Opening Eyes on Fiber Weave and CAF

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Executive Summary

The signal channels that link high speed processors to memory and various other peripherals, are limited by the inherent characteristics of the printed circuit board. These are what ultimately connect information to the outside world. One limiting factor is the effect of non-uniformity of the glass fiber distribution in the printed circuit substrate material, also known as fiber weave effect (FWE). FWE introduces signal skew and timing errors which place an upper limit on bit rate and trace length.

Using unique fabrication techniques and a proprietary low dielectric constant glass composition, a revolutionary glass fabric is presented that is essentially free of fiber weave effect while demonstrating inherently improved resistance to conductive anodic filament (CAF) formation. Improved laminate performance is demonstrated with finite element modeling and HyperLynx simulations, and corroborated with dielectric property measurements on prototype substrates.

A printed circuit board using this material demonstrates superior signal integrity performance over the traditional glass-based solution. By uniformly distributing glass fibers the maximum surface area becomes available to bond with the resin, which is enhanced by direct application of a finish to provide a high quality interface between glass and resin. Two high profile performance issues, fiber weave effect and CAF, are addressed by a unique laminate reinforcement.

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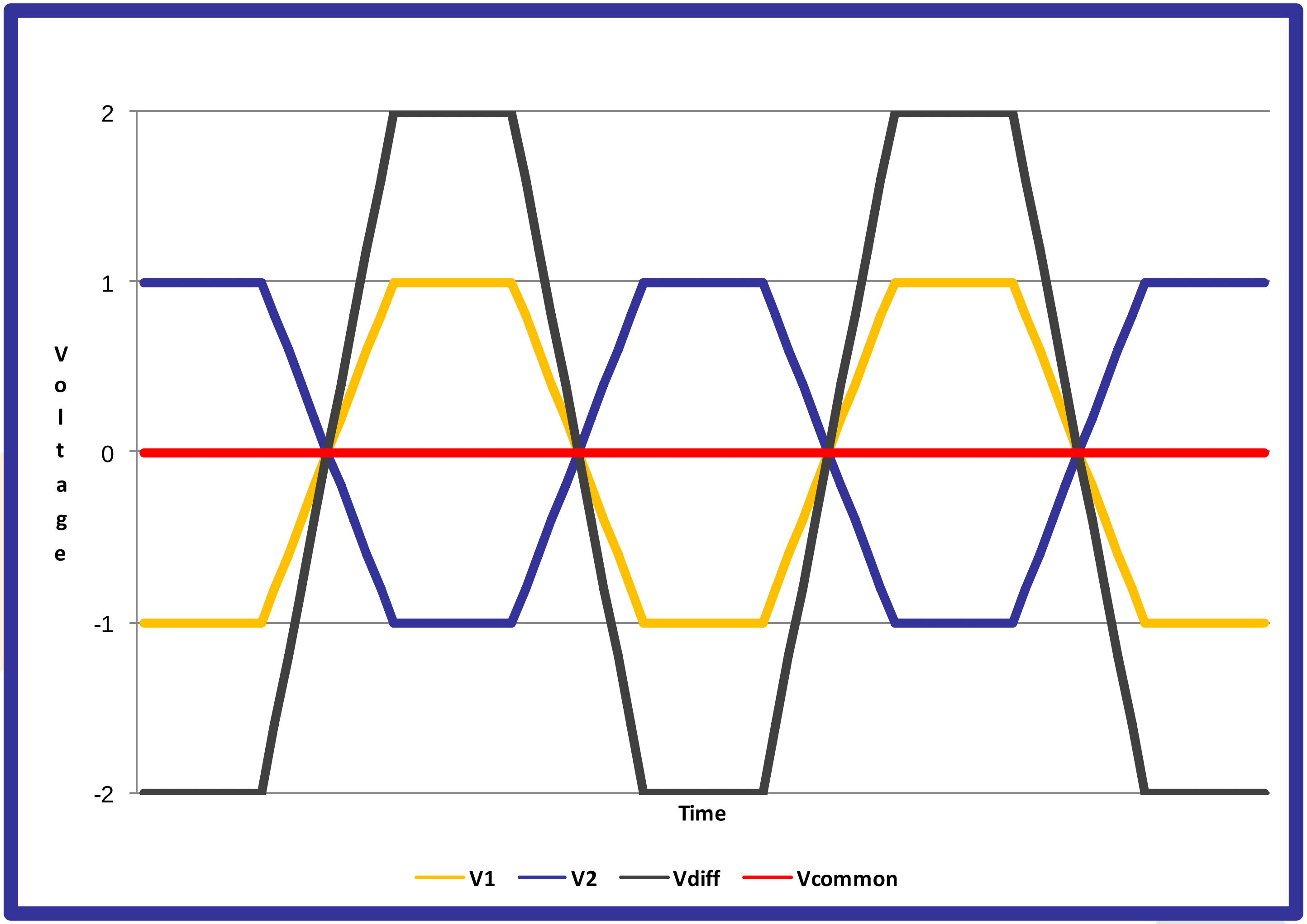
Intro

- Fiber Weave Effect (FWE)
- Signal Skew and Timing Errors
- One Solution for Two Performance Limiting Issues

Why worry about FWE ?

- FWE Causes Variation in Signal Propagation
- Propagation Delay Differences Result in Signal Skew
- As Bit Periods Decrease, Signal Skew Related Issues Increase
- Jitter Budget
- However, is it Significant?

Differential Skew and Voltage



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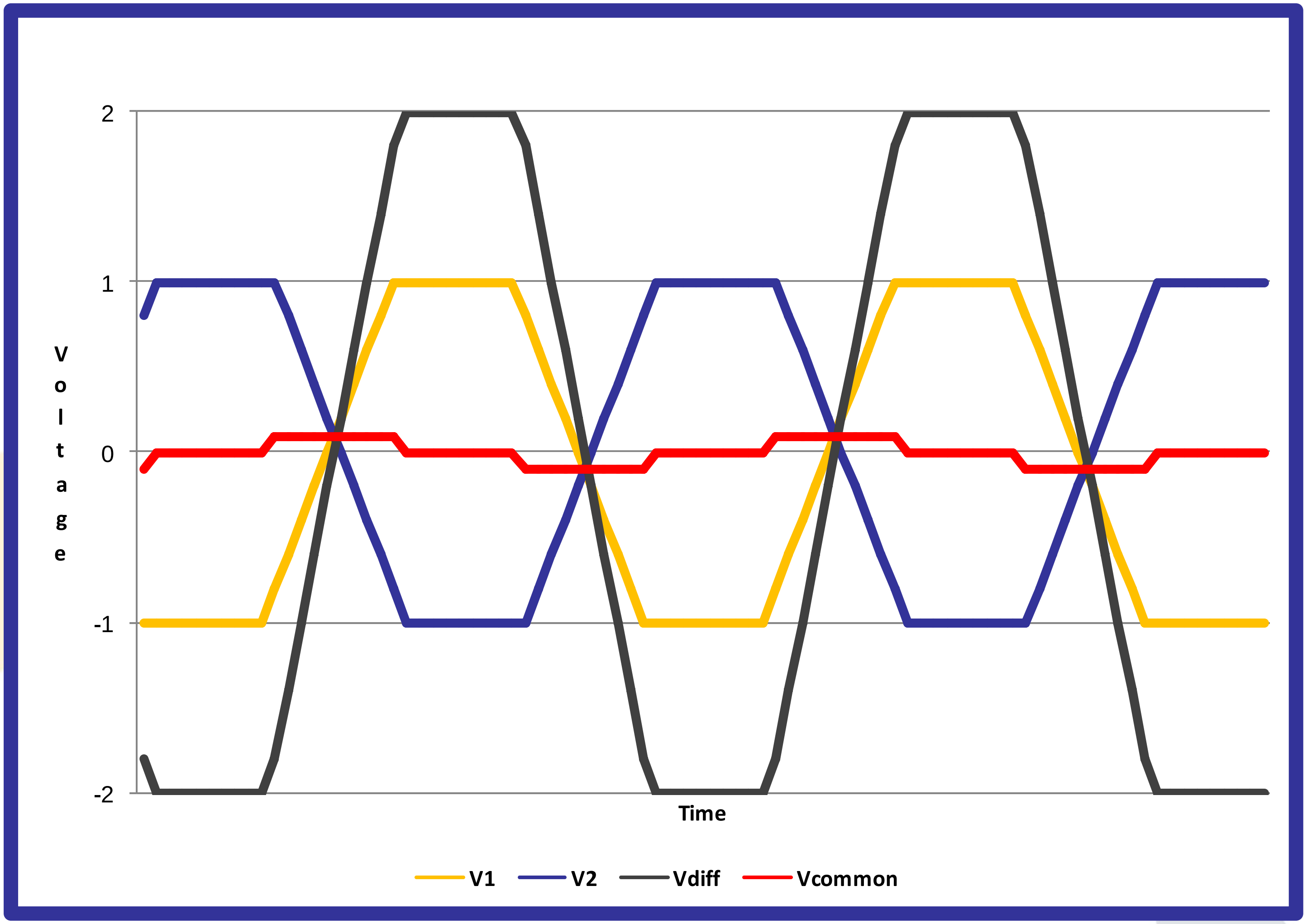
Differential Skew and Voltage



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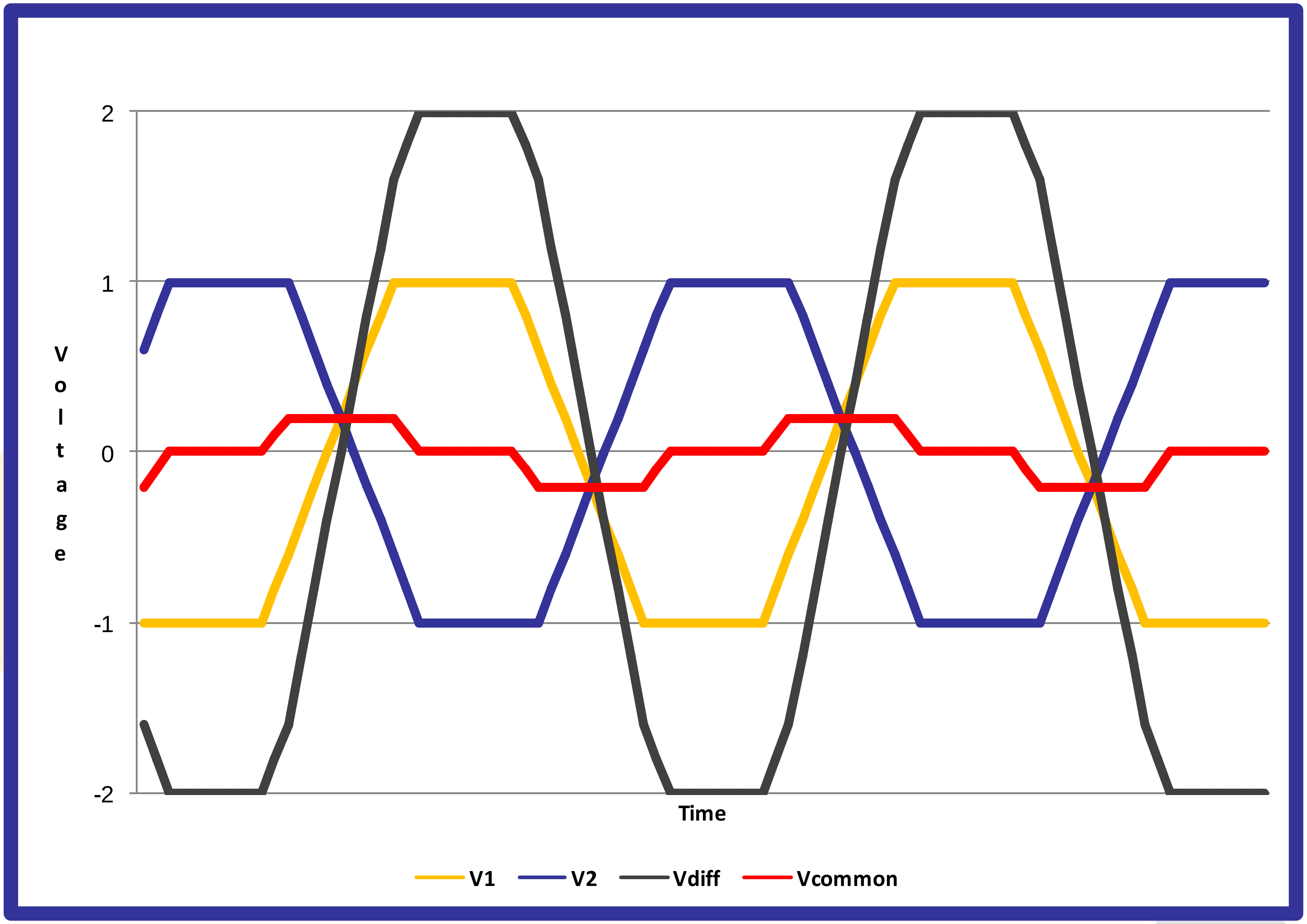

