Improved scope-based transmitter specification

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Supporters

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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 a special reference receiver that was difficult to obtain
    - Repeatability could be better, depending on how calibration is done
      - A bit different for OMA-TDP and for TDP and for OMA – some errors cancel
  - One proposal, OMA-TxVEC with 0.005% criterion*, 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 4 or 5 dB range is much too much margin left on the table!
      - This can be reduced to ~0.75 dB? by choosing a different percentile
    - But TxVEC avoids the reference transmitter and special reference receiver
      - Uses one instrument, an oscilloscope, with bandwidth representing receiver and channel
  - Another proposal, "soft TDP"* is intended to relate even better to performance in service than classic TDP
    - Also avoids the reference transmitter and special reference receiver
      - Also uses one instrument, an oscilloscope, with bandwidth representing receiver and channel
      - Pretty much the same measurement
  - Recently it has become clear that oscilloscope noise can affect the results by on the order of 1 dB
- This presentation investigates TxVEC or "soft TDP" and shows a practical method that gives consistent results even when scope noise is present

* References in backup

Method

- Optical signal is measured at TP2 with an oscilloscope
  - Oscilloscope has a bandwidth that represents the bandwidth of the usual optical receiver and the worst-case optical channel
    - No reference transmitter is needed
  - Oscilloscopes with this bandwidth are becoming available
  - Vertical histograms are taken
    - There is good consensus on what to do, the method has been documented* and trialled in at least three labs
  - A figure of merit or predicted penalty ("metric") is calculated from the histograms
    - There are many options for the calculation
      - Two options* have been fully documented
      - Both allow short measurement time and take negligible compute resource
      - Correlation to predicted link performance and the effect of scope noise depend on the calculation
      - This presentation investigates the options
- Terminology
  - "Percentile TxVEC" based on a particular percentile on the histograms. Turn the position of this into dB
  - "Noise adding TxVEC", "improved TxVEC" or "soft TDP". Multiply histograms by a weighting function chosen to give the target BER, turn the weighting noise parameter into a penalty in dB

* See first two references at back of slide pack

What makes a good signal metric?

