Improved 100GBASE-SR4 transmitter testing

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Introduction

- The way of defining transmitter signal quality is under review
  - The incumbent, OMA-TDP, relates well to performance in service
    - But uses a reference transmitter that is difficult to obtain and calibrate
    - And uses a special reference receiver that WAS difficult to obtain
    - Repeatability depends on how calibration is done
      - A bit different for OMA-TDP and for TDP and for OMA – some errors cancel

  - One proposal, OMA-TxVEC, relates poorly to performance in service
    - More than 2 dB scatter seen, may be more with worst case channel and spectral width
      - 2 dB in a 0 to 4.1 dB range is too much! If transmitter implementer has to provide better than 2 dB TDP to pass a test and the user of the transmitter can't rely on better than 4 dB, the industry would be very poorly served
    - But TxVEC avoids the reference transmitter and special reference receiver
      - Uses one instrument, an oscilloscope

  - This proposal is intended to relate even better to performance in service than classic TDP does
  - And avoid the reference transmitter and special reference receiver
  - Uses features available in the current generation of oscilloscopes, takes advantage of 100GBASE-SR4's circumstances

Transmitter signal quality must be controlled

- Point of interest is after fibre, connectors and receiver front end
- Fibre contributes loss, filtering and noise
- Connectors contribute loss and noise
- Receiver contributes filtering and noise
- Item of interest is BER
  - Strictly, frame loss ratio after FEC correction

- We want metric(s) that:
- We can measure at TP2 *(which is not the point of interest)*
- Correlate to BER after receiver front end
- Treat different transmitters with the same link penalties reasonably equally
- Treat transmitters with different link penalties reasonably proportionately
- Avoiding false passes (test escapes)
- Keeping false fails to a reasonable level
- Repeatable, reproducible, cost effective

Control is by a combination of specifications

Spec	10GBASE-SR	40GBASE-SR4	16GFC 1600-SN	32GFC 3200-SN	100GBASE-SR4 D2.1	Notes
TDP	Y	Y	-	-	Y	
OMA-TDP	Y	Y	-	-	Y	
OMA	Triple trade-off with wavelength	Y	Y	Y	Y	
Spectral width		Y	Y	Y	Y	
Eye mask	Y	Y	Y	Y	Y	
VECPq	-	-	Y	Y	-	
RIN_OMA	Y	-	Y	Y	-	
Extinction ratio	Y	Y	-	-	Y (relaxed)	

- Primary control of signal quality is OMA-TDP

Test equipment required

Spec	Optical power meter	Scope	Reference Tx *Want to eliminate this*	Optical attenuator	Reference Rx *Preferably use scope for this*	BERT	Noise meter or spectrum analyser
TDP (no FEC)	Y	Y (for OMA) C (for VECP)	C	Y	Y	Y	-
TDP (for FEC)	-	Y	-	-	(scope)	-	-
OMA-TDP (no FEC)	Y	C (for OMA) C (for VECP)	C	Y	Y	Y	-
OMA-TDP (for FEC)	Y	Y	-	-	(scope)	-	-
OMA	Y	Y	-	-	-	-	-
Eye mask	-	Y	-	-	-	-	-
VECPq	-	Y			-		
RIN_OMA	Y	Y (for OMA)	-	-	Y	-	Y
Extinction ratio	-	Y	-	-		-	-

- Y = needed testing each time, C for calibration (once per shift/month/whatever)
- Implementers can think of alternative methods that use different equipment

Simplified transmitter testing 1/2: for BER <= 1e-12

- For BER <= 1e-12, TDP is done with a reference receiver and BERT because the sampling rate of a scope doesn't collect enough statistics in a reasonable time
  - Some extrapolation could be used
  - A lot of extrapolation could leave holes in the spec
- Reference receiver's sensitivity is calibrated to an ideal signal
- Something close to an ideal signal has to be generated (the reference transmitter), and the impairments in it calibrated out
  - Which is done with a scope
  - When we have learnt how to measure the penalty of the reference transmitter with a scope, we are on our way to knowing how to do transmitter testing with a scope

Simplified transmitter testing 2/2: for BER <= 5e-5

- For BER <= 5e-5, TDP or other signal metric can be done with a sampling scope in a reasonable time
- Receiver noise can be included by calculation
- Same scope measurement can find apparent OMA (as seen by the scope)
  - Don't need to know what it really is, for finding TDP
- So everything is relative, from the same instrument
  - No need for a reference transmitter
  - Scope's own noise contribution does not dominate and can be measured and corrected for if desired
  - Errors caused by variable connector loss are eliminated
- No reference transmitter needed! No reference transmitter calibration
- To find OMA-TDP, need power meter to calibrate scope's apparent OMA

What makes a good signal metric?

- We want metric(s) that:
  - ...
  - **Correlate to BER after receiver front end**
  - **Treat different transmitters with the same link penalties reasonably equally**
  - **Treat transmitters with different link penalties reasonably proportionately**
  - ...

- It seems we achieve this with:

- **Right bandwidth** Most important
- **Right statistics** Much more important for 100GBASE-SR4 than 40GBASE-SR4
  - At 1e-12, dual Dirac model is reasonably valid
  - At 5e-5, it seems it isn't
- **Right noise** Take proper account of transmitter and channel noises

Candidate metrics vs. criteria

	Right bandwidth?	Right statistics?	Right noise?	Practical pattern length
TDP with BERT	Yes	Yes	Mostly	Unlimited
TDP with 12.6 GHz scope	Yes	Yes	Mostly (could be yes)	Unlimited
TDP with 19 GHz scope	Post-processed	Yes	Mostly (could be yes)	PRBS15?*
VECPq in 19 GHz	No	Yes	No^	PRBS15?*
VECPq in 12.6 GHz (actual or post-processed)	Yes	Yes	No^	PRBS15?*
VEC (all but x%) in 19 GHz	No	Poor	Some	Unlimited
VEC in 12.6 GHz	Yes	Poor	Some	Unlimited or PRBS15*

* PMA pattern is PRBS9 but external pattern generator could be used
Long pattern is good for a solid spec

^ Could add a separate RIN_OMA spec – not attractive

Improved 100GBASE-SR4 transmitter parameter

- High level summary

1. Find the eye of the signal under test in the right bandwidth
   - Find the OMA of the signal under test
   - Take histograms from the eye
2. Find the amount of noise that a receiver could add, and still deliver the target BER
3. Find the amount of noise that a receiver could add to an ideal eye with the same OMA
4. The ratio of the two noises is the "soft TDP"

- **Item 1 is the only measurement – no reference transmitter, no other reference receiver**
- Items, 2, 3 and 4 are calculation – see later

