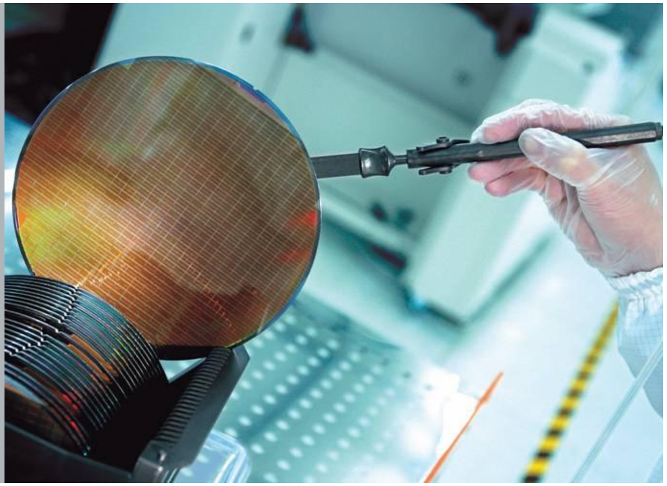
HSS Serial Standards Measurement @ 10G and 25G, Electrical Focus

Pavel Zivny



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Agenda

- Transmitter (TX) test
  - Mask test changes to Statistical Mask
  - TWDP measurement: SFP+, 10 and 8 Gb/s due to IP problems
  - Bandwidth required in test equipment; new interconnect problems and solutions

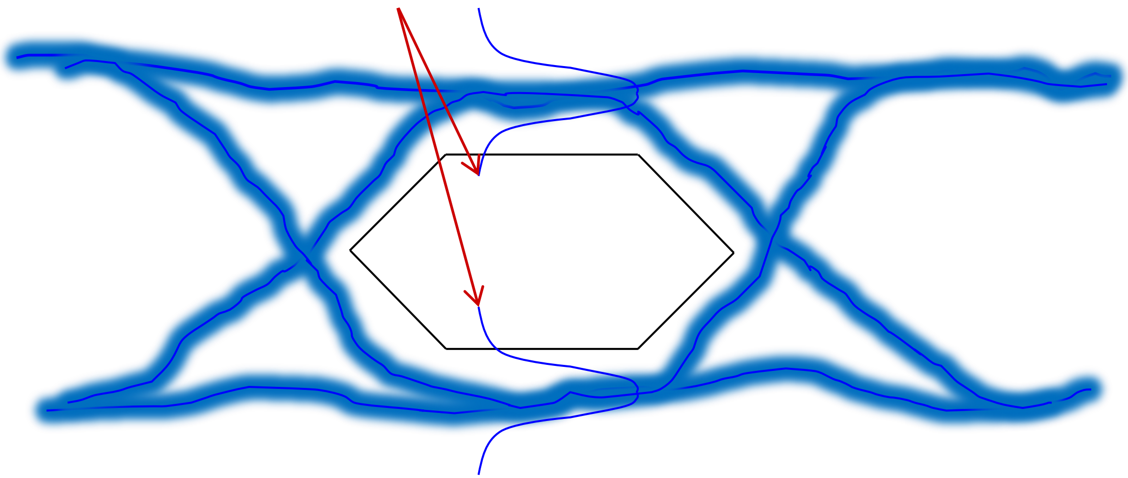
- Channel related
  - ICR – Insertion to Crosstalk ratio
  - Crosstalk-aware jitter analysis

Standards: Industrial

- Infiniband
  - Server, Military, Supercomputers
  - Maps nearly 30 Gb/s lanes
- Interconnect (defined in OIF/CEI and Ethernet)
  - 10.3125 Gb/s (nAUI, nPPI (aka XLAUI, CAUI)
  - 10.3125… Gb/s (SFI for SFP+)
  - Move to 25 Gb/s underway
    CAUI-4, CPPI-4 (100 Gb/s is an aggregate)
- Storage networks move to:
  - 12 Gb/s (SAS)
  - 14.025 Gb/s i.e. 16GFC (mostly optical)
- Backplane (defined in Ethernet)
  - 10GBASE-KR the main backplane
  - 40GBASE-KR4 at 10 Gb/s
  - 100GBASE-KR4 with 25 Gb/s signaling underway

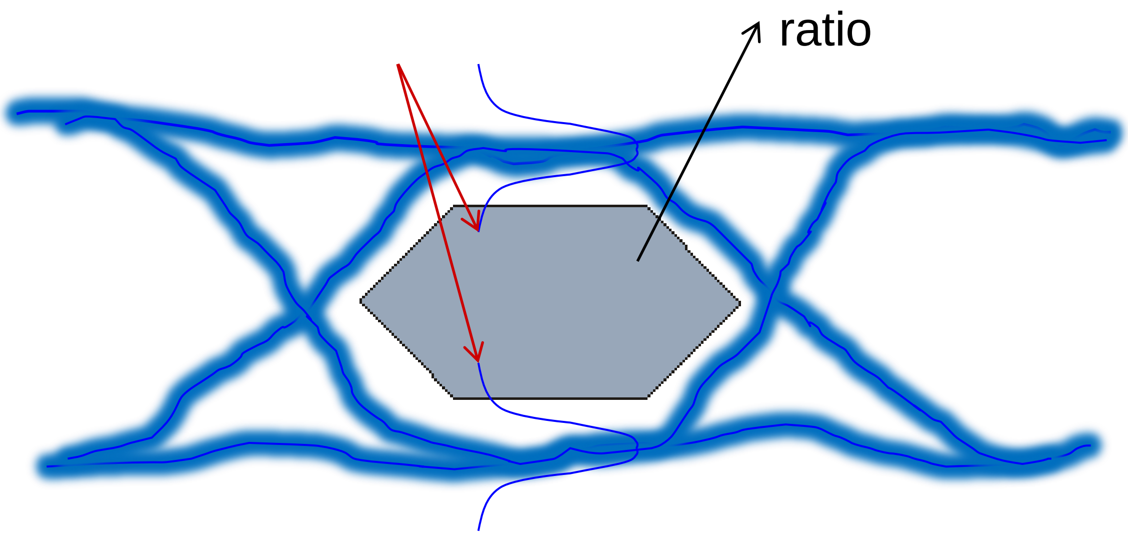
Mask Test Has Problems… always had on digital scope

- Standard Mask is a Pk-Pk measurement in 2D
- A single outlier fails the device under test (DUT)
- Running longer generates more failures – pressure to test too little
- A more statistical behavior is needed



Mask Test Now Improving

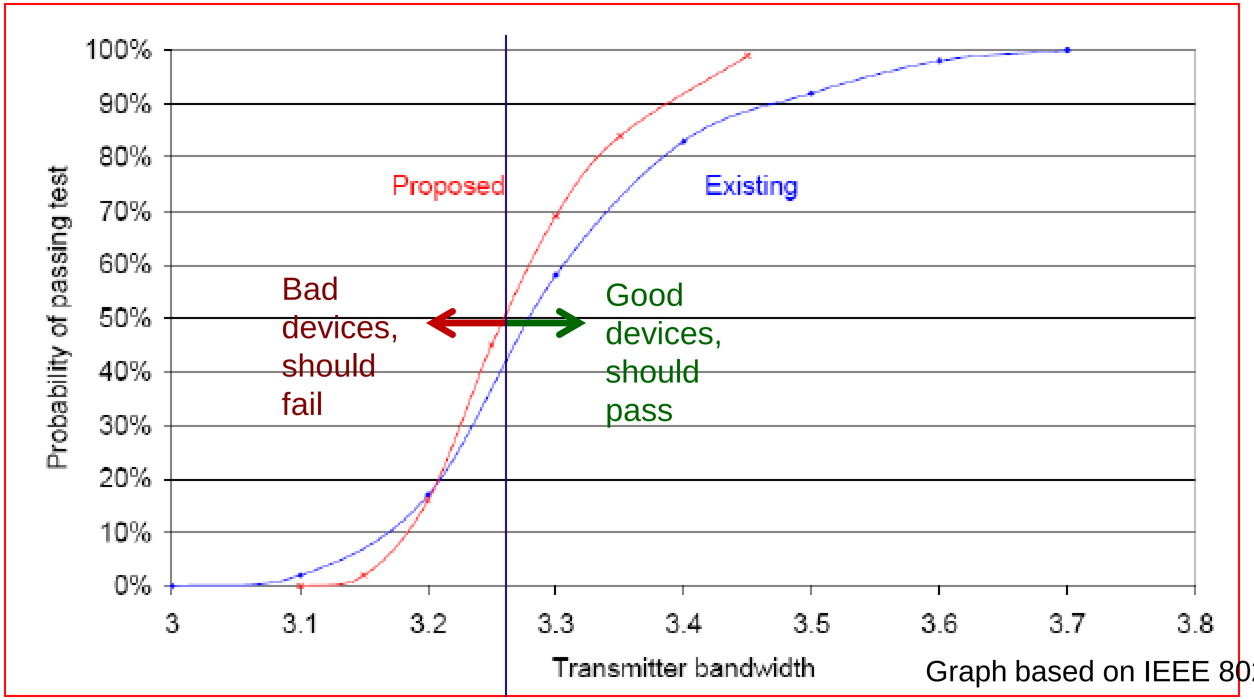
- Instead of saying, 1 hit is a fail, say …
- 1 hit in 20,000 is o.k. (ratio 5E-5)
- So now the mask is a probability (sampling) mask
- Running longer now gives more accurate result (rather than more failing result)



$$MaskHitRatio = \frac{NrOfMaskHits}{NrOfSamplesInUI}$$

Mask Test Change, The Solution Is "Statistical Mask"

- Statistical Mask (red) more clearly -sharper step- fails the bad devices



Graph based on IEEE 802.3 / Jonathan King

- Currently this is available in oscilloscope math only (contact your Tek office)
- Will be implemented in the oscilloscope FW in the future
- Talk to Tektronix

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Other new measurements in standards:

TWDP, WDP, Transmitter Waveform Penalty, Transmitter Waveform Distortion Penalty, Transmitter Waveform Dispersion Penalty, etc.

