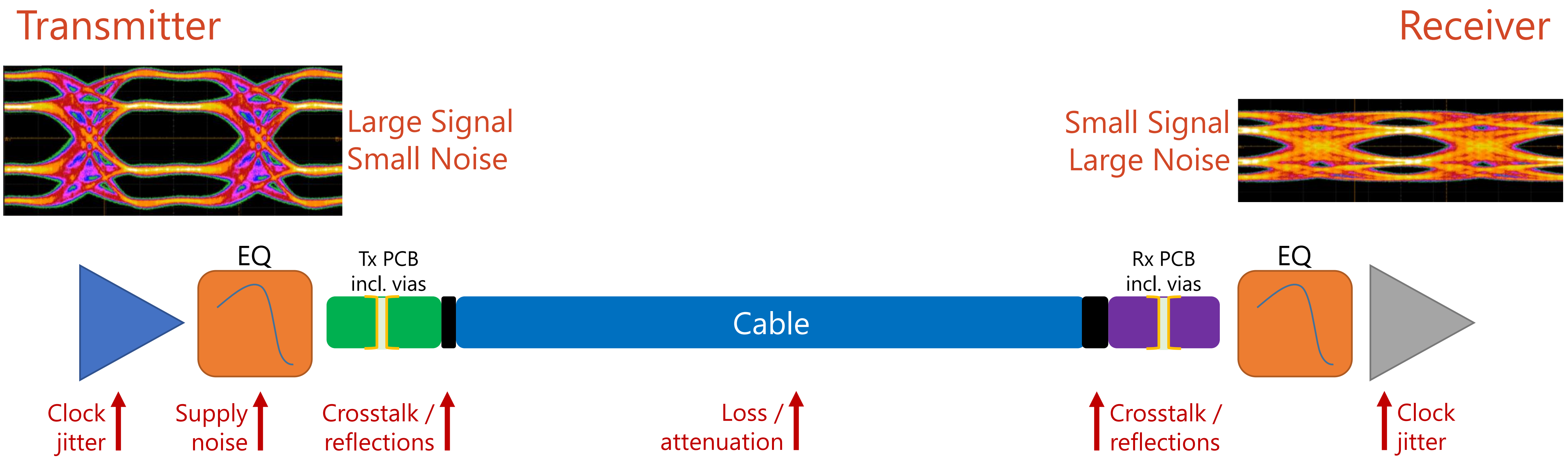
Correlating VNA and BER Results in a Cable Testing Environment