Proposal for soft TDP – simple method with only a 19 GHz scope

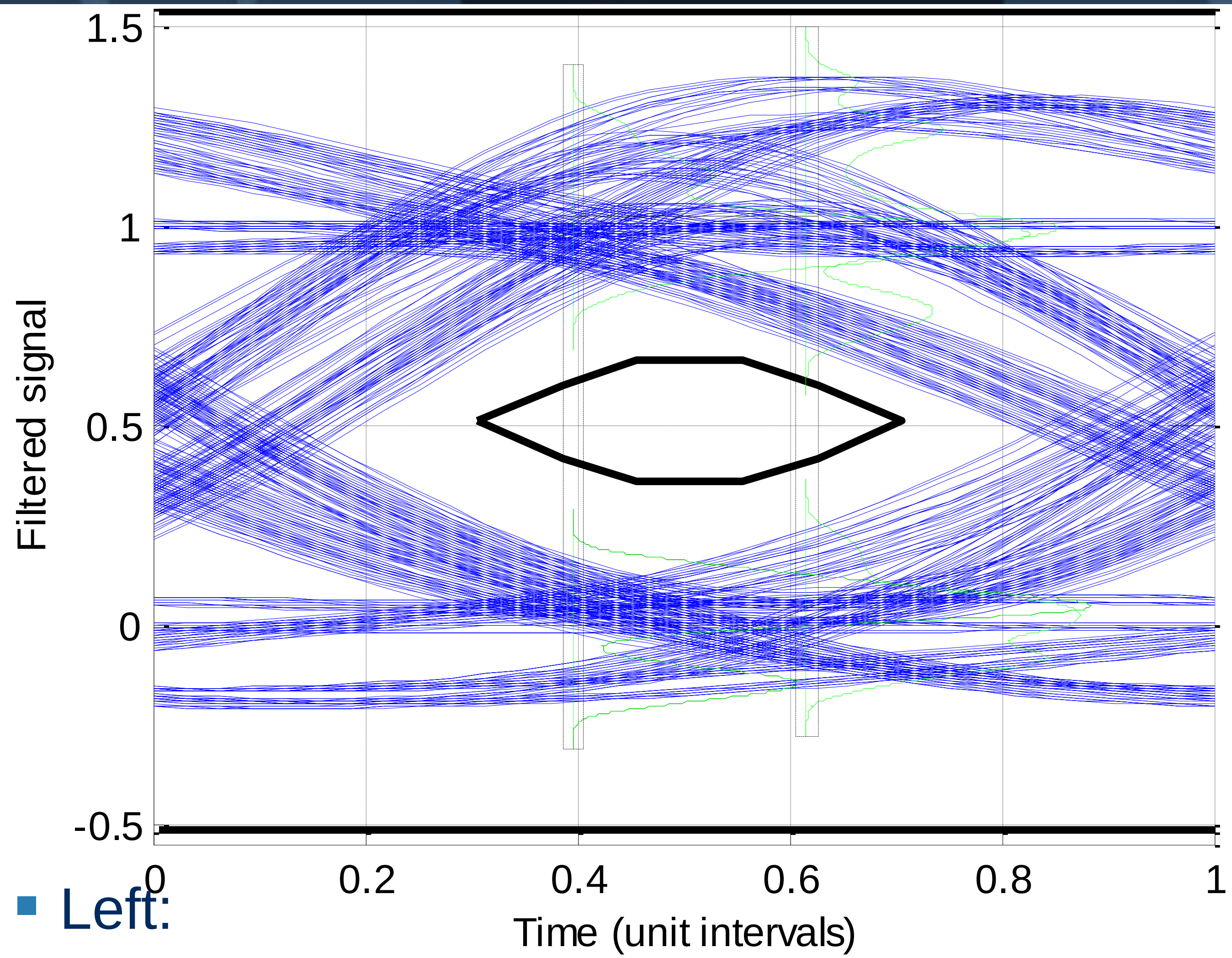
1. Capture averaged PRBS9 with 19 GHz scope
   - 1a Create histograms from averaged eye
2. From non-averaged eye, capture histograms
3. Deconvolve 1a from 2, giving an estimate of the noise
   - (including any caused by random jitter)
4. In software, filter waveform 1 as if in 12.6 GHz
5. Convolve with noise 3 giving an estimate of the eye we would see in 12.6 GHz
6. Calculate TDP

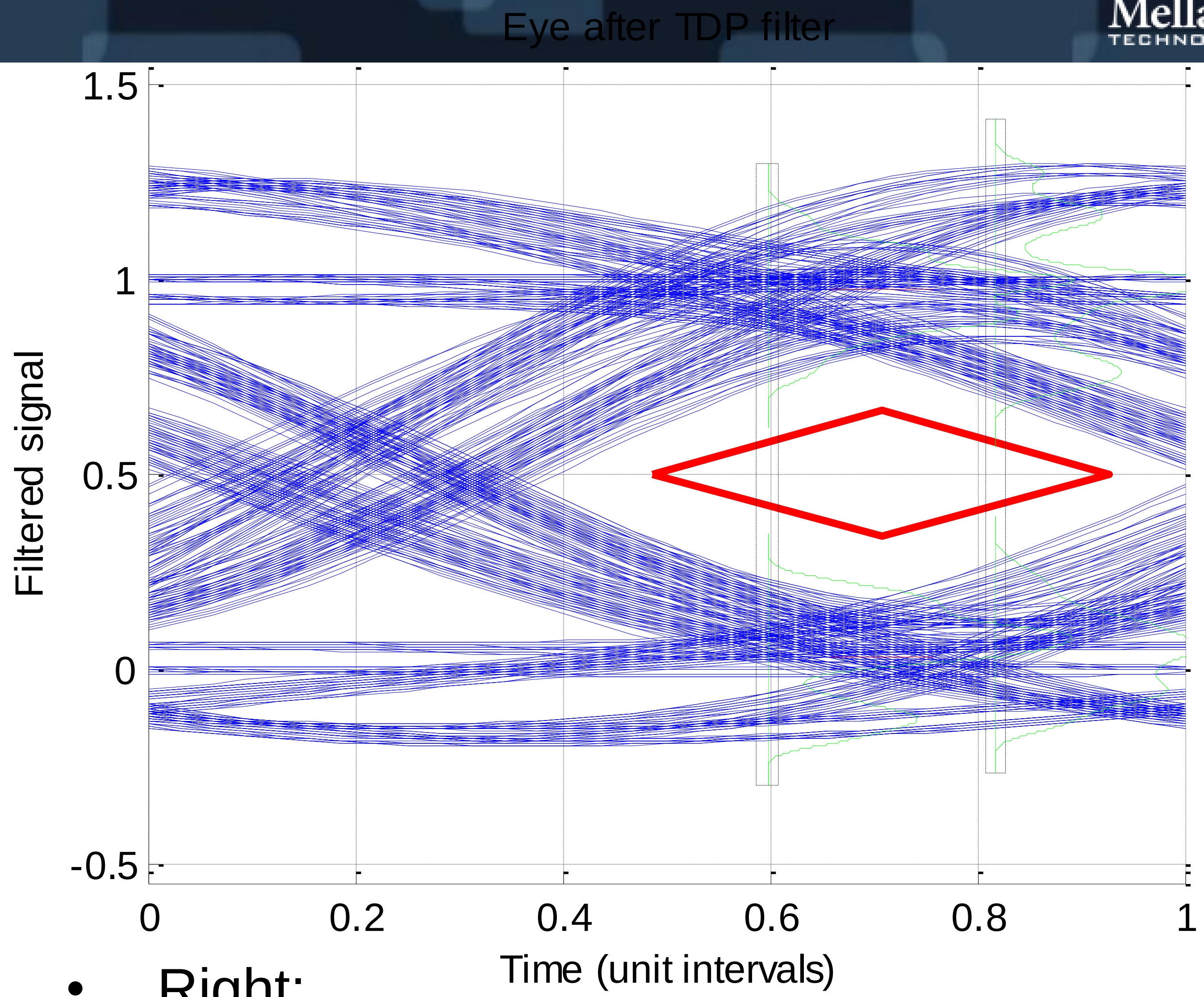
- Notes
  - New scopes can do steps 3, 4, 5 (or equivalent) by themselves
  - If a 12.6 GHz scope is available, steps 3, 4, 5 can be avoided
  - This method allows a trade-off of signal strength against signal quality (OMA-TDP), better than VECPq
  - This method gets the bandwidth and statistics right – better than VEC
  - But it can be improved – see slide 14