10Gb/s

▪TWDP	Optical(LRM)	IEEE Std 802.3aq-2006	10GBASE-LRM transmit characteristics
▪TWDPc	Electrical	SFF 8431, D4.1	SFP+ Host Transmitter Output Specifications at B for Cu
▪dWDP	Electrical	SFF 8431, D4.1	Linear Module Receiver Specifications at C’
▪dWDPc	Electrical	SFF 8431, D4.1	10GSFP+Cu Cable Assembly Specifications at B’ and C’

8Gb/s

▪TWDP	Optical (SR)	FC-PI-4, REV 8.0	Transmitter waveform distortion penalty (TWDPo)
▪TWDPc	Electrical(Cu)	FC-PI-4, REV 8.0	SFP+ host transmitter output specifications at B for Cu
▪WDPi	Electrical(Cu)	FC-PI-4, REV 8.0	SFP+ direct attach cable ass’y specifications at B’ and C’
▪WDP	SAS Electrical(Cu)		SAS (see John Calvin’s class)

- The code is now available from Tektronix for SAS in Serial Express and for SFP+
- Future standards are avoiding this due to IP (patent) issues

dWDPd, WDP*, TWDP* contain intellectual property of Clariphy Inc.

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8 to 28 Gb/s: "How Much Bandwidth Do You Need in the test equipment?"

- 5th harmonic! – or … no, 3rd harmonic! But … wait! It's the risetime…
- Bandwidth can be expensive
- The fact that *Serial Data Link Analysis* (SDLA*) is being used routinely above 6 Gb/s *does* have an impact
- Connectors – it's not all just SMA

Consider these changes one by one….

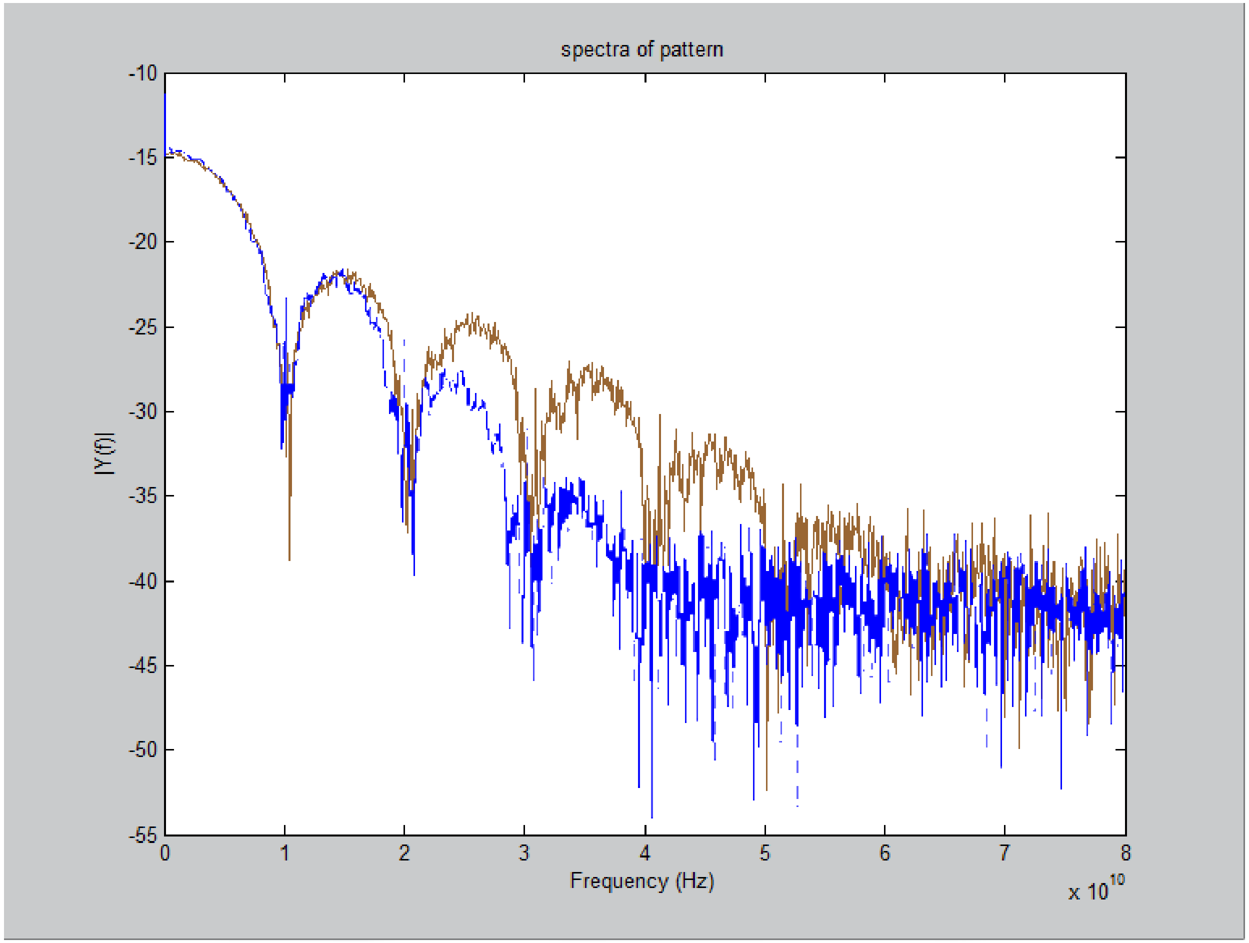
*SDLA: Channel Emulation, Equalization and Fixture De-embedding in oscilloscope's software

10 Gb/s Signal Spectrum – So… It's Just About Risetime?

- Here are two lab signal sources running at 10 Gb/s. The brown one is 2.4 mm connectorized, the blue one 3.5 mm (34 GHz).

The blue source is limited by its output amplifier. Energy stops above ca. 35 GHz.

The signals were captured with Tek 80E10 module, 50 GHz BW nominal, V-connector to 2.4, 2.9 adapter to SMA. Energy to 55 GHz is visible…



Bandwidth needed for TX Measurements for Bit Rate >8 Gb/s:

Conclusion for previous slide:

T&M sources are different –faster- than typical SERDES signal, but they are still different.

Fast sources can have energy to over 50 GHz – and such T&M (PPG, BERT TX) sources are often used to evaluate equipment.
Keeping that in mind, for datacom the following is still a good guide:

- 3rd to 4th harmonic for system test, and 5th harmonic for silicon.
  - The 4th harmonic idea – comes from the industry. See later slides.

Bandwidth Needed For TX Measurements What are the trade-offs

<u>Reasons to push for more bandwidth (BW):</u>

- Process changes – same chip might come a bit faster next batch and *oscillate*
- Obsolescence prevention
- Reflections on shortest channel

<u>Reasons to make do with less bandwidth (BW) :</u>

- Today's DUTs just don't have any extra BW – they barely work at speed
- All that speed will get lost in the loss of the channel anyway
- No investment ages worse than High Tech

Discussion?

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Standard bit-rate vs. Bandwidth vs. Connector

connector info from http://www.wa1mba.org/rfconn.htm

Example: Working with 12 Gb/s signals, what connectors and cables do I need to capture the 4th harmonic?
Answer: In left column find the Bit Rate of 12 Gb/s.
Follow horizontally to 4th harmonic (24 GHz),
..find nearest faster connector below-right (it's the 26 GHz capable SMA)

BitRate [Gb/s]	3rd h. [GHz]	Con. BW [GHz]	& name [-]/or[mm]	4th h. [GHz]	Con. BW [GHz]	& name [-] /or [mm]	5th h. [GHz]	Con. BW [GHz]	& name [-]/[mm]	B.R. [Gb/s]	1st h. [GHz]
5	7.5			10			12.5			5	2.5
6	9			12			15			6	3.0
8	12			16			20			8	4.0
10	15			20			25			10	5.0
								26SMA			
12	18			24			30			12	6.0
					26	SMA		34	3.5		
14	21			28			35			14	7.0
		26	SMA		34	3.5		40	2.9 / "K"		
		34	"3.5"		40	2.9 / "K"		50	2.4		
25	37.5			50	50	2.4	62.5			25	12.5
		40	2.9 / "K"					60	1.85 / "V"		
28	42			56			70			28	14.0
		50	"2.4"		60	1.85 / "V"					
		60	1.85 / "V"								
		110	1 / "W"		110	1 / "W"		110	1 / "W"		