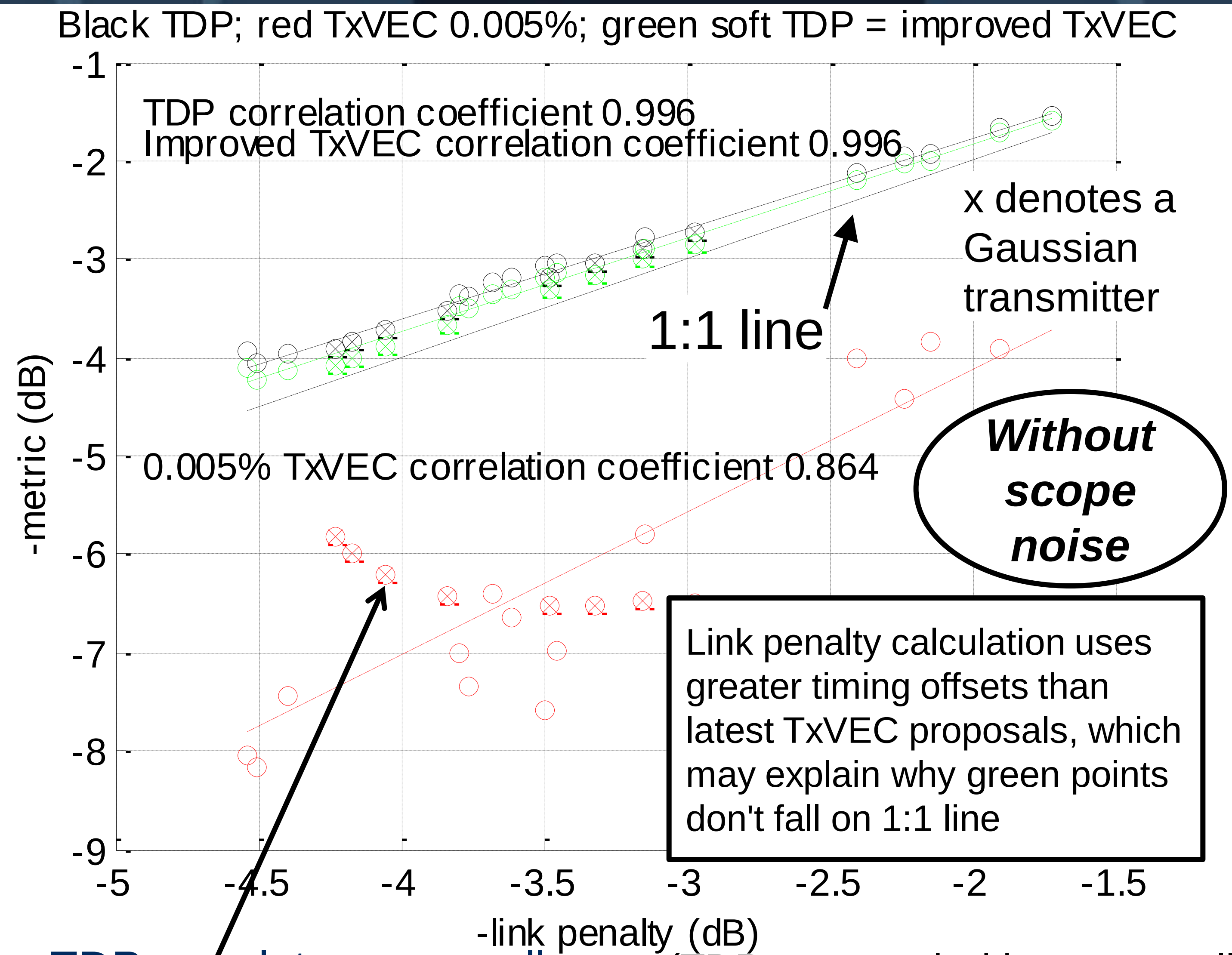
- We want metric(s) that:
  - **Correlate to link performance (BER after receiver for a worst case channel)**
  - **Treat different transmitters with the same link penalties reasonably equally**
  - **Treat transmitters with different link penalties reasonably proportionately**