Availability of test equipment

- 19 GHz scopes are expected anyway: several optical PMD specs expect them for eye mask
- 10.5 GHz and 19.33 GHz scopes are available
  - 12.6 GHz would be suitable
- Software to post-process a waveform to a different bandwidth is available with new scopes
  - If pattern is not too long
  - Noise is not changed
- Ability to post-process for algorithms such as VECPq or soft TDP is available in new scopes
  - User can insert any algorithm

Example waveforms





- Left:
- Averaged PRBS9, filtered in 19 GHz
- Vertical histogram windows +/-0.11 UI from eye centre
- Histograms in green
- (Y axis is normalised to 0, 1 from OMA algorithm)

- Right:
- Refiltered eye in 12.6 GHz with histograms ready for penalty calculation

Improved proposal – more detail

A. Capture averaged PRBS9 with 19 GHz scope
   - A1 Create histograms from averaged eye
B. From non-averaged eye, PRBS9, capture histograms
C. Deconvolve A1 from B, giving an estimate of the wideband noise
D. From non-averaged eye, PRBS31, capture histograms
E. Deconvolve C from D, giving an estimate of the low frequency noise and patterning
F. In software, filter waveform A as if in 12.6 GHz
G. Convolve with ~80% of noise C and all of noise E
   - 80% being sqrt(12.6/19.34): assuming noise C is white
H. Calculate TDP (see next slide)

If scope plug-in supports 12.6 GHz in hardware, measure directly, jump to here

Calculate soft TDP

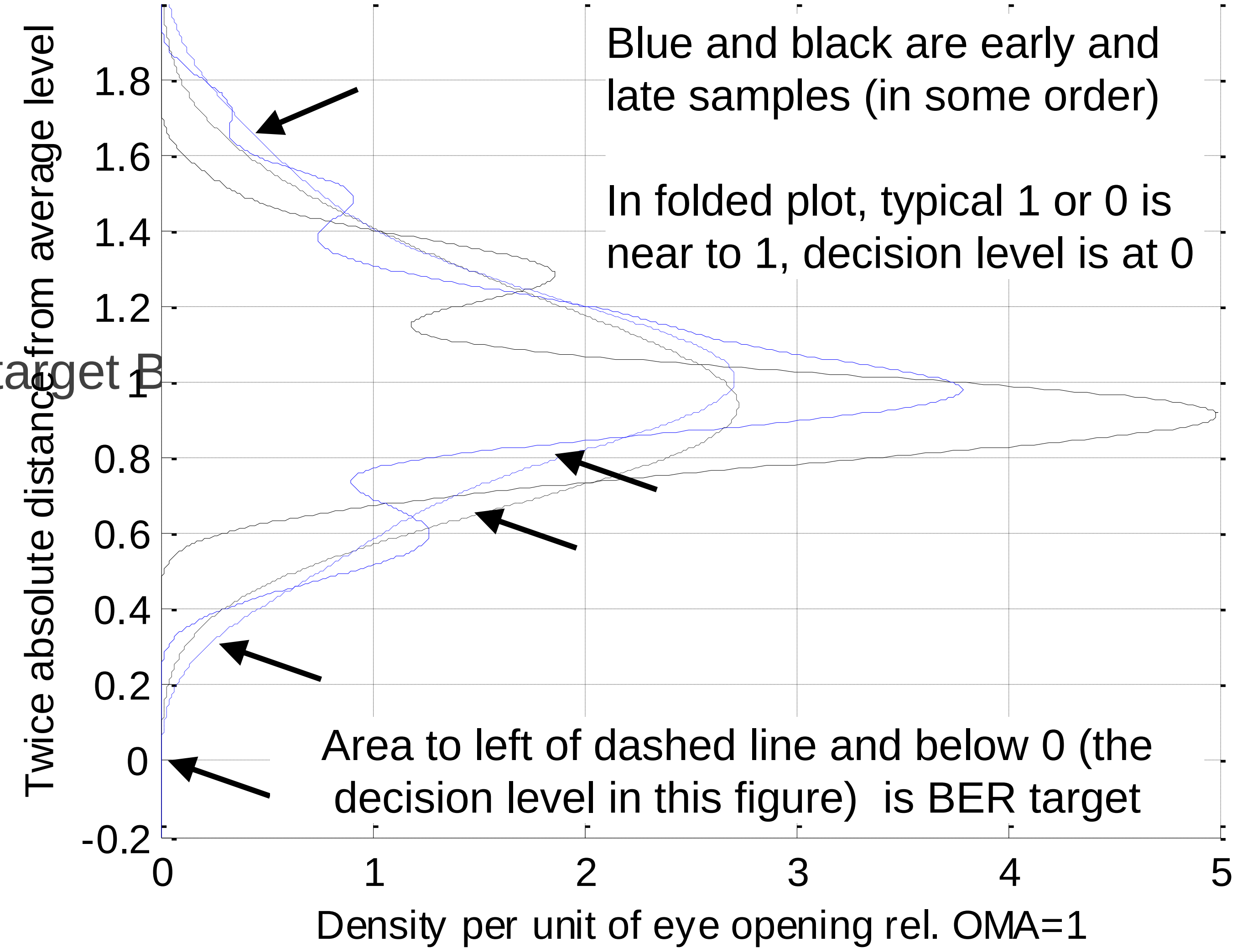
- Now we have histograms (probability distribution functions) of the signal and scope noise in the right bandwidth
- Assume scope noise, receiver noise, modal noise and mode partition noise are all Gaussian and additive
- Measure scope noise with no input
- Find the amount of Gaussian noise that a receiver can have, relative to signal F's OMA, for the target bit error ratio
  - F's OMA should be close enough to A's OMA – convenient for 12.6 GHz scope owner
  - Estimate modal noise e.g. assuming that it is proportional to signal's amplitude (see e.g. dawe_04_0114_optx.pdf – scaling from 10GBASE-SR and 40GBASE-SR4)
  - Estimate mode partition noise from worst case transmitter and channel spectral properties, using established formulas e.g. in the 10 Gigabit Ethernet link model
  - RSS the noises, giving the required maximum receiver noise
- The "soft TDP" is proportional to this/OMA
  - Obviously there are variants and simplifications of this method that could be used for e.g. factory production testing