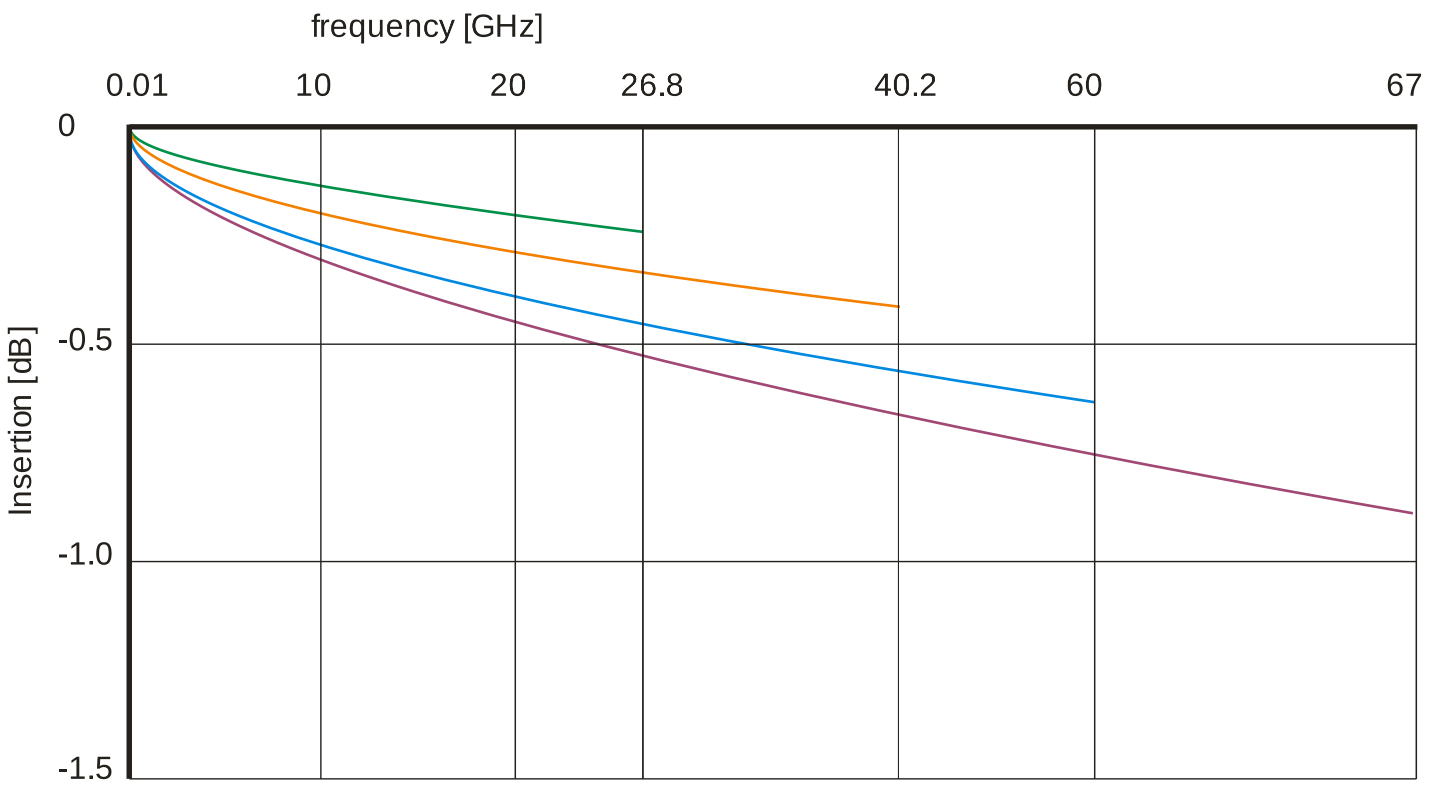
SMP to 40 GHz
(pic. after Rosenberger)

Interconnect for serial data

So you need fast interconnect. Is faster cable better?

- High-quality 2.92 mm, 2.4 mm, and 1.85 mm cables, e.g. W.L. Gore
  - http://www.gore.com/tektronix
  - Variety of pre-defined cable lengths
- 1.85mm, 2.92mm and 3.5mm calibration kits, Maury Microwave
  - http://www.maurymw.com/tektronix.htm
  - Also, recommended adapter kits, connector savers, airlines, connector gauges, torque wrenches
- SMA DC block: Picosecond Pulse Labs, Marki Microwave,
- SMA power splitter: Tektronix PN 015-0565-00

Loss of HF cables: you don't get what you pay for



- cheap; 3.5 mm connector
- less cheap; 2.9 mm connector
- expensive; 2.4 mm connector
- very expensive; 1.85 mm connector

The fastest cables have the smallest geometry… because mode-ing would occur if they were larger.
But smaller geometry means more loss – even at lower frequencies

Practical setup made more complex by the cable losses:

- So above 10 GHz, the signal require cables with smaller diameters …

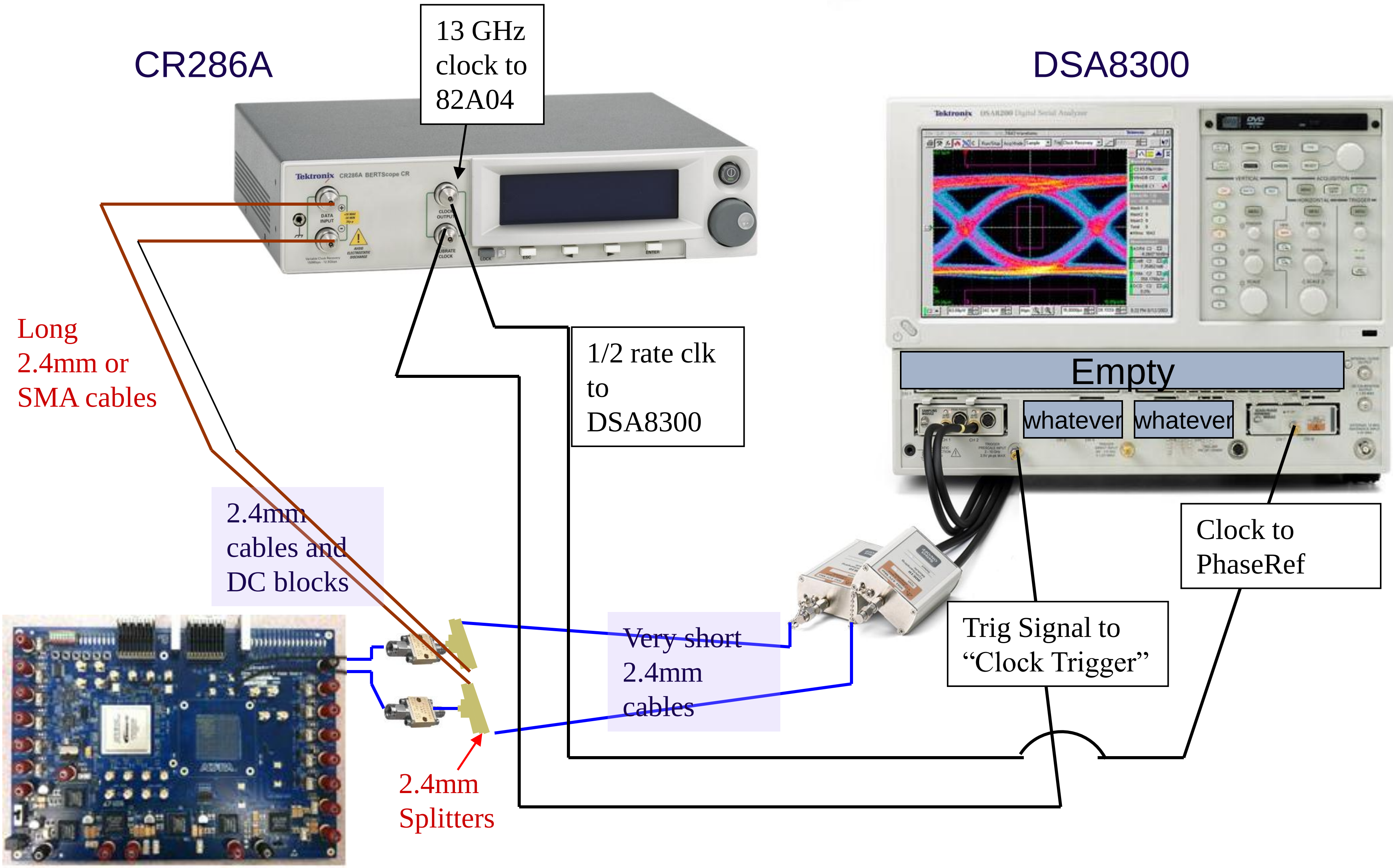
…which are too lossy. What to do?

Two options:

- Remote head acquisition
- De-embedding
  Tektronix SDLA tools for Real-time oscilloscope, and
  80SJNB Advanced (SDLA) for Sampling oscilloscope

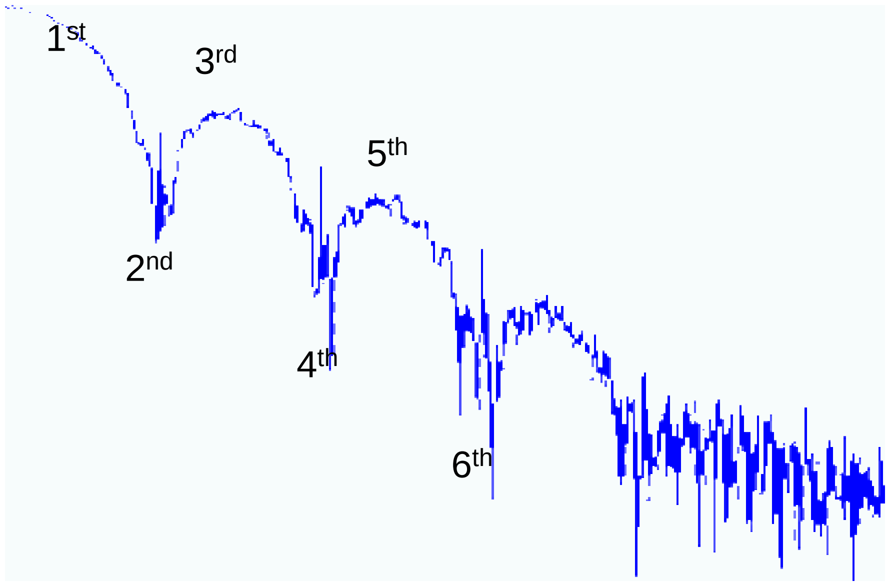
- Example of a acquisition with Remote head (next slide):

Examples of a Practical Setup of 25/28 Gb/s test: Altera 25/28 G World Tour Sampling Setup



What Do The Standards Say About Measurement Speed Why The 4th Harmonic?

- You can start playing at 0.75 * Bit Rate! (as shown by optical standards)
- Ethernet: for 25 Gb/s the S-parameters to f ≥ 40 GHz (3.2th harmonic)
  – Which doesn't mean that the captured signal must do the same…, but it *is* a number
- SAS argues: since de-embed is used, a SW filter roll-off is used. Place it to an energy minima. That is, 2nd, 4th, or 6th harmonic…. Practical considerations dictate the 4th. (proposal by Micky Felton of EMC)



Making It Work For Your Needs: What measurements are needed?

