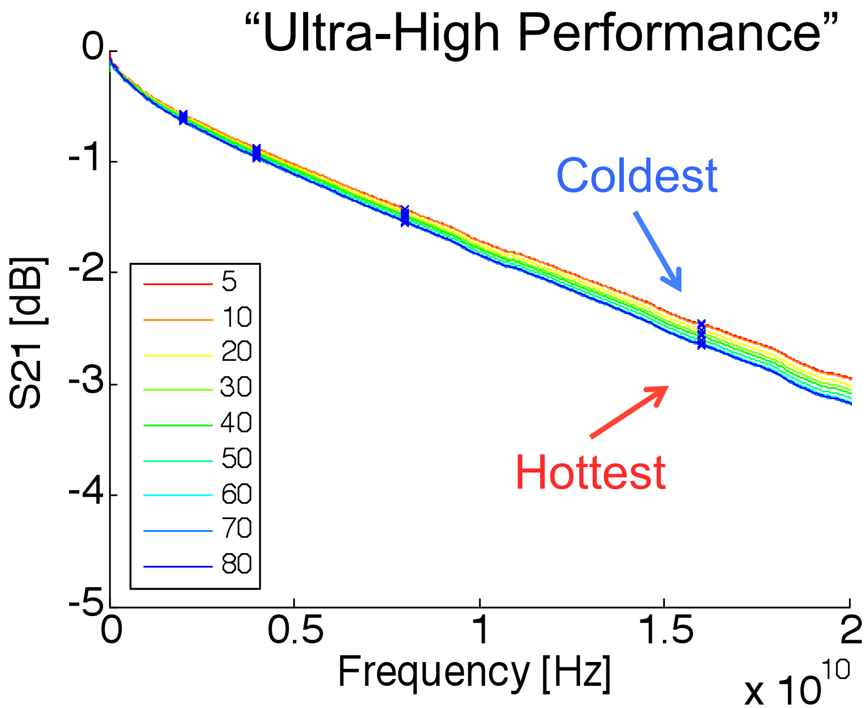




PCB Measurements





46 mm, ambient humidity

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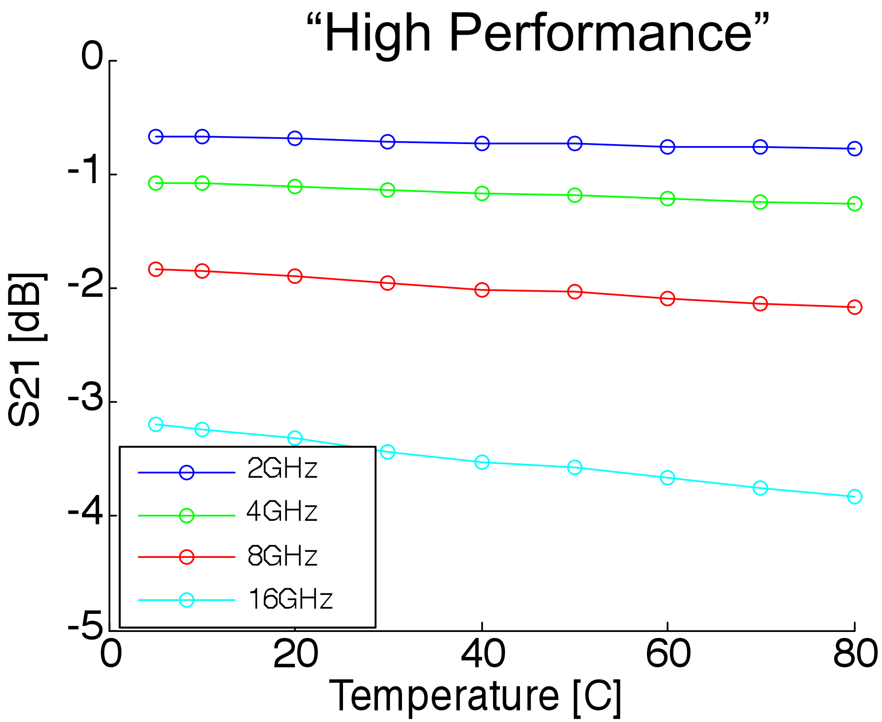
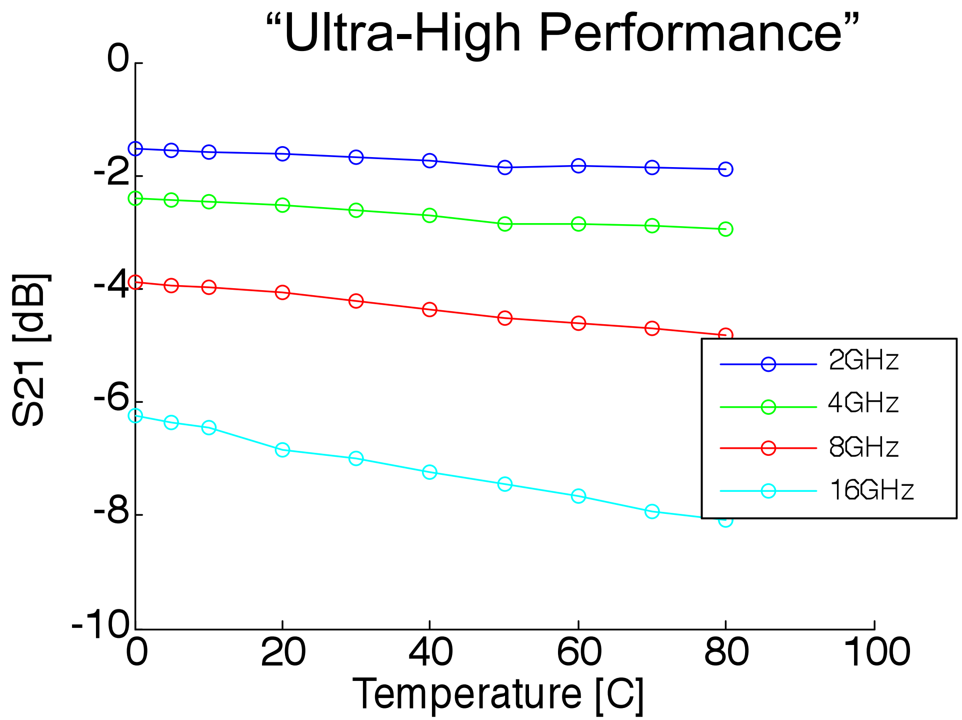
PCB Measurements





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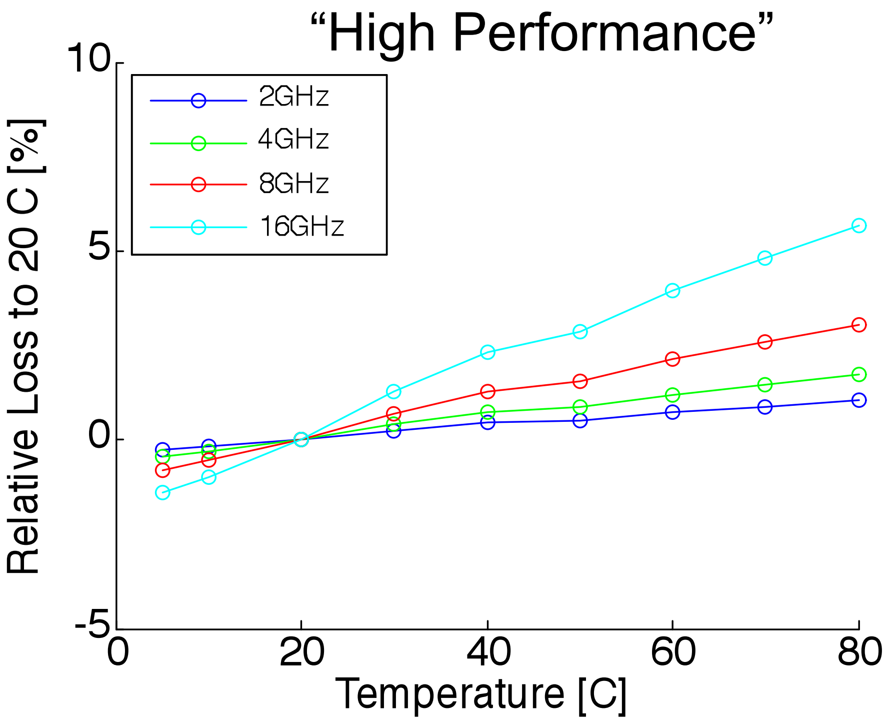
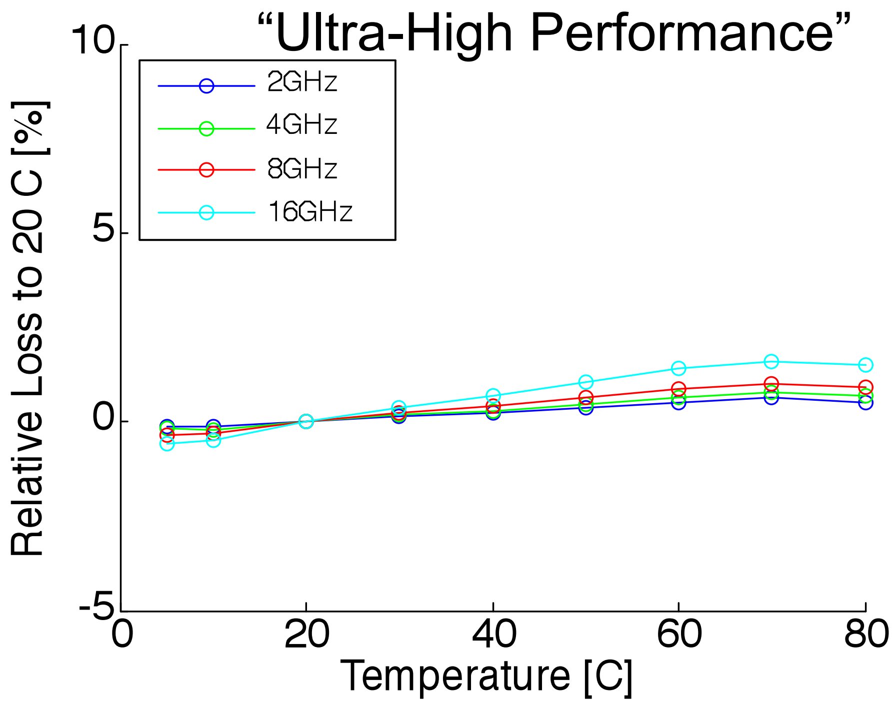
PCB Measurements





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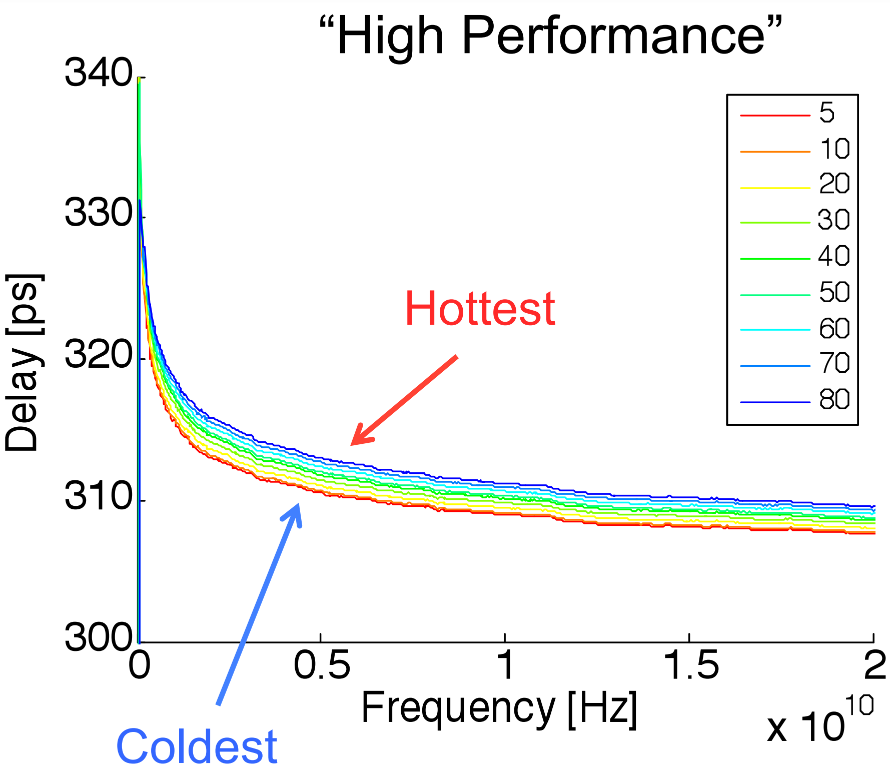