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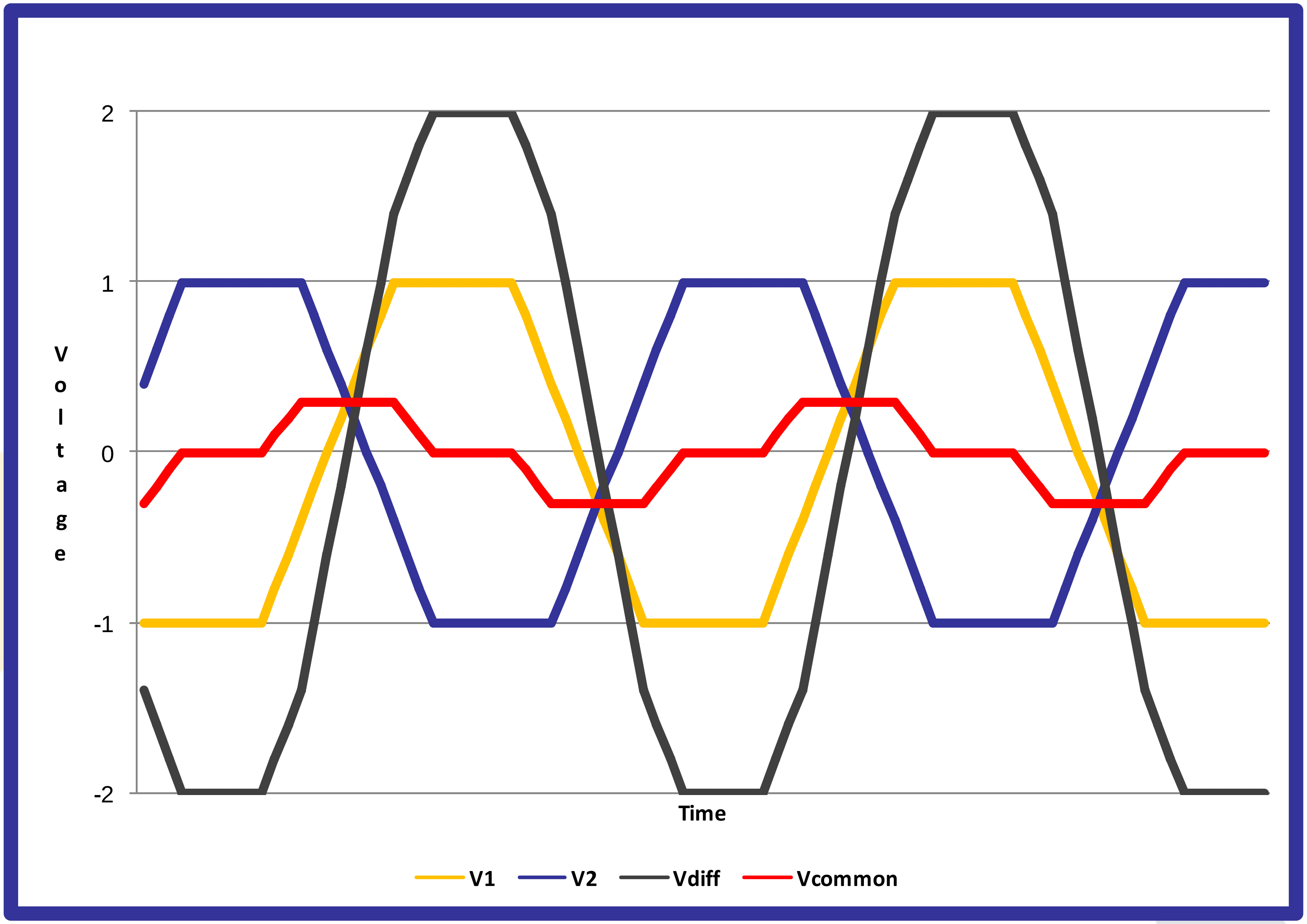

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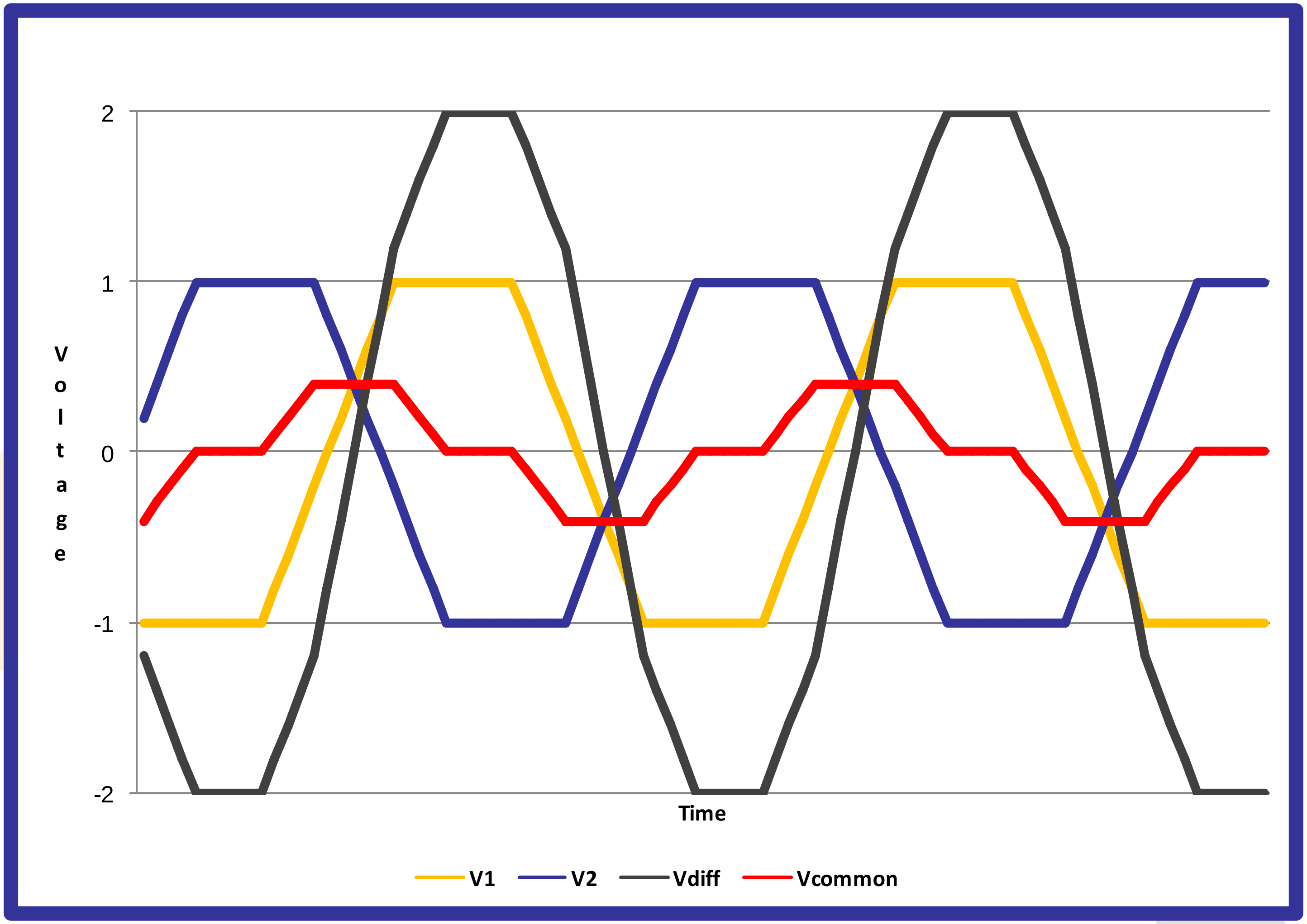

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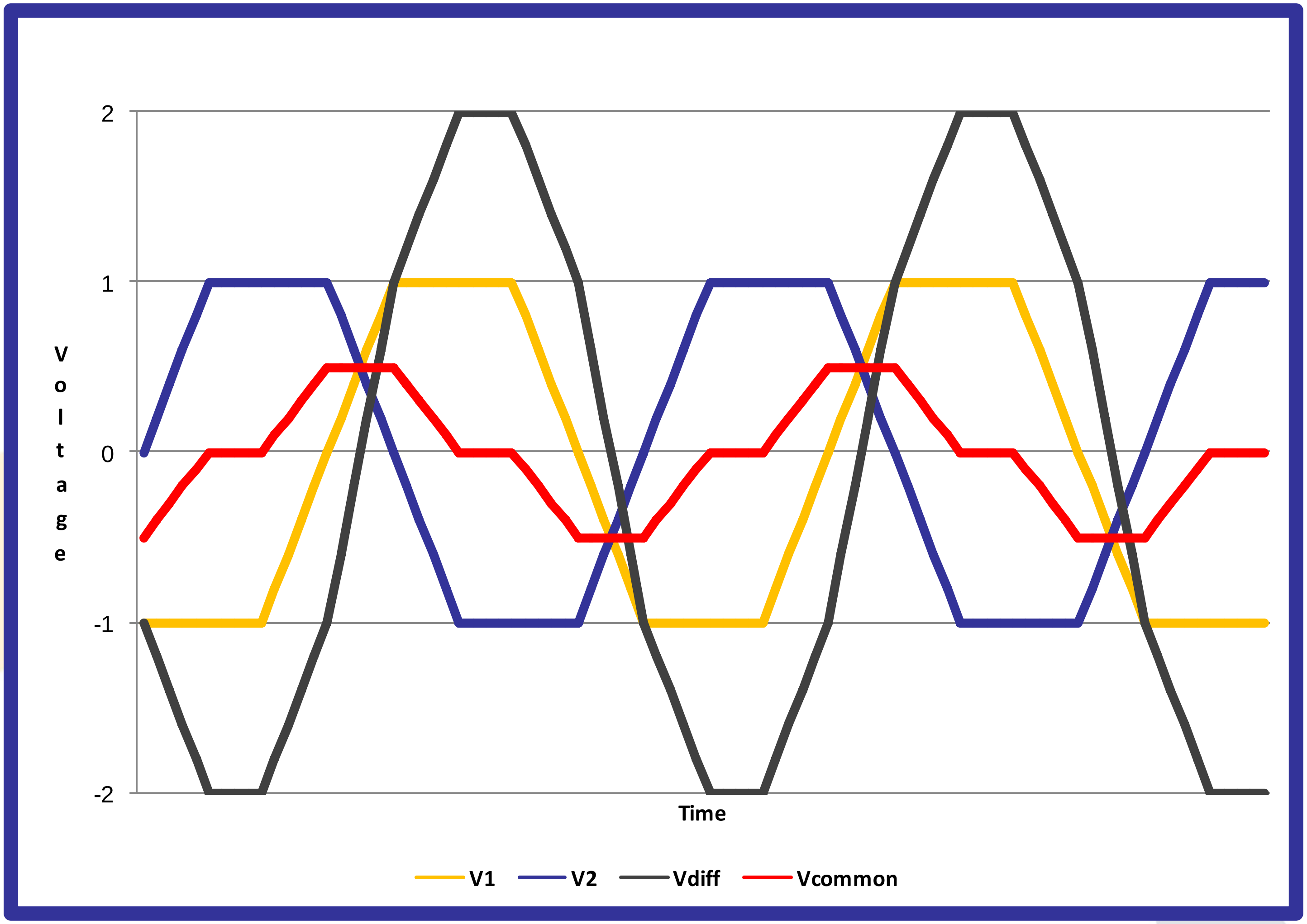

