

# Layout Basics for Universal Serial Bus (USB) Designs

TI Precision Labs - USB

Prepared by Julie Nirchi

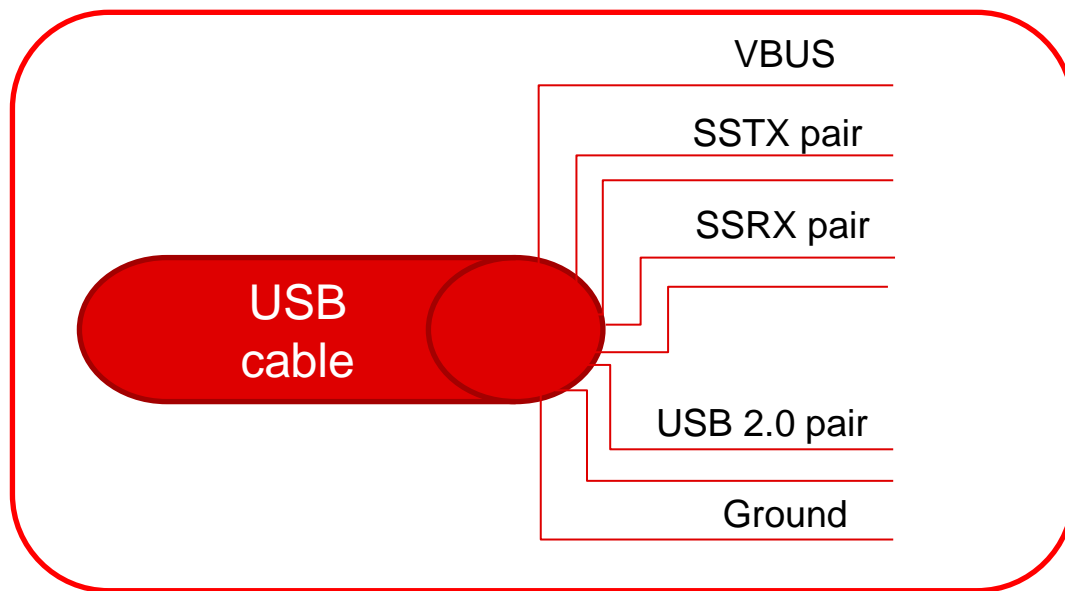
Presented by Nicholas Malone



# USB signal impedance

## USB specification requirements:

- USB 2.0 differential impedance: 90 ohms +/- 15%
- USB 3.2 differential impedance: 72 ohms (min) / 120 ohms (max)



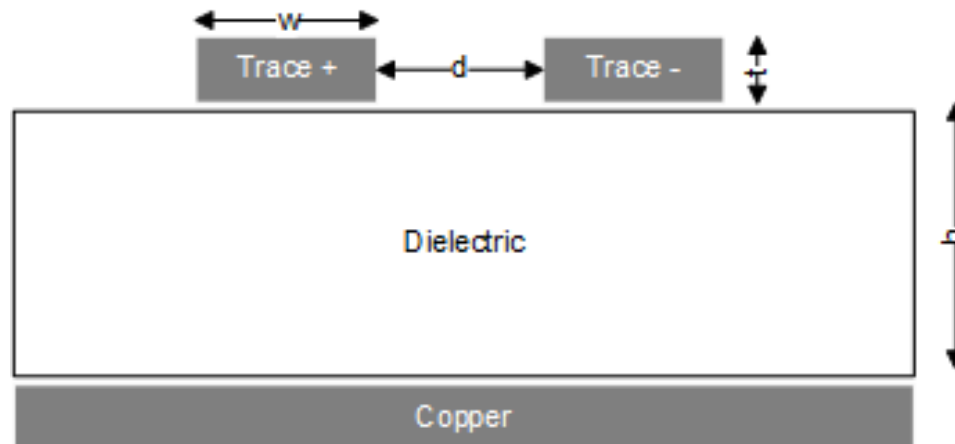
# Impedance calculation

Single-ended ( $Z_0$ ) and differential impedance ( $Z_{DIFF}$ )

$$Z_0 = \frac{87}{\sqrt{\epsilon_r + 1.41}} * \ln\left(\frac{5.98 * h}{0.8 * w + t}\right)$$