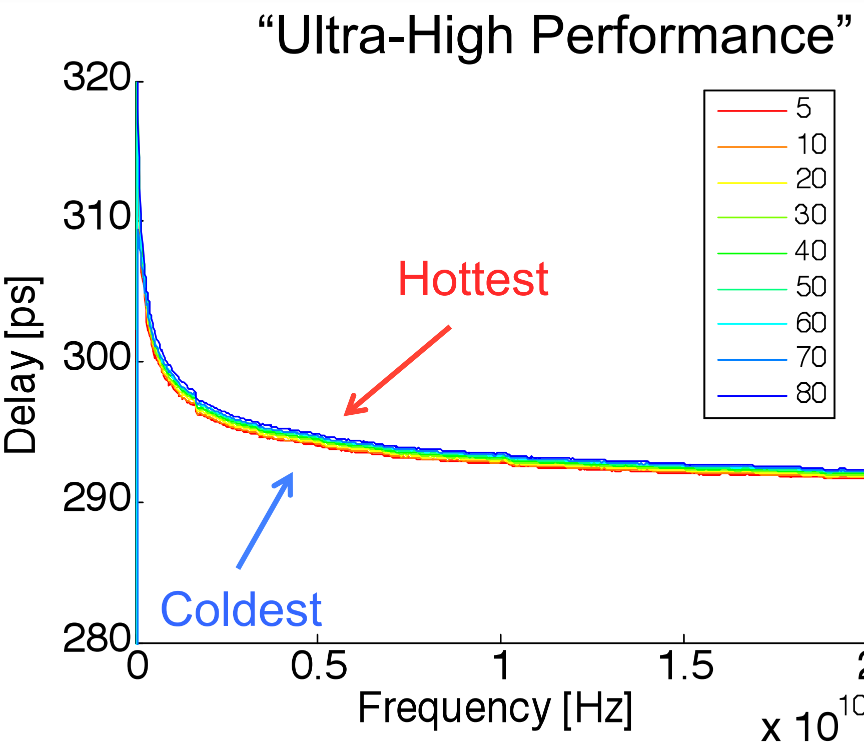

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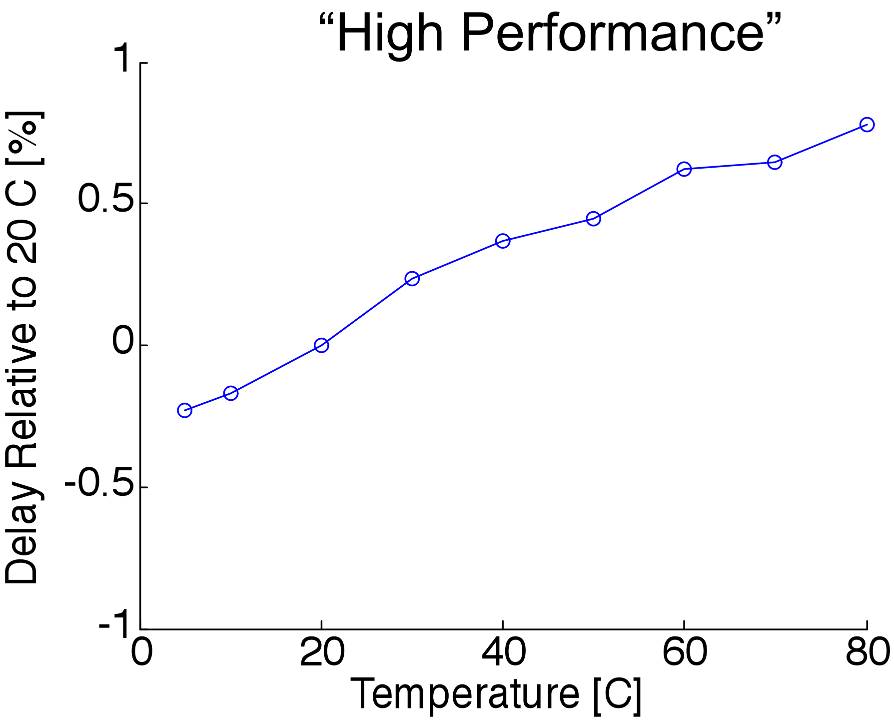

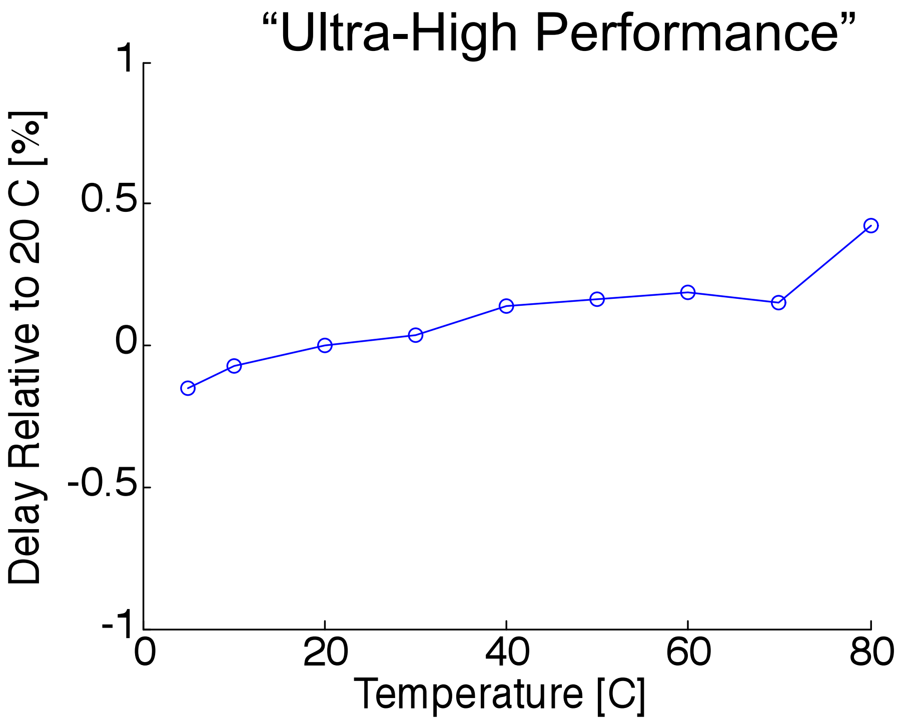

Measurement Section Summary

- Dielectric loss of organic packages is a fairly strong function of temperature
- Dielectric loss of low-loss PCB material shows less sensitivity to temperature
- Dielectric constant over temperature is relatively moderate for all the packaging and PCB materials tested
- Moisture accentuates the temperature dependence of the complex permittivity
- As frequency increases, the loss variation across temperature increases

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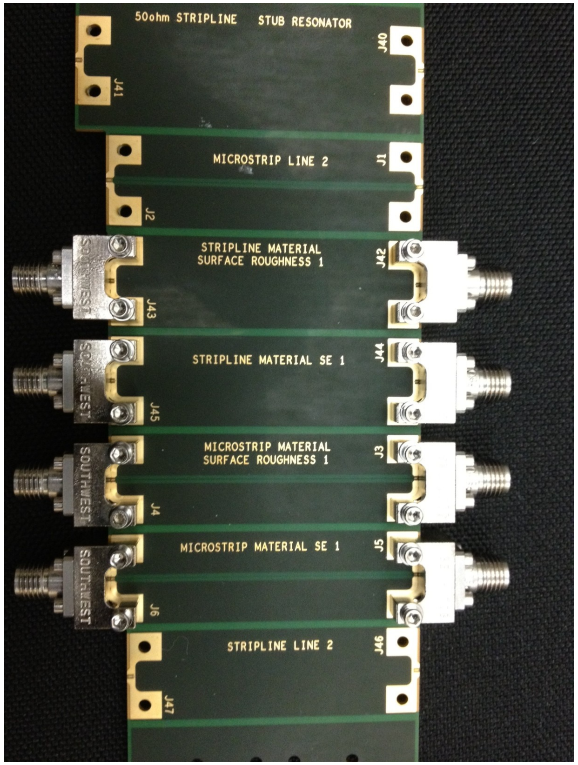
Temperature-Moisture Modeling

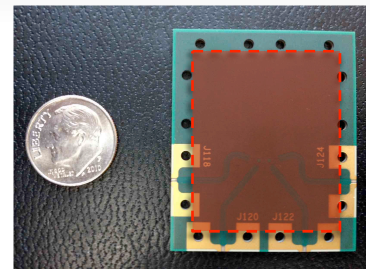
Lots of questions, like:

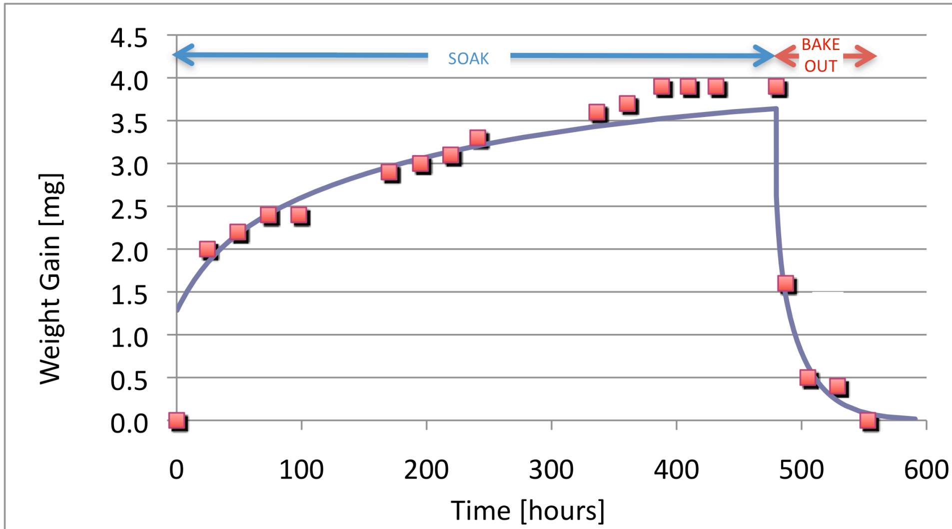
- How saturated were the samples we measured?
- What is the pathway and mechanism in which moisture penetrates the samples?
- How quickly do packages and PCB materials respond to changes in ambient moisture conditions?



Temperature-Moisture Modeling

- Soaked & baked a smaller test structure
- Performed weight measurements over time
- Modeled moisture absorption/ desorption using a numerical method described in paper and in [1]
- Moisture ingress is through edges or openings then limited by diffusion process
- Once diffusion coefficients are determined, these can be applied to real structures





[1] Guenin, Bruce. "Transient Modeling Of High-Power IC Package." *ElectronicsCooling*, 2011: Vol. 17, No. 4.