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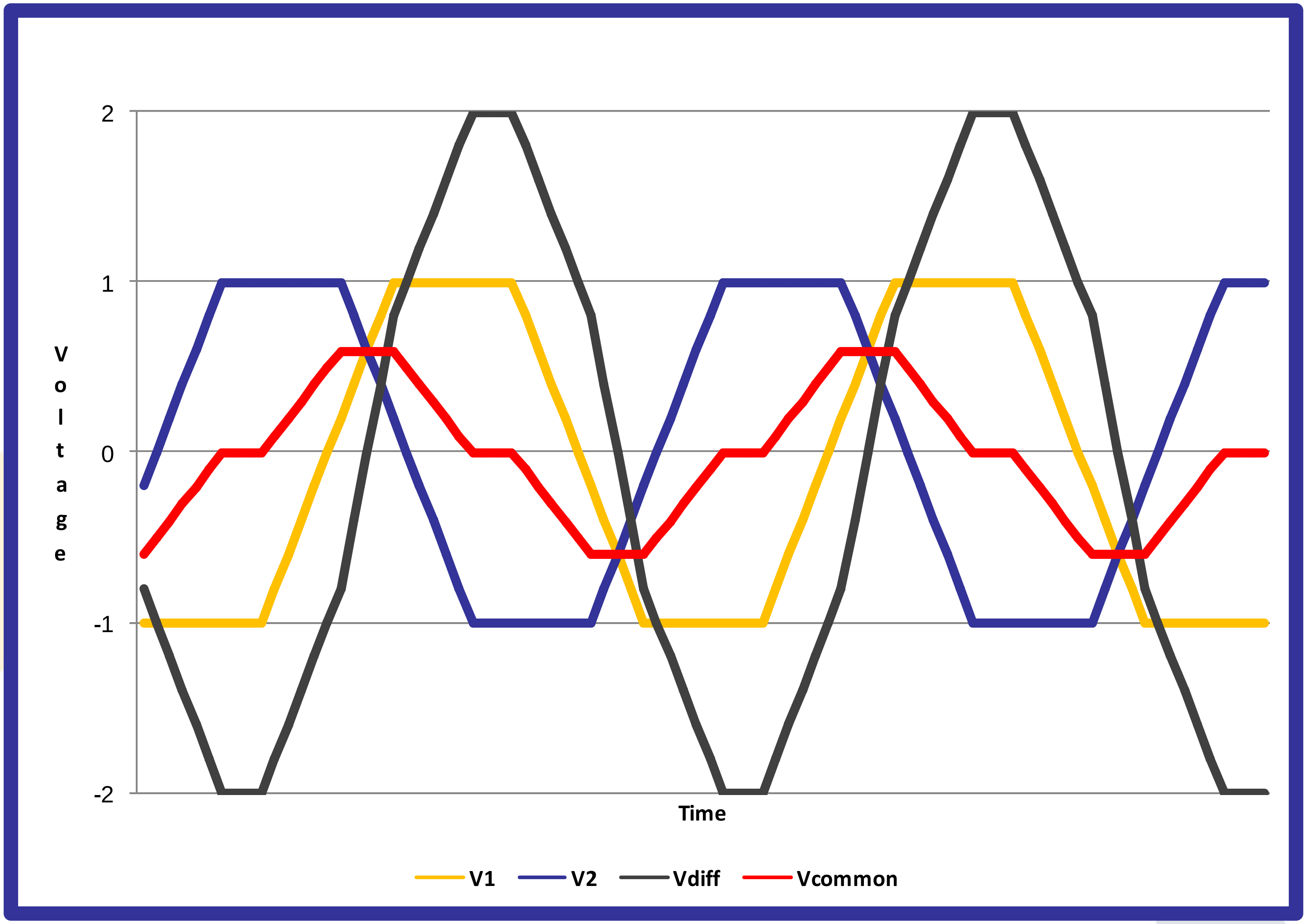

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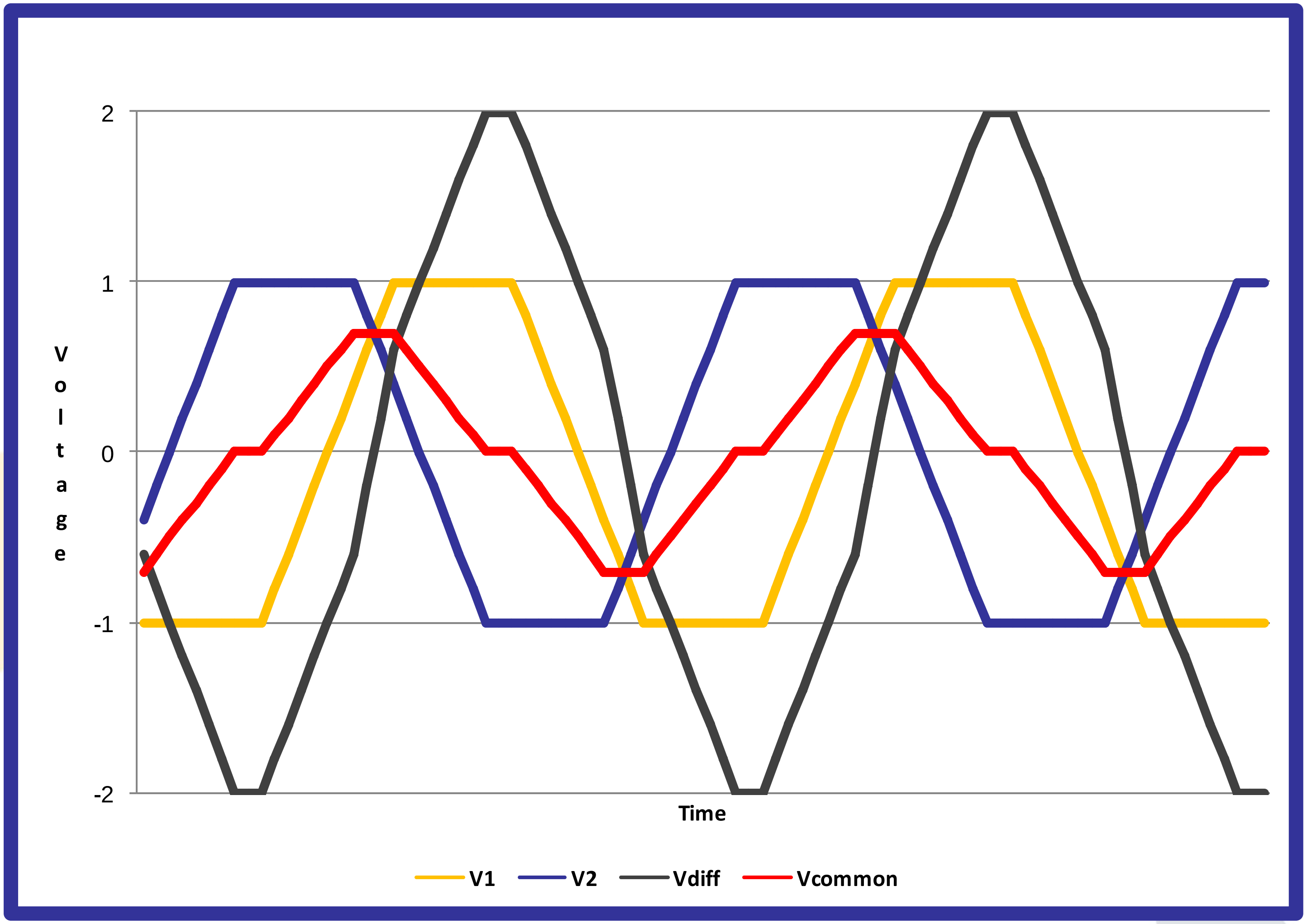

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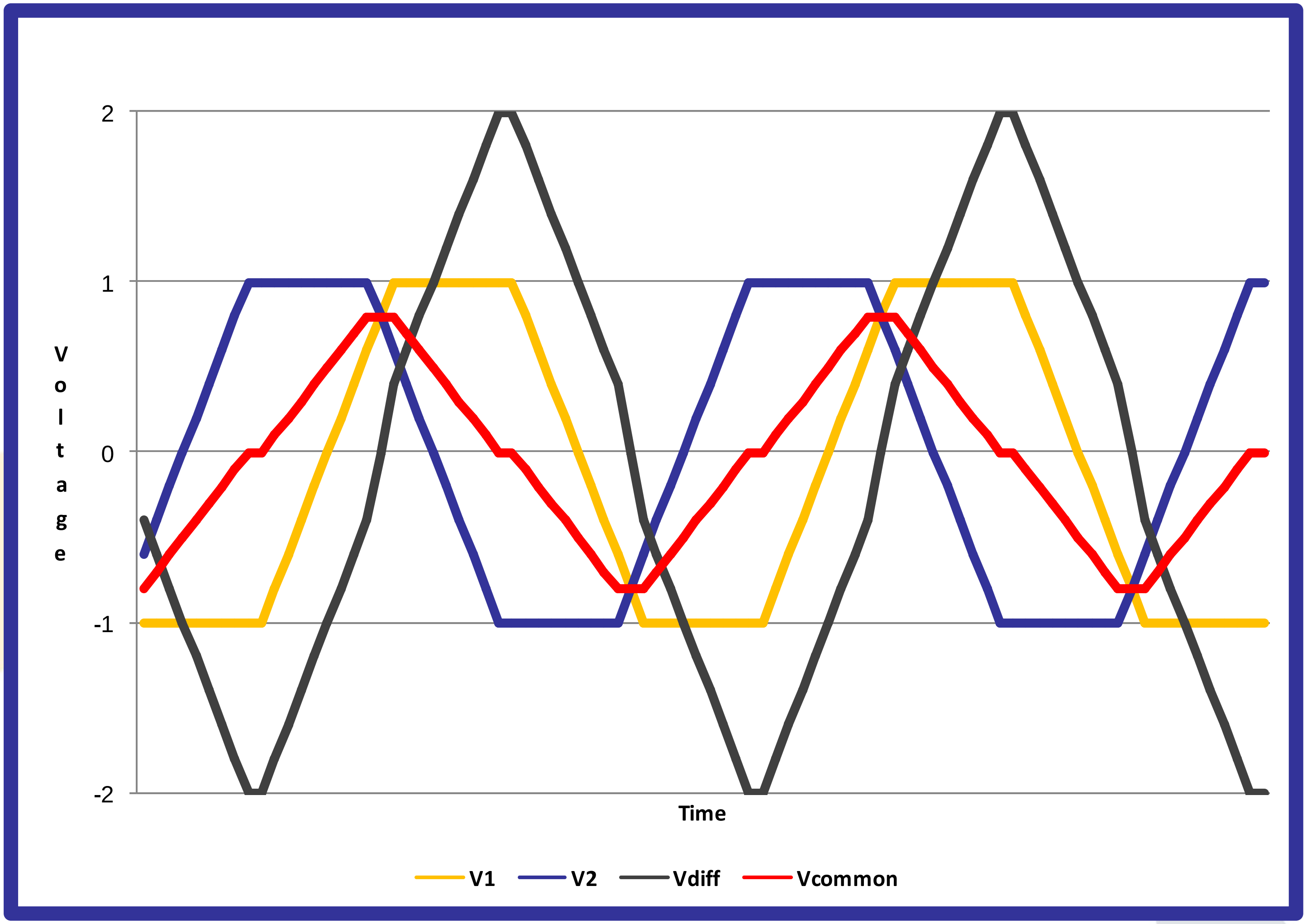