Topics Covered

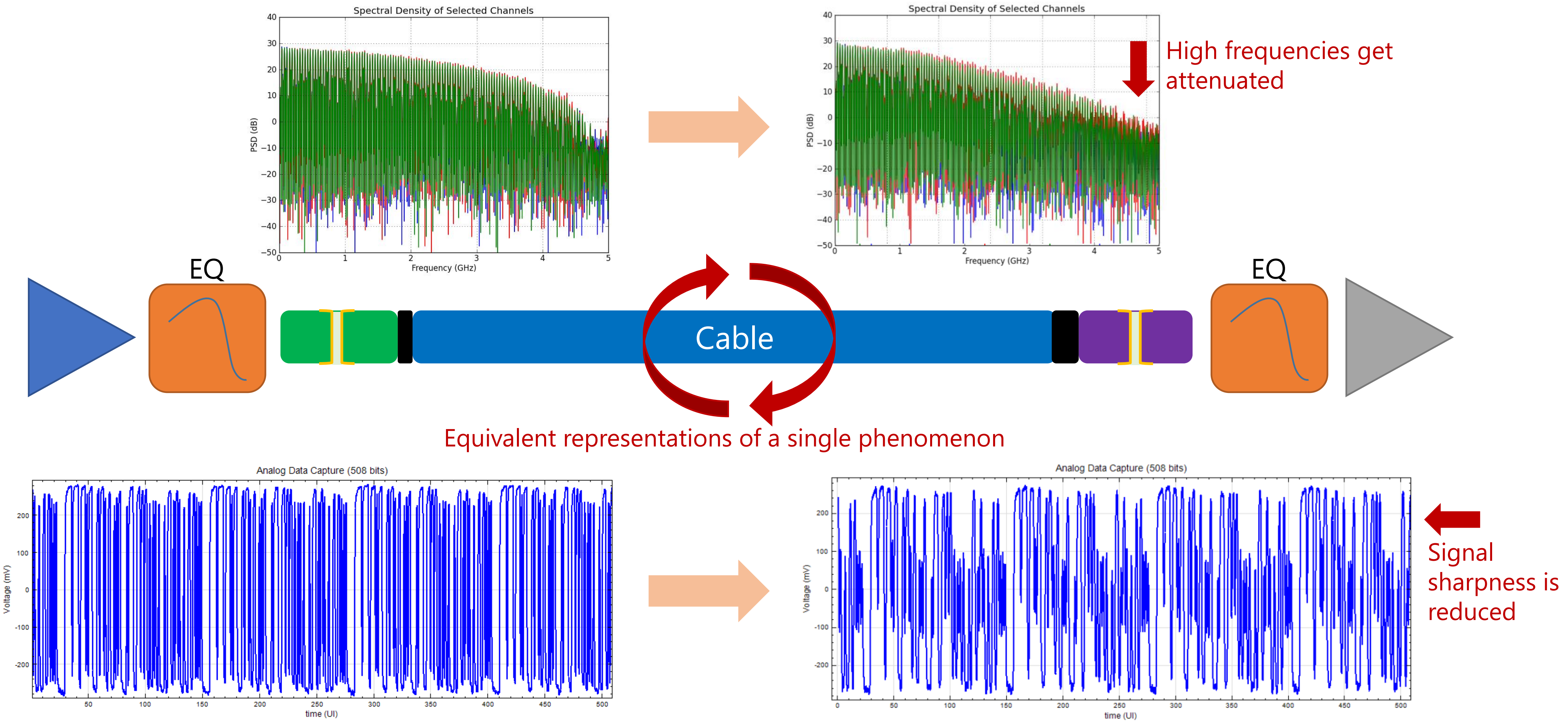
- Eye Diagram Representation of Signal Transmission
- Time-Domain and Frequency Domain Representations
- Cable Assembly as a Multi-Port Network
- Measurement Techniques for Multi-Port Networks
- A Key Property for Correlating with Eye Diagrams
- The Linear Phase Behavior
- Practical Cable Behavior
- Correlating Eye Height With the VNA Plot
- Case Study
- S21 Frequency Responses
- Measured Eye Diagrams
- Setting Up a Pass/Fail Condition

Eye Diagram Representation of Signal Transmission

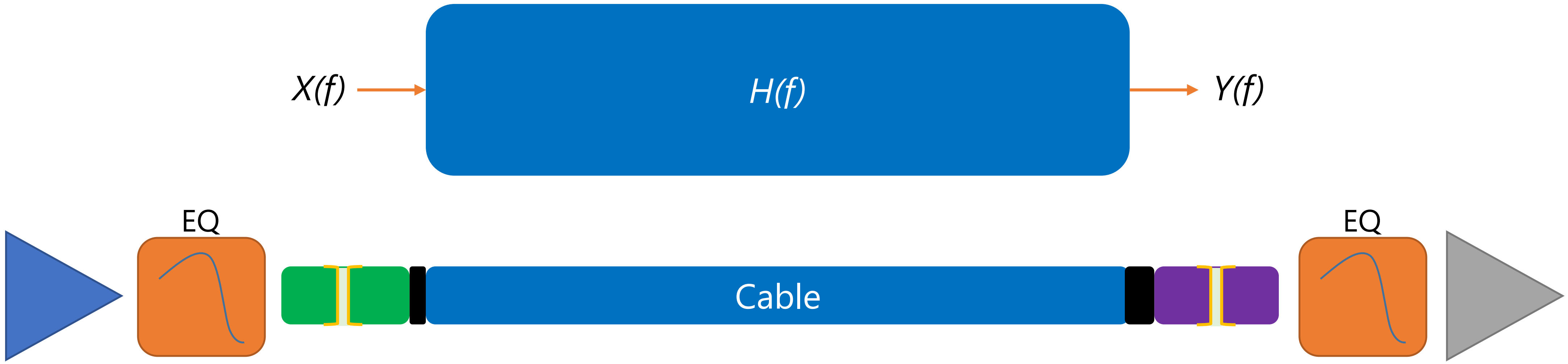


- The eye diagram is a convenient representation of signals for assessing BER performance
- This is related to receiver design architecture, which includes linear and non-linear equalization blocks, clock recovery circuitry, and a sampling flip-flop
- Knowing the eye opening helps designers quantify the available setup & hold time for the sampling flip flop
- The eye diagram is a time-domain view of the signal