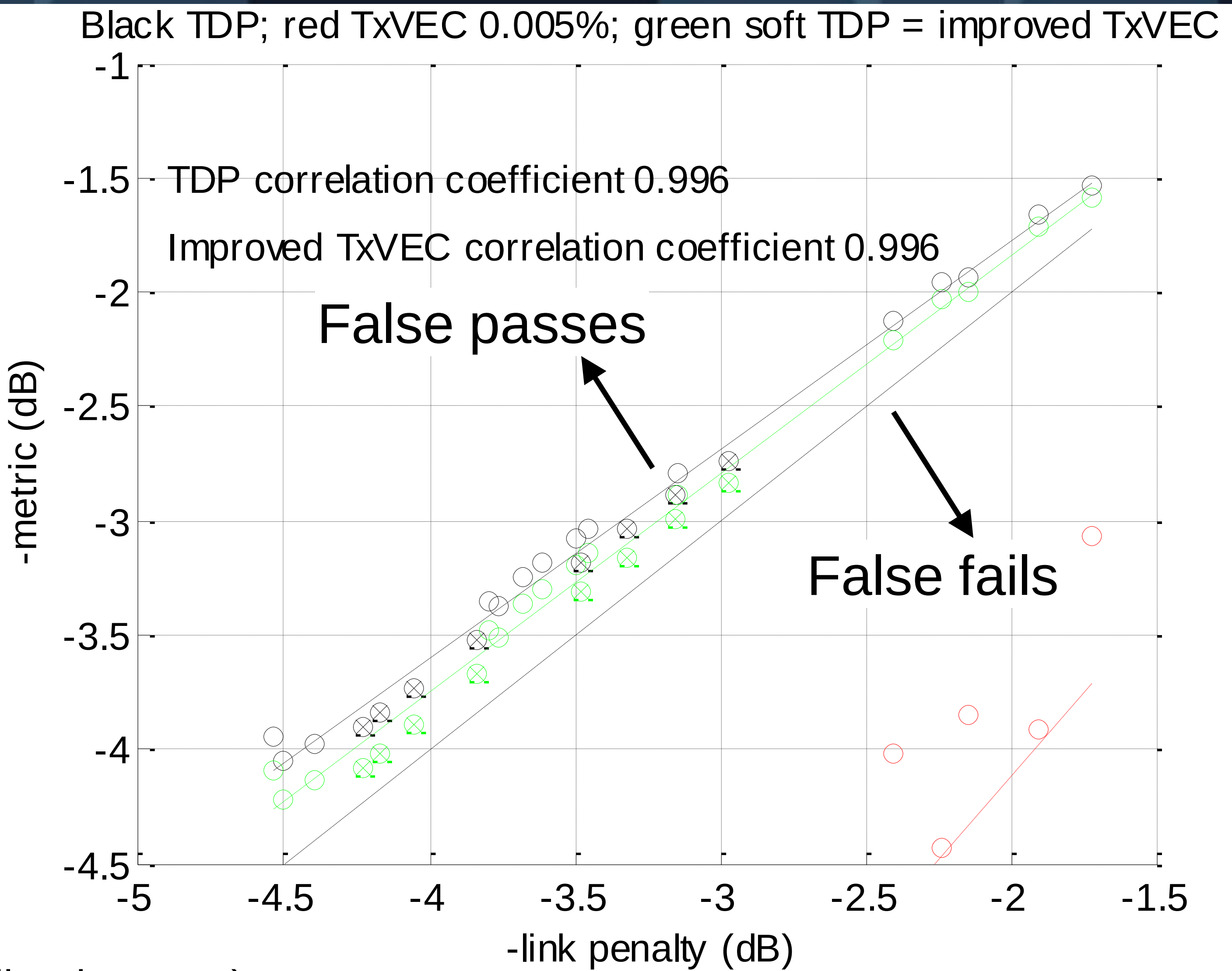
- It seems we achieve this with:
- **Right bandwidth** Most important. New scope plug-ins make this convenient
  - ✓12.6 GHz agreed

? **Right statistics** Much more important for 100GBASE-SR4 than 40GBASE-SR4
  - At 1e-12, dual Dirac model and "worst bit" assumption is reasonably valid
  - At 5e-5, it seems it isn't
  - Just one point on a histogram won't tell you what you want to know

? **Right noise** Take proper account of transmitter and channel noises, and scope's own noise