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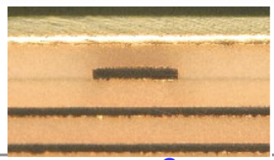
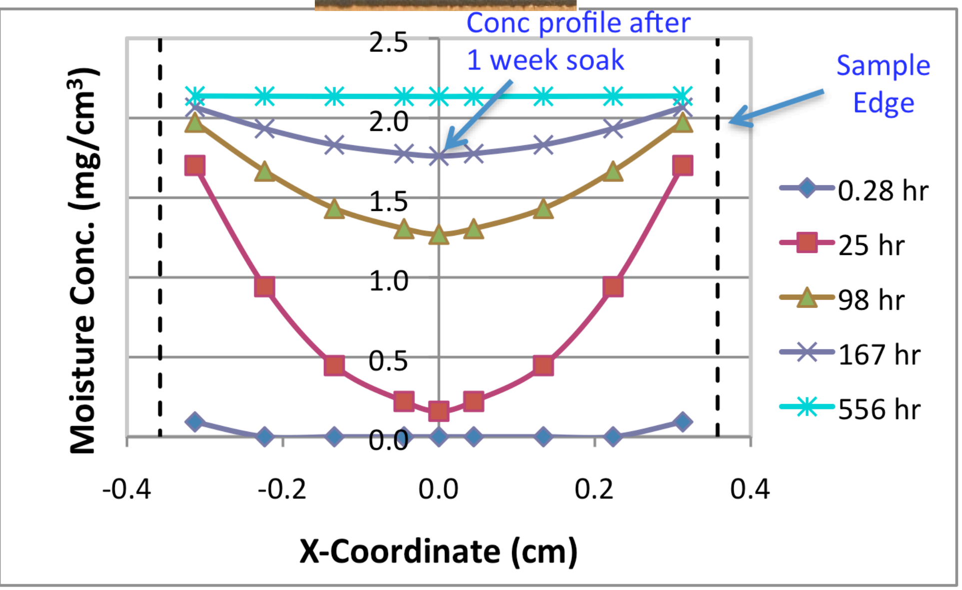
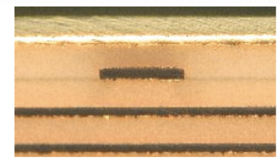
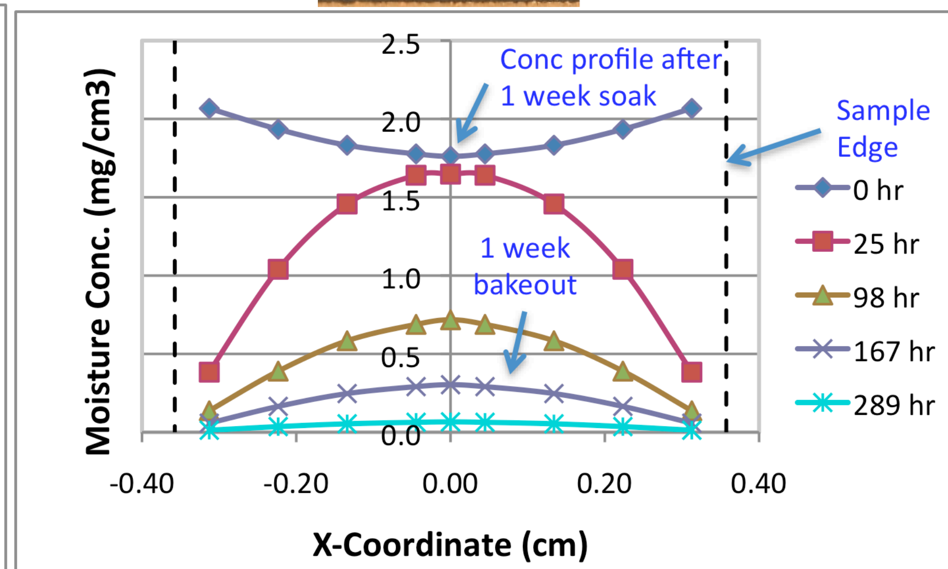
Temperature-Moisture Modeling





Soak





Bake

Temperature-Moisture Modeling Summary

- Moisture ingress occurs along edges unless cutouts exist. This absorption/desorption process was modeled and correlated to weight gain/loss measurements.
- The soak and bake time used in the measurement section didn't fully saturate the structures that were characterized
  - This implies that further sensitivity to temp is likely for the soaked samples
- Typical organic packages and PCBs will most likely soak and bake on the order of days.
  - Electrical characteristics can slowly change over time

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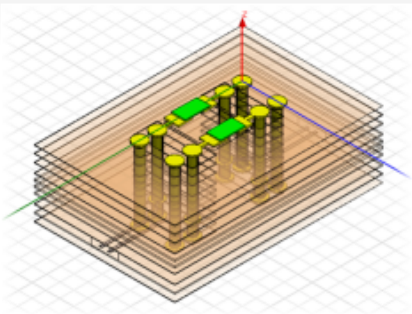
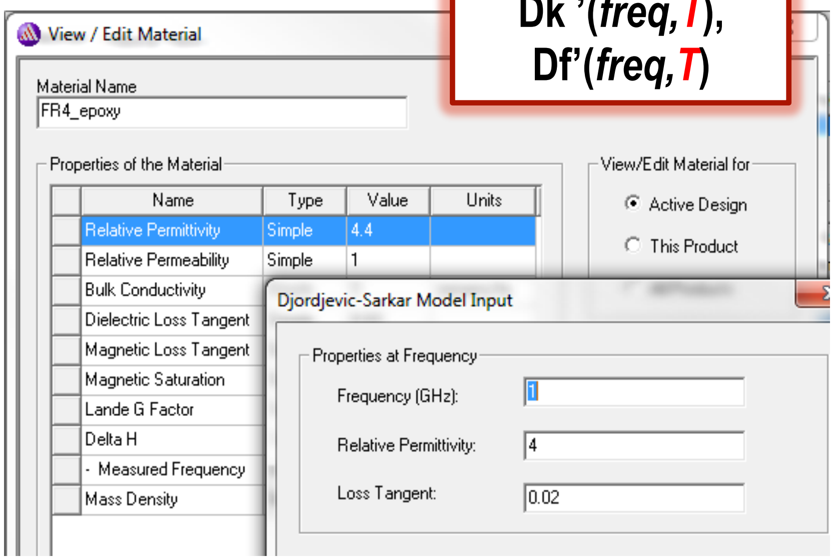
Temperature Dependent Debye Model

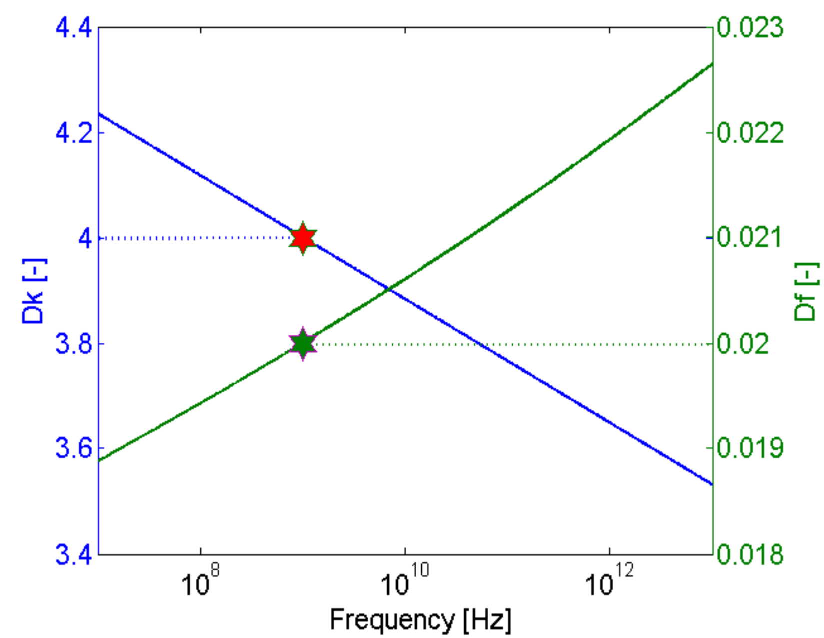


Material
Dk(*freq*), Df(*freq*)

↓

Material
Dk '(*freq*,*T*),
Df'(*freq*,*T*)





- ❑ HFSS
- ❑ CST
- ❑ Analytical
- ❑ …

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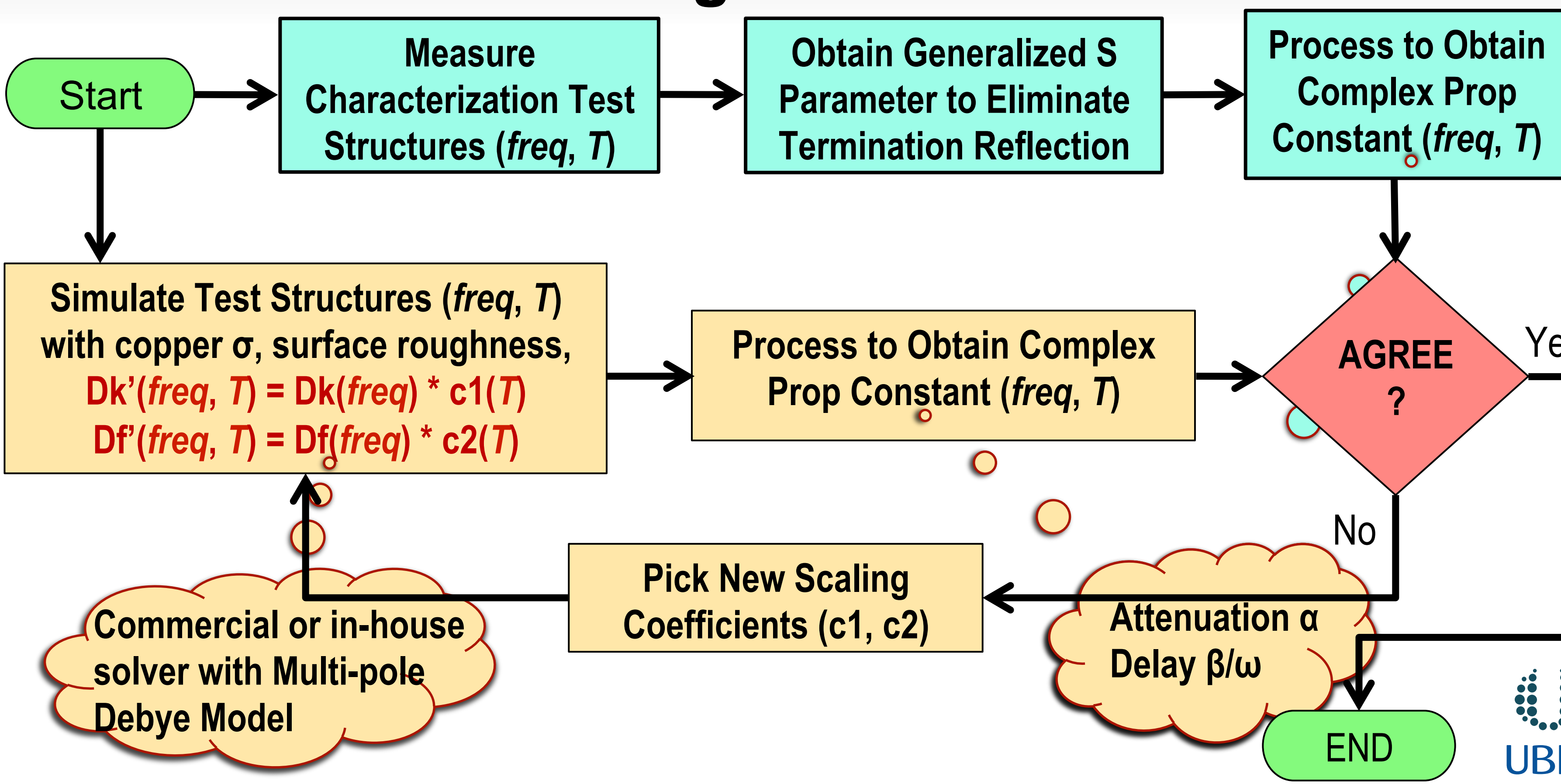
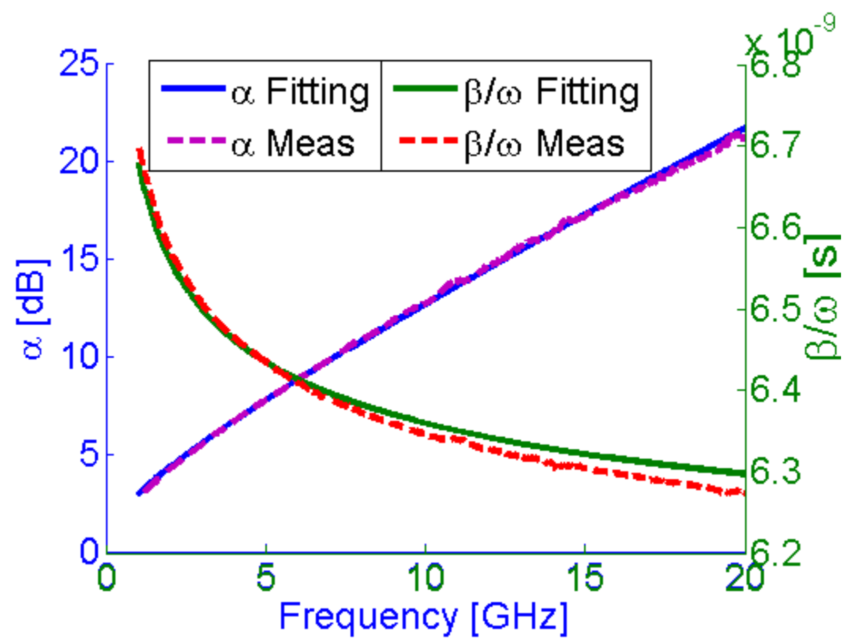
Temperature Dependency Coefficients Fitting Algorithm