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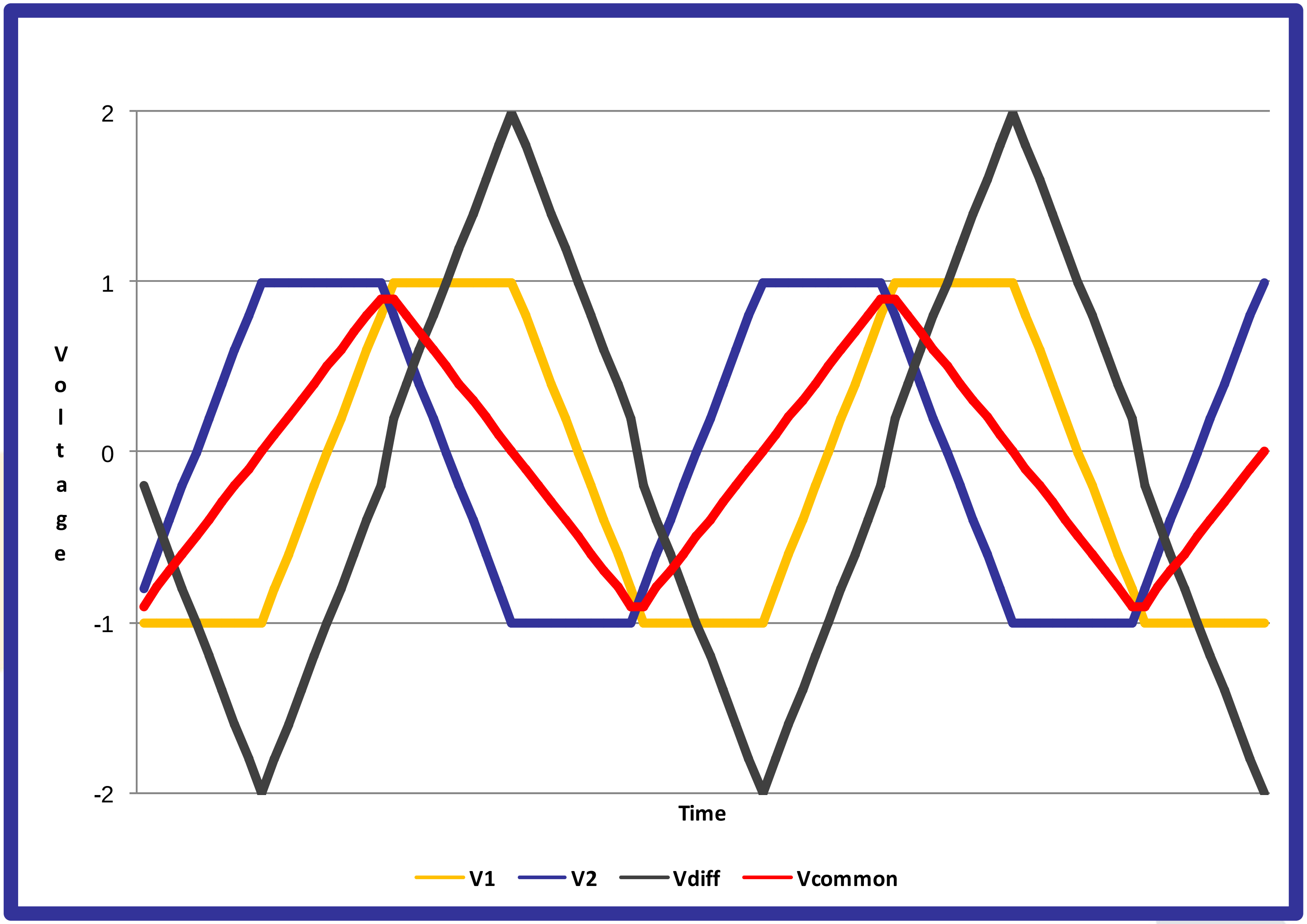

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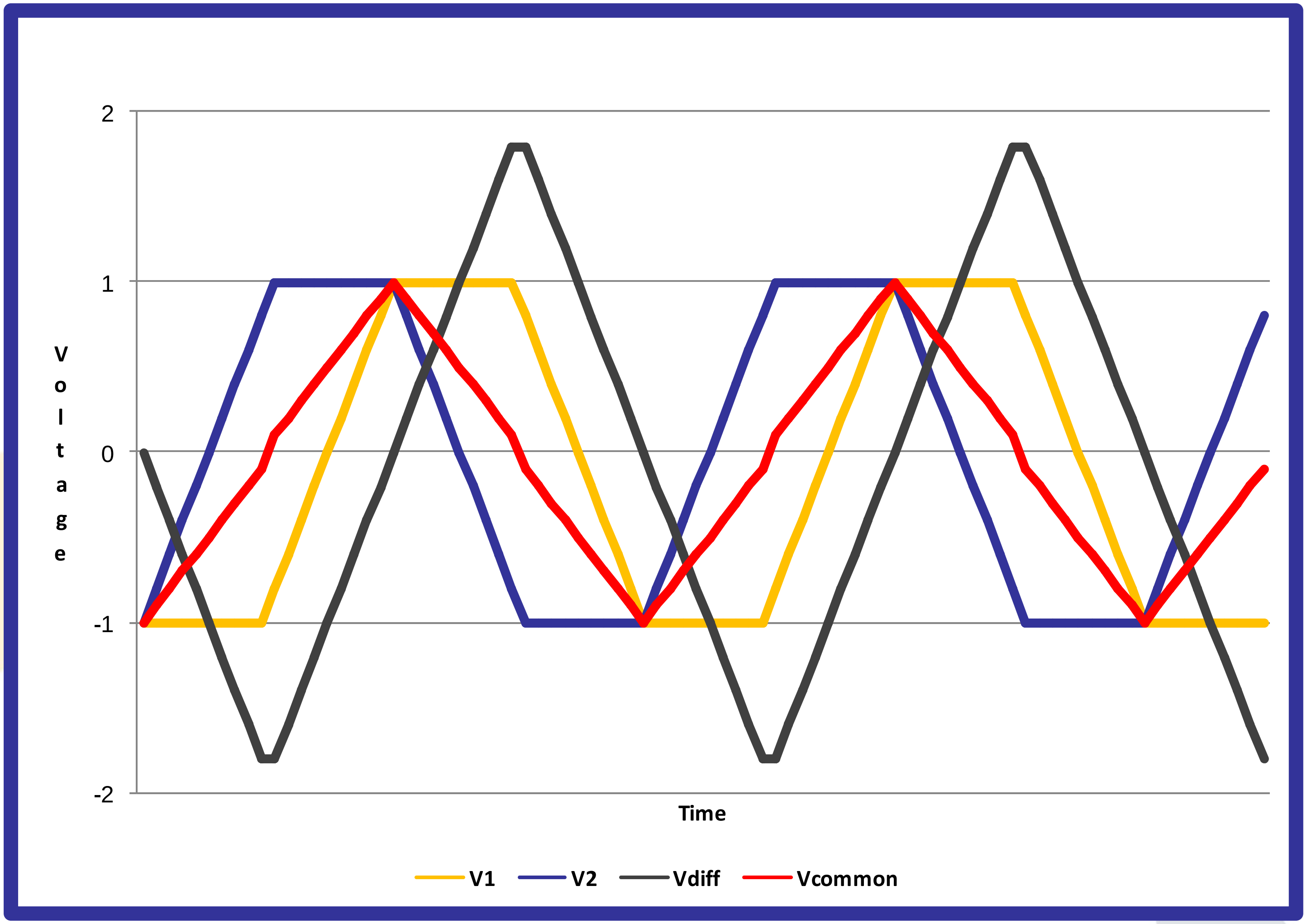

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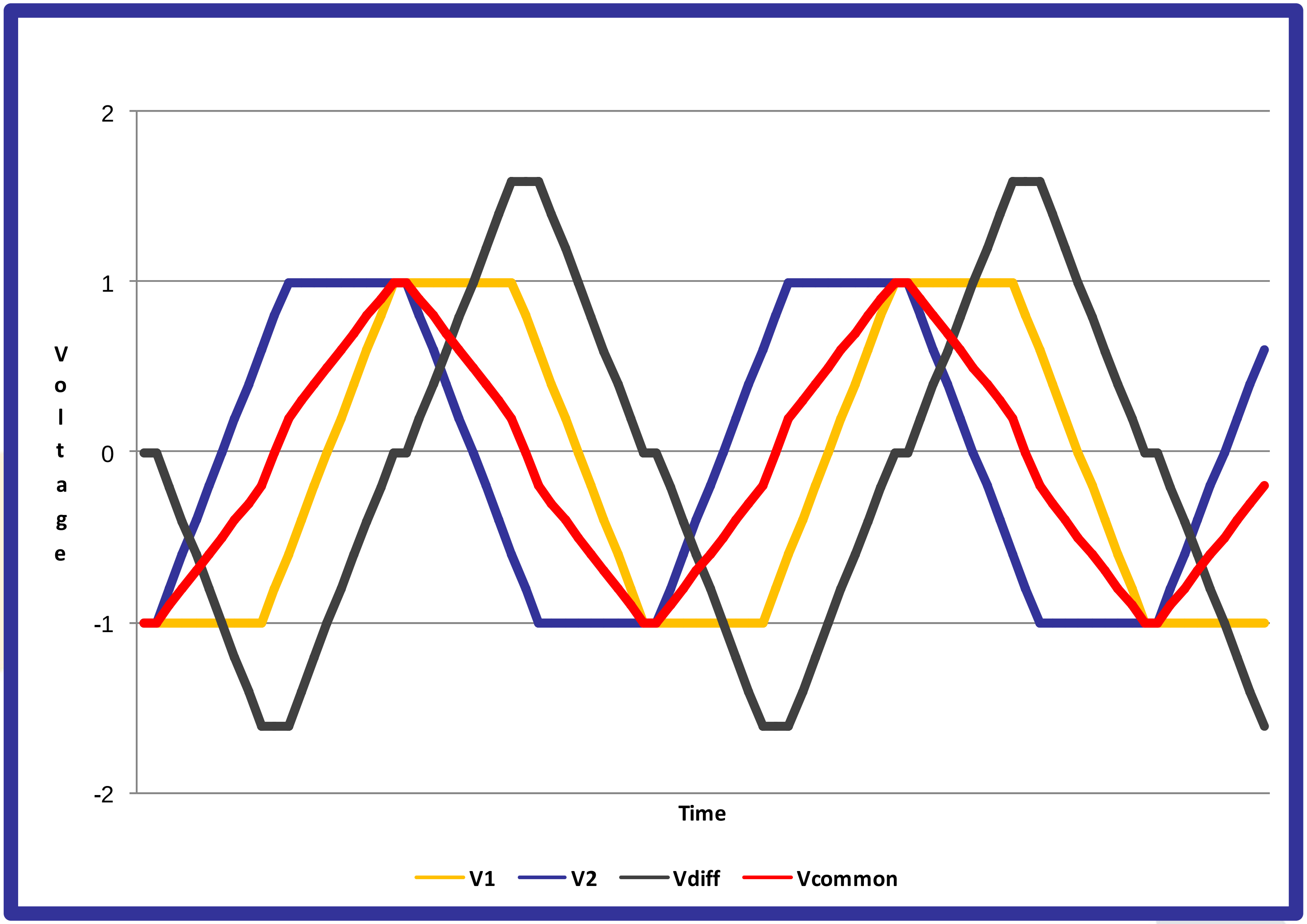