Time-Domain and Frequency Domain Representations



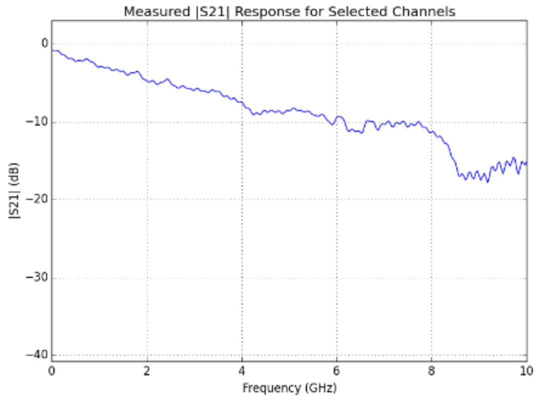
Cable Assembly as a Multi-Port Network

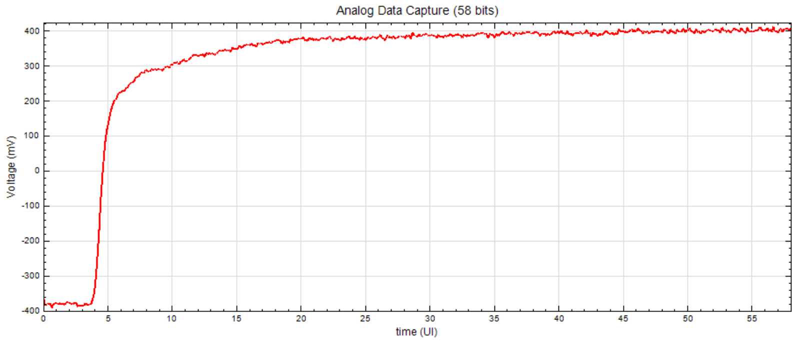


- A cable is typically measured in the frequency domain using a VNA or in the time domain using a TDR
- In the frequency domain, a VNA has limited channel count and needs significant mathematical post-processing to “translate” to a system BER measurement
- In the time domain, a TDR has limited channel count and has no easy way to translate to a system BER measurement
- In this document, we focus on using direct BER measurement to achieve a system-level test during high-volume production of cables
- We demonstrate how the BER measurement can be correlated to VNA measurements

Measurement Techniques for Multi-Port Networks

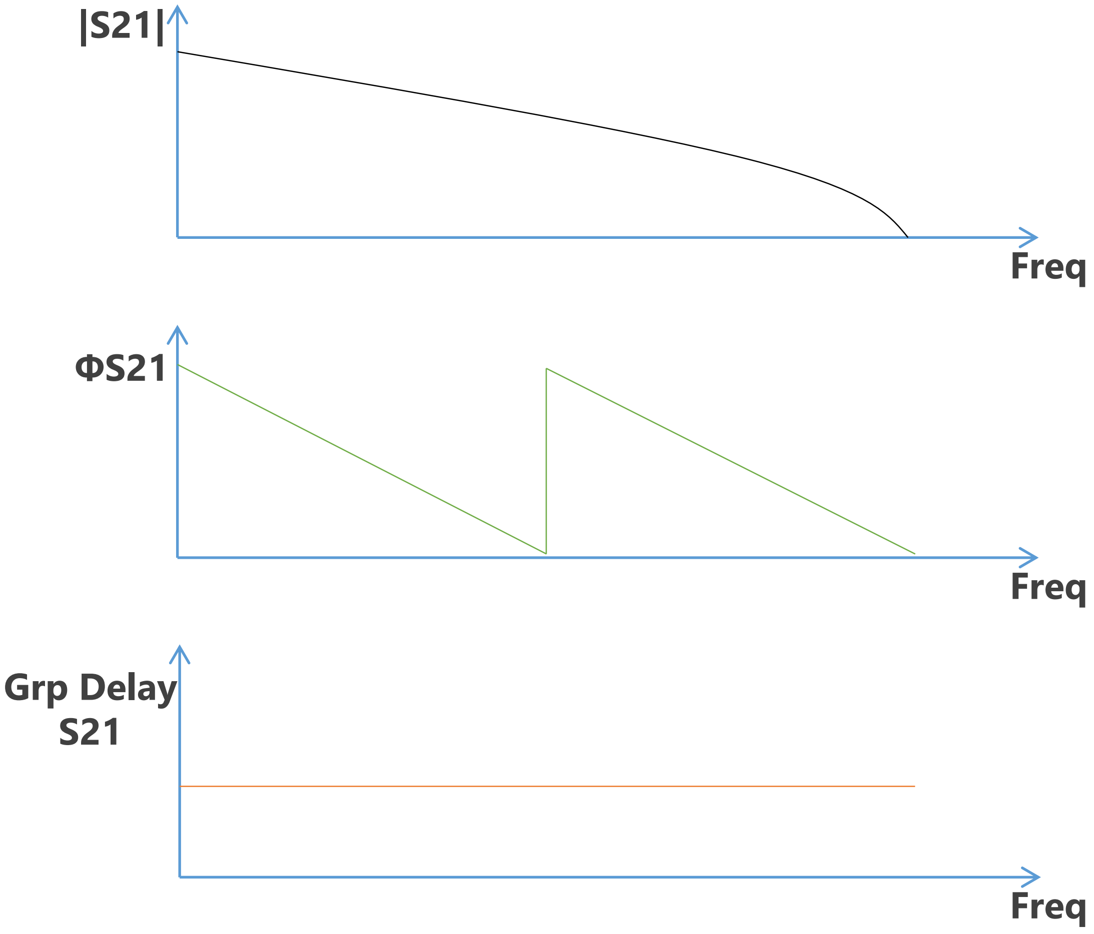
Typical VNA trace of a
cable frequency response