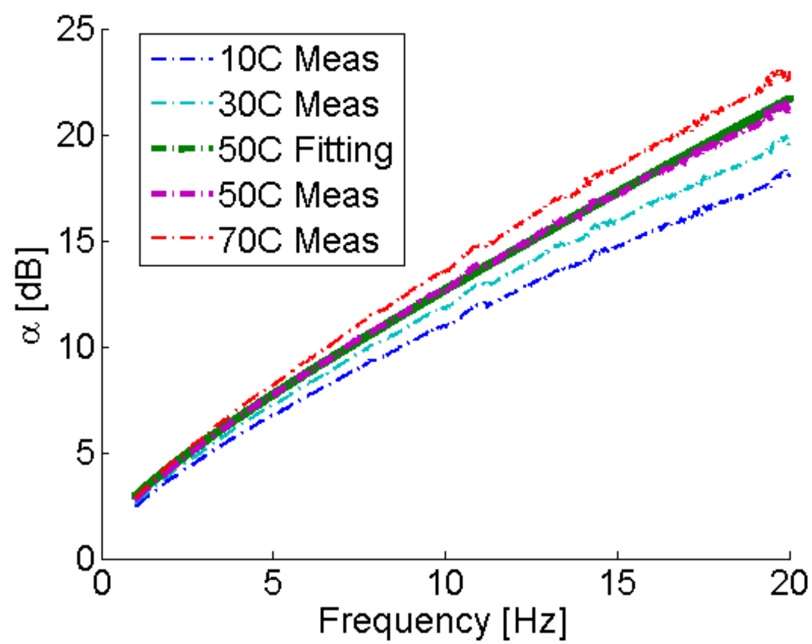


Temperature Dependency Coefficients Model Fit

Fitting criteria - Attenuation α and Delay β/ω

Typical fitting for package material soaked case





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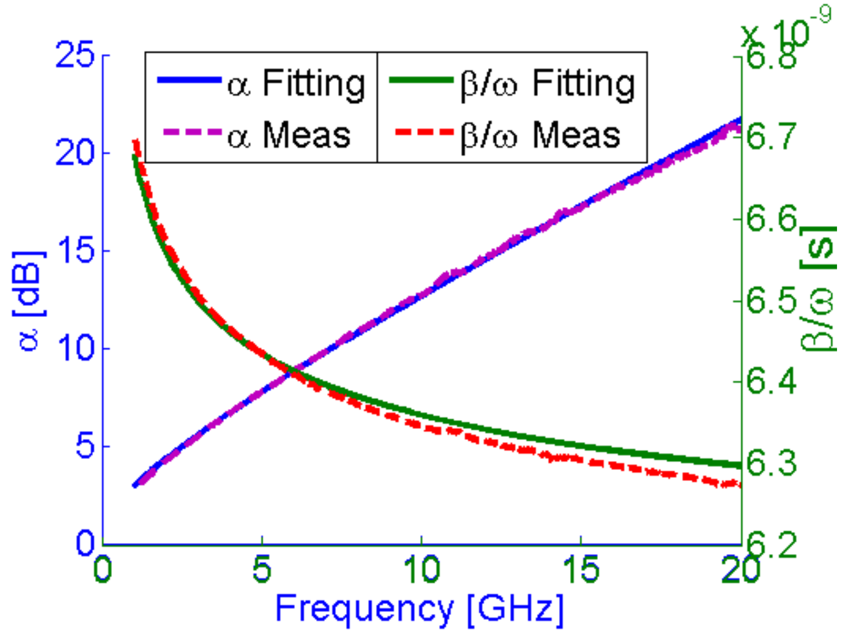
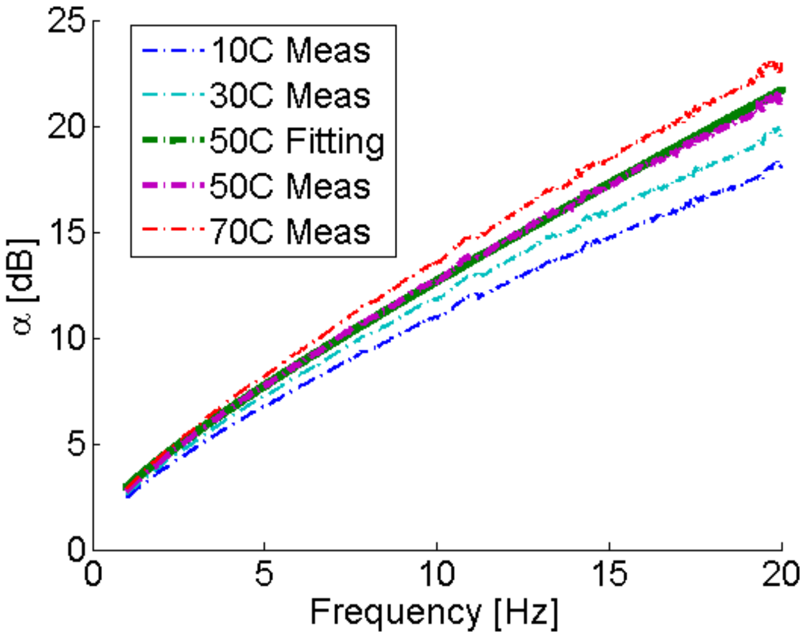
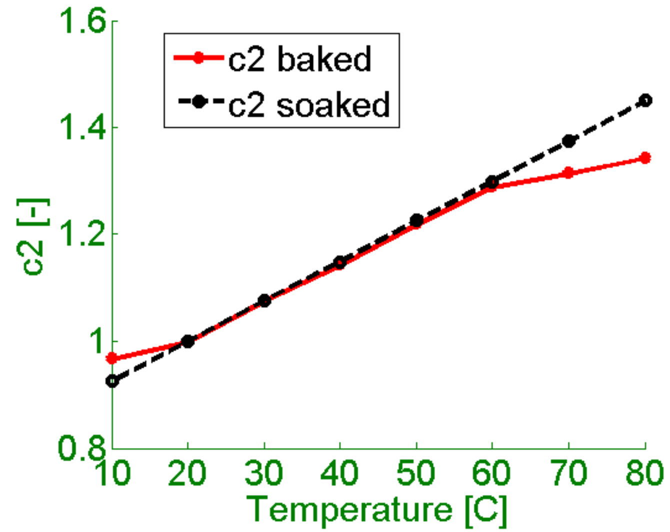


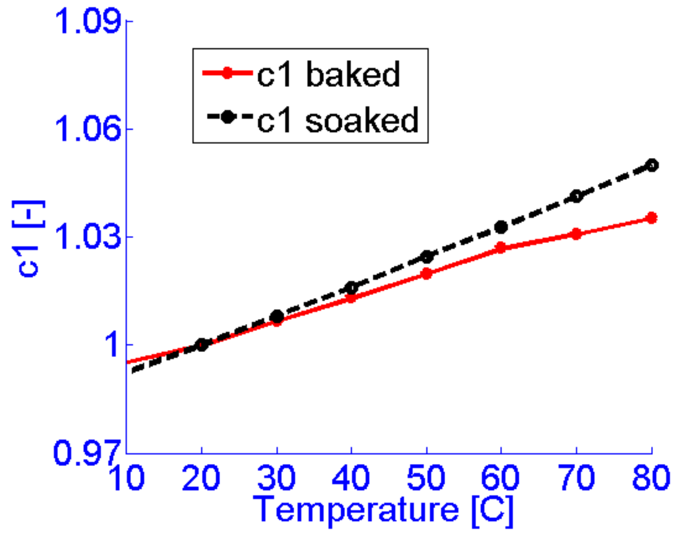


Temperature Dependency Coefficients Model

Df'(*freq*, *T*) = Df(*freq*) * c2(*T*)



Dk'(*freq*, *T*) = Dk(*freq*) * c1(*T*)

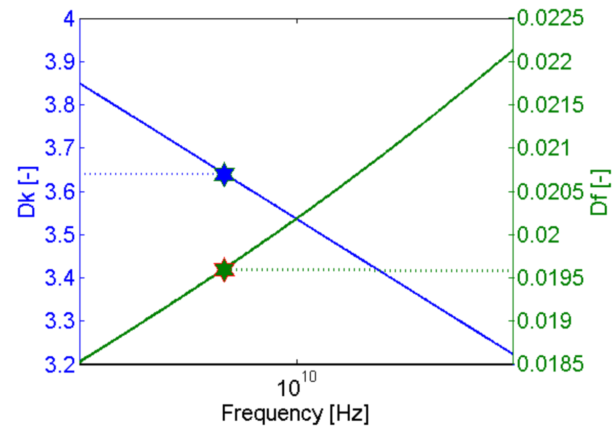


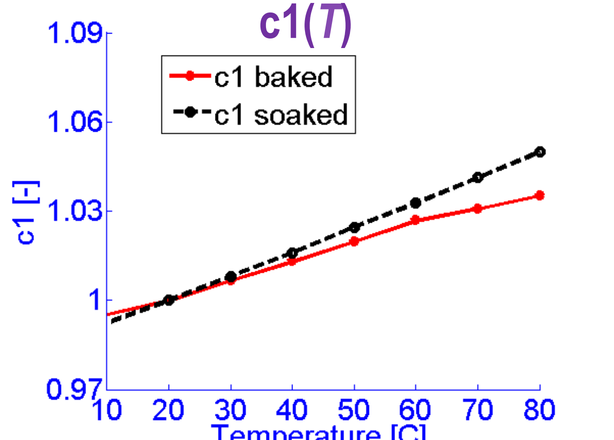
	Baseline Df@1GHz	Baseline Dk @1GHz
Baked / Soaked case	0.016/0.0196 (↑22%)	3.614/3.640 (↑0.7%)

Dk and Df can be scaled linearly to re-simulate at any other temperature.