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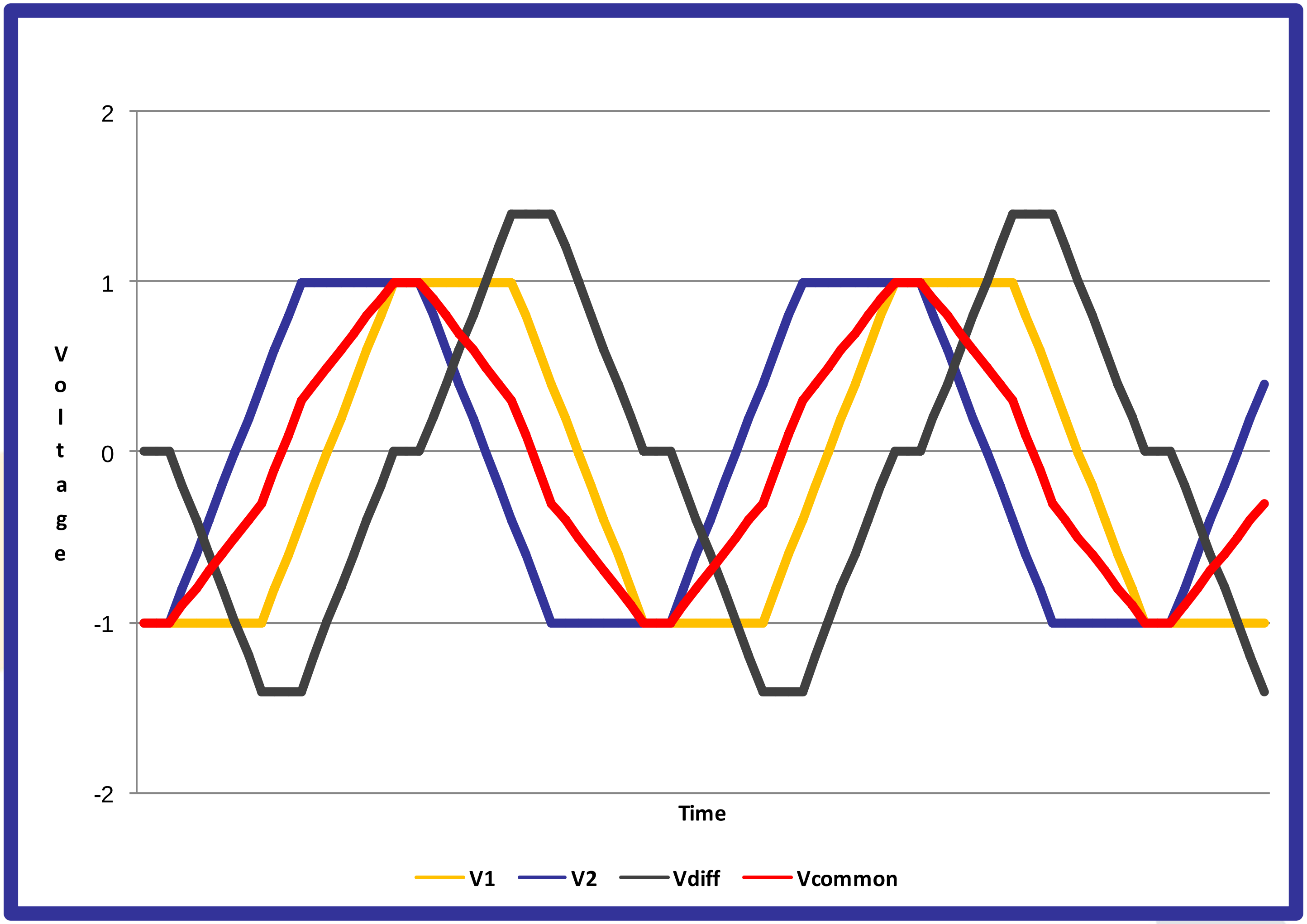

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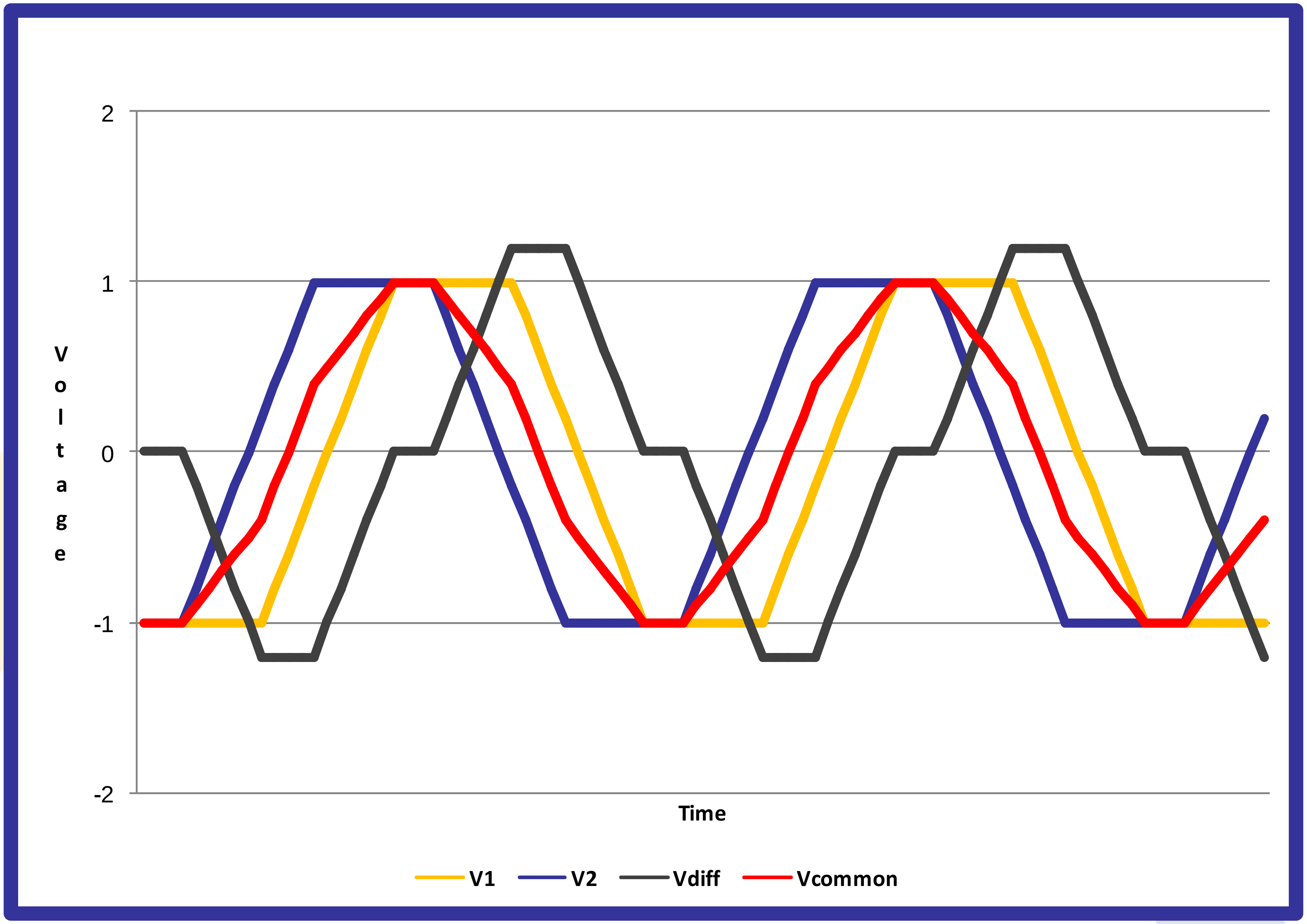

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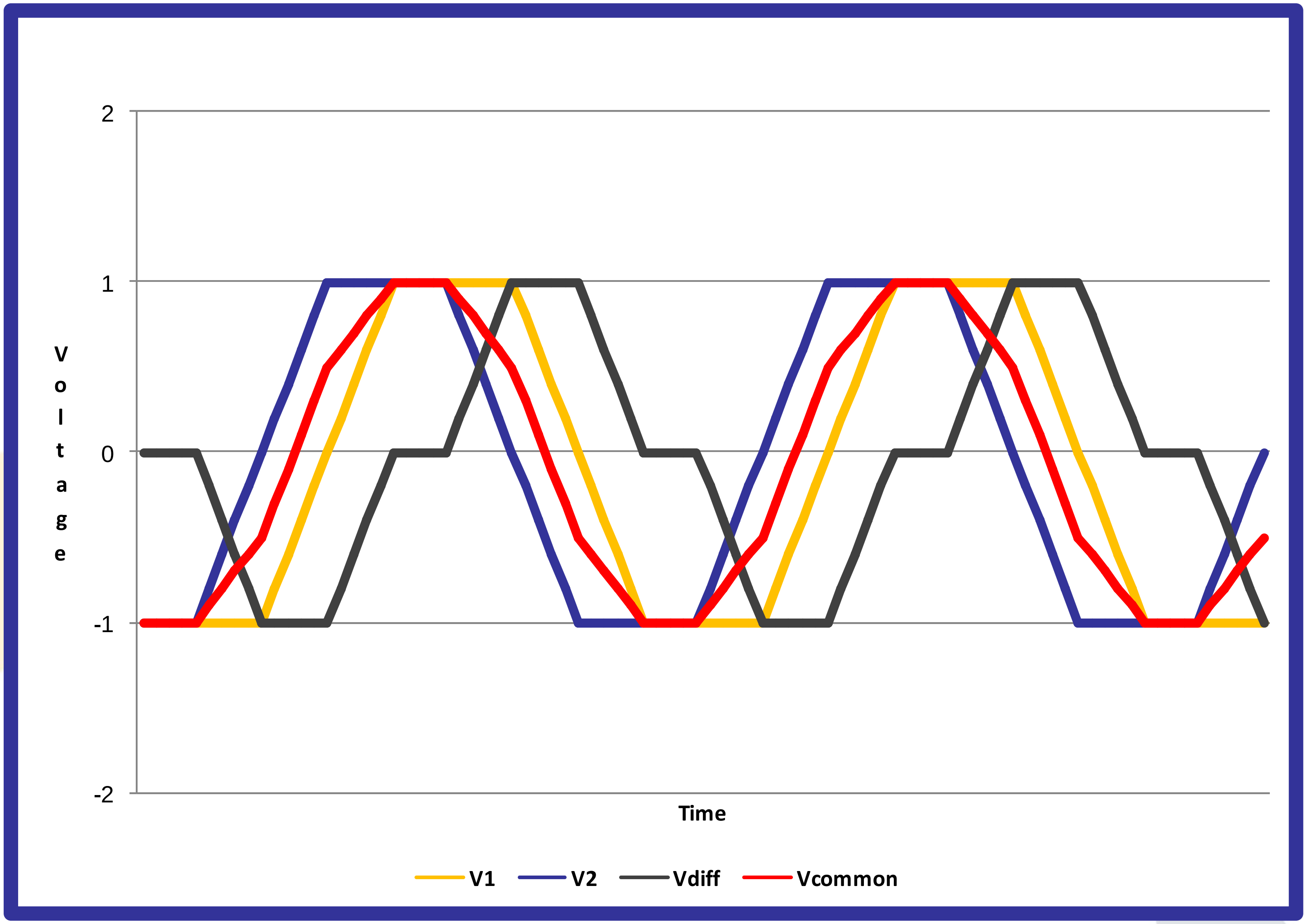
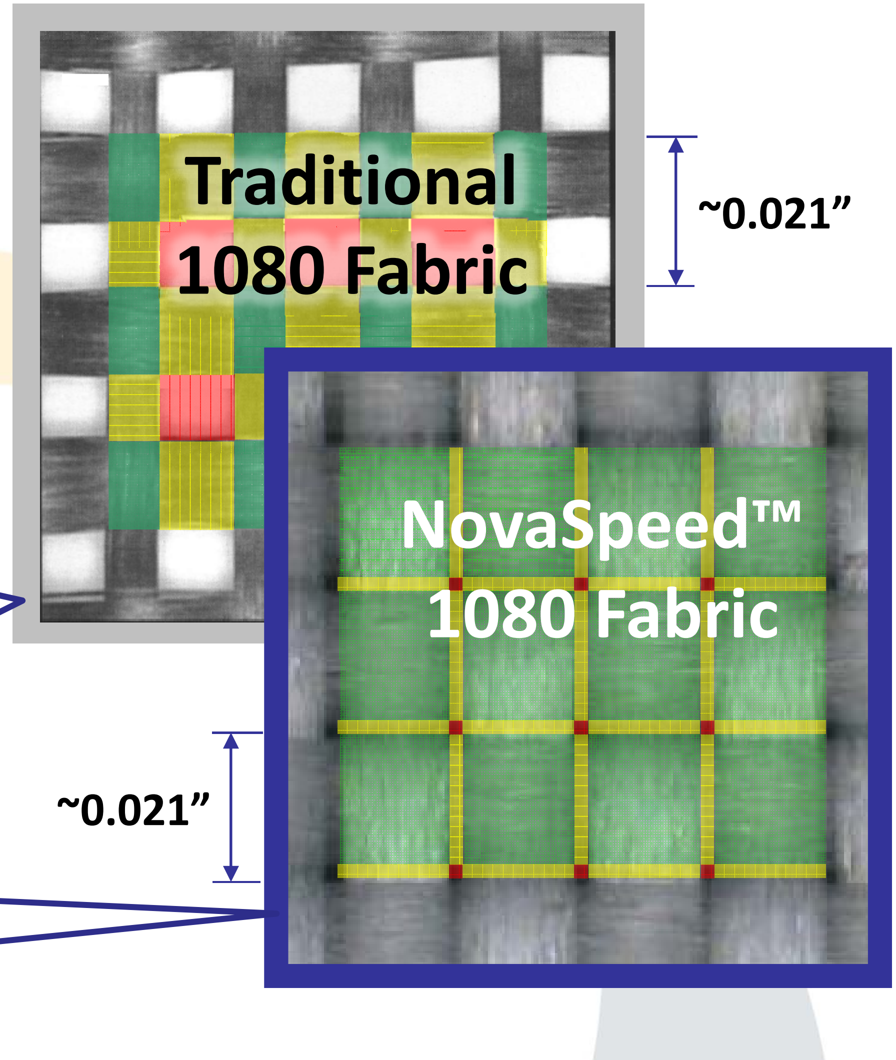