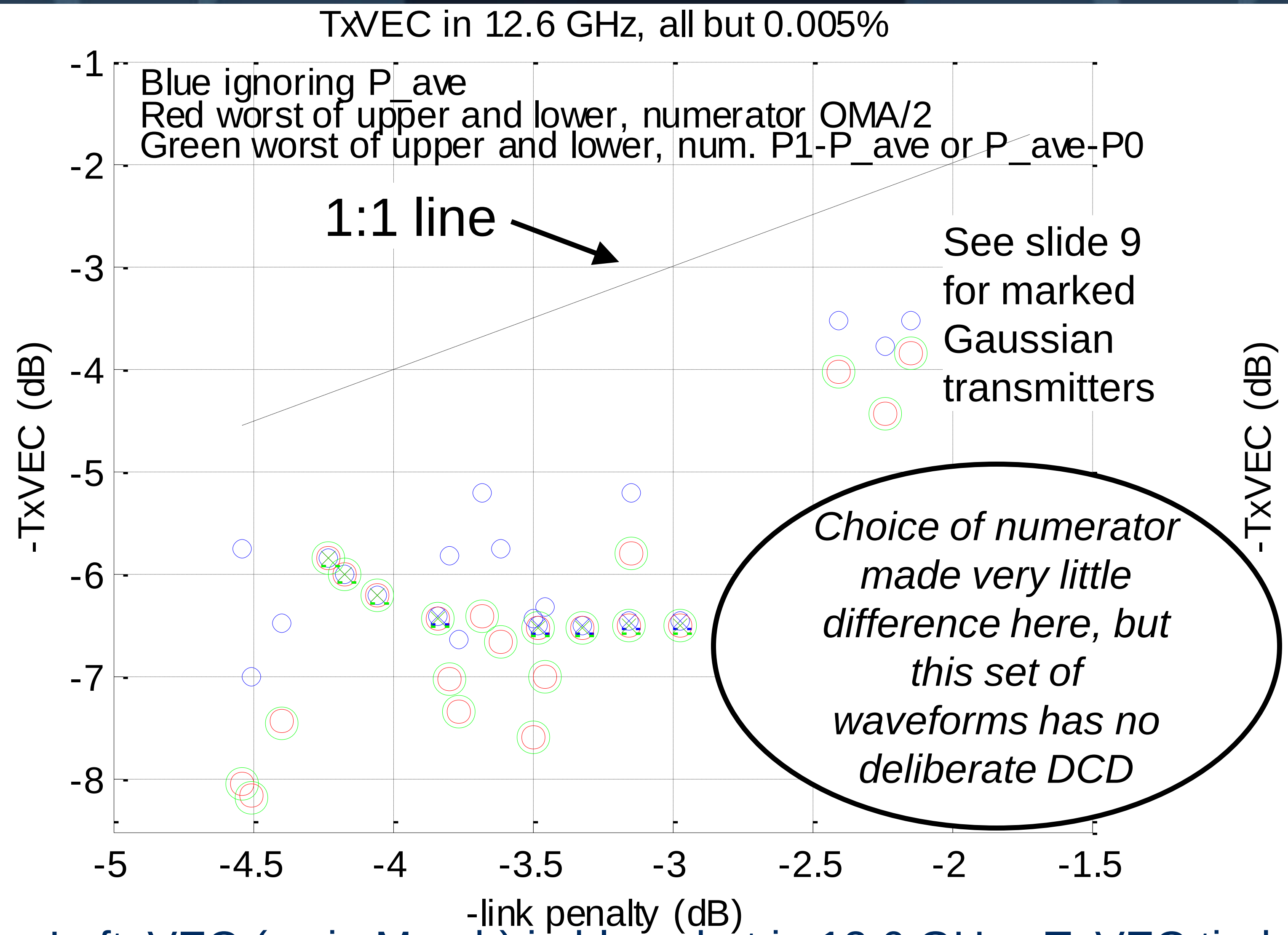
Different "product" transmitters measured by candidate metrics