$$Z_0 = 36.1 * \ln\left(\frac{5.98 * h}{0.8 * w + t}\right)$$

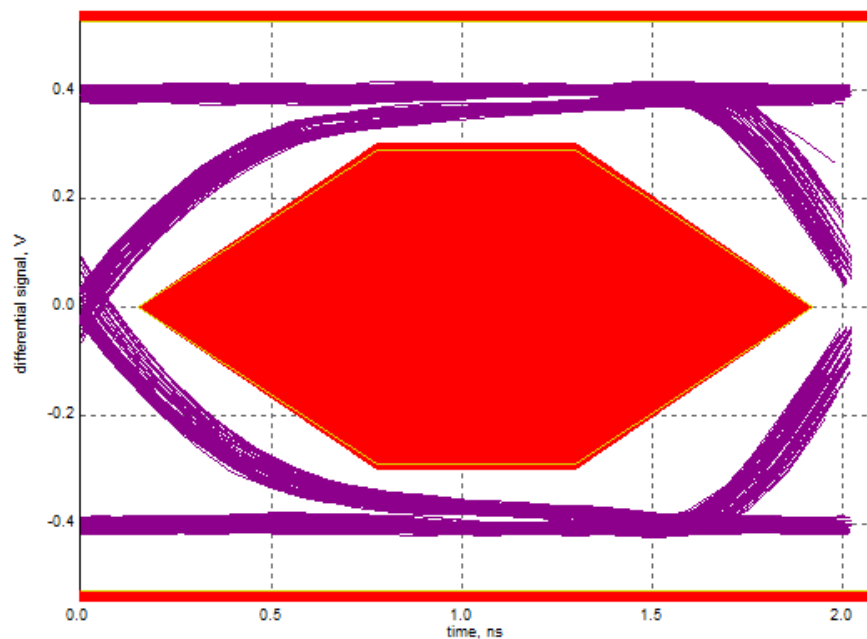
$$Z_{Diff} = 2 * Z_0 * (1 - 0.48 * e^{-0.96 * \frac{d}{h}})$$