Fiber Glass Fabric Explained: Quantifying Glass Fiber Distribution

- **Multiple Thicknesses of Glass Fiber**
- **Localized Glass/Resin Volume Fractions**
- **Localized Laminate Dk**

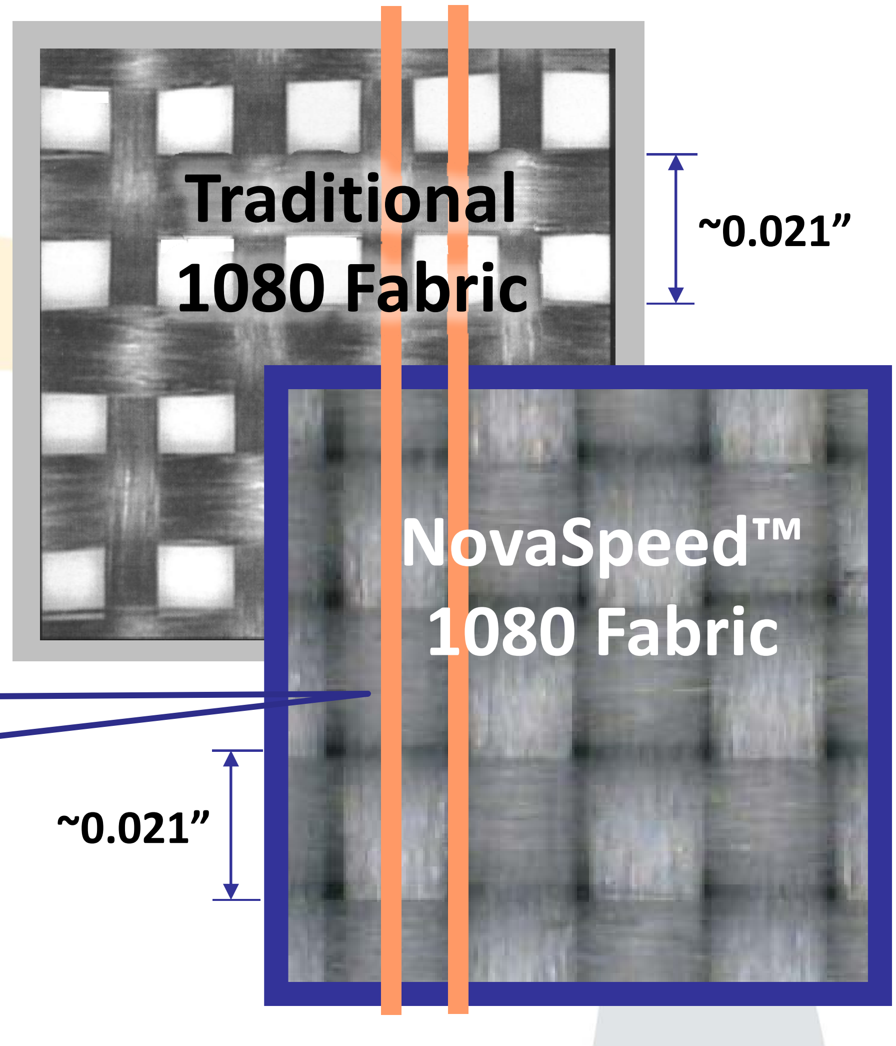


- 2 layers (2.1 mil) – 22%
- 1 layer – 55%
- Absence of Glass – 23%

- 2 layers (1.4 mil) – 77%
- 1 layer – 22%
- Absence of Glass – 1%

Fiber Glass Fabric Explained: Traditional vs. Spread Fiber Fabric

- ΔDk Across Differential Transmission Line
- Signal Skew
- Potential Timing Induced Errors



Differential Pair
0.003”/ 0.004” L/S

Finite Element Modeling (FEM)

- An Array of Elements were Modeled Based on a Traditional Fabric Construction
- FEM Predicts the Differential ΔDk of a Worst Case Scenario
- By Maximizing Intra-pair ΔDk, a Worst Case Scenario of Intra-pair Skew is Modeled
- Corroborates with 60,000 Point Intel Study Analyzing Skew

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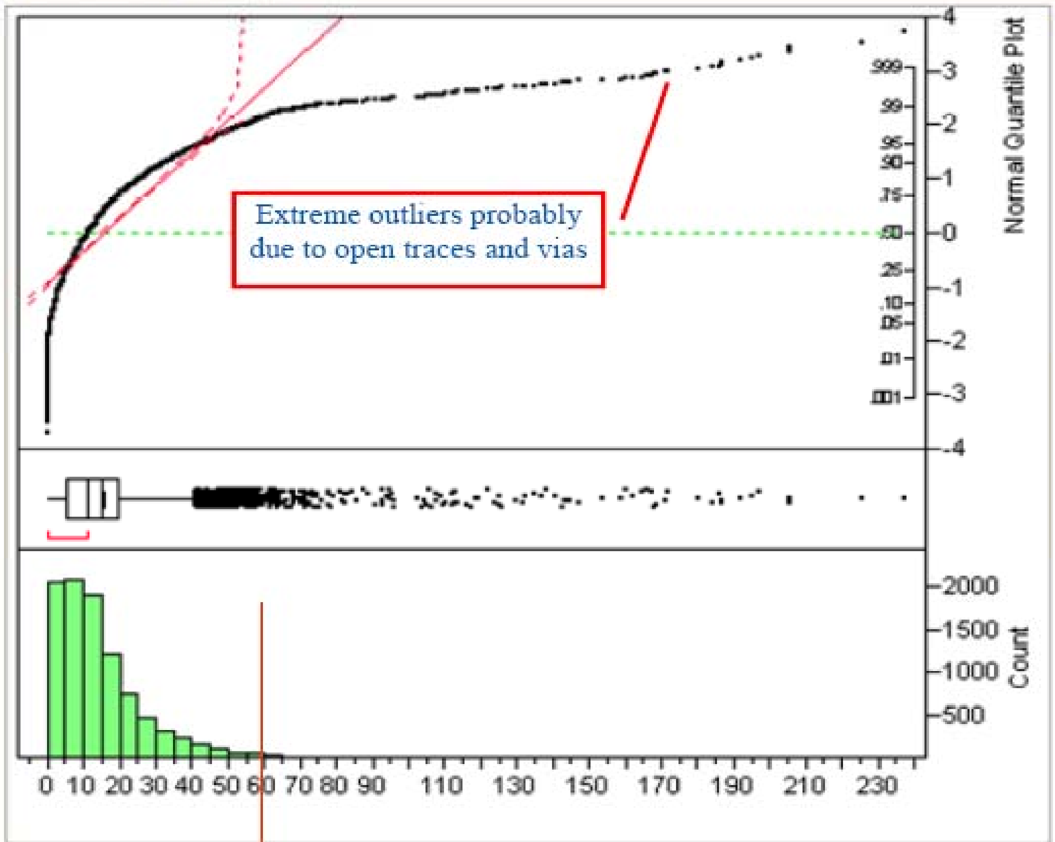
Significance of FWE

CH1-CH2 Delay



Quantiles

100.0%	maximum	237.50
99.5%		111.44
97.5%		53.00
90.0%		32.00
75.0%	quartile	19.50
50.0%	median	11.50
25.0%	quartile	5.50
10.0%		2.00
2.5%		0.50
0.5%		0.00
0.0%	minimum	0.00

Moments

Mean	15.397733
Std Dev	16.58344
Std Err Mean	0.1683359
upper 95% Mean	15.727707
lower 95% Mean	15.06776
N	9705

- **2.5 Gbps PCI-express**
- **9705 data points of 60K**
- **~1% are ID'd as Outliers**
- **Not Outliers but <u>real</u> hardware failures**

From J. Loyer, et al, "*Fiber Weave Effect: Practical Impact Analysis and Mitigation Strategies,*" *CircuiTree, March 2007.*

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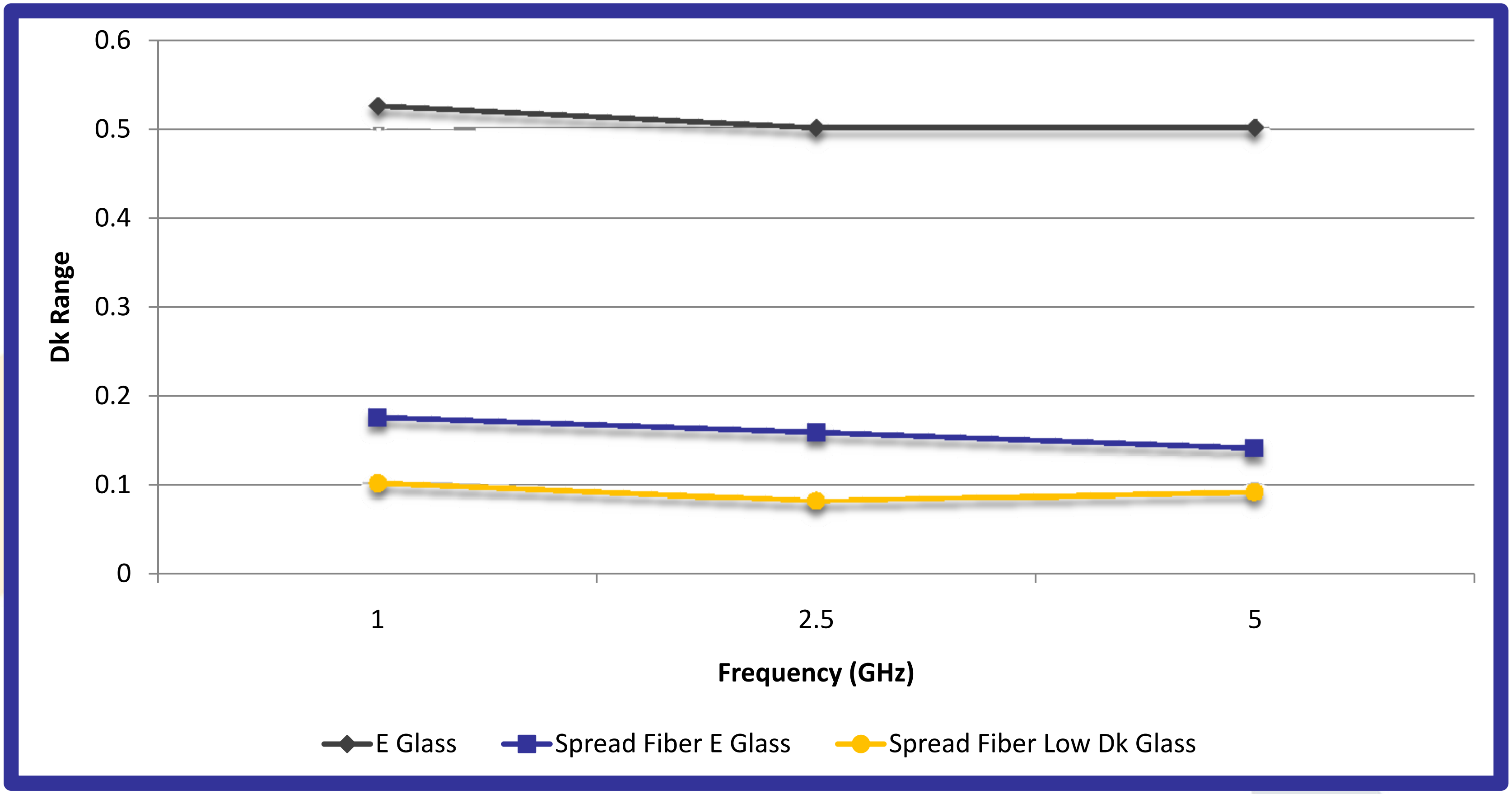
Verification of Model