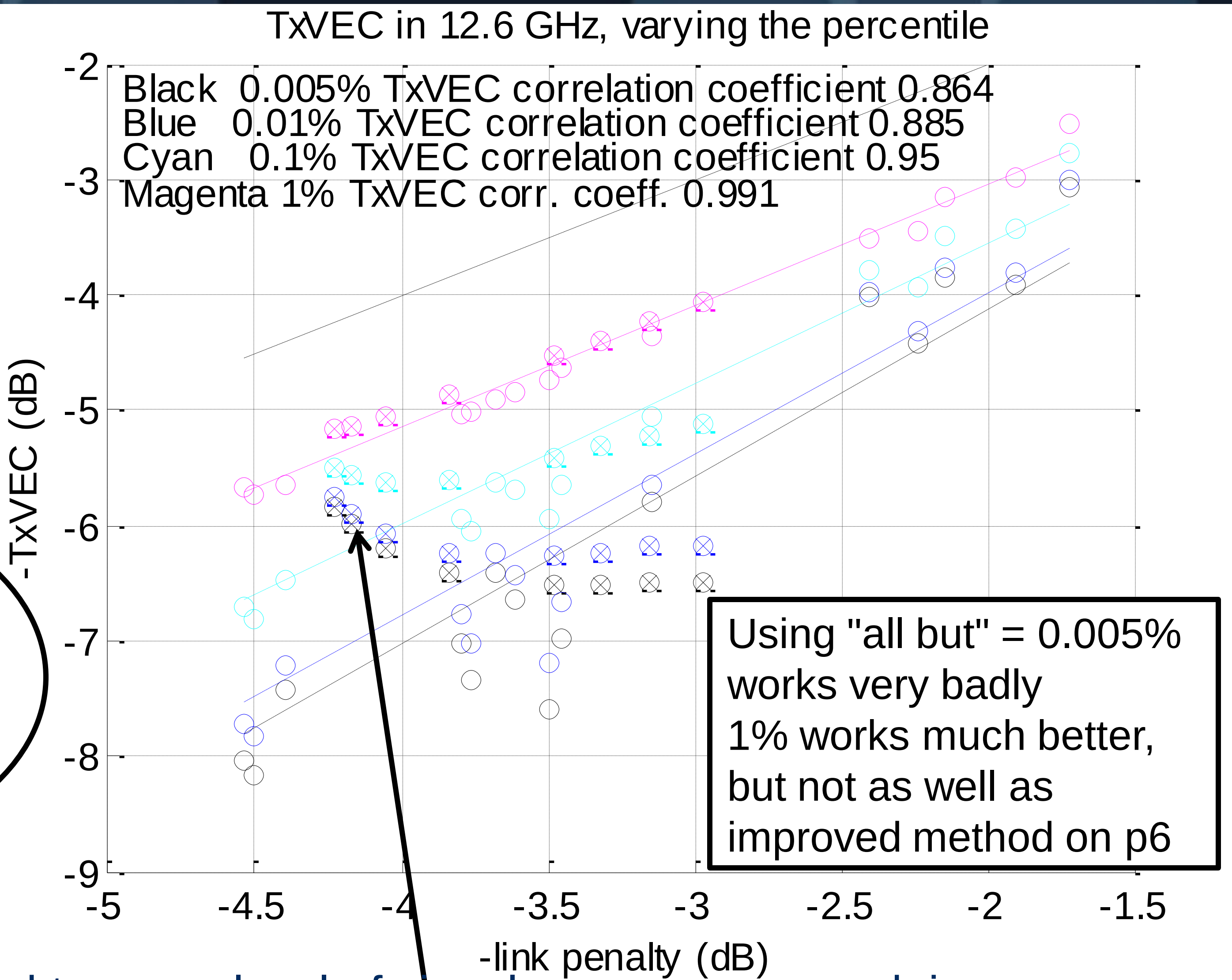




- TDP correlates very well (TDP assumed without any calibration error)
- Soft TDP = improved TxVEC correlates very well and avoids some practical causes of error in traditional TDP
- 0.005% TxVEC doesn't correlate well
  - False passes: according to petrilla_01_0114_optx.pdf slide 22, 0.005% TxVEC flatters very slow or very noisy transmitters: would need additional spec(s) to screen them