Now find out how much Gaussian noise we can fit between the histograms for the target BER

- It is convenient to fold the upper and lower histograms over and add them together – that's why there are four histograms shown here, not eight
- The calculation could be by trial and error or iteratively – like finding mask margin for a given hit ratio
- Call this added noise σ_A

- Solid lines: from scope, including noise and patterning
- Two histograms for early and late sampling points

- Dashed lines (arrowed): including Gaussian noise for target BER
- Two histograms for early and late sampling points



Finding the allowable receiver noise

- This Gaussian noise is assumed to come from four sources
  - Receiver noise σ_{Rx} – to be found

  - Mode partition noise from 10 Gigabit Ethernet link model
  - $\sigma_{MPN} = (k_{MPN}/\sqrt{2})*(1-e^{-(\pi B_{eff}.D.L.\sigma_W)\hat{}2}) = 0.0514 * OMA/2$
  - k_{MPN} is 0.3, D is chromatic dispersion -108.4 ps/nm/km worst case, L is 100 m, σ_W is 0.6 nm
  - Beff is the effective signalling rate
    - Assume that it's the same as the nominal signalling rate, 25.78125 GBd

  - Modal noise σ_{MN} 0.0075 * mean 1, or e.g. 0.03 * OMA/2 depending on extinction ratio
    - By scaling from previous projects: see dawe_04_0114_optx.pdf
    - Use the eye mask alignment algorithm to find the mean 1 level from the same eye as used for TDP – no separate measurement needed
  - Baseline wander: $\sigma_{BLW} = 0.025 * OMA/2$ Example from 10 Gigabit Ethernet link model, if we want to include it
- And the measurement already includes:
  - Oscilloscope noise: $\sigma_{scope} = 0.05 * OMA/2$ (example)
- RSS the noises to find σ_{Rx}
  - $\sigma_{Rx} = \sqrt{(\sigma_A^2 - \sigma_{MPN}^2 - \sigma_{MN}^2 + \sigma_{scope}^2)}$