Typical TDR/TDT trace of
a cable step response

A Key Property for Correlating with Eye Diagrams



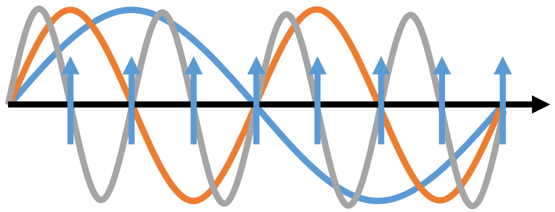
- Frequency response graphs are often plotted only in the magnitude scale as shown in the left |S21| plot

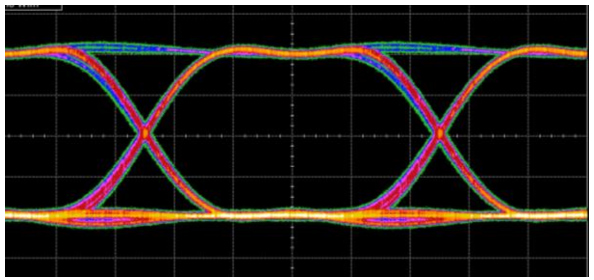
- In reality, cable assemblies possess a phase response as well
- Phase response is generally linear in the absence of defects

- Linear phase results in relatively constant group delay
- Such behavior impacts eye diagram shape out of a cable in a particular manner

The Linear Phase Behavior

A digital signal such as a PRBS pattern consists of the superposition of different frequency sine waves

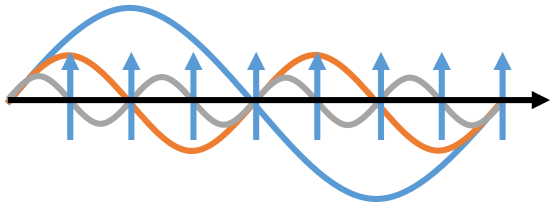


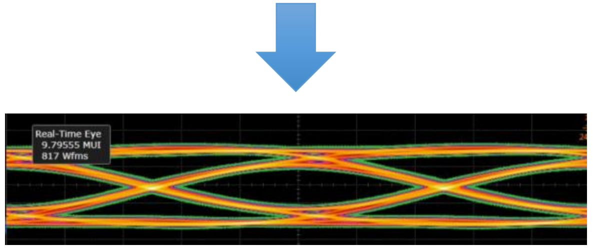


Timing Edges Largely Unaffected in a Linear Channel

Eye Height Affected More Than Eye Width

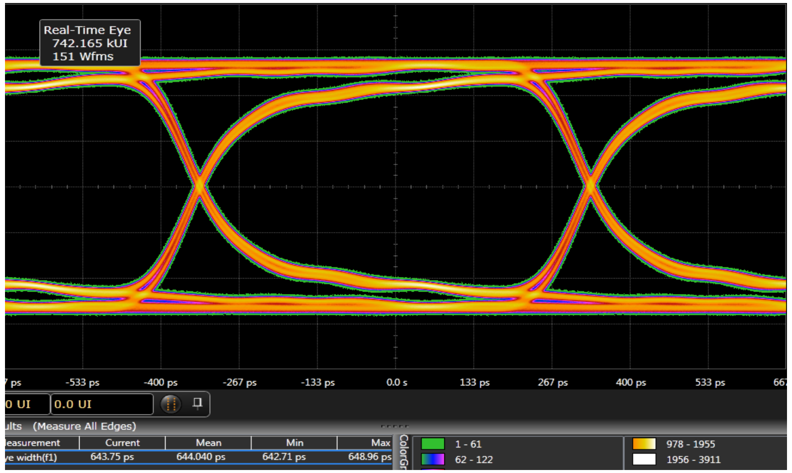
A constant group delay means that all frequencies in the digital signal will have the same propagation delay even if their amplitudes are attenuated