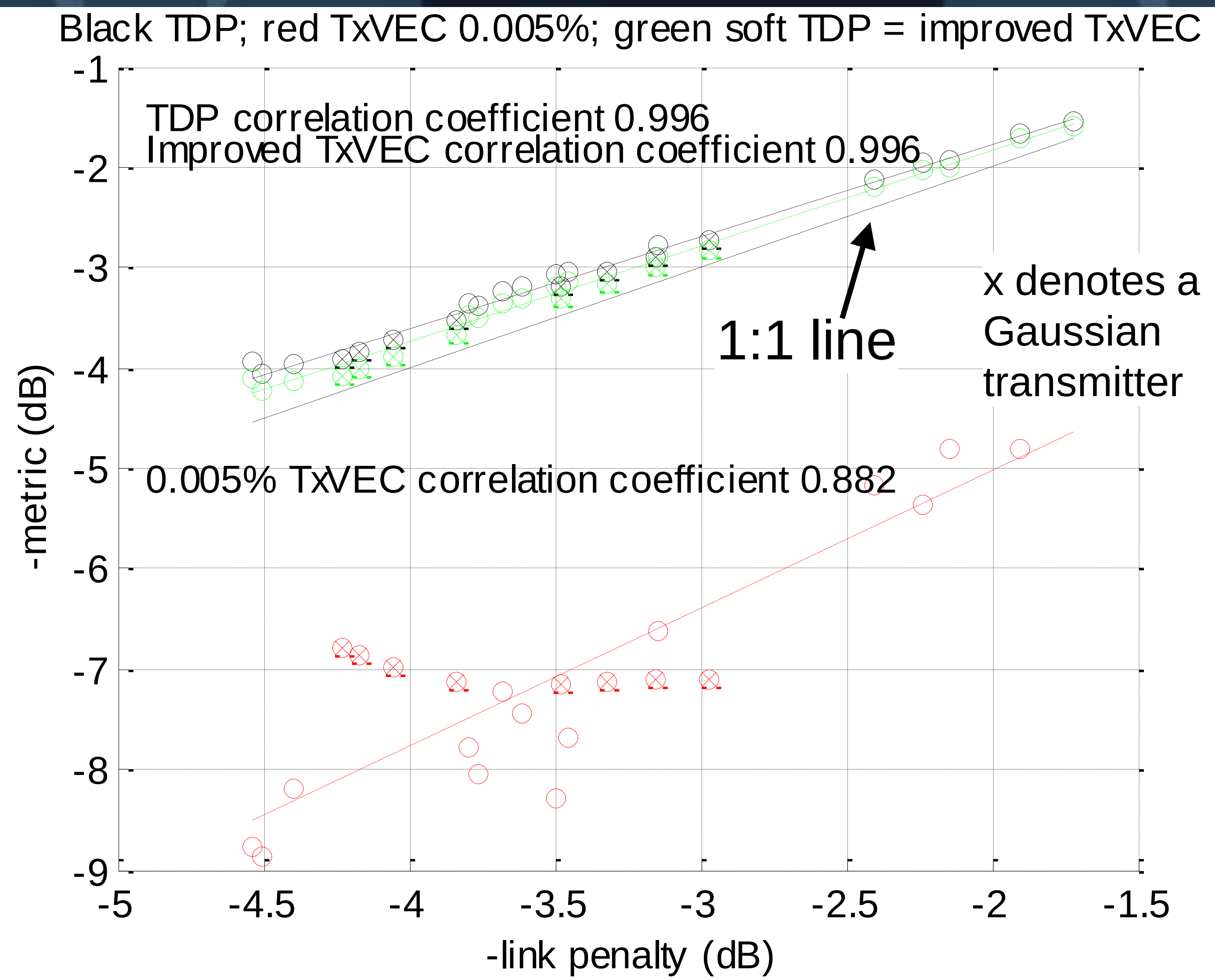
Different "product" transmitters measured by percentile TxVEC