- Test Boards Built with Microstrip Coupons
  - Hi Tg, low loss resin system
  - Control was traditional fiber glass fabric
  - Two types of spread fiber glass fabric, E glass and low Dk
- Characteristic Impedance Measured
- ΔDk Calculated

Comparison of Traditional, Spread Fiber and Low Dk Fabric Weaves in a Low Loss Resin

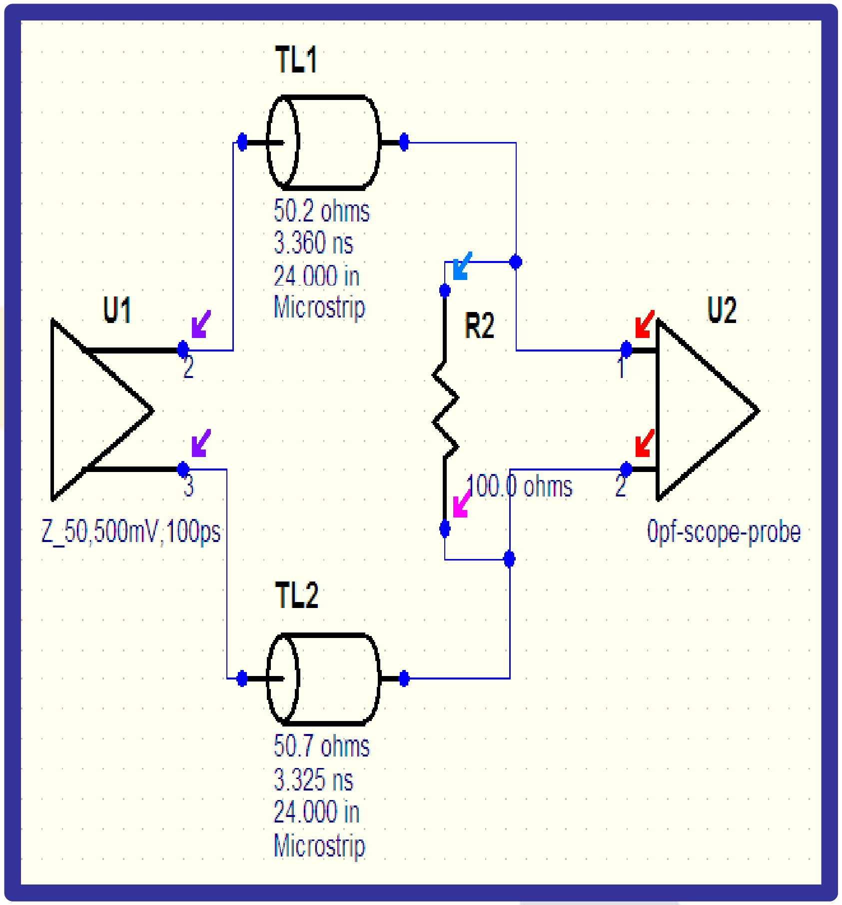


Measured and Predicted Laminate Dk Range, at 10Gbps (5GHz) and 68% Resin Content

Fabric Type	Resin Type	Average Dk	Measured ΔDk	Predicted ΔDk
E Glass	Low Loss	3.80	0.50	0.62
E Glass	FR-4	4.25	---	0.47
Spread Fiber (E Glass)	Low Loss	3.80	0.14	0.12
Spread Fiber (Low Dk)	Low Loss	3.65	0.09	0.08

FWE Simulation

- Mentor Graphics' HyperLynx GHz software simulation
- Quantified the benefit of eliminating FWE
- Assessment of impact on signal integrity
- Performance predictions corroborated



Simulation Details

- 50 ohm, 5V, 100 ps differential driver
- ΔDk defines transmission line skew
- 10 bit pseudo-random binary sequence
- BER $\leq 1 \times 10^{-12}$
- 0.32 UI minimum eye opening
- Trace lengths up to 60”
- Bit rates up to 10 Gbps
- Trace length and bit rate adjusted to meet BER and minimum eye opening threshold
- One held constant while the other was varied

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Predicted and Simulated Skew of 100 Ohm Differential Pair

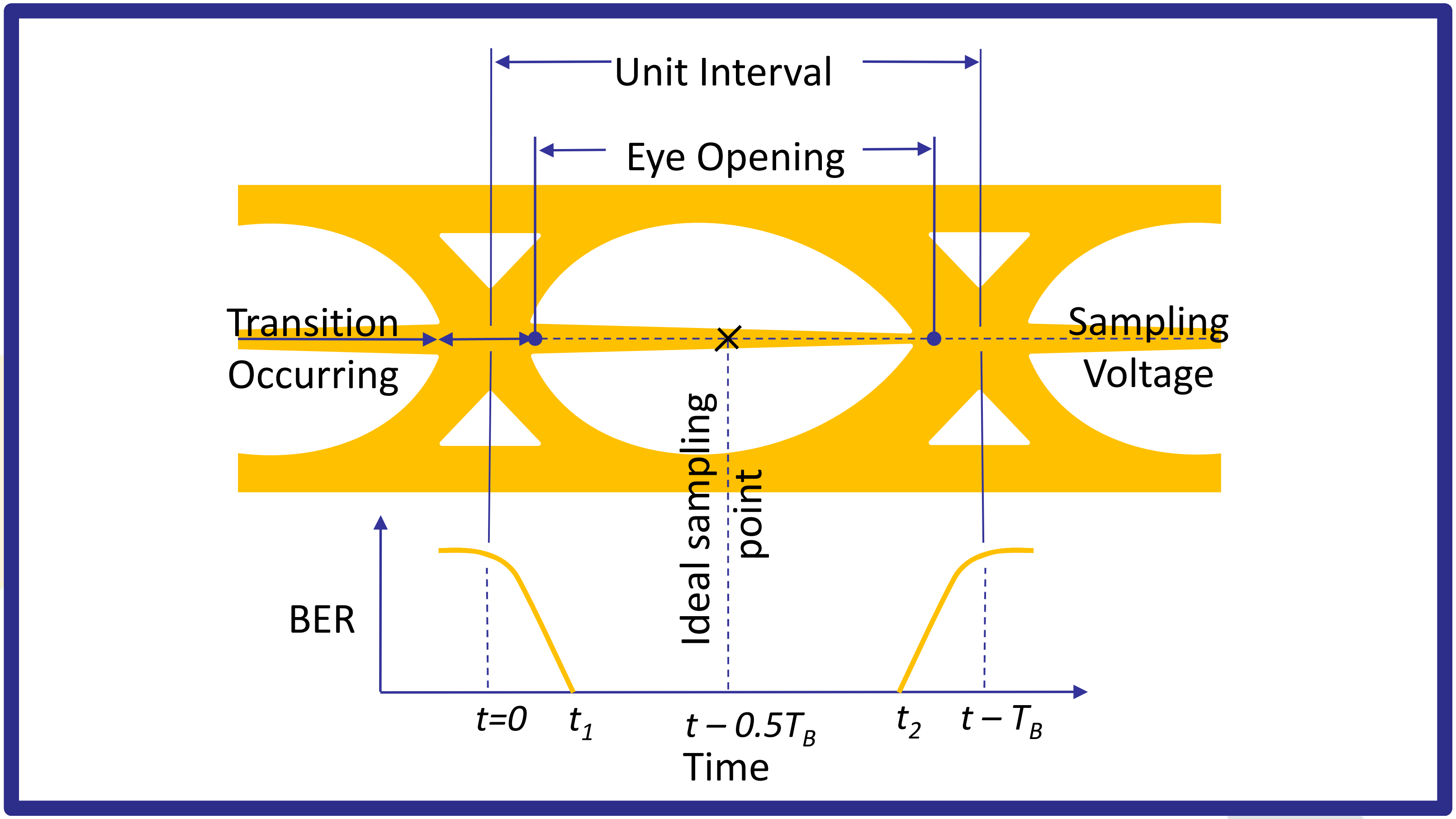
Fabric Type	Resin Type	HyperLynx Simulation (ps/in.)	FEM Predicted (ps/in.)
E Glass	Low Loss	9.87	13.8
E Glass	FR-4	7.26	9.71
Spread Fiber (E Glass)	Low Loss	2.23	2.52
Spread Fiber (Low Dk Glass)	Low Loss	1.46	1.83

Bit Error Rate (BER)

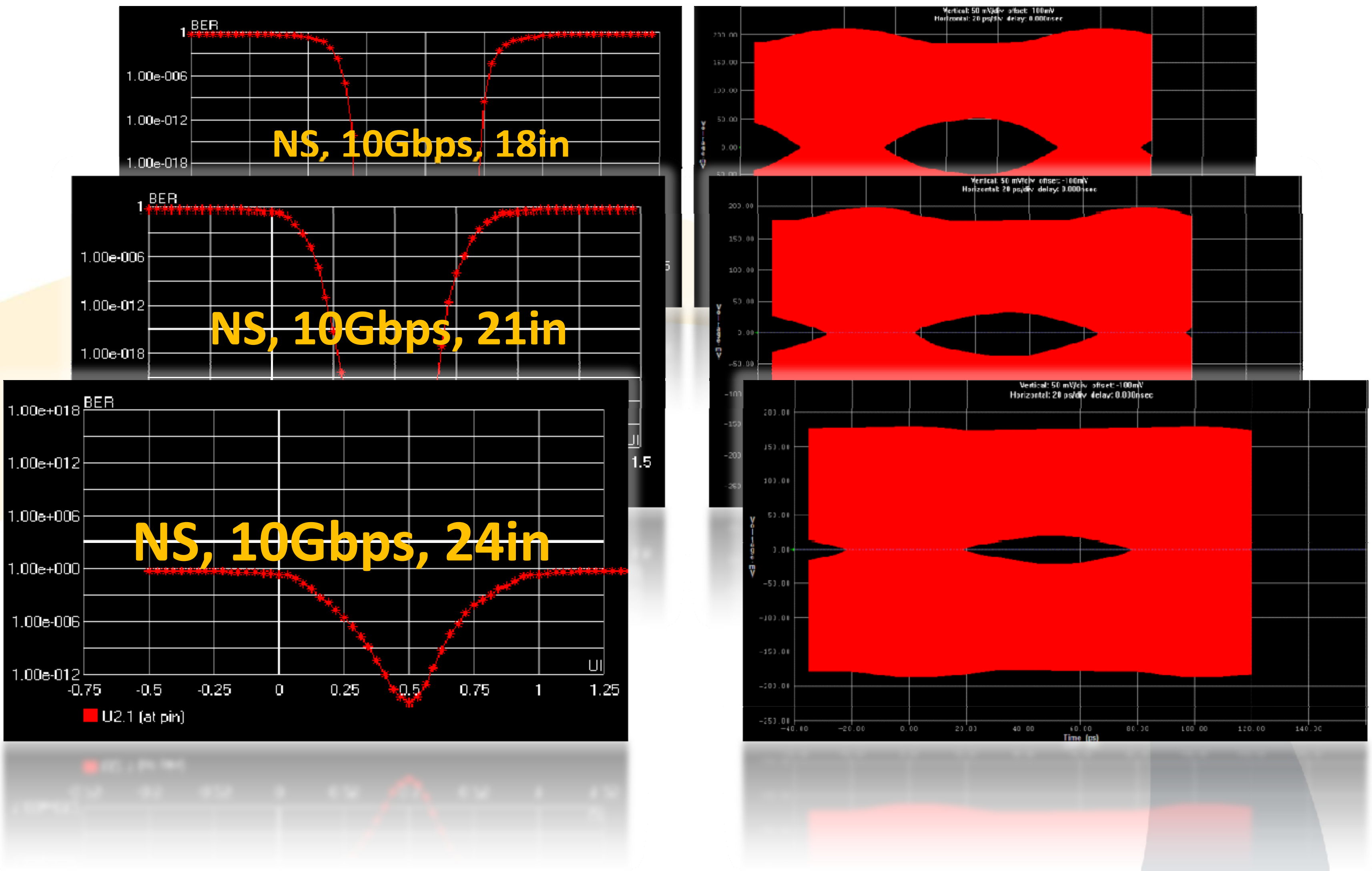
- Erroneous bits divided by transmitted bits
- BER test times are determined by Gaussian distribution
- Mean time between errors (MTBE)
- $BER = 1X10^{-12}$