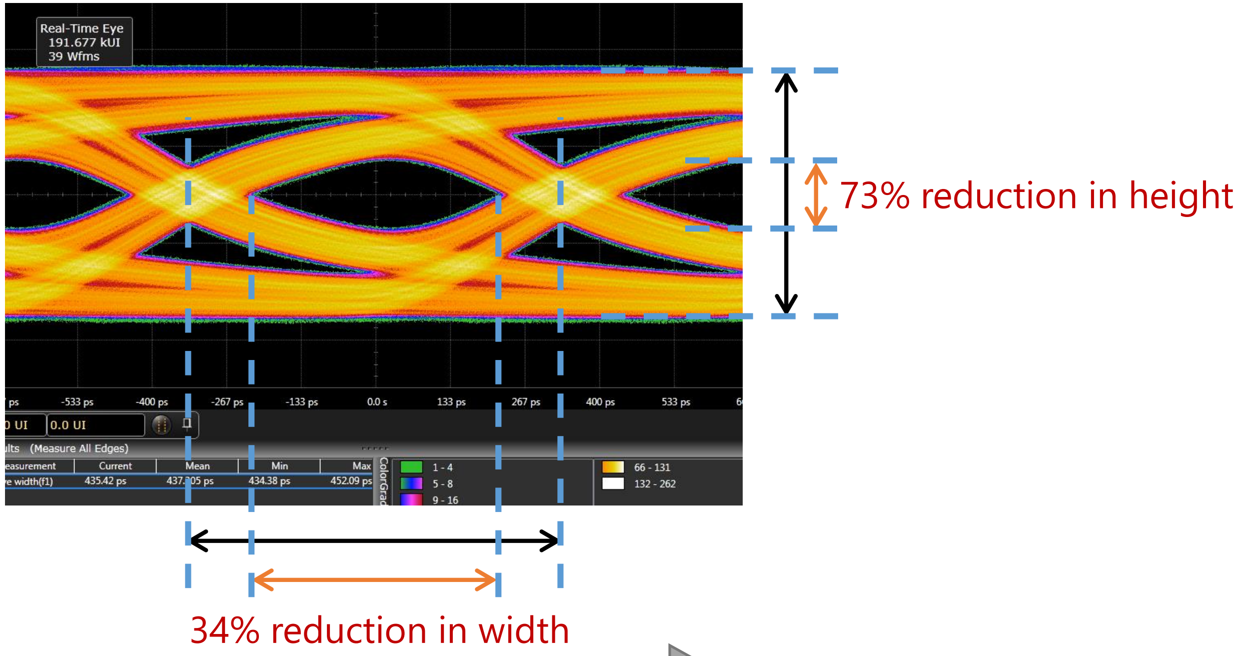


Practical Cable Behavior

Tx Eye Diagram



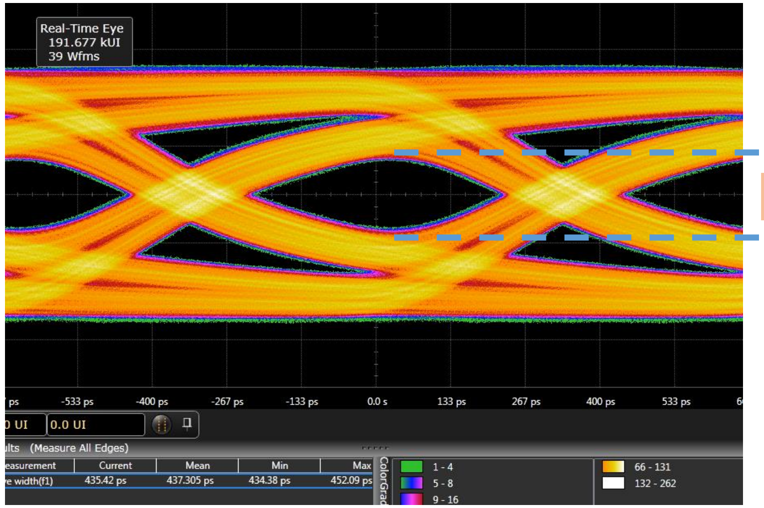
Eye Diagram at Output of Cable



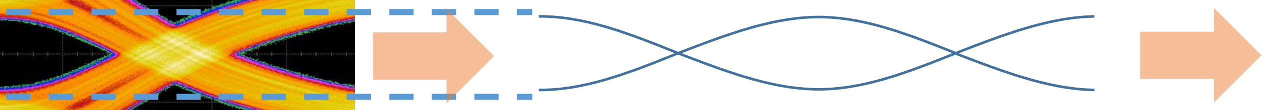
- Even in a real cable, vertical eye opening represents the most significant indicator of cable loss

Correlating Eye Height With the VNA Plot

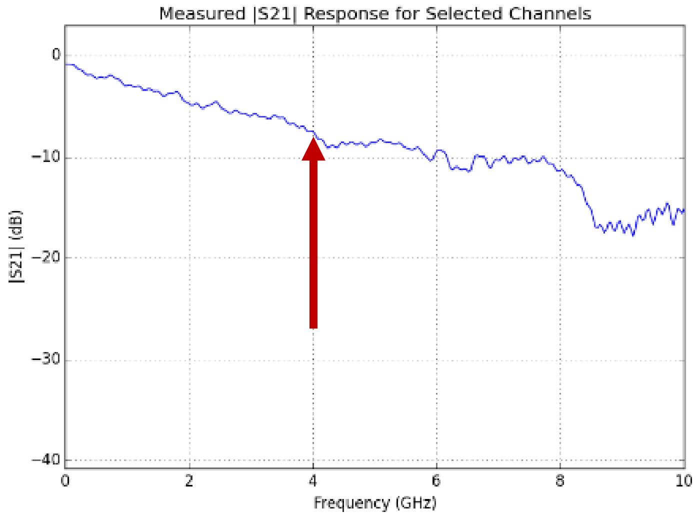
Accumulated Eye



Inner Eye (Dominated by Highest Frequency)



Highest Frequency Location



- In a largely linear cable assembly (i.e. without defects), the inner eye height is dominated by the largest frequency in the signal
- This frequency is typically equal to the data rate divided by two in modern half-rate systems (e.g. 8 Gbps data transmission would possess a high frequency tone at 4 GHz)
- The attenuation of the highest frequency in the signal is represented as a single point on the VNA |S21| graph (right hand side illustration)