Bandwidth

- System/compliance: 3rd harmonic going to 4th
- Device/characterization: 5th harmonic if possible, 4th if not

Oscilloscope type – Real-Time O. (RTO) vs. Sampling O. (SMP) ?

- Some applications are mostly RTO – e.g. PCIe
- Some applications are mostly Sampling – e.g. Chip Characterization
- The obvious is right: debug->RTO, characterization->Sampling

When to use the BERTScope Receiver (the ED) ?

- The input BW, the noise floor and the jitter floor of a BERTScope are no match for fastest scopes, … but
- TJ, TN (total jitter/noise) and Error Count are the last call in every lab

Network impedance measurements for 8 .. 10 Gb/s and for 25/28 Gb/s

8 and 10 Gb/s systems used 20 GHz TDR or VNA (network analysis in Time domain or Frequency domain). This is well established equipment and practice.

Looking past 10 Gb/s, what are the standards proposing?

IEEE 802.3bj (100GBASE-KR4 underway) accepted this proposal (presented: Tektronix/Pavel Zivny and Agilent/Greg Lecheminant) in 2011/03 meeting in Singapore:

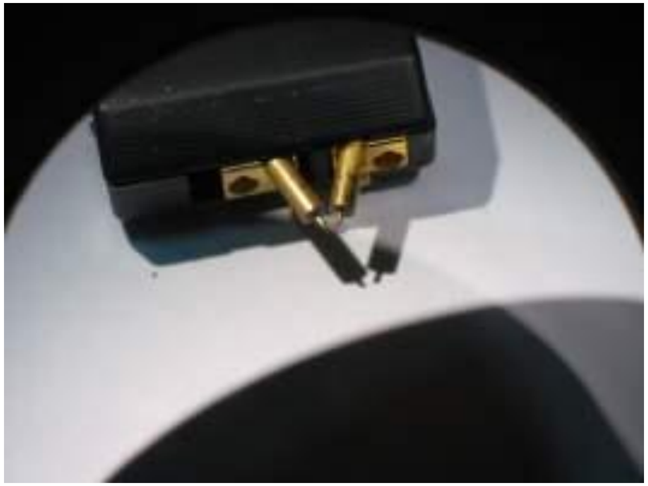
Requirements:

- The S-parameters should be captured to 40 GHz
- Frequency step spacing: 10 MHz below 1m; 5 MHz for longer devices

TDR Acquisition settings: 2.5 ps sample spacing, and sufficiently long record length to capture at least 3x of electrical length of the DUT

Network impedance measurements for 8 to 10 Gb/s and for 25/28 Gb/s: Probes and Microprobes

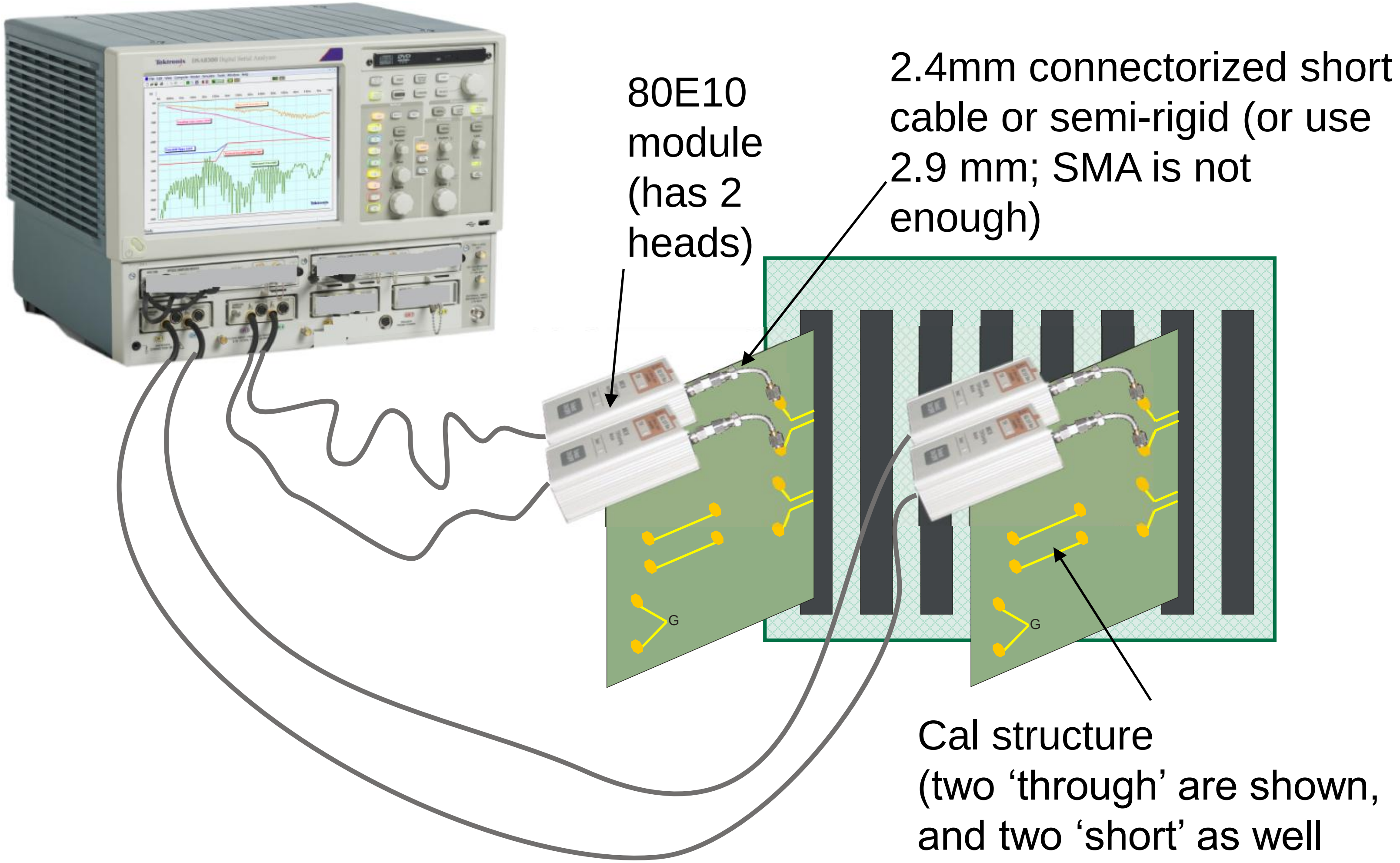
- **P80318 – 18GHz 100 Ω** Differential Impedance Hand Probe
  - Adjustable probe pitch from 0.5mm to 4.2mm
  - Works with TDR and BERTScope
- Not for common-mode or single ended; Use P8018 for single ended!
- **„30 GHz“ 100 Ohm** (TDR) probe from Gigaprobes); http://www.gigaprobestek.com
- **Microprobes** (Cascade, etc) above 50 GHz



- **Preffered solution: fixturing (next page)**

Example of a fixtured measurement setup: Measuring impedance of backplane via paddle cards

DSA8300 with IConnect



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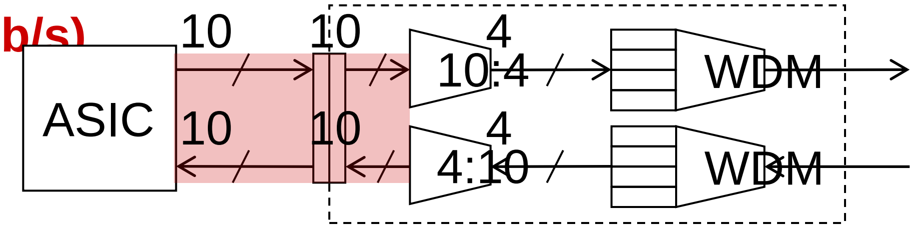
  - ICR – Insertion to Crosstalk ratio
  - Crosstalk-aware jitter analysis

Many signals, many parallel lanes in Serial Data➔ Crosstalk is ever-present

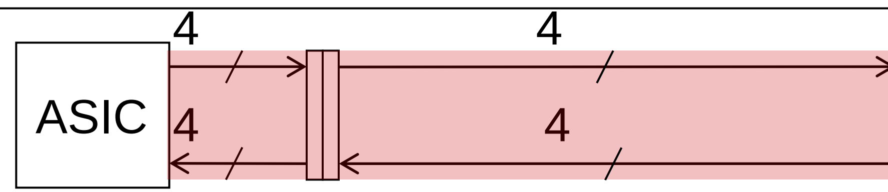
- From PCIe with typically 4x configuration, to 10x 10 Gb/s signal in 100 Gb/s Ethernet… crosstalk is very present.
- Crosstalk is a problem. DesignCon 2012 has 4 papers with crosstalk in the title, one a best-paper runner-up
- Some examples why is crosstalk more important today…

Crosstalk in Serial Data: Example 1
Many parallel lanes in Serial Data

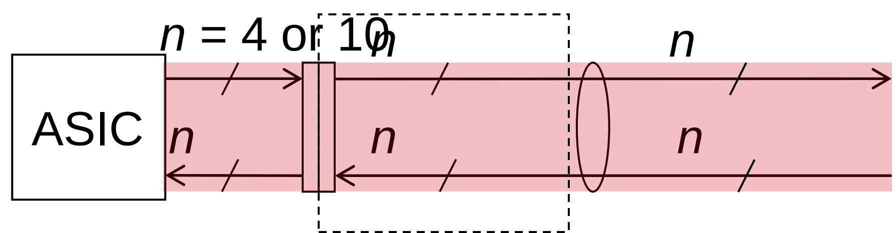
XLAUI (40 Gb/s) and CAUI (100 Gb/s)
- Chip-to-chip (not shown)
- Chip-to-module (retimed)
  - showing here LR4/ER4