BR (Gbps)	Test Time, 95%CL (min)	MTBE (min)
1.0	50	16.67
2.5	20	6.67
5.0	10	3.33
7.5	7	2.22
10.0	5	1.67

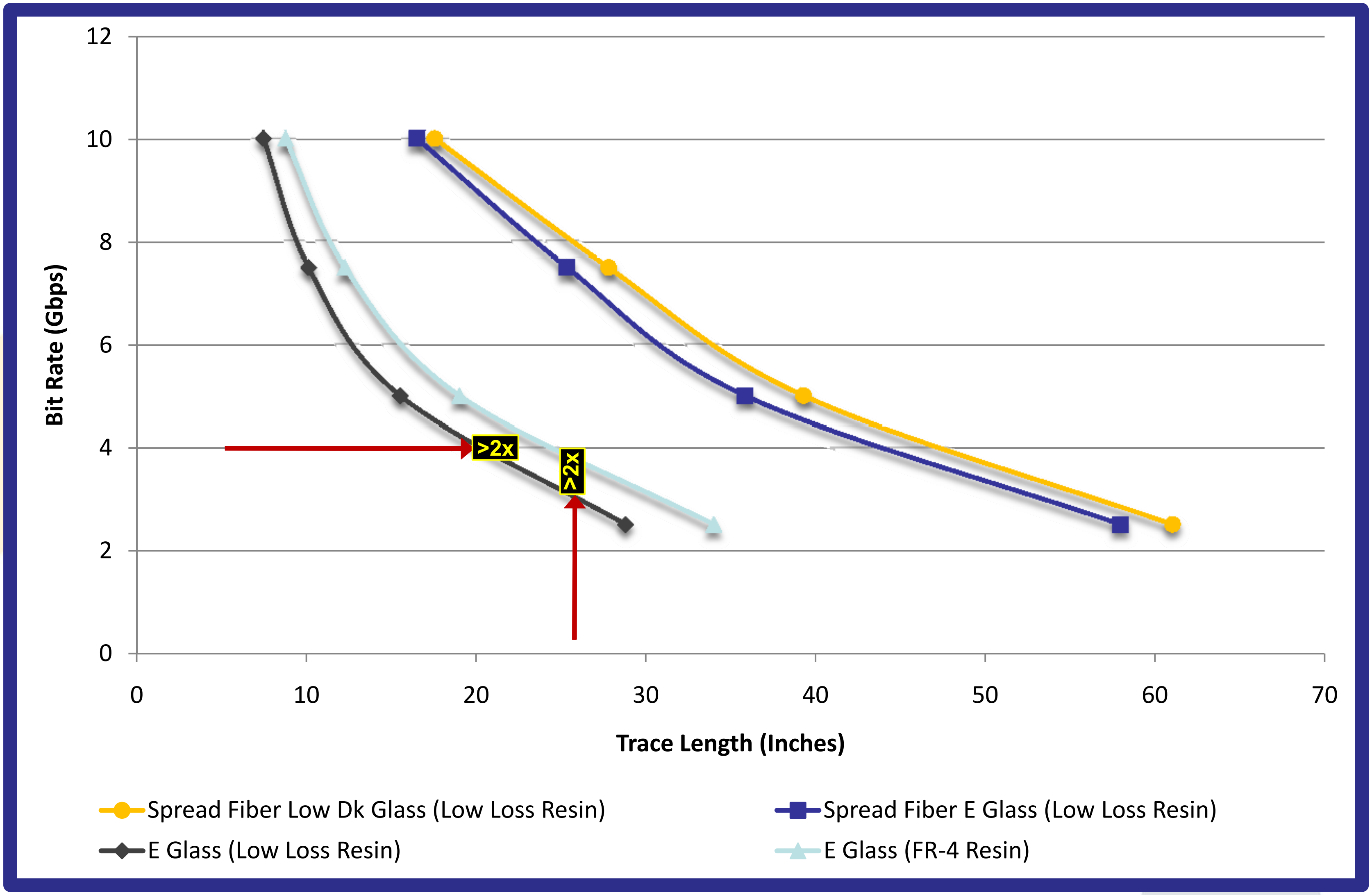
Eye Diagram Showing Eye Opening Relation to a Bathtub Plot



Eye Diagram screen shots



Max Bit Rate Achievable as a Function of Skew for Varying Trace Lengths



Conclusions – FWE

- Two Contributing Factors to FWE
  - ΔDk between resin and glass reinforcement
  - Homogeneous/uniform fiber distribution
- Double either Bit Rate or Trace Length
- This Solution *Eliminates* FWE

Predictors to CAF Resistance

- Spread Fibers
  - Maximum surface area for resin bonding
- Direct Finish technology
  - Resin-compatible finish
  - Pristine glass fiber surface
- Improved CAF resistance
  - Due to improved resin bonding

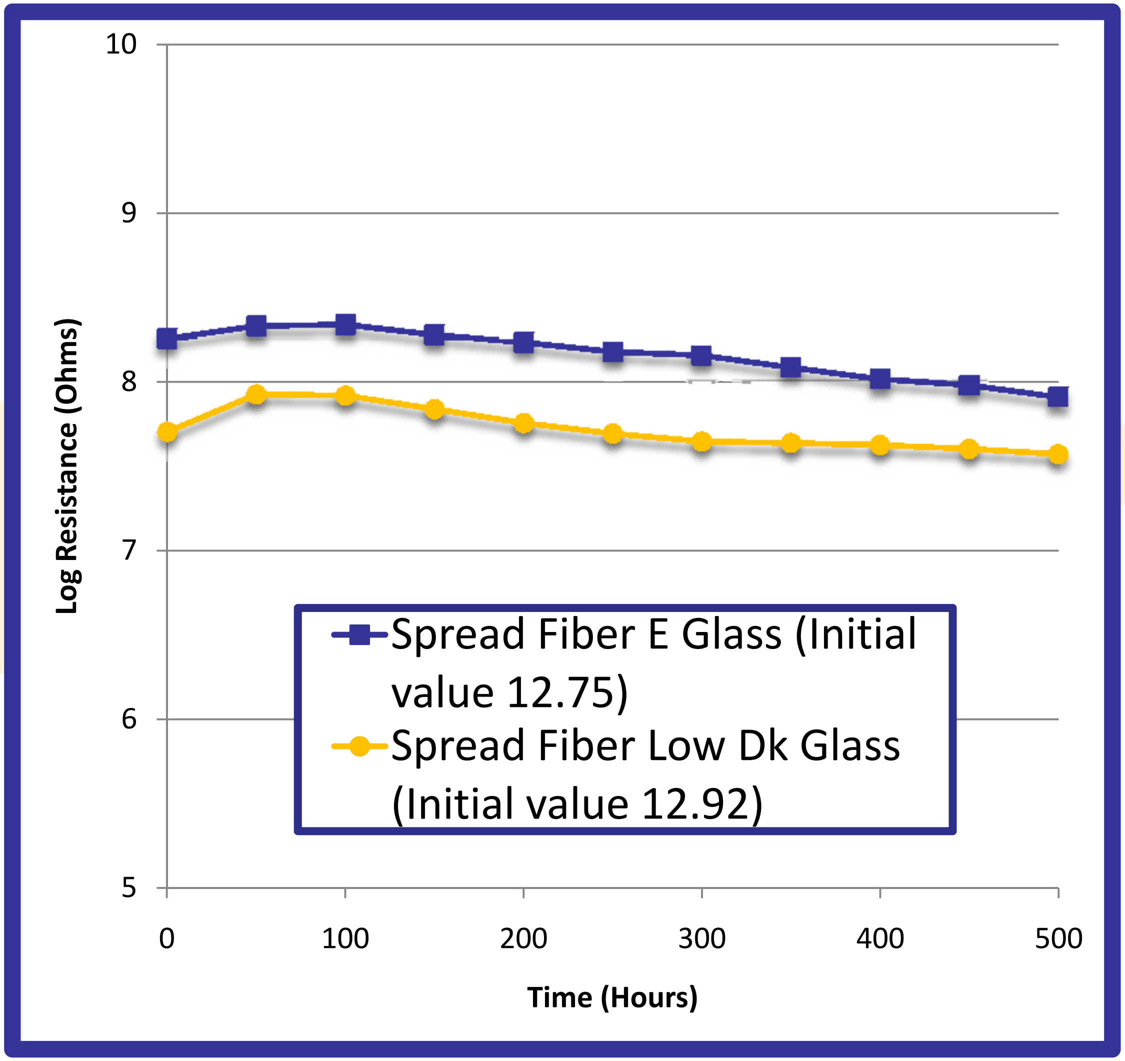
CAF Resistance Testing

- Three sets of test boards
- High Tg CAF-resistant resin system
- Four consecutive Pb-free reflow cycles
- Test similar to IPC-TM-650 2.6.25

CAF Test Details

- 6-layer stack-up, using 1080 cores and prepreg
- 16 coupons per glass style, 500 hole sets per coupon, 0.010” diameter, 0.010” wall-to-wall spacing
- Bake at 105° C for 6 hours
- Four reflow cycles (preheat to 210° C, spike to 245° C or 260° C)
- Precondition at 23° C, 50% RH for 24 hrs
- Initial resistance measurement
- Condition at 85° C, 85% RH, zero bias for 96 hrs
- Monitor resistance at 10/50 VDC bias, 85/85 for 500 hrs
- Ramp to 85° C, 10-15% RH over 15-20 min., then hold at lab ambient for 1 hr.
- Measure final resistance

CAF Log Resistance Measurements and Test Results



Glass Fabric	% Pass
Traditional 1080 E Glass	0%
Spread Fiber E Glass	31%
Spread Fiber Low Dk Glass	56%

Conclusions – CAF resistance

- By Using a Spread Fiber Glass Fabric with Direct Finish Technology…
  - Improved resin-to-glass bonding
  - Improved resistance to conductive anodic filament formation

But Wait…There's MORE!

- Hollow fibers – eliminated; certified HF-free
- Improved drilling using a flat, smooth, homogeneous glass fabric
  - Laser
  - Mechanical
- More robust composite (laminate)
  - better able to withstand mechanical and thermal stresses

Fiber Weave Effect Resistant vs. Traditional Electronics Grade Fiberglass Fabrics

	Traditional	FWE Free
Thickness of Fiberglass Fabric (1080)	0.0021”	0.0014”
Dk of Glass	6.8	4.8
Laminate Dk in HSR (RC = 68%)	3.8	3.65
ΔDk in a High Speed Resin	0.5	0.09
Relative Differential Timing Skew	100%	15%
Bit Rate at Length Increase (BER=1X10^{-12})	x	2x
Electrochemical Migration (CAF)	Resistant	Extremely Resistant

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Thank You!

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