# Impedance impact on USB 2.0 signal quality

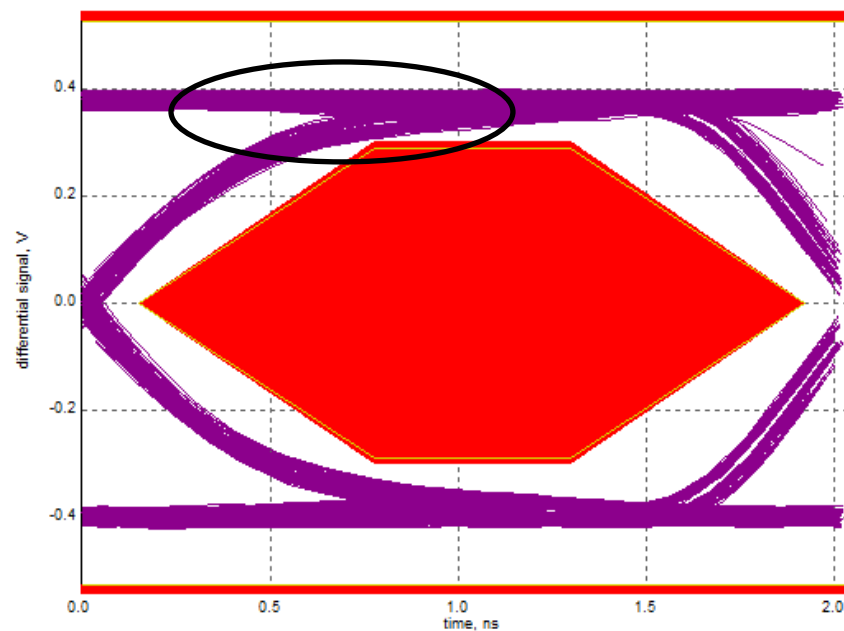
## Matched

$90 \Omega \leftarrow \rightarrow 90 \Omega \leftarrow \rightarrow 90 \Omega$

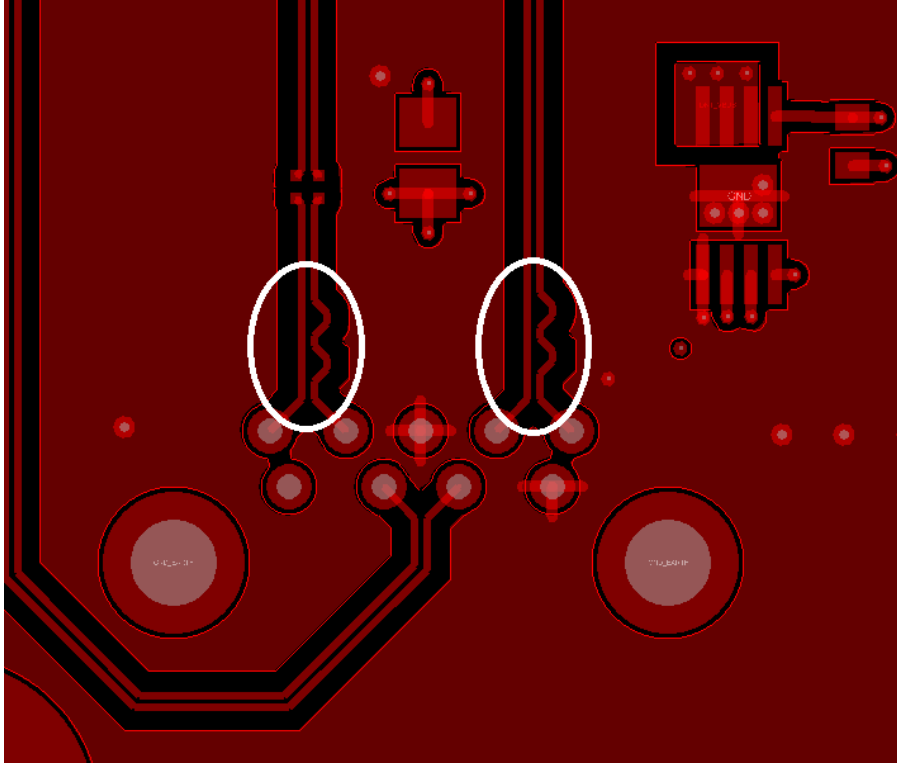


## Mismatched

$90 \Omega \leftarrow \rightarrow 100 \Omega \leftarrow \rightarrow 90 \Omega$



# USB signal trace length



Microstrip propagation delay in ps/in

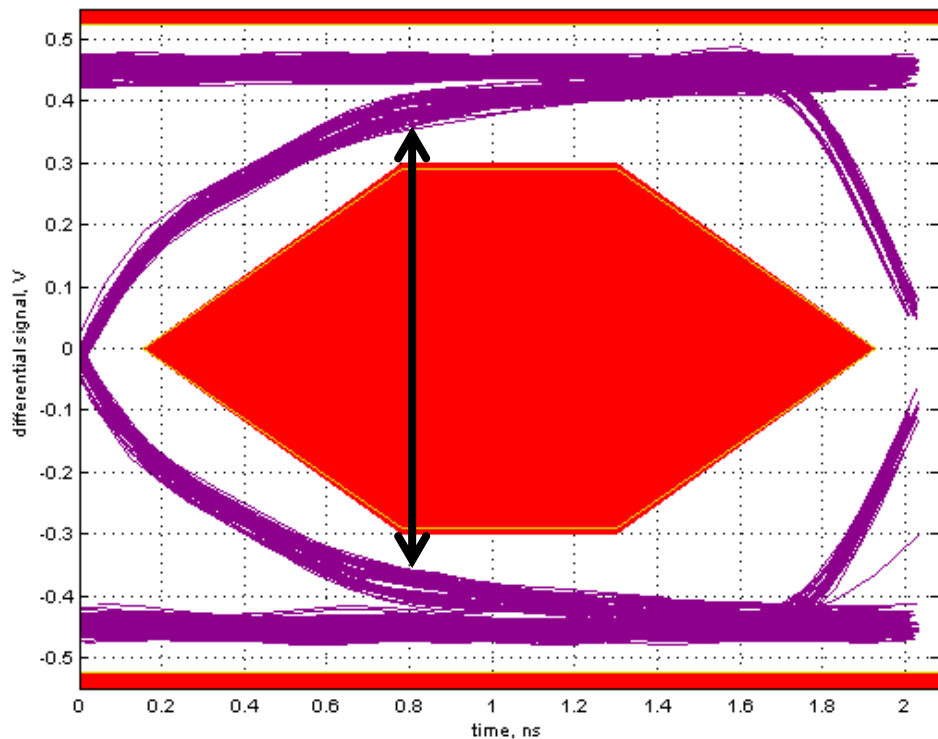
$$t_{PD} = 85 * \sqrt{0.475 * \epsilon_r + 0.67}$$

Internal RKM wire length mismatch for TUSB8040			
Signal name	Pin #	Bond wire length (mil)	Difference (mil)
USB_SSTXM_UP	A42	125	28
USB_SSTXP_UP	B39	97	
USB_SSRXM_UP	B40	89	20
USB_SSRXP_UP	A44	109	
USB_DM_UP	B42	81	22
USB_DP_UP	A46	103	