Correlating Eye Height With the VNA Plot

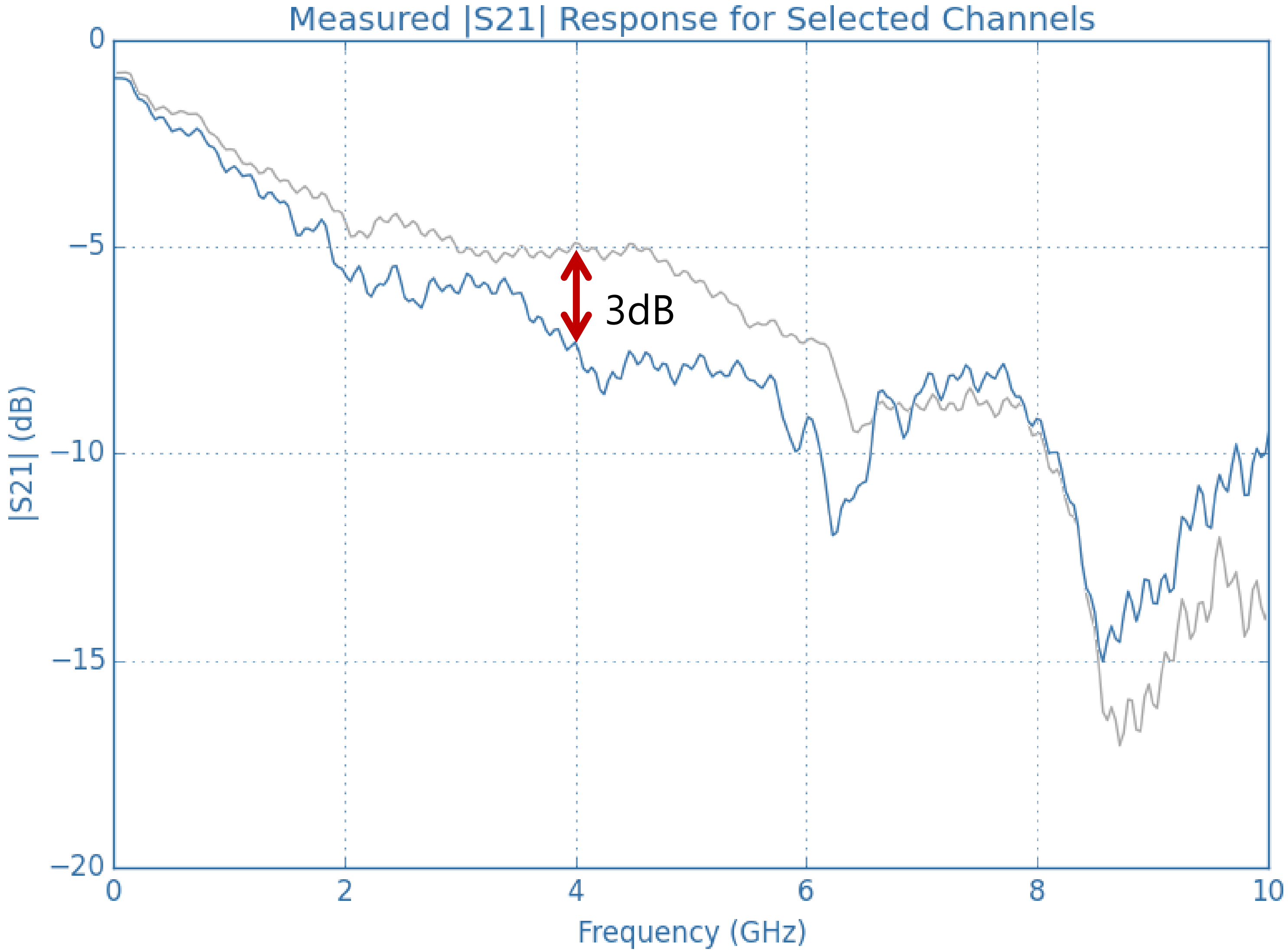
Simplified Methodology

- Setup a BERT system to stimulate a cable at the target data rate
- Compare vertical eye height after passing through the cable to the vertical eye height obtained through an ideal short reference channel (i.e. loopback)
- Correlate the attenuation in eye height to the half-rate attenuation point on the S21 plot

Case Study

- A commercial high-speed assembly was tested with reference breakout boards
- Two different lengths were selected to investigate the |S21| response and corresponding eye diagrams