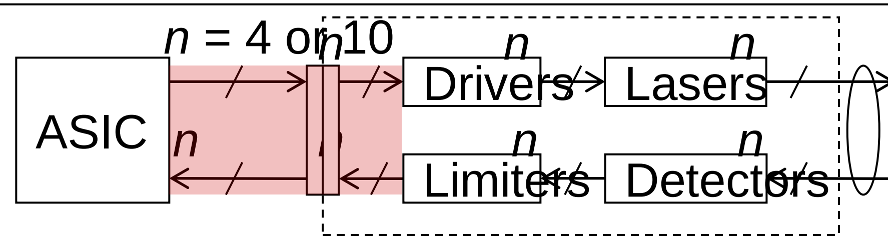
40 Gb/s Backplane Ethernet
- Up to 1 m and 2 connectors
- 40GBASE-KR4



Copper cable assembly
- Up to 10 m
- 40GBASE-CR4 (40 Gb/s)
- 100GBASE-CR10 (100 Gb/s)



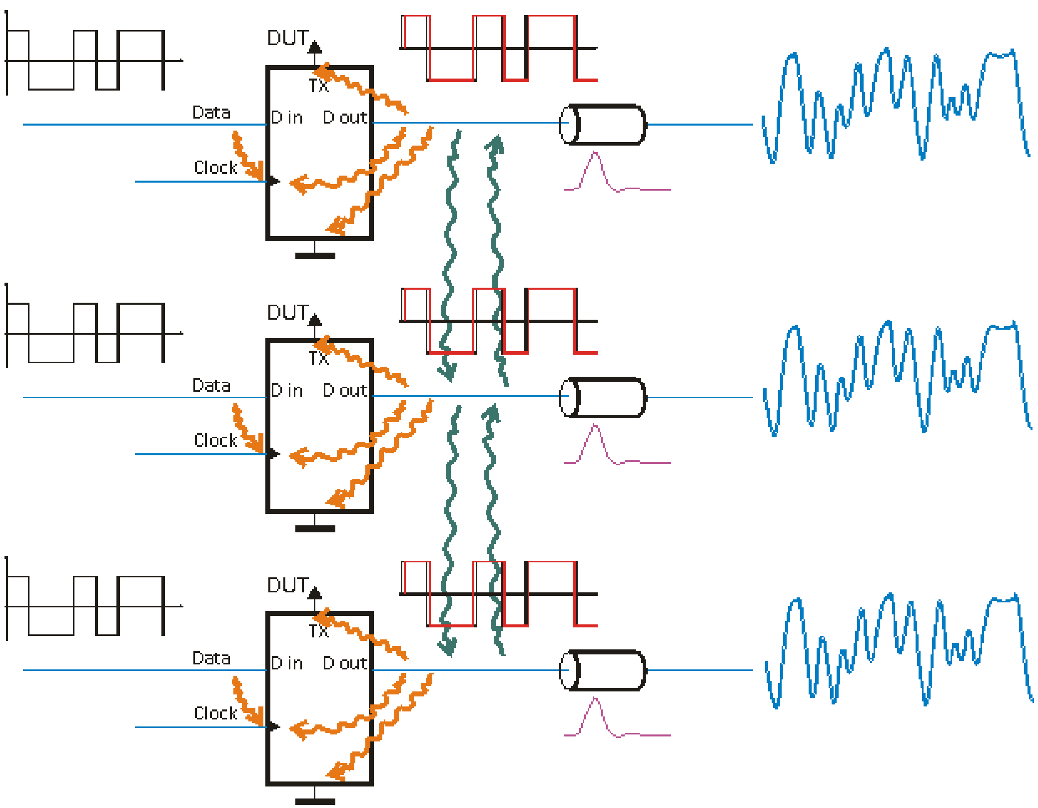
Parallel Physical Interface (PPI)
- Chip-to-module (limiting)
- 40 and 100 Gb/s



Interfaces consist of an aggregation of 10 Gb/s serial lanes
➔ Crosstalk everywhere !

Crosstalk in Serial Data: Example 2
100 Gb/s Transceivers: 2x10x10 Gb/s lines ➔ Crosstalk!

- Mechanisms of crosstalk generation in a multi-lane serdes, such as 4x25 serdes of a 100Gb/s Ethernet module
- Note that besides the basic coupling between lines (of a circuitboard, or runs on a chip) … here shown in green…
- …there also is coupling between power planes and ground planes, and clocks and data.



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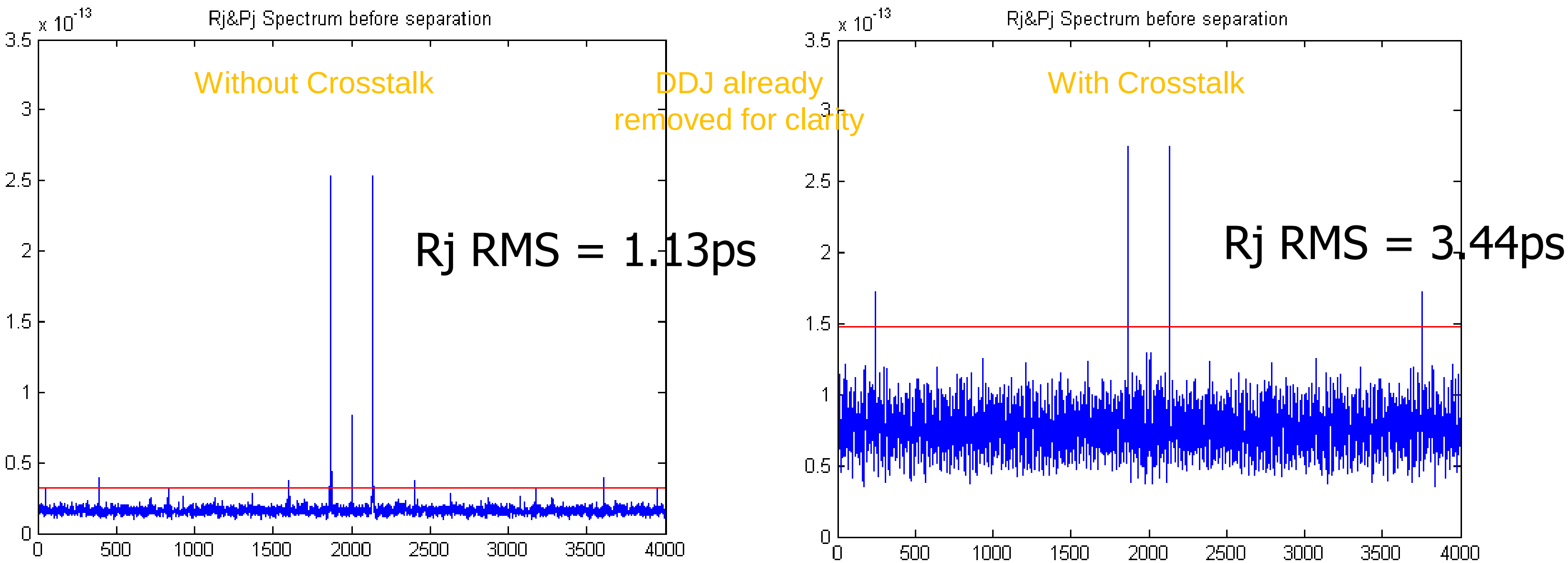
Measurements of Jitter in the presence of Crosstalk

- At DesignCon 2008 Tektronix (including this presenter) showed a paper demonstrating how complex crosstalk breaks our jitter tools Crosstalk breaks jitter measurements on oscilloscopes' jitter solutions, and on older Tek jitter solution
- At DesignCon 2012 Tektronix described a jitter measurement solution that works reliably in the presence of crosstalk, and even reports the crosstalk-caused jitter!
- First: why is the measurement so difficult?

In the presence of crosstalk; spectral separation fails WHY?

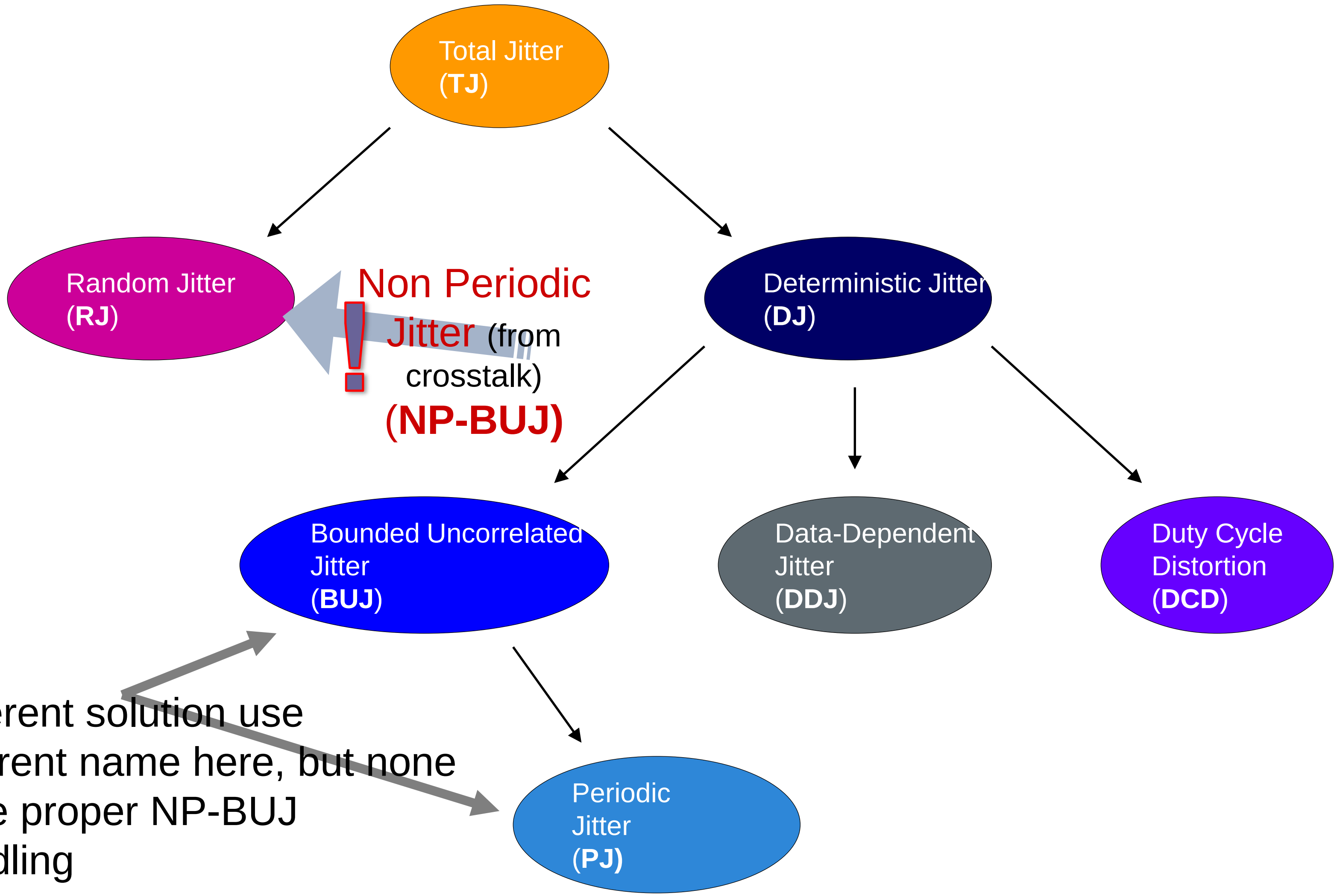


A Dual-Dirac example:

$TJ@1e\text{-}12 = DJ_{dd} + 14*RJ_{dd}$

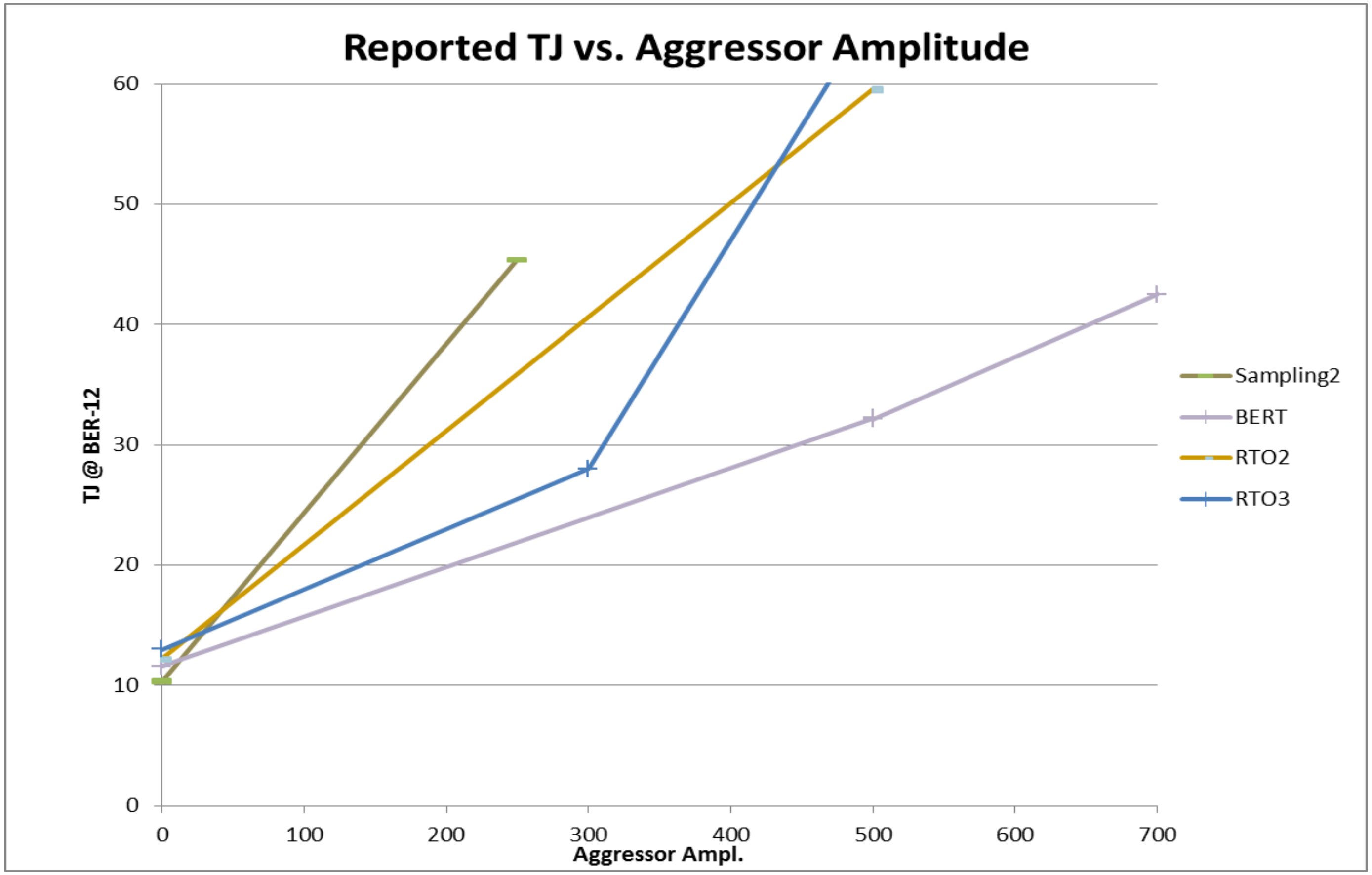
- Aggressor’s pattern length, it’s a/synchronicity, and analysis observation interval impact the result heavily, but in most cases the result is overestimation of RJ which results in significant overestimation of TJ@ BER

jitter analysis in presence of crosstalk: the jitter decomposition breaks.. why



Different solution use different name here, but none have proper NP-BUJ handling

Experiment results: TJ@BER10^{-12} vs. crosstalk amplitude



VMA victim:
500 mV

Assuming that the value measured with the BERT receiver is a reference, an error plot can be shown (next slide)…

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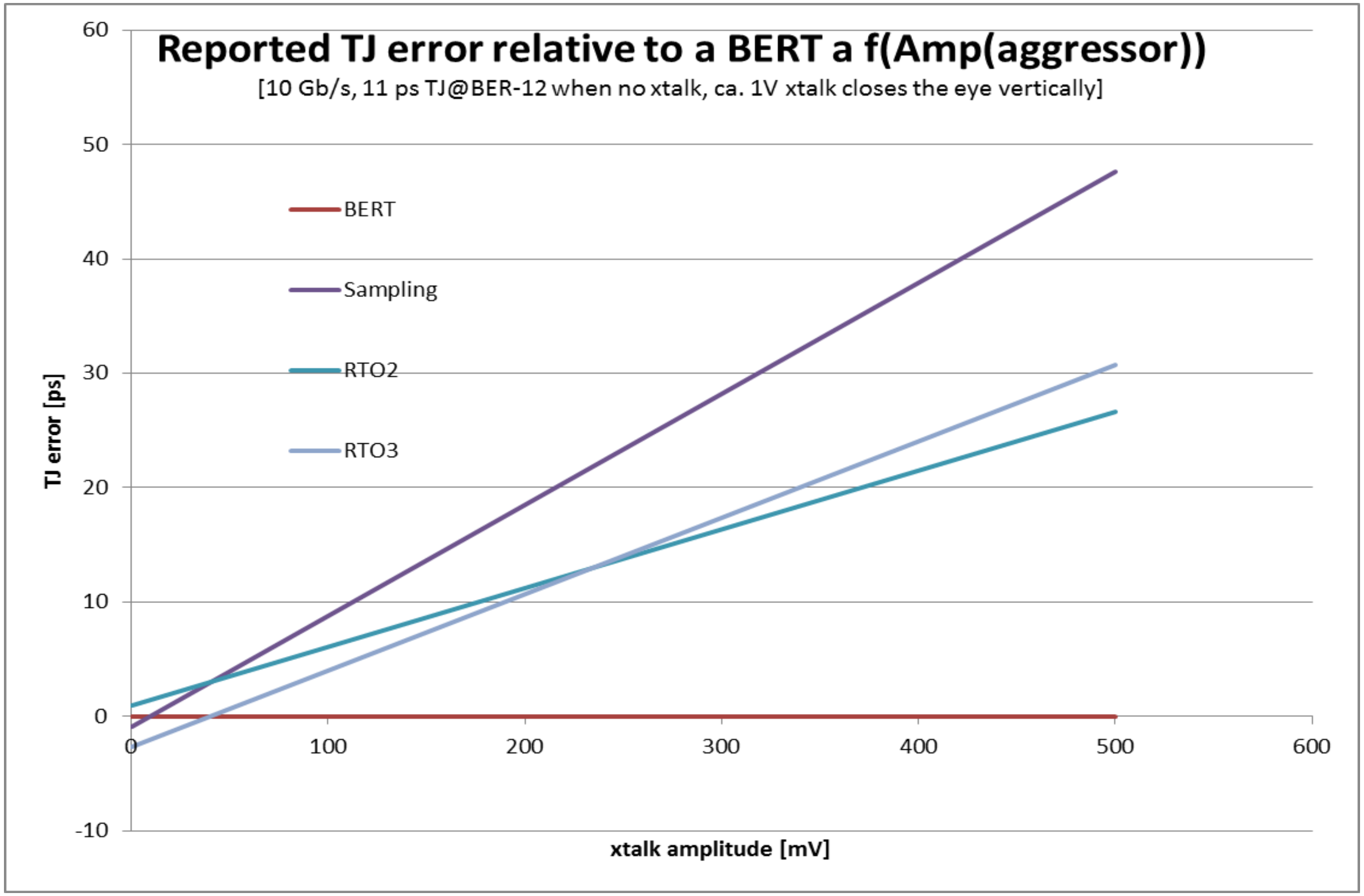
Experiment results: TJ error relative to a BERT result

- Oscilloscope measurements of jitter generally pessimistically bundle BUJ or NP-BUJ into RJ, and then over-report TJ as well.



VMA victim:
500 mV

(fitted line results). Results as of Q1 2011.