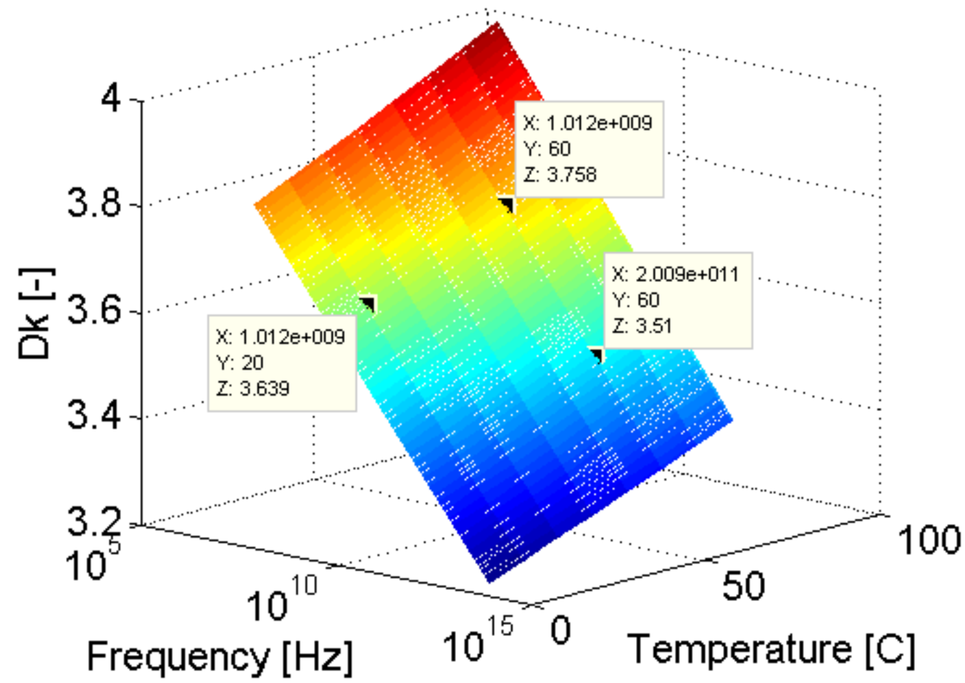
Temperature Dependent Debye Model

Dk(*freq*)





Dk'(*freq*, *T*) = Dk(*freq*) * c1(*T*)



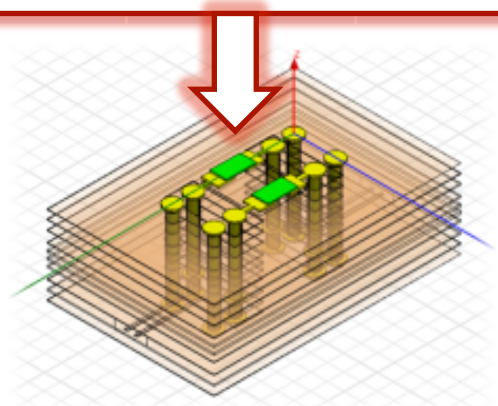
Debye model
Dk(*freq*)

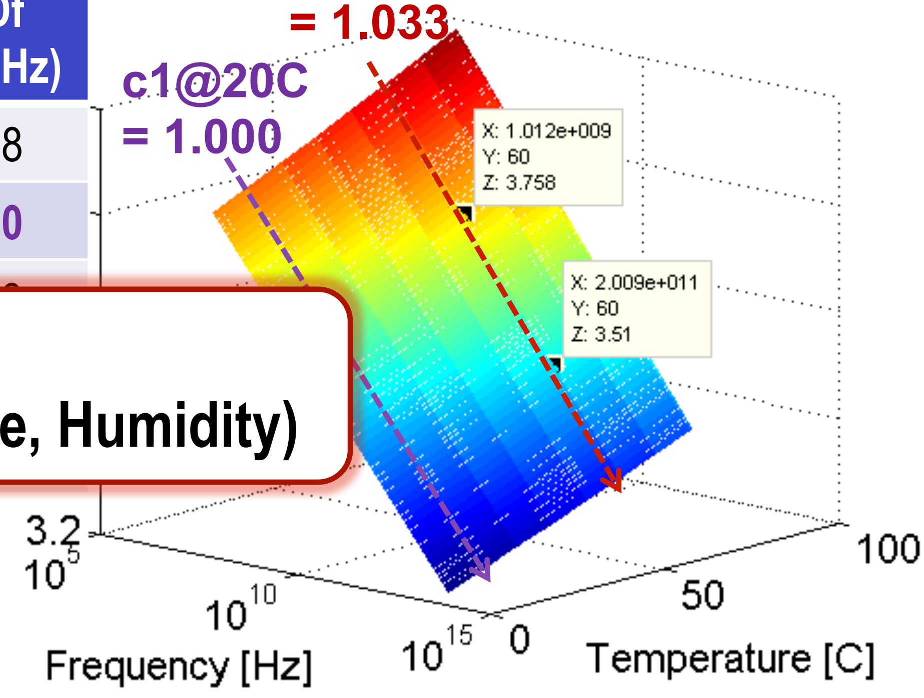
c1(*T*)

Temperature Dependent Debye Model

Temp (C)	c1	c2	c1*Dk (@ 1GHz)	c2*Df (@ 1GHz)
10	0.992	0.925	3.611	0.018
20	**1.000**	**1.000**	**3.640**	**0.020**

c1*Dk, c2*Df
(Material, Frequency, Temperature, Humidity)





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Direct Scaling of Solved s-parameters

Unfortunately, many engineers find themselves:

- A package model at 20 C but no means of simulating it under different moisture/temperature conditions
- Not knowing whether it is worth their time and effort to include these effects

A quick estimate of the likely impact of temperature and moisture on the package (or PCB) is desirable.

We present an approximation that requires some basic parameters of the package:

- Nominal s-parameters
- Characteristic impedance of the line
- Length of the trace (can be estimated from s-parameters if not known)
- Temperature- and/or moisture-dependent Dk and Df
- We do not require any knowledge of the inevitable discontinuities

Explanation of the Approach

- The effect of discontinuities and temperature difference is small and can be approximated with an expansion around zero:

$$A(\delta x, \delta T) \approx A + \frac{\partial A}{\partial x}\delta x + \frac{\partial A}{\partial T}\delta T$$

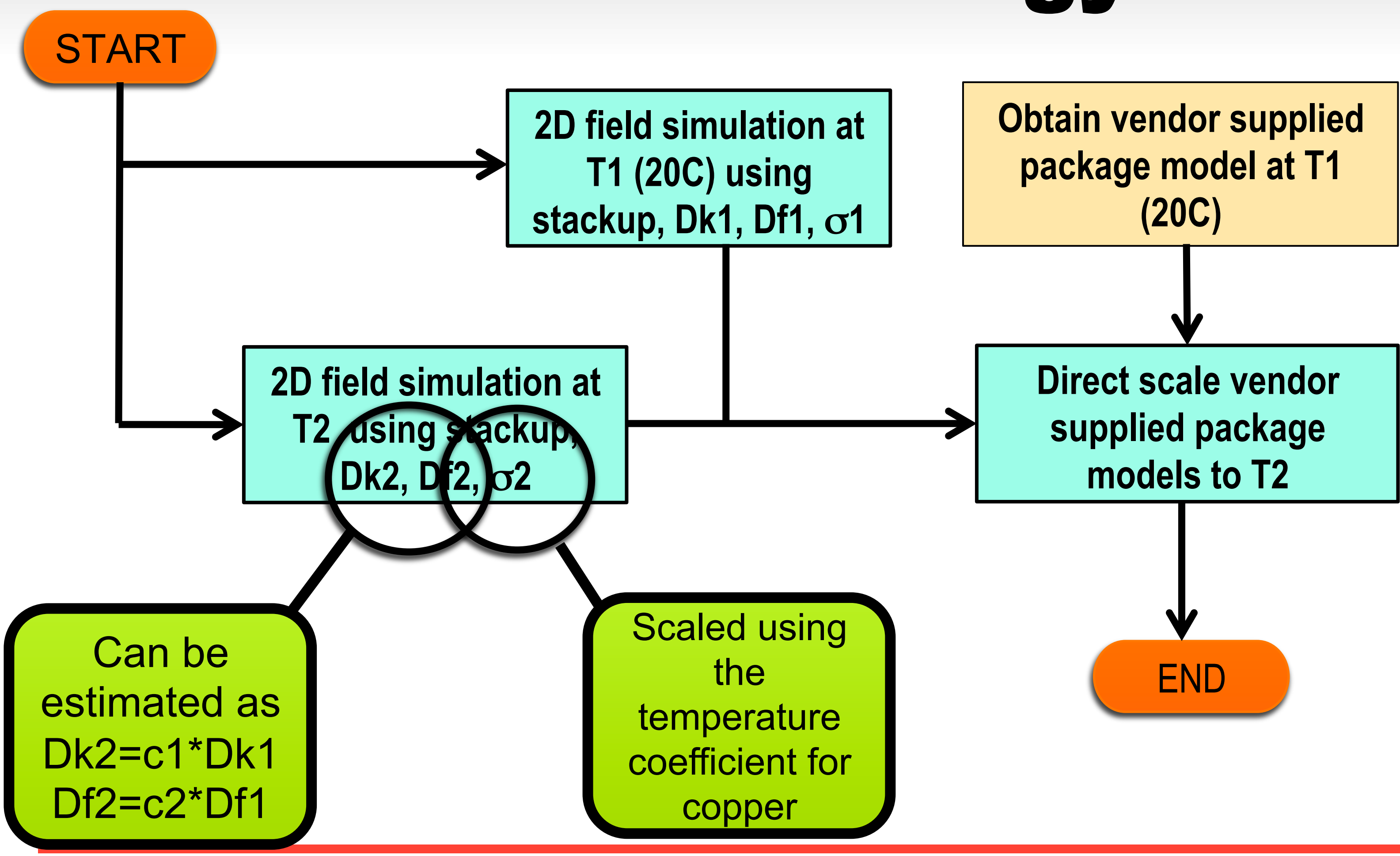
and

$$A(\delta T)A^{-1}A(\delta x) \approx (I + \frac{\partial A}{\partial T}\delta T A^{-1})AA^{-1}A(I + A^{-1}\frac{\partial A}{\partial x}\delta x) \approx A + \frac{\partial A}{\partial x}\delta x + \frac{\partial A}{\partial T}\delta T$$