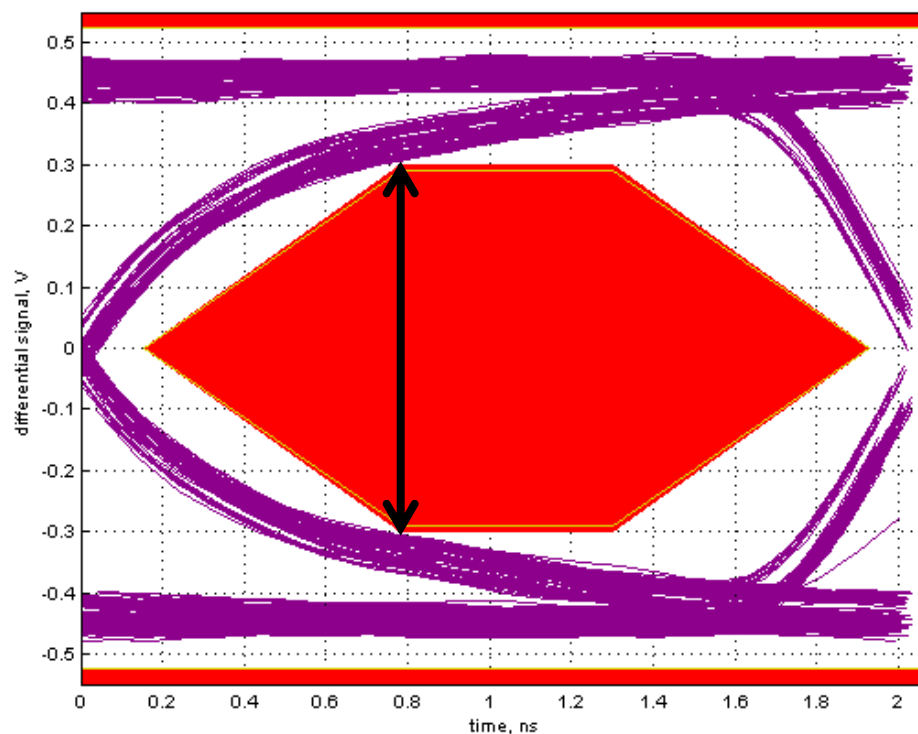
USB SuperSpeed trace length matching with serpentine routing