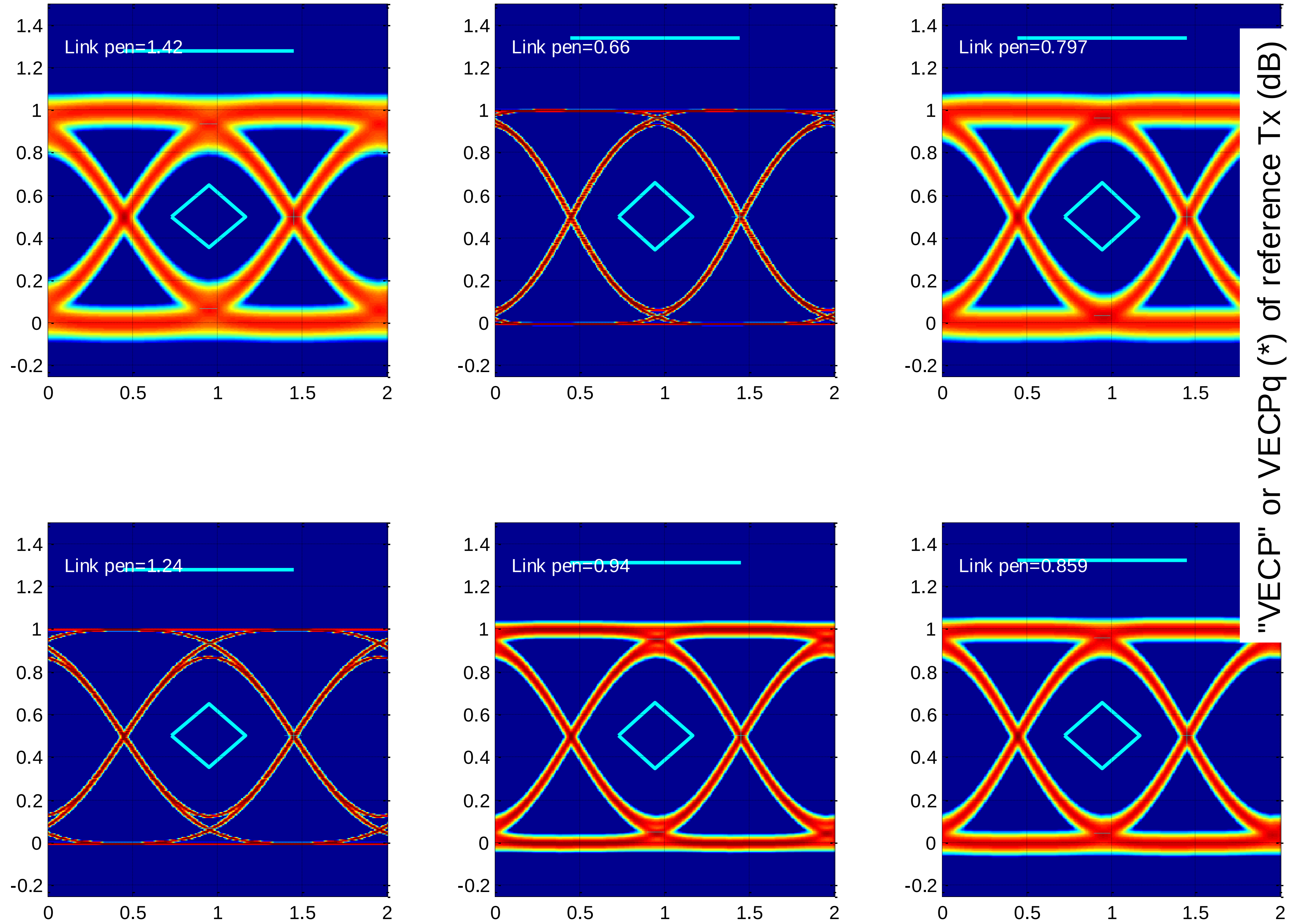
Comparing the candidate metrics

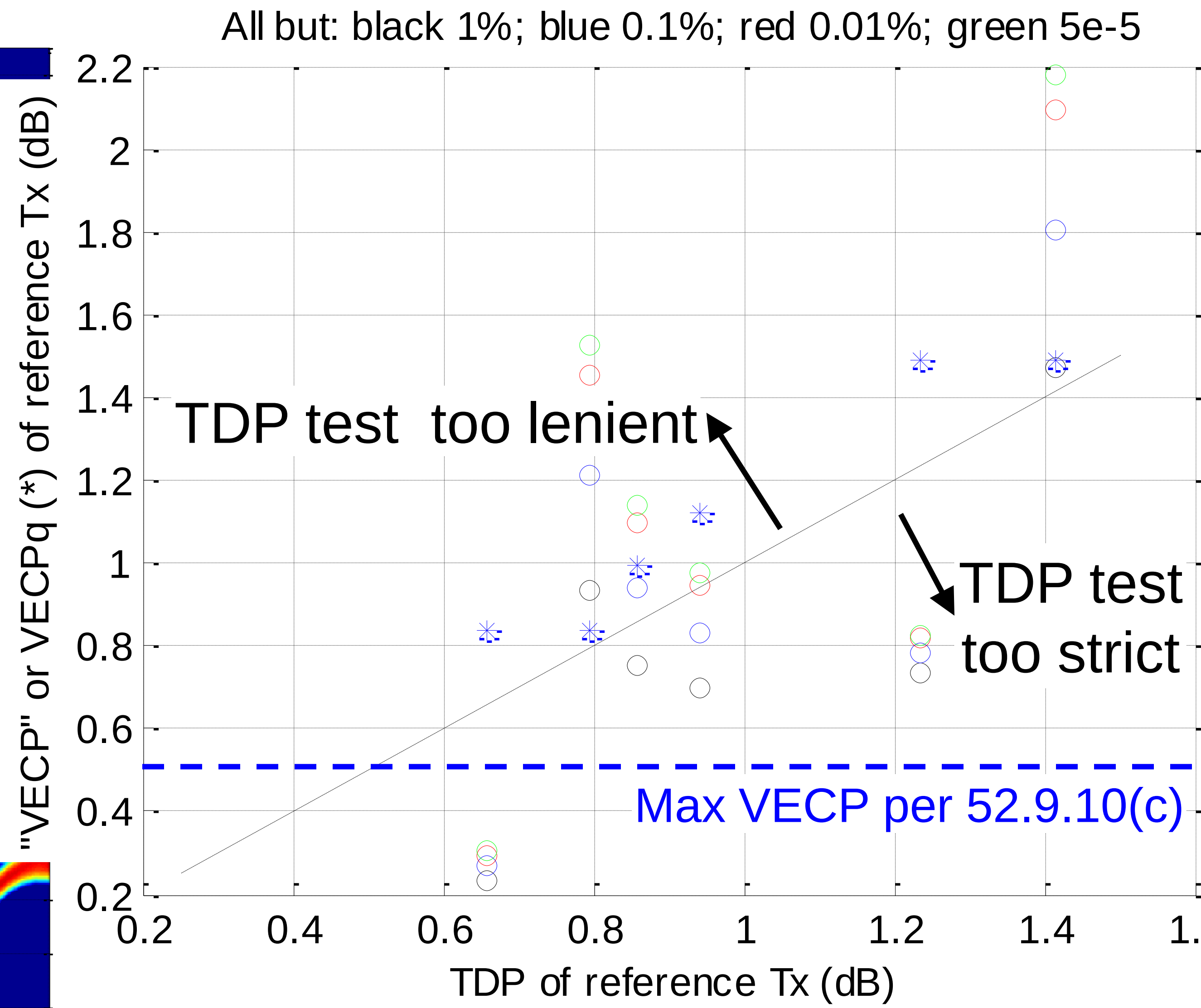
	Right band-width?	Right statistics?	Right noise?	Includes by measurement	Includes at worst case	Not included: have to reserve margin for these items
Hardware TDP in 12.6 GHz	Yes	Yes	Mostly	Baseline wander, RIN, RJ	Modal dispersion, chromatic dispersion	MPN, modal noise
Soft TDP in 12.6 GHz	**Yes**	**Yes**	**Yes**	Baseline wander, RIN, RJ	Modal dispersion, chromatic dispersion, MPN, modal noise	
VECPq in 19 GHz	No	Yes	No		Modal dispersion, chromatic dispersion	Baseline wander, RIN, RJ, MPN, modal noise
TxVEC (all but 5e-5) in 19 GHz	No	Poor	Some	Baseline wander, RIN, RJ (too much of all?)		Modal dispersion, chromatic dispersion, MPN, modal noise