S21 Frequency Responses

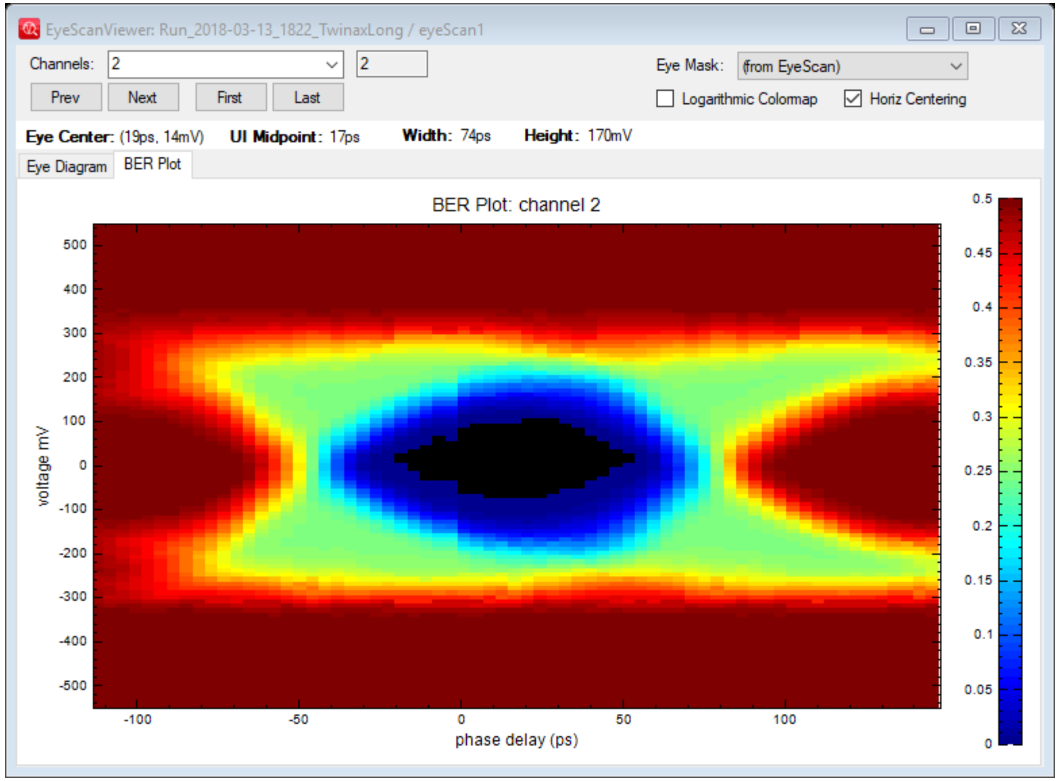


DUT	Eye Height (mV)	Eye Ratio (dB)
1	170	N/A
2	118	-3 dB

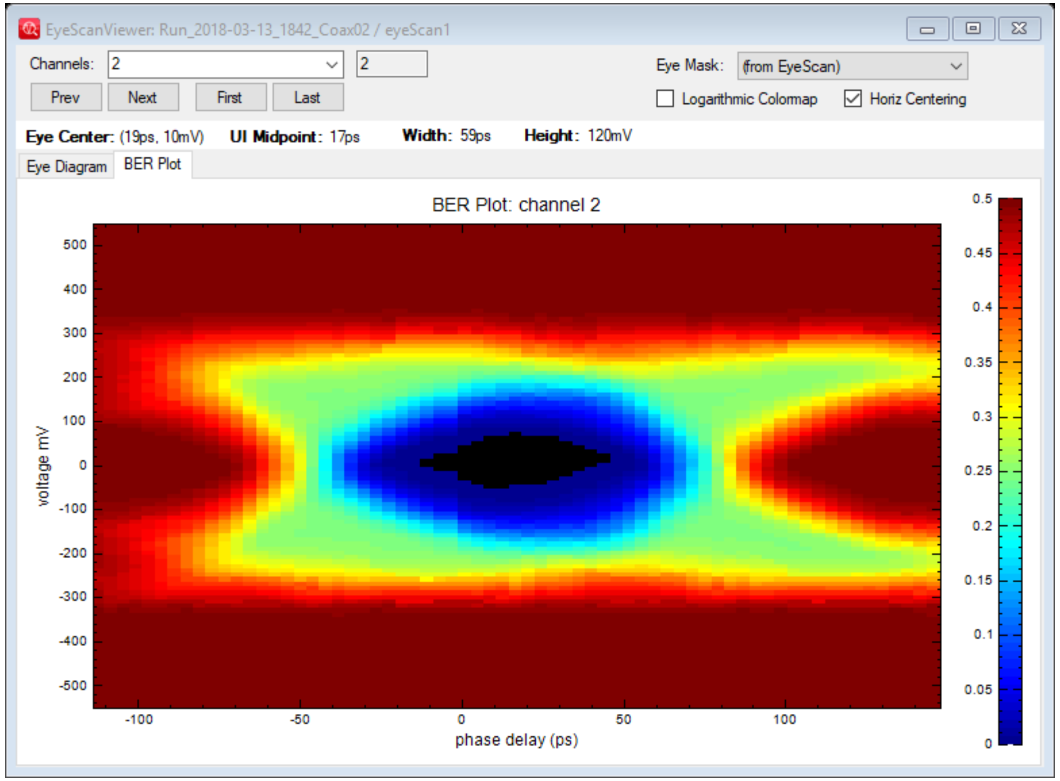
Computing the eye height ratio and converting it to dB, we observe that the relative difference in eye closure between the two cables corresponds reasonably closely to the difference in S21 at 4 GHz

Measured Eye Diagrams

DUT 1



DUT 2



Setting Up a Pass/Fail Condition

During production, it might be desirable to run a BER test instead of measuring an eye diagram

In this case, the following procedure is recommended:

- Identify the range of |S21| variation that is acceptable (e.g. 5 dB at the half-rate frequency) for a production screen
- Select a device under test that is at the bottom of the selected pass/fail range (e.g. 5 dB)
- Tune the receiver equalization settings of the tester to pass this device with a reasonable BER test time (e.g. 1e9 compared bits)
- Test all manufactured parts with the same settings

Conclusion

- BER eye diagrams are true system-level representations of the behavior of any high-speed digital system, including a cable assembly
- In order to simplify the correlation of BER measurements with more conventional VNA measurements, this document highlighted key properties of cable assemblies
- We demonstrated that non-defective cable assemblies exhibit a largely linear response, and this can help in identifying pass/fail BER test limits that are easily correlated with VNA frequency responses

Thank You!

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