# Trace length impact on USB 2.0 signal quality

## Short trace length (2'')

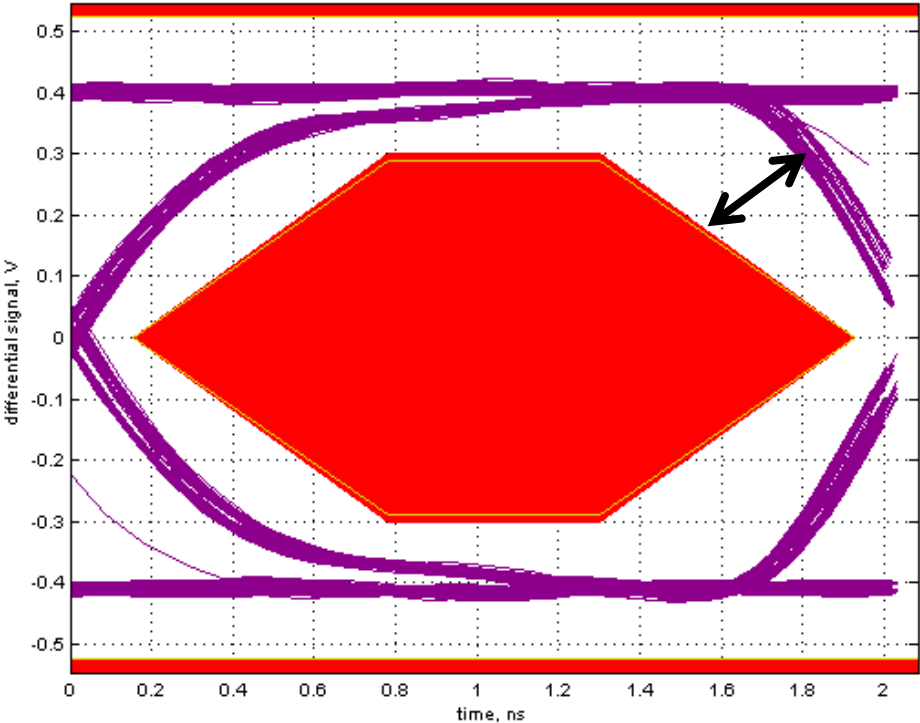


## Long trace length (10'')

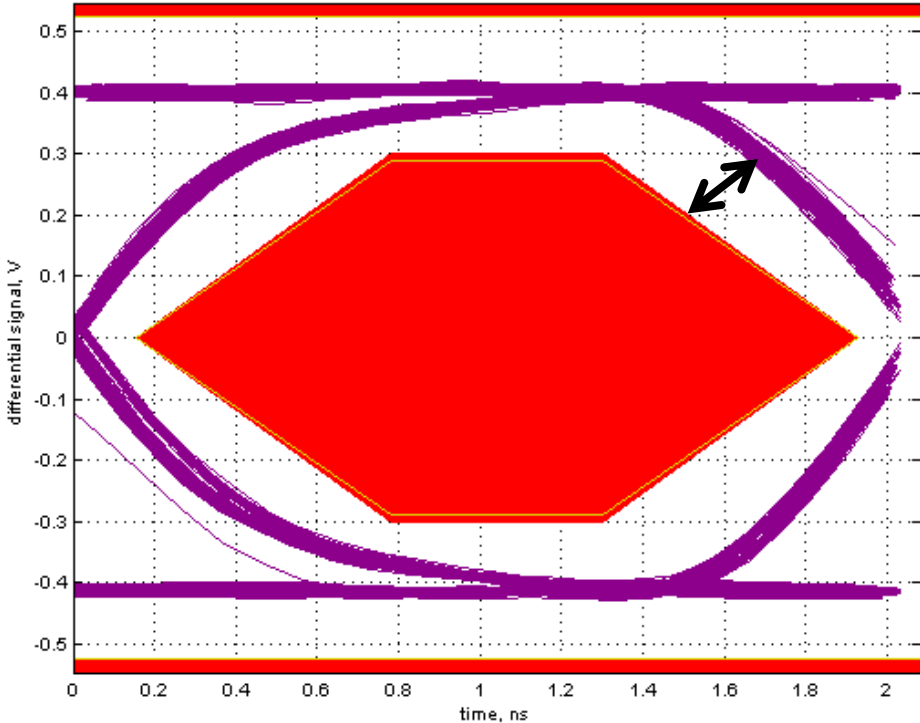


# Matched length impact on USB 2.0 signal quality

## Matched length differential pair

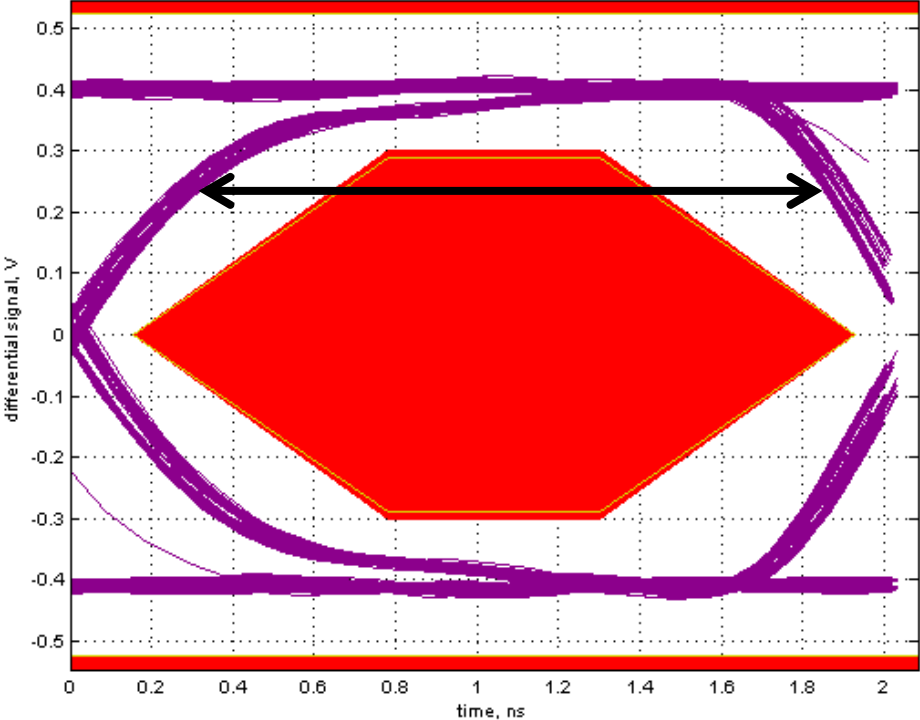