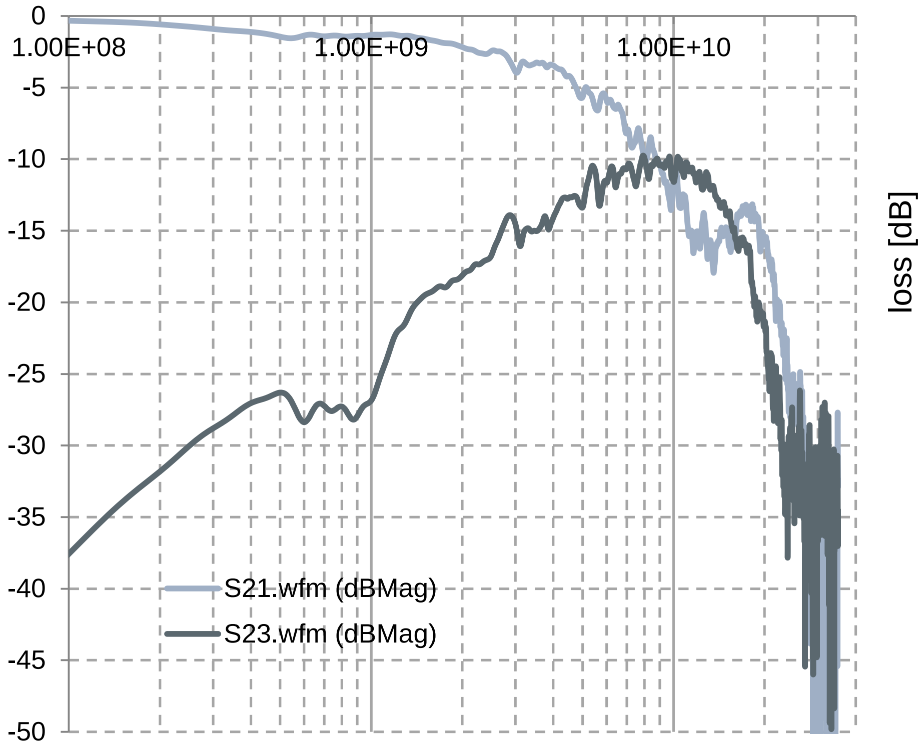
Taking a step back:
Is crosstalk evaluated by standards…?

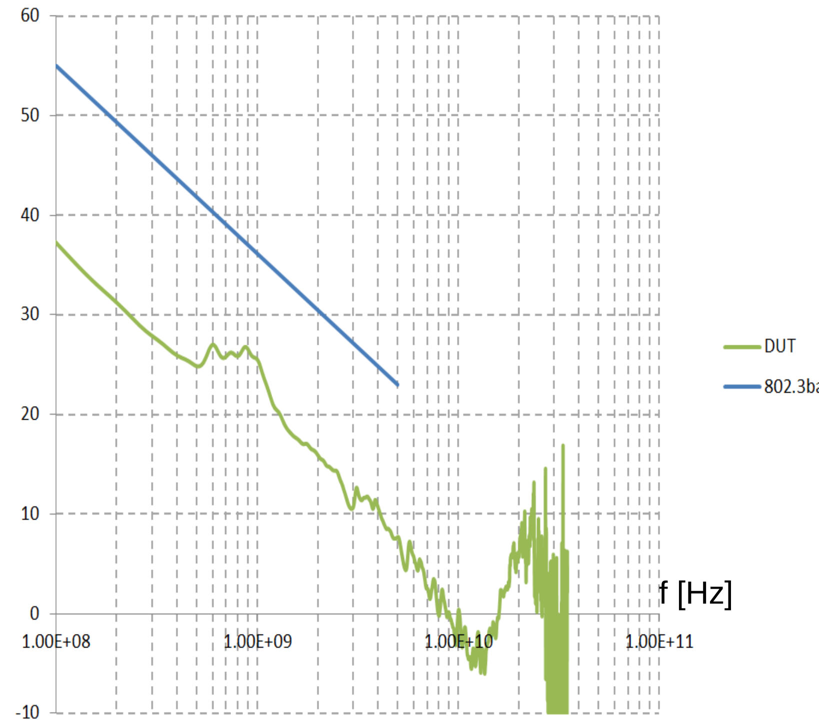
Crosstalk matters relative to signal:

- Crosstalk analysis is part of the IEEE standards in several ways: for example the ICR, Insertion loss to Crosstalk Ratio as a function of frequency, is part of the specification of the 10GBASE-KR measurement standard.

Let’s review the ICR specification on an example of a bad channel, a channel with large amount of crosstalk:
(next page)

Is crosstalk evaluated by standards…?
Measure of crosstalk: ICR (Insertion Loss to Crosstalk Ratio)





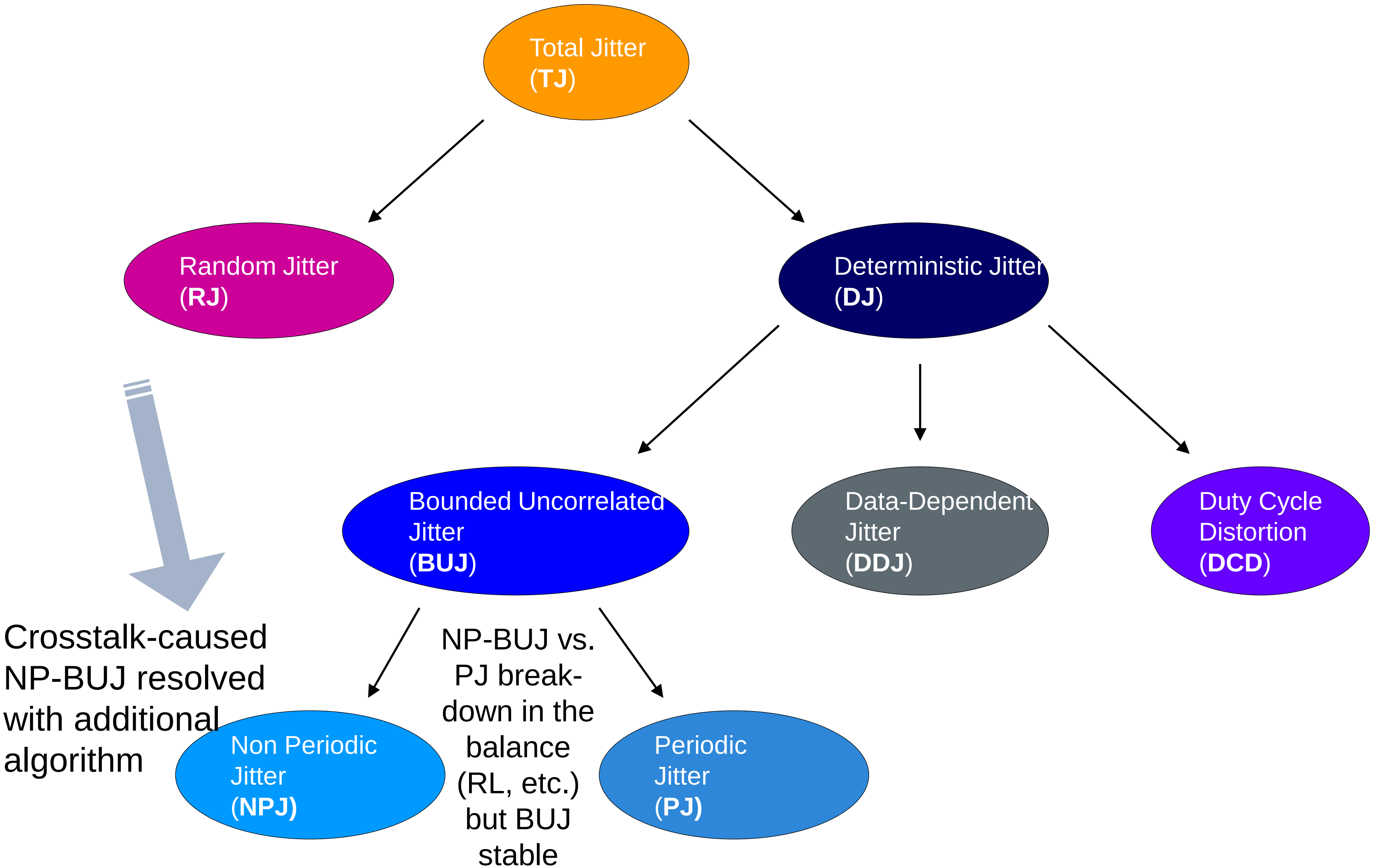
Crosstalk and insertion loss plotted on the left.
The ratio – ICR – is shown on the right, together with the limit (blue line) given by the IEEE 802.ap 10GBASE-KR standard for 10 Gb/s backplane. Methodology for the 25 Gb/s backplane signaling is currently being developed at 802.3bj 100GBASE-KR4 work group; this builds on the 10 Gb/s work.

Challenge of 40/100 Gb/s Transceivers: 20x10 Gb/s lines … Crosstalk!