therefore

$$A(\delta x, \delta T) \approx A(\delta T)A^{-1}A(\delta x)$$

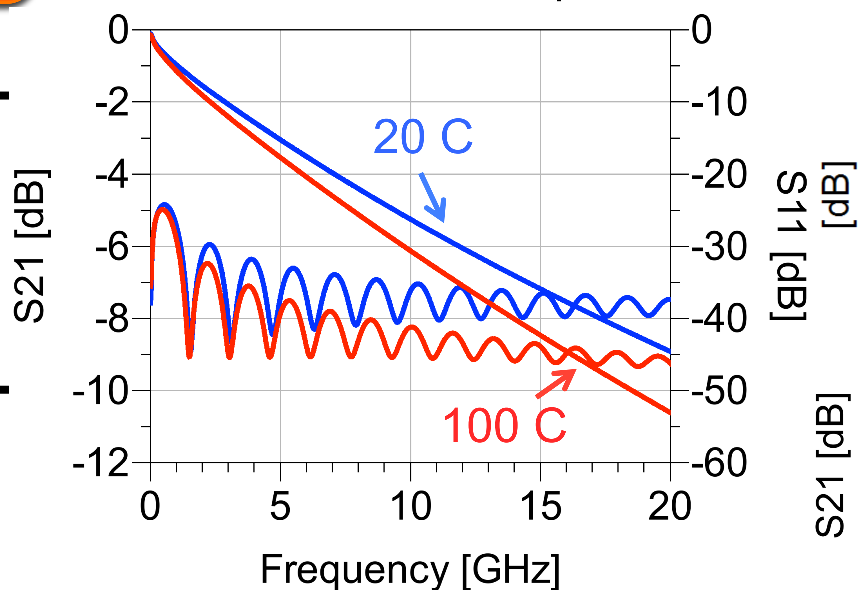
Methodology



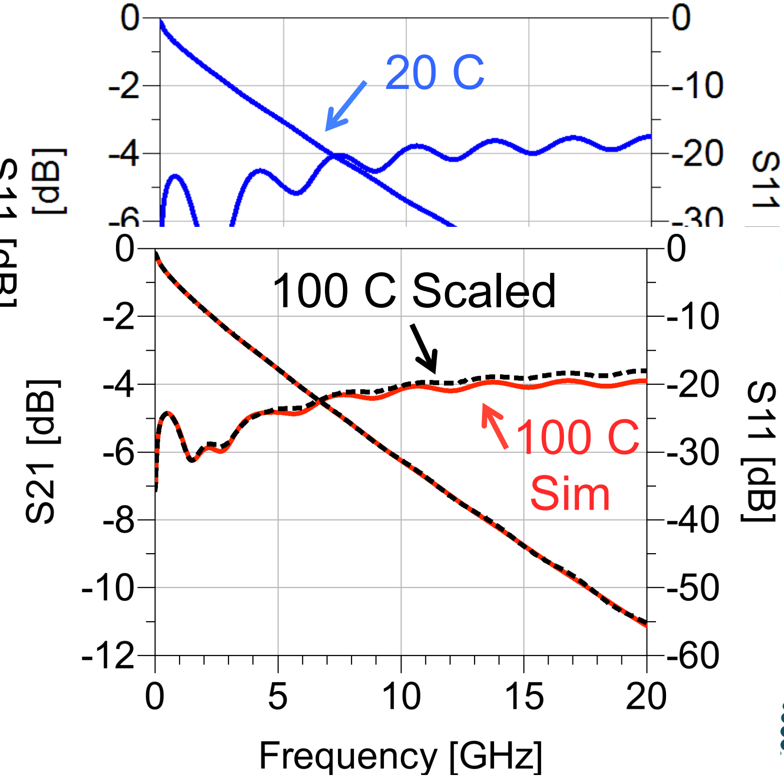
Direct Scaling Example

START

50 mm uniform striplines



50 mm stripline w/ via



Direct Scaling of Solved s-parameters

- Vendor supplied models don't usually include temperature and moisture effects
- A method was shown for including temperature and moisture effects in existing s-parameter models

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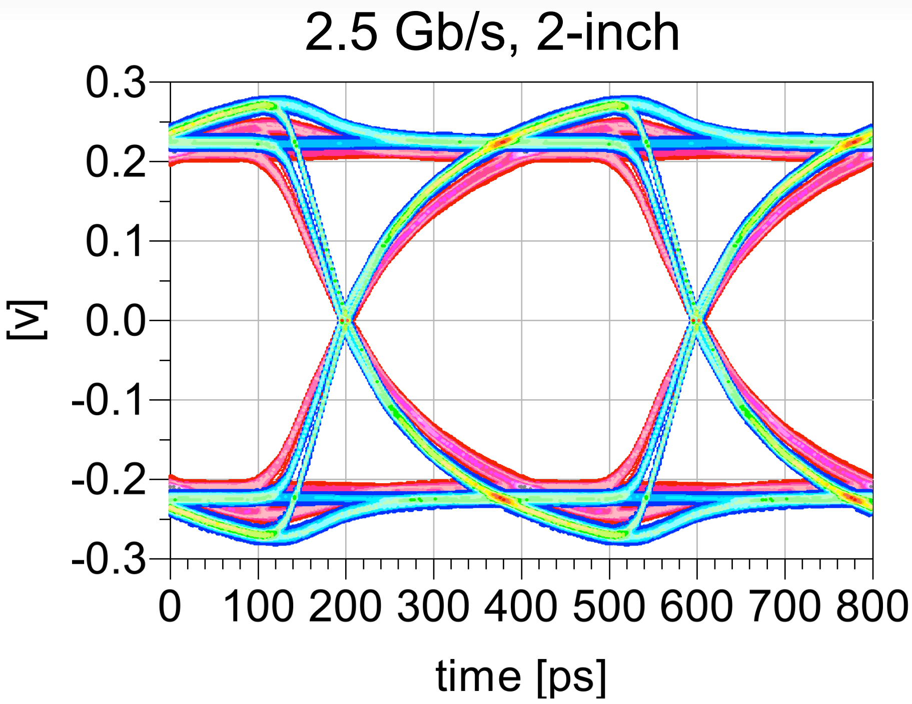
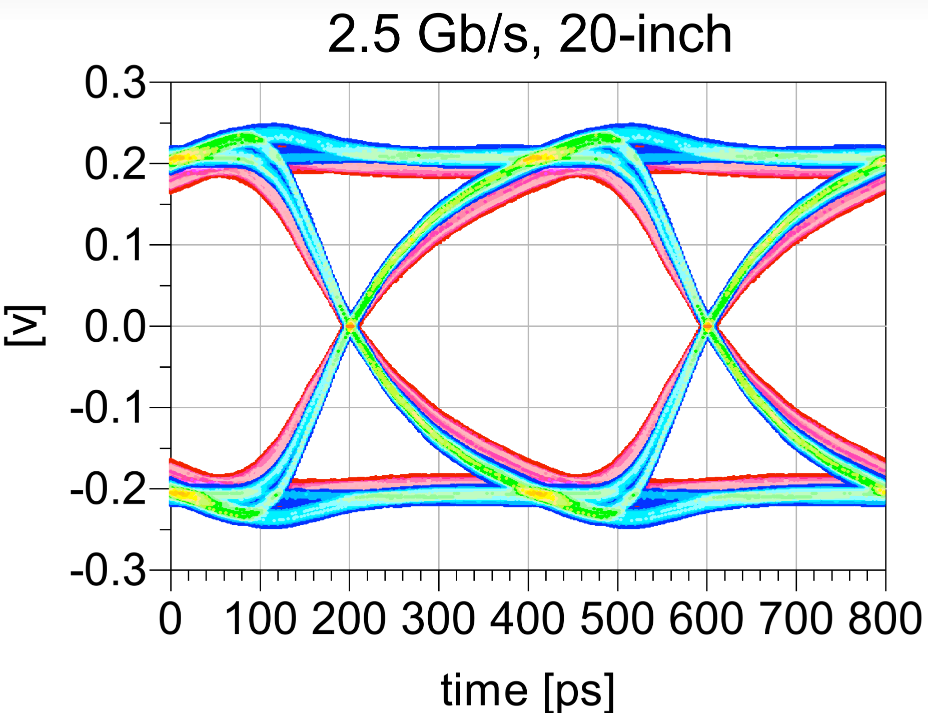
Real-World Impact of Temperature

- What is the impact of temperature on the overall channel performance?
- Focus on package temperature effects on channel performance
  - Package models are typically generated at 20 C
  - Package operating temperature can be much higher in reality
- Assumptions:
  - 2” or 20” standard FR-4 PCB at 20 C
  - Tx package & Rx package at 20 C or 100 C
  - Assume -3.5 dB of de-emphasis and CTLE at Rx
  - Simulate eye diagram at 2.5, 5.0, 8.0 Gb/s