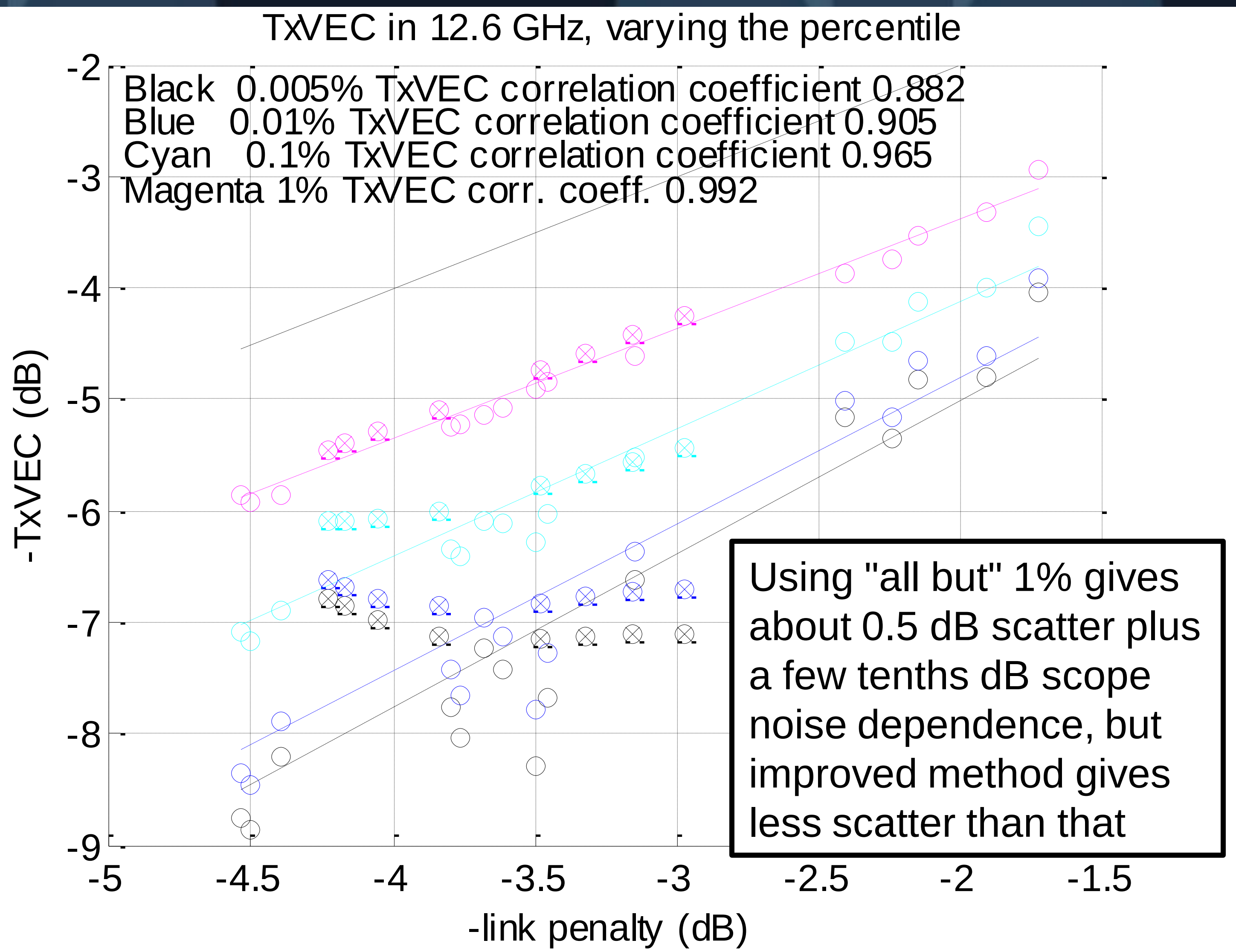




- Left: VEC (as in March) in blue., but in 12.6 GHz. TxVEC tied to mean level of signal, as now proposed, in green. TxVEC tied to mean level of signal and scaled correctly to OMA, in red. Very bad correlation for all three
- Right: trying different percentiles. 1% is the best tried, and much less bad for false passes, but improved method is significantly better
- A 1%ile test might need another test to guard against non-Gaussian noise e.g. intermittent crosstalk

How does scope noise affect the situation?