More detail on calculating soft TDP

- σ_{Rx} = OMA/(2*Qmin)
  - Where Qmin = 3.8905

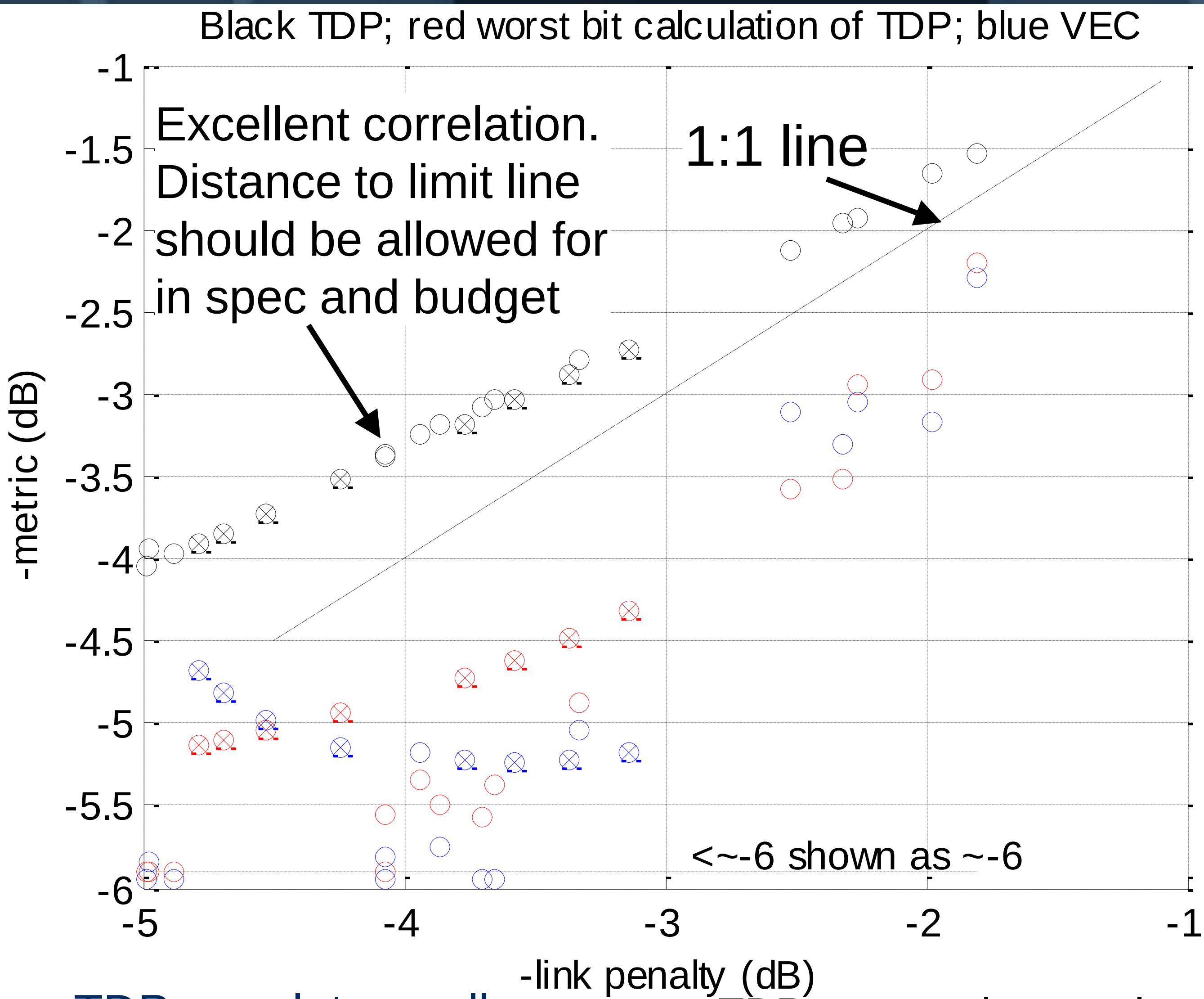
Different compliant reference transmitters

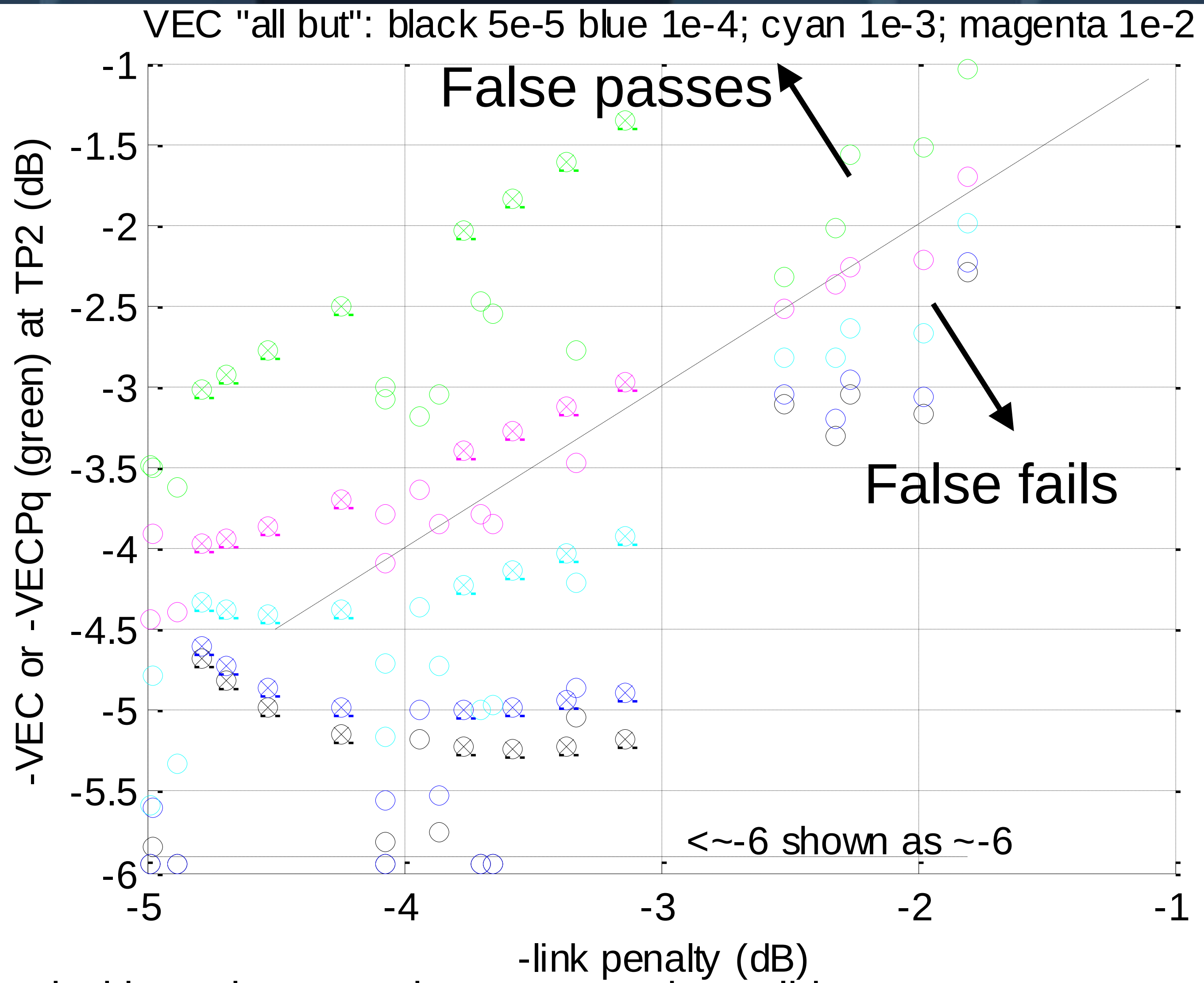




- Remarkably bad correlation with VECP
- In spite of its name, VECP is not a penalty
- VECPq works much better; tighter RIN spec could improve this