## Mismatched differential pair – 1.5 inches

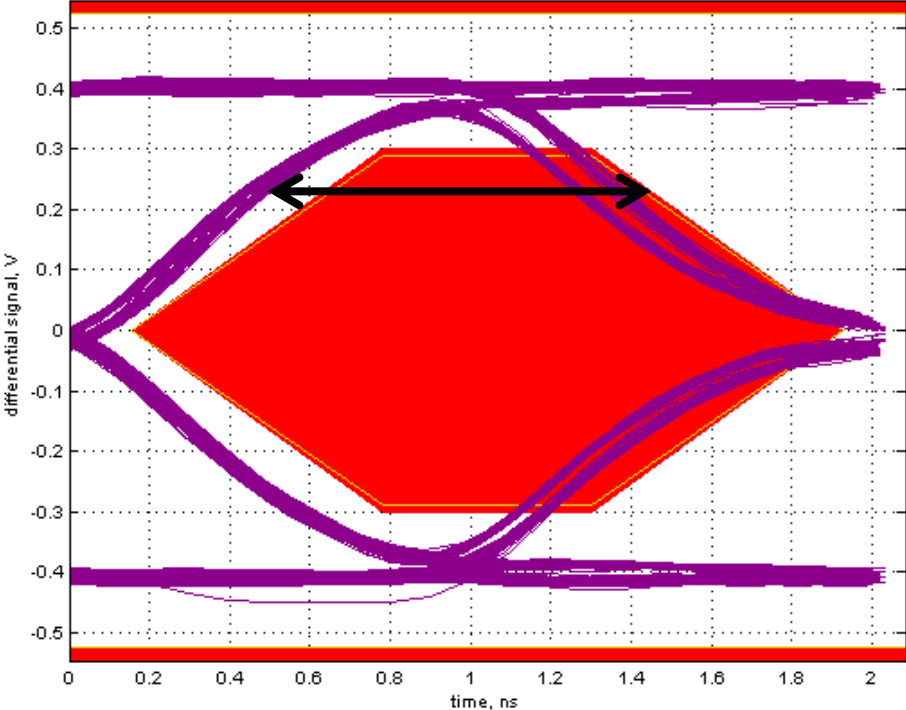


# Matched length impact on USB 2.0 signal quality

## Matched length differential pair



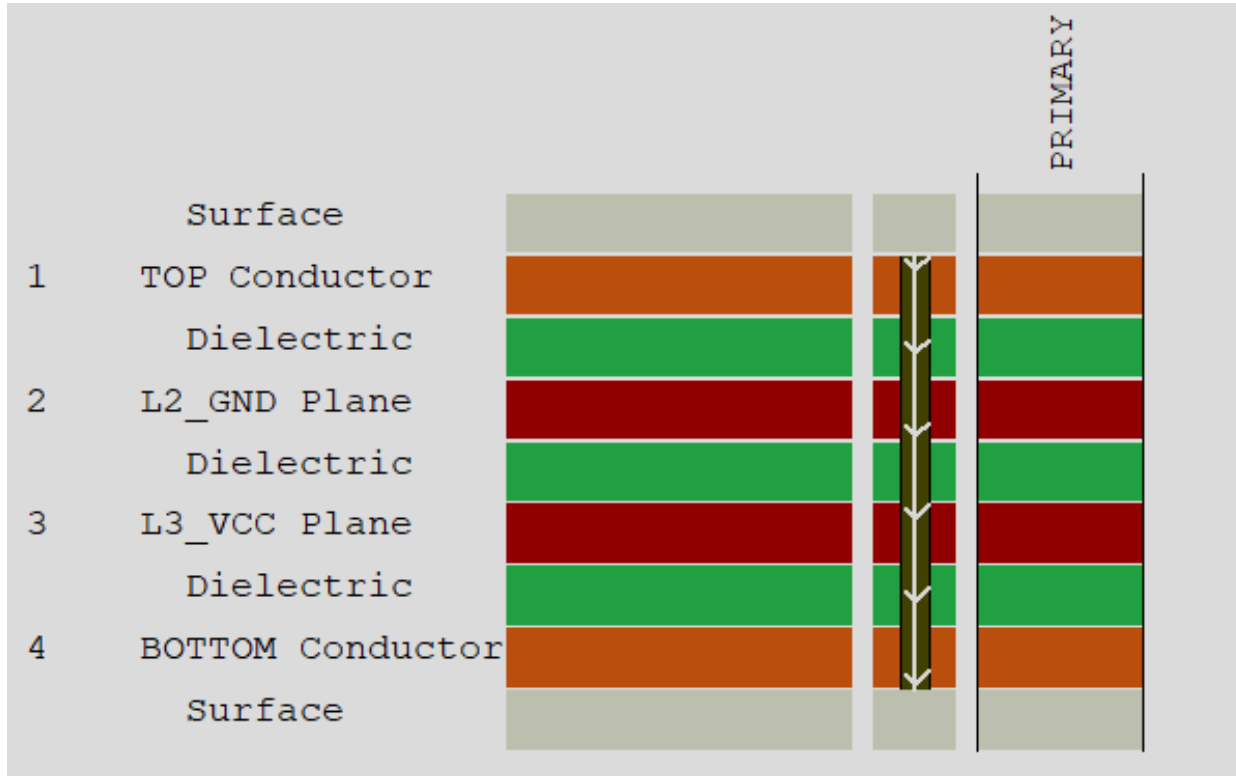
## Mismatched differential pair – 7 inches