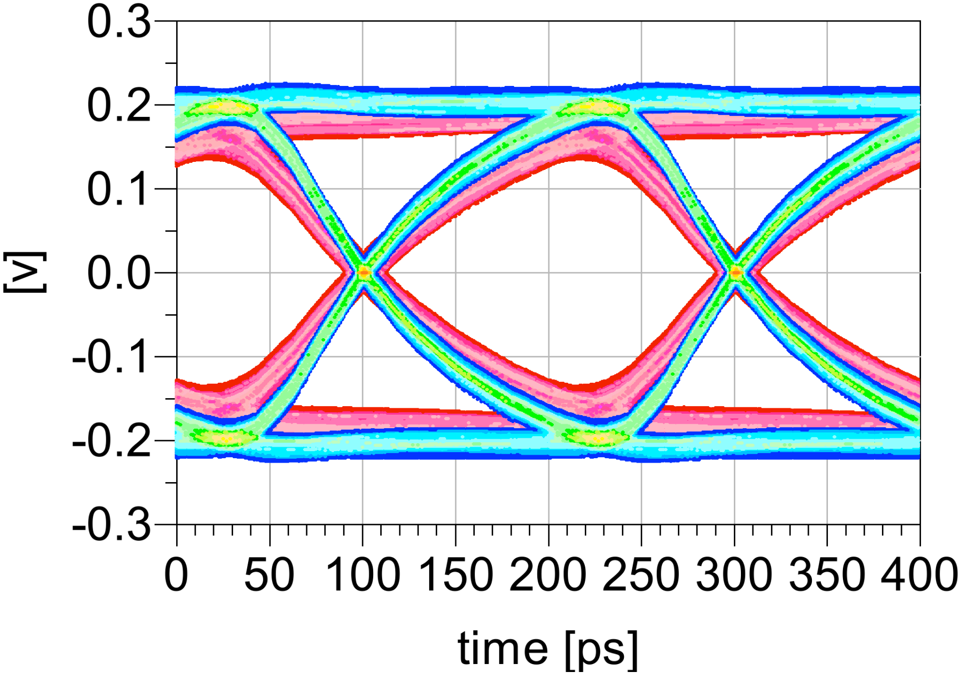
Real-World Impact of Temperature



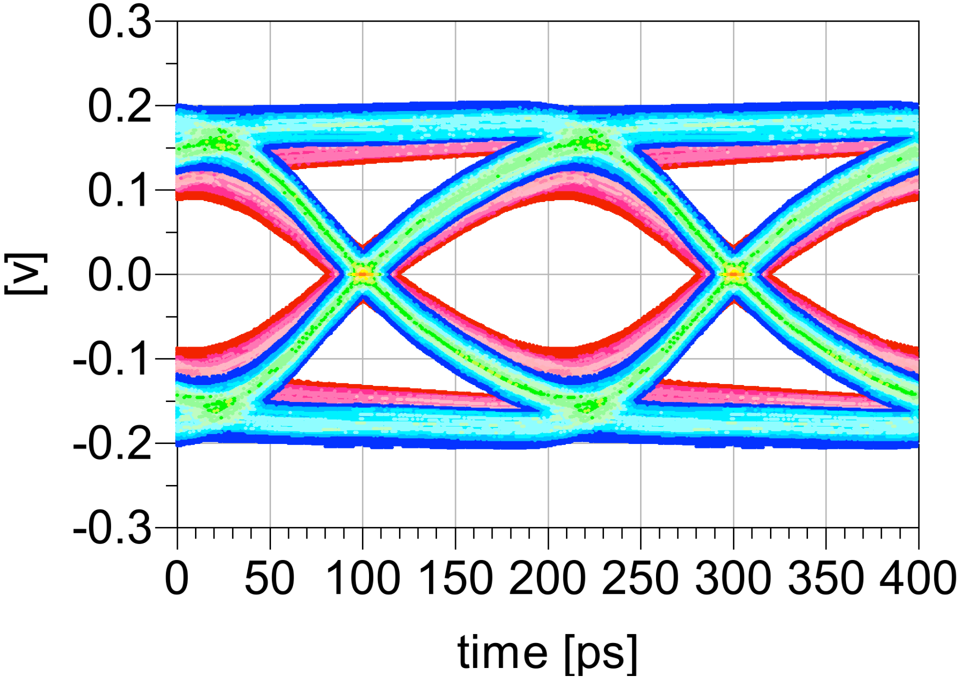


Real-World Impact of Temperature

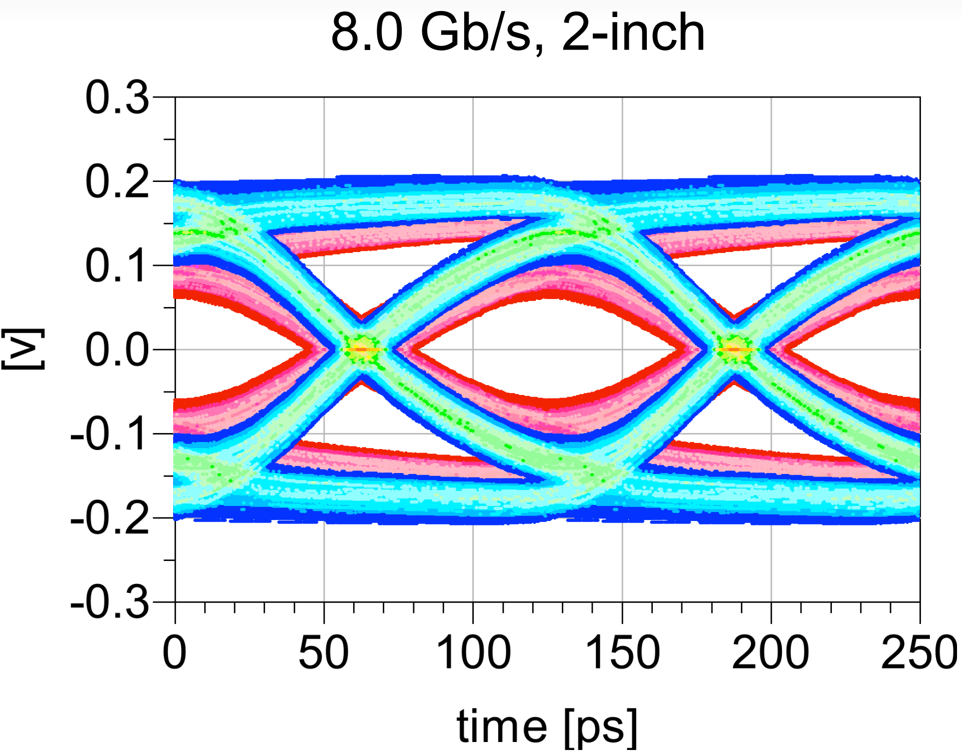
5.0 Gb/s, 2-inch

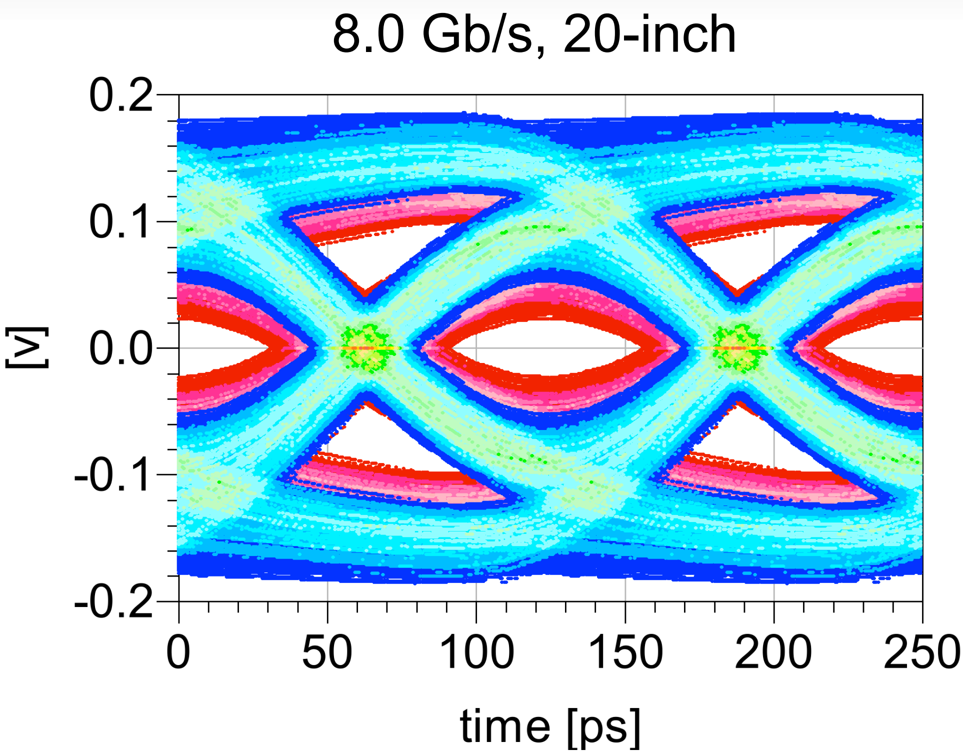


5.0 Gb/s, 20-inch

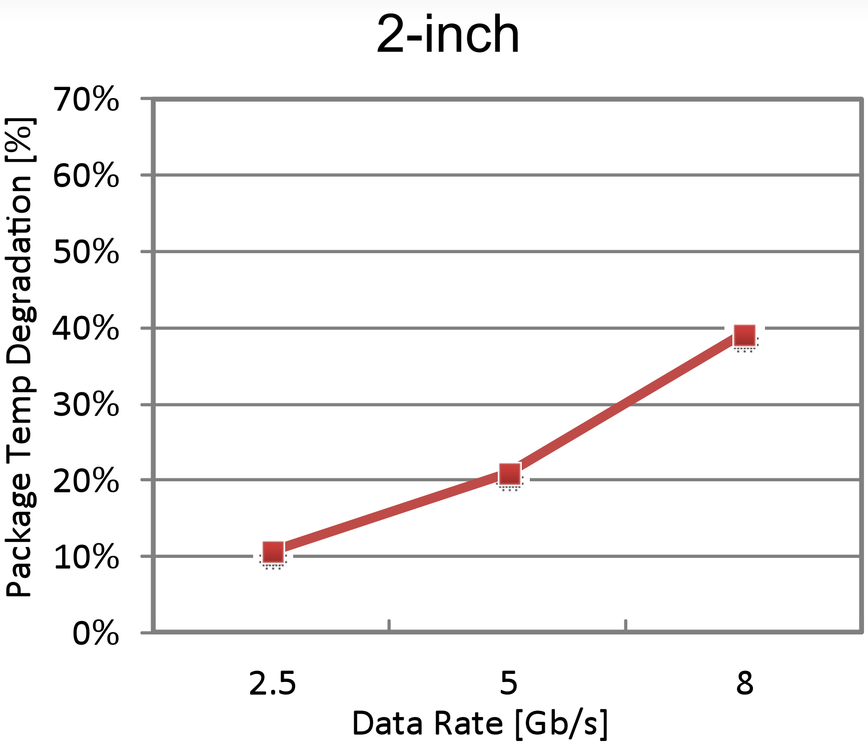


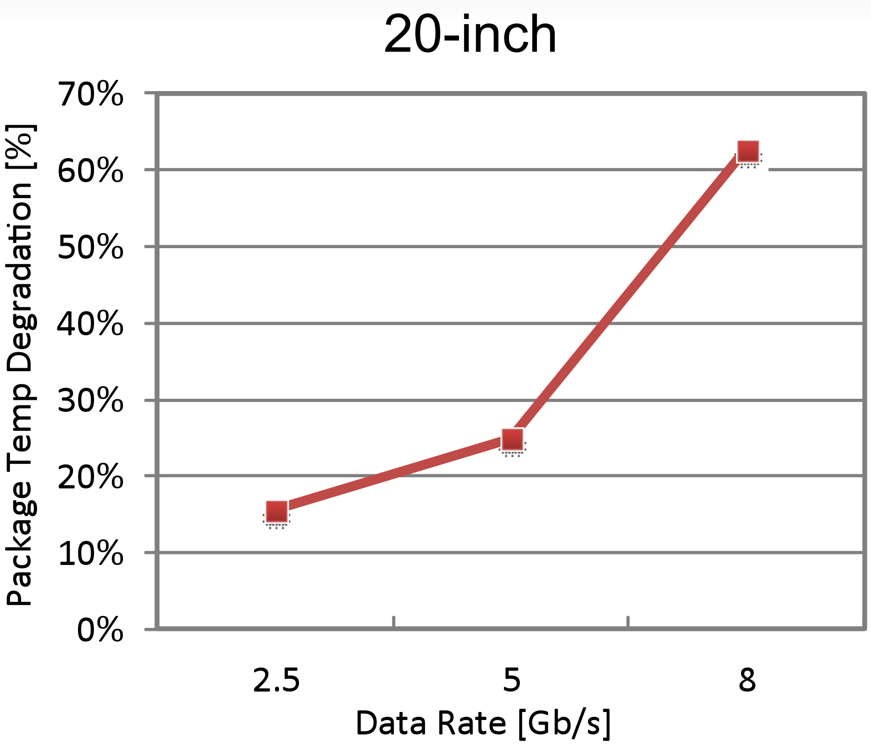
Real-World Impact of Temperature



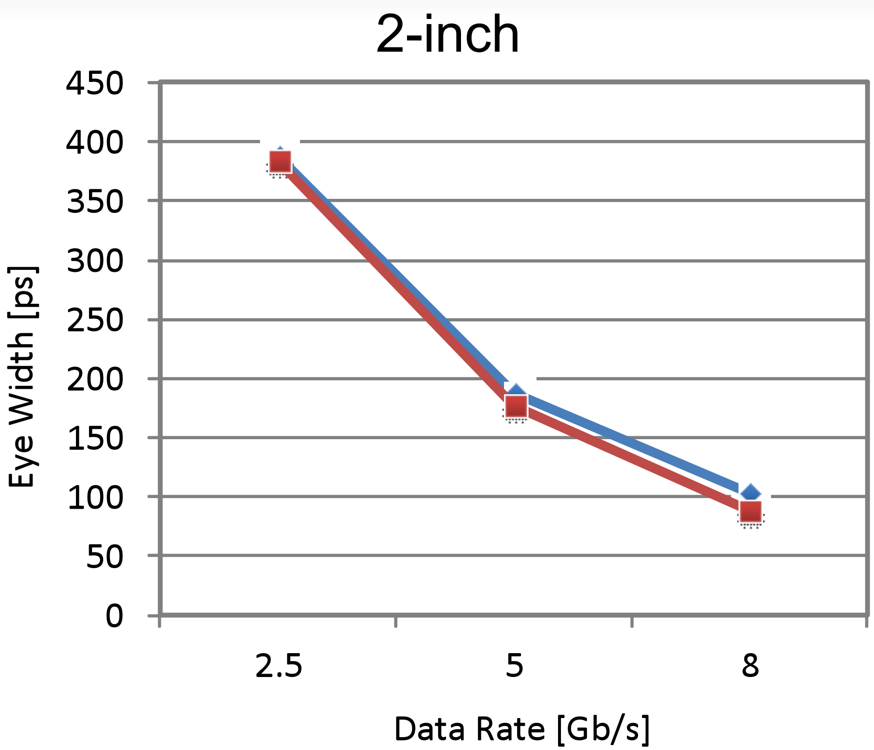


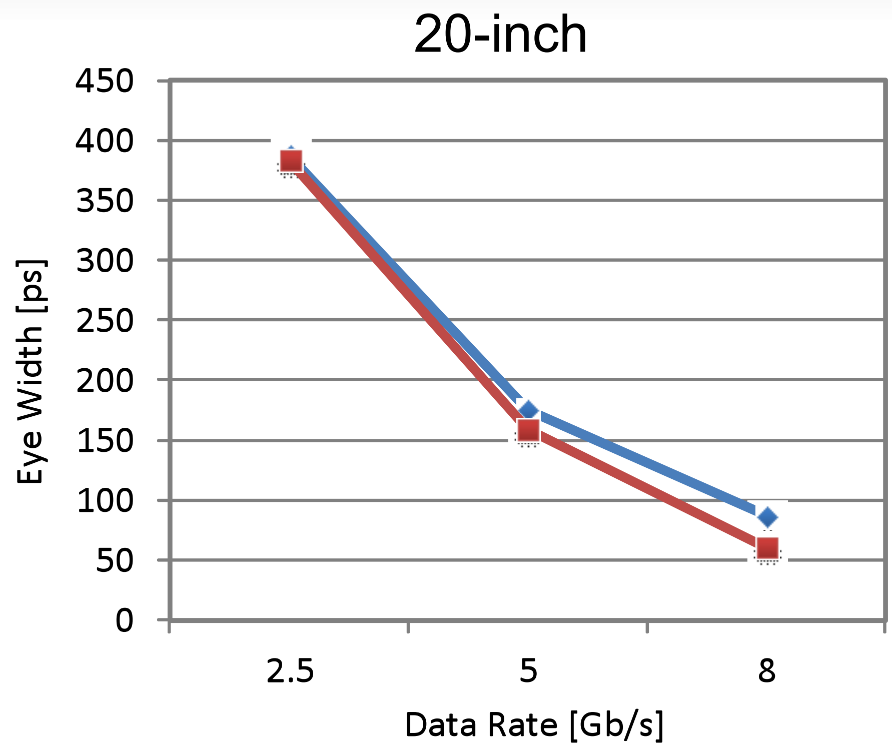
Real-World Impact of Temperature





Real-World Impact of Temperature





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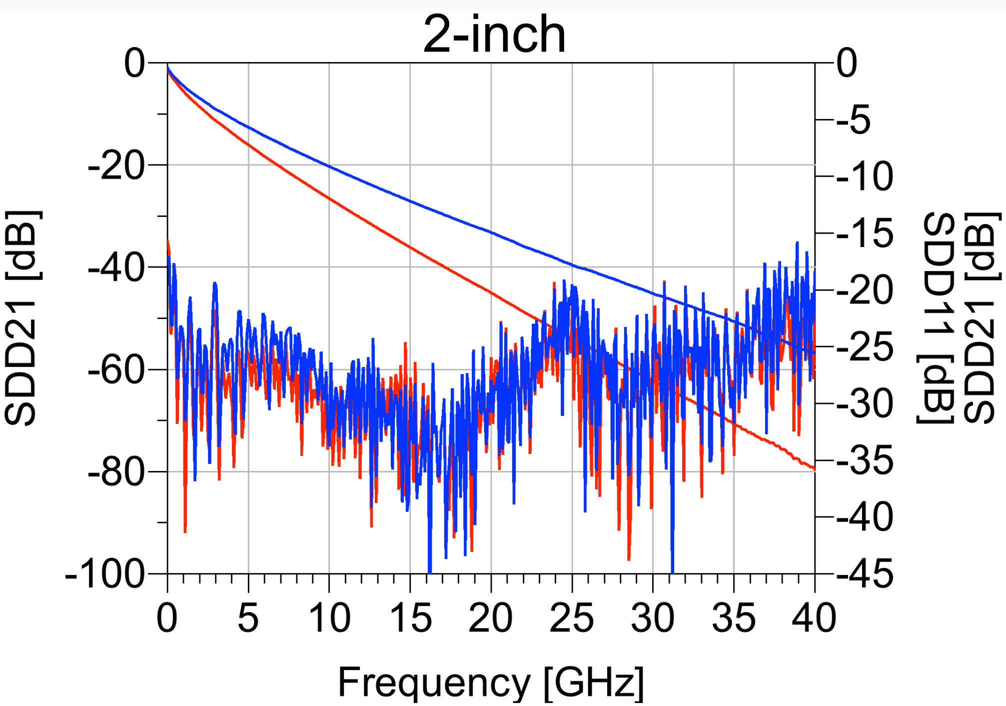

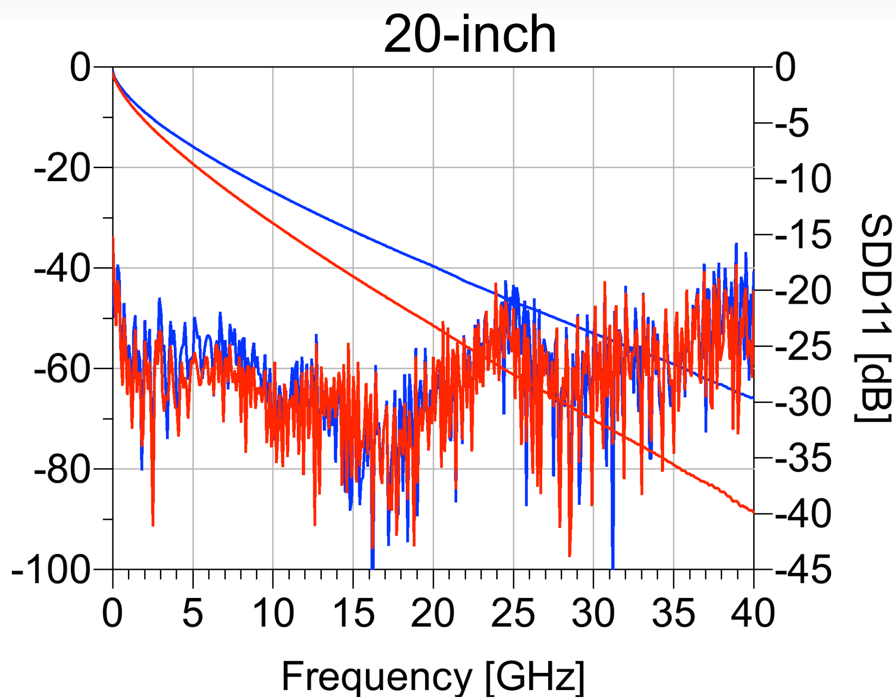

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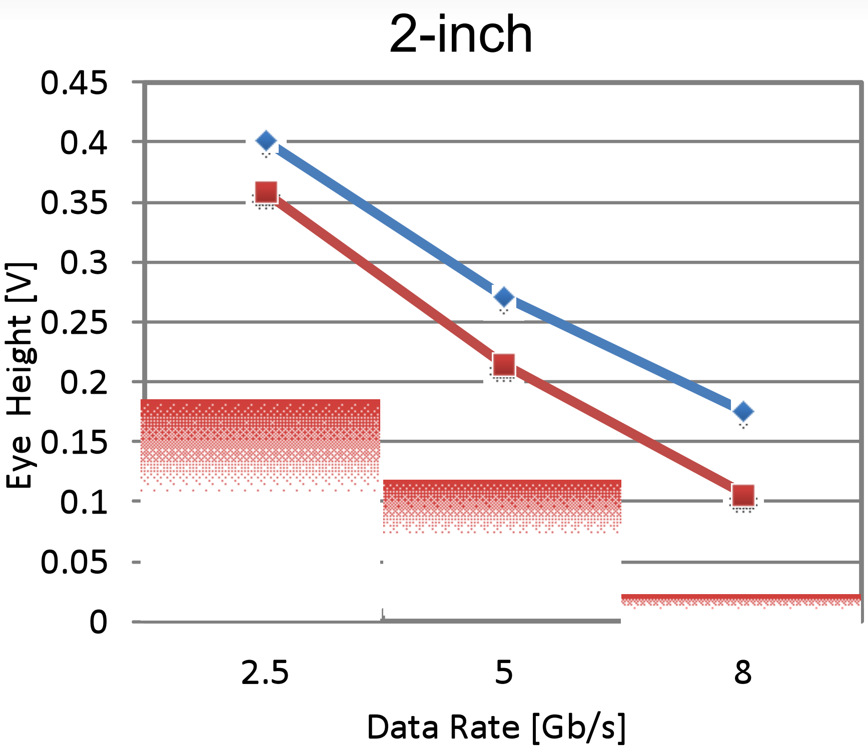