Different "product" transmitters

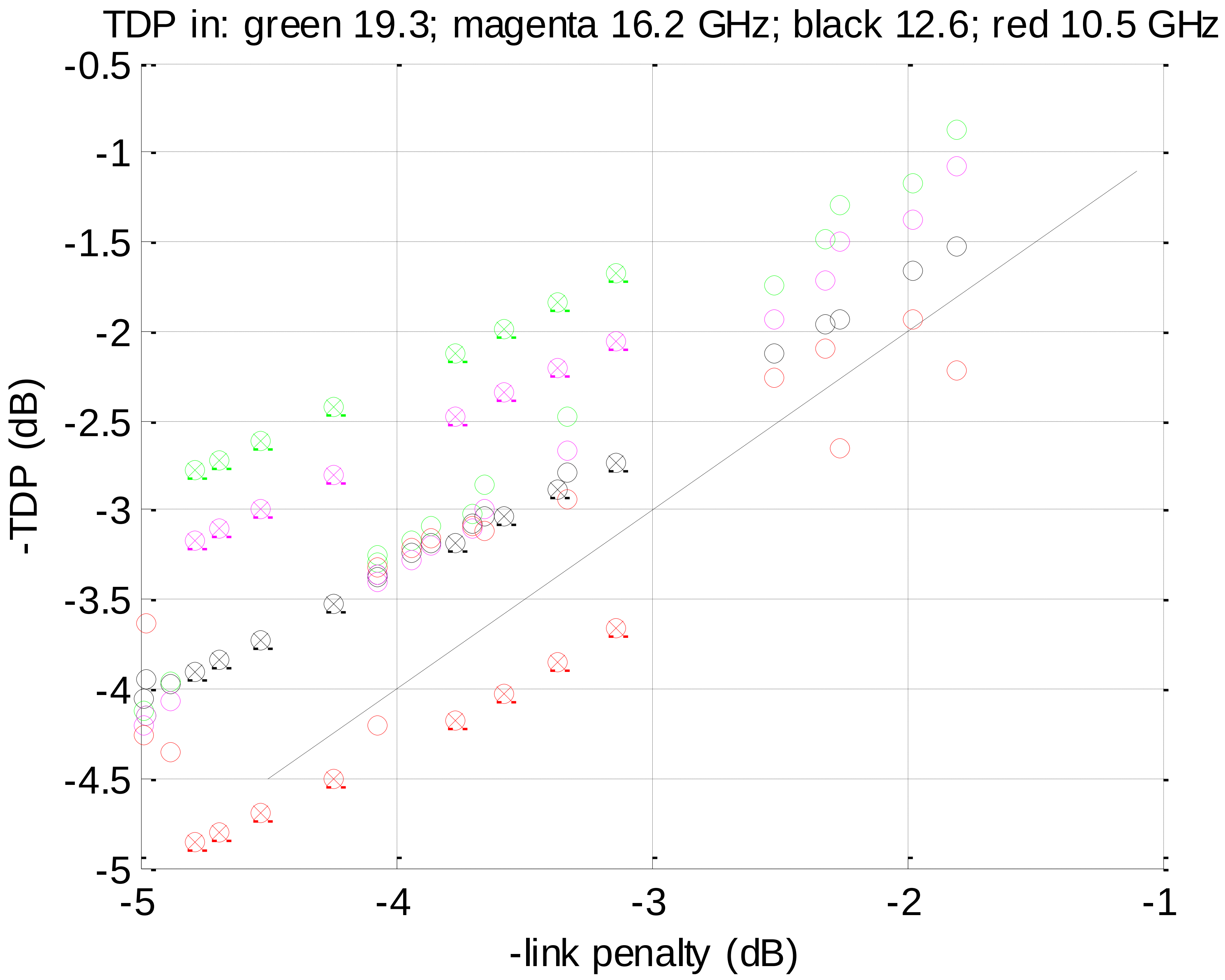




TDP assumed correctly calibrated without the error shown on previous slide

- TDP correlates well
- VEC doesn't. VEC tied to mean level of signal might be a bit better but points marked x would not change
  - According to petrilla_01_0114_optx.pdf slide 22, VECP flatters very slow or very noisy transmitters: would need additional spec(s) to screen them
- VECPq seems to work badly here, although apparently good enough for reference Tx calibration (see slide 25)