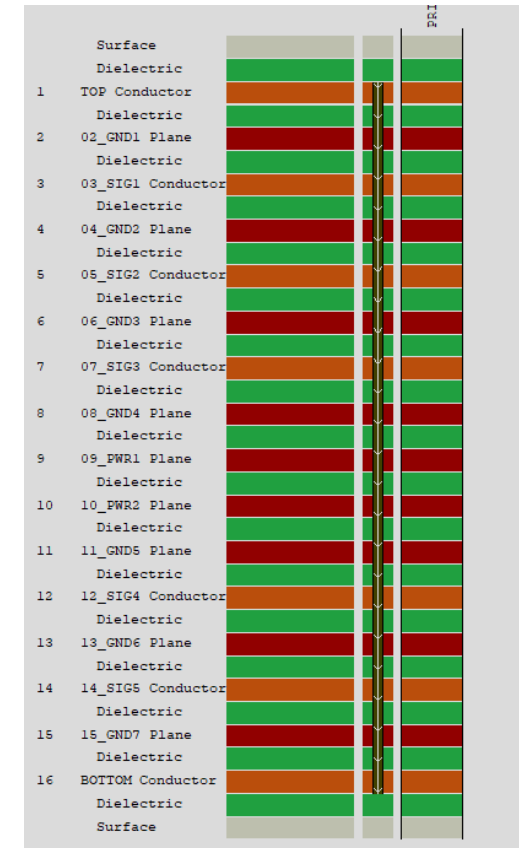


# Printed circuit board stack-up for USB signals:

## Ideal 4-layer stack-up

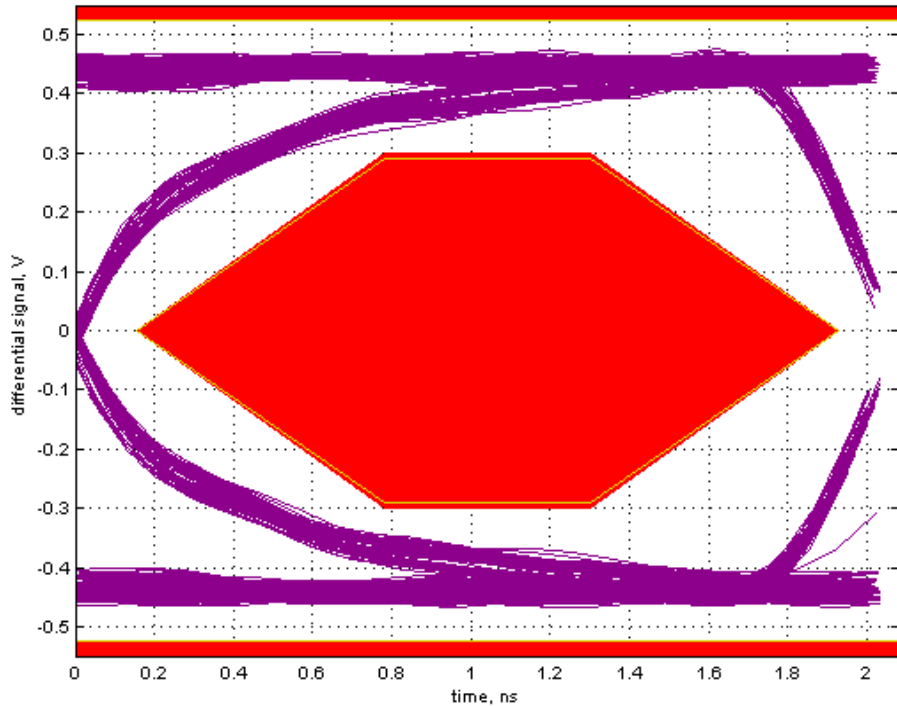


## Sample motherboard stack-up

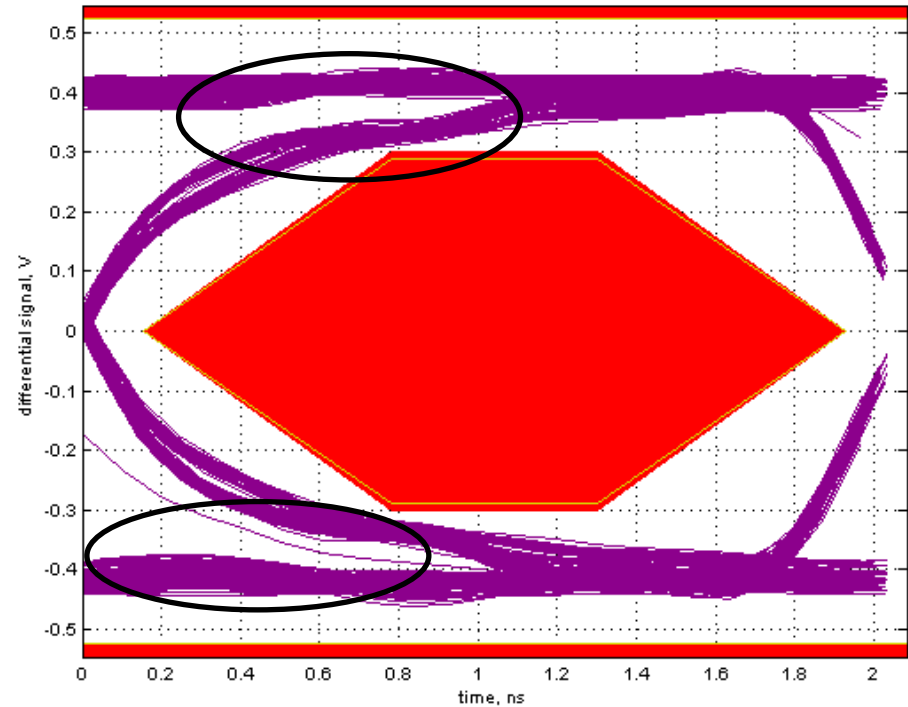


# PCB stack-up impact on USB 2.0 signal quality

## Solid ground plane reference



## No ground plane reference – 2 layer boards



# Short quiz

1. True or False: The spacing between the two signals of a differential pair impacts the differential characteristic impedance.