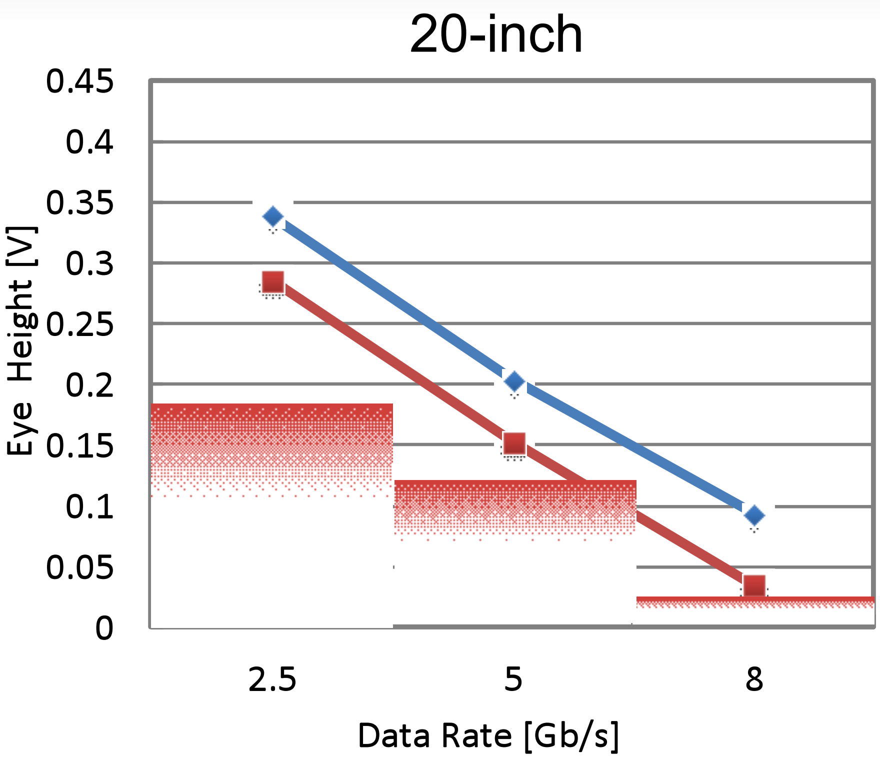

Summary

- As data rates increase, losses due to temperature effects increase while simultaneously operating margins decrease.
- Temperature and humidity variation of passive models is not commonly captured in channel simulations
- For example, package models are typically extracted at room temperature although packages are typically used in a much hotter environment.
- These results stress the importance of including temperature dependent effects for 8 Gb/s and beyond
- Methods were presented to include temperature-dependent effects in channel simulations for model generation (field-solver simulations) and by scaling solved s-parameter solutions.