Different observation bandwidths



- Correct choice of observation bandwidth is very important

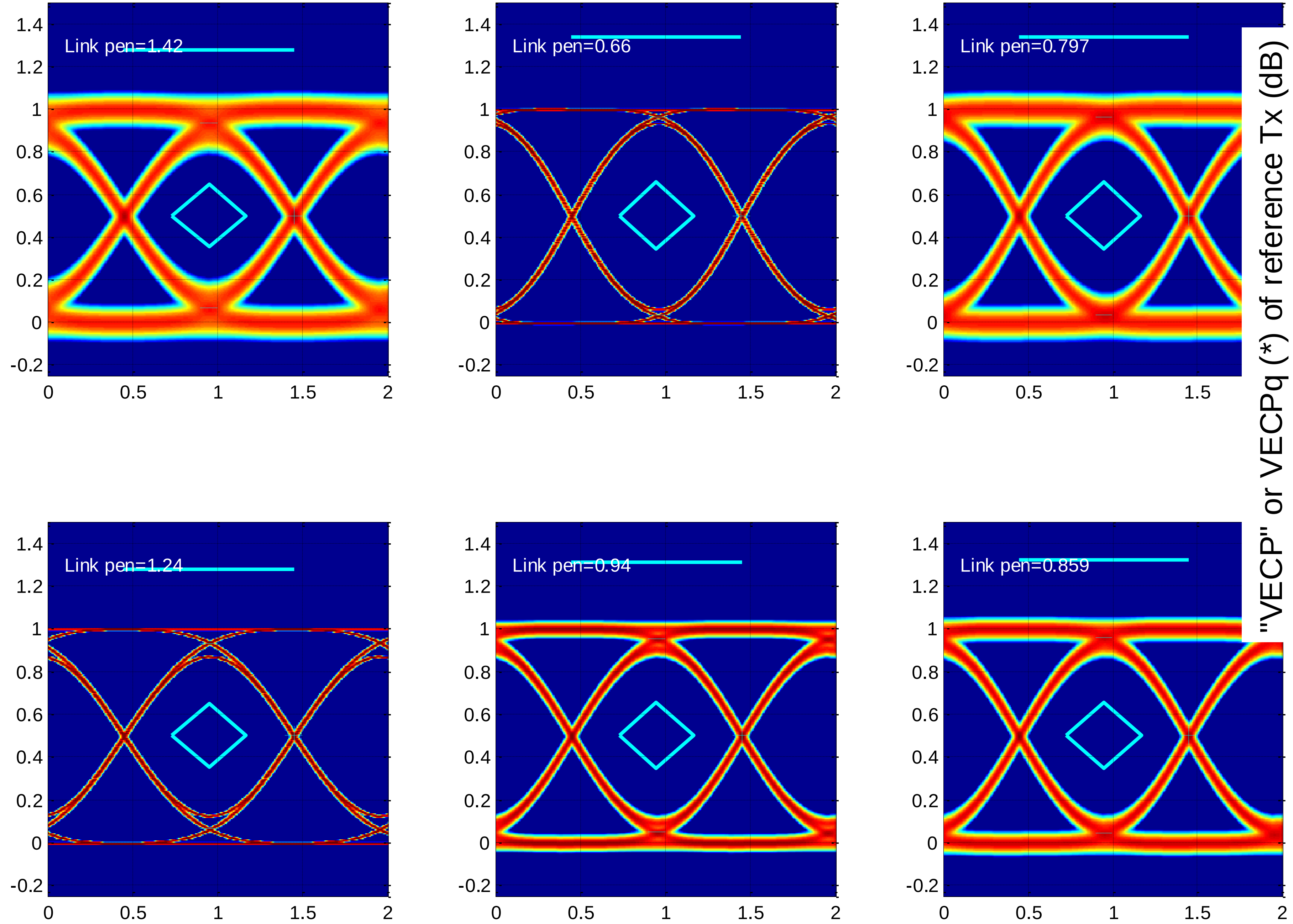
Conclusions

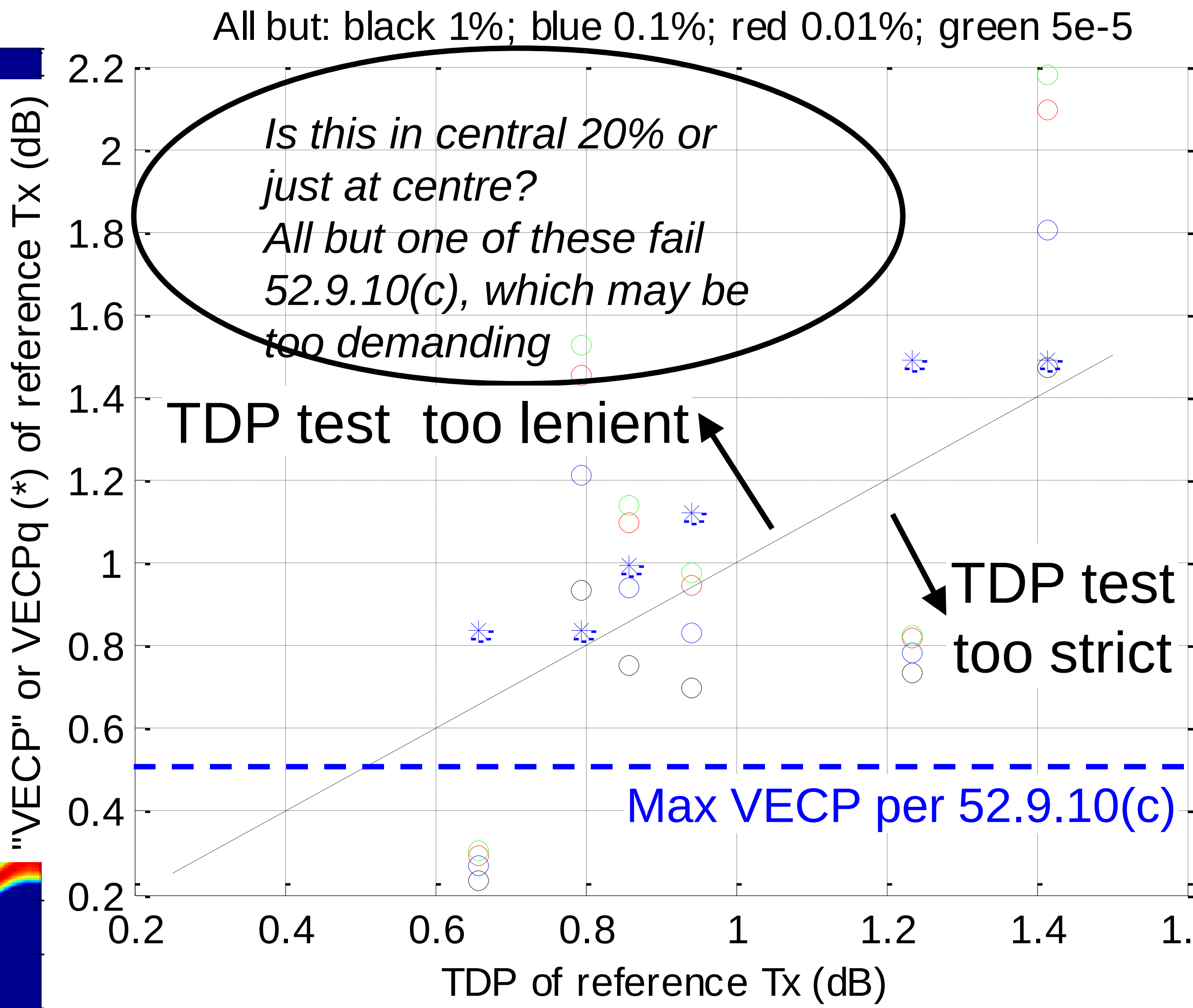
- An improved 100GBASE-SR4 transmitter testing is presented
- Eliminates the reference transmitter and its calibration traditionally used for TDP
  - Also avoids debugging the transmitter calibration recipe in the draft
- Avoids the statistical, noise and/or bandwidth compromises of VEC and VECPq
- Suitable oscilloscopes are available
  - Direct measurement with "hardware bandwidth" would be simplest
  - measurement with "software-adjusted bandwidth" can be used
- The definition in the standard should be the accurate metric
  - Right bandwidth
  - Right statistics
  - Right noise
  - Complete
- Implementers can use alternatives if they choose, considering the effect on accuracy
  - E.g. could use a traditional TDP test, or could simplify this proposed method

Backup

- For eye diagrams as TP2 and TP3a used in the scatter plots, see backup slides in dawe_01_0314_optx.pdf

Different compliant reference transmitters





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References

- Simplified 100GBASE-SR4 transmitter testing, Piers Dawe, http://ieee802.org/3/bm/public/mar14/dawe_01_0314_optx.pdf
- TDP See e.g.
  - http://ieee802.org/3/ae/public/jan02/dawe_1_0102.pdf slide 17 or
  - http://ieee802.org/3/ae/public/jan02/dawe_2_0102.pdf slide 5
- VEC (or TxVEC or VECP)
  - 100G SR4 TxVEC -TDP Update(D2.1 comment 94), John Petrilla, http://ieee802.org/3/bm/public/mar14/petrilla_01_0314_optx.pdf
  - Presentation to MMF ad hoc, 1 May 2014 petrilla_01d0_0501_mmf.pdf
- Modal noise in 100GBASE-SR4,
  - Piers Dawe, http://ieee802.org/3/bm/public/jan14/dawe_04_0114_optx.pdf
- 10 Gigabit Ethernet link model,
  - http://ieee802.org/3/ae/public/adhoc/serial_pmd/documents/10GEPBud3_1_16a.xls

Thank You