**TRUE**

2. True or False: As long as the traces of a differential pair are matched in length, the total length has no impact on signal quality.

**FALSE**

3. True or False: The traces of a differential pair must be perfectly matched in length.

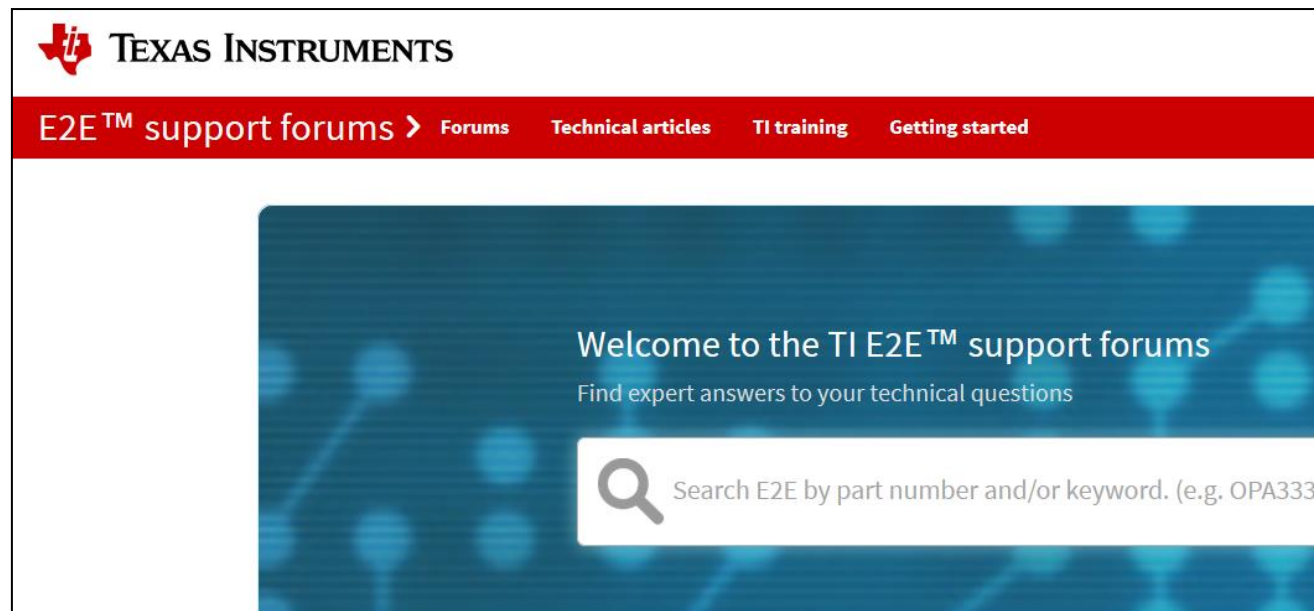
**FALSE**

4. True or False: High-speed differential pairs should be routed over a solid ground plane when possible.

**TRUE**

# Thank you

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