- The complexity of crosstalk mechanisms leads to the breakdown of the standard oscilloscope jitter analysis methods.
- This in turn led the standard bodies towards simplified-but-bullet-proof jitter measurements, such as J2 and J9; measurements with limited insight into the cause of jitter, but still reliable enough.
- The jitter analysis tools now (in 2012) addressed the problem with the first generation of “crosstalk aware jitter analysis/decomposition ” tools; Tektronix’ 80SJNB Jitter-Noise-BER analysis and extrapolation tool employs such mechanisms in the latest versions, with the jitter breakdown given in an extended tree as follows

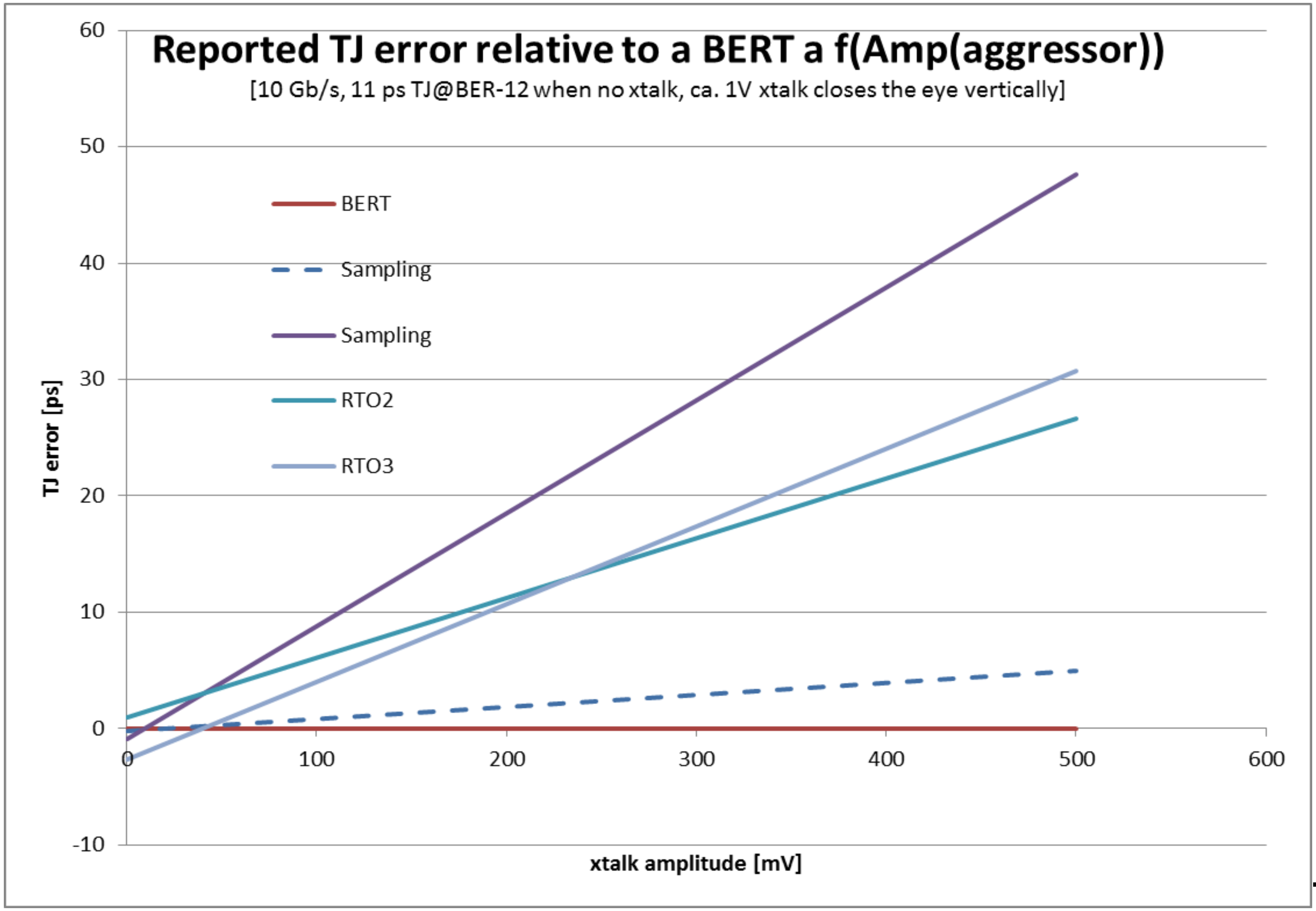
(next page)

Crosstalk-Aware jitter analysis: Jitter decomposition map



Crosstalk-Aware jitter analysis: Result – DUT with large xtalk

New algorithm – dashed line (Sampling shown, Real-time slightly worse)



VMA victim: 500 mV

(fitted line results). Results as of Q1 2011 except for dashed line (Q2)

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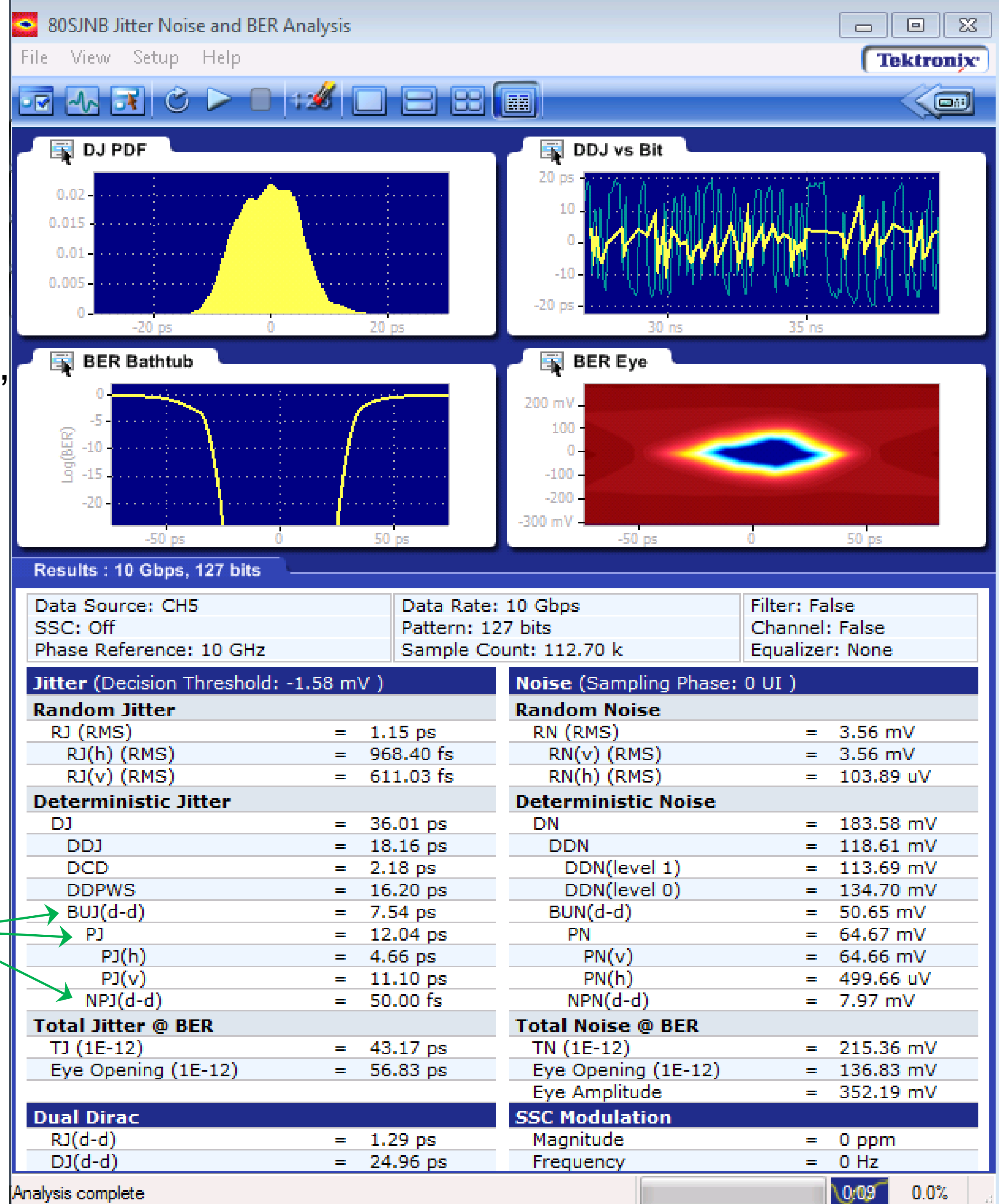
Challenge of 40/100 G: Crosstalk!

- The decomposition algorithm implemented in the "80SJNB Jitter Noise BER" Analysis SW – sample results screen:

(note: the 80SJNB analysis the jitter (left column) and also noise/vertical eye opening (right column) with this same improved breakdown).

New breakdown



Crosstalk-aware jitter analysis – Conclusion

- New measurement algorithms open the jitter/noise analysis in the presence of crosstalk, as well as new possibilities for future compliance tests
- Last consideration: ultimate verification for your TJ prediction?
  (next slide)

Verifying TJ with a BERT; Stressed Eye generation for RX test

- Any time the jitter analysis is in question, we recommend a simple TJ measurement with a BERT receiver – for example with the Tektronix BERTScope. No amount of analysis confirms your result as clearly as a raw measurement.

- The complex signal for Stressed Eye test of the Receiver:

  Tek BERTScope provides the 25 Gb/s signal, with adjustable stressors.

  The BERTScope also provides the error detector, for true BER measurements.

Demonstrations

- Fastest DUTs and test equipment were demonstrated recently at OFC 2012 “OIF Interop”, where Tektronix equipment was the only present test and measurement company
- Additional presence at Ethernet Alliance InterOp… see slides:

Testing 40/100 Gb/s Ethernet: Ethernet Alliance 100 GbE Interop in Silicon Valley

- Traffic generation capable of simulating >1M subscribers

Testing 40/100 Gb/s Ethernet: Tektronix Sampling Oscilloscope + BERTScope in action at an Interop

Conclusion

- We have discussed several new measurement trends in systems moving forward from 8 and 10 Gb/s to even faster designs, such as 10 14, 25, and 28 Gb/s
- Tektronix Oscilloscopes cover the acquisition of all of these signals, adding new tools such as the Crosstalk-aware jitter analysis
- The BSA260C BERTScope
sources signals and stressed signals, and performs BER measurement and error detection all the way to full physical speed

Thank you for attention. Additional resources:

- DesignCon 2012 papers on jitter analysis, Zivny et al.
- Lightwave seminar "New Test Requirements for 40/100 GbE Transceivers", presented in 2010/03, Shaffer/White/Zivny, http://www.tek.com/webinar/beyond-receiver-interoperability-testing-webinar
- IEEE 802.3 website, esp. http://www.ieee802.org/3/bj/

Questions?

thank you,

Pavel