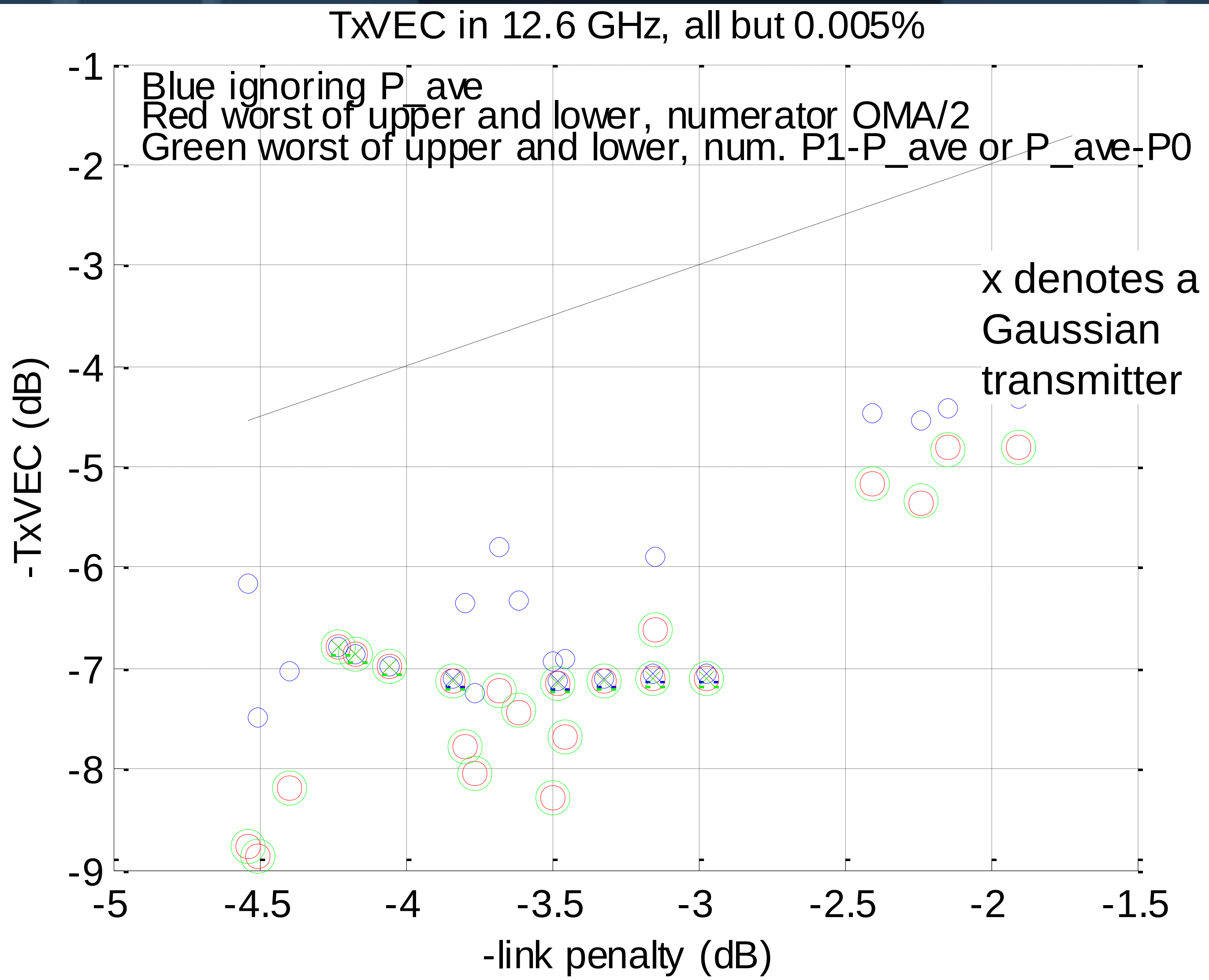
- Repeat of slide 6 left with 10 uW scope noise
- TDP correlates very well (TDP assumed without any calibration error)
- Soft TDP = improved TxVEC still correlates very well and avoids some practical causes of error in traditional TDP
- 0.005% TxVEC doesn't correlate well

Repeat of slide 7 right with 10 uW scope noise

All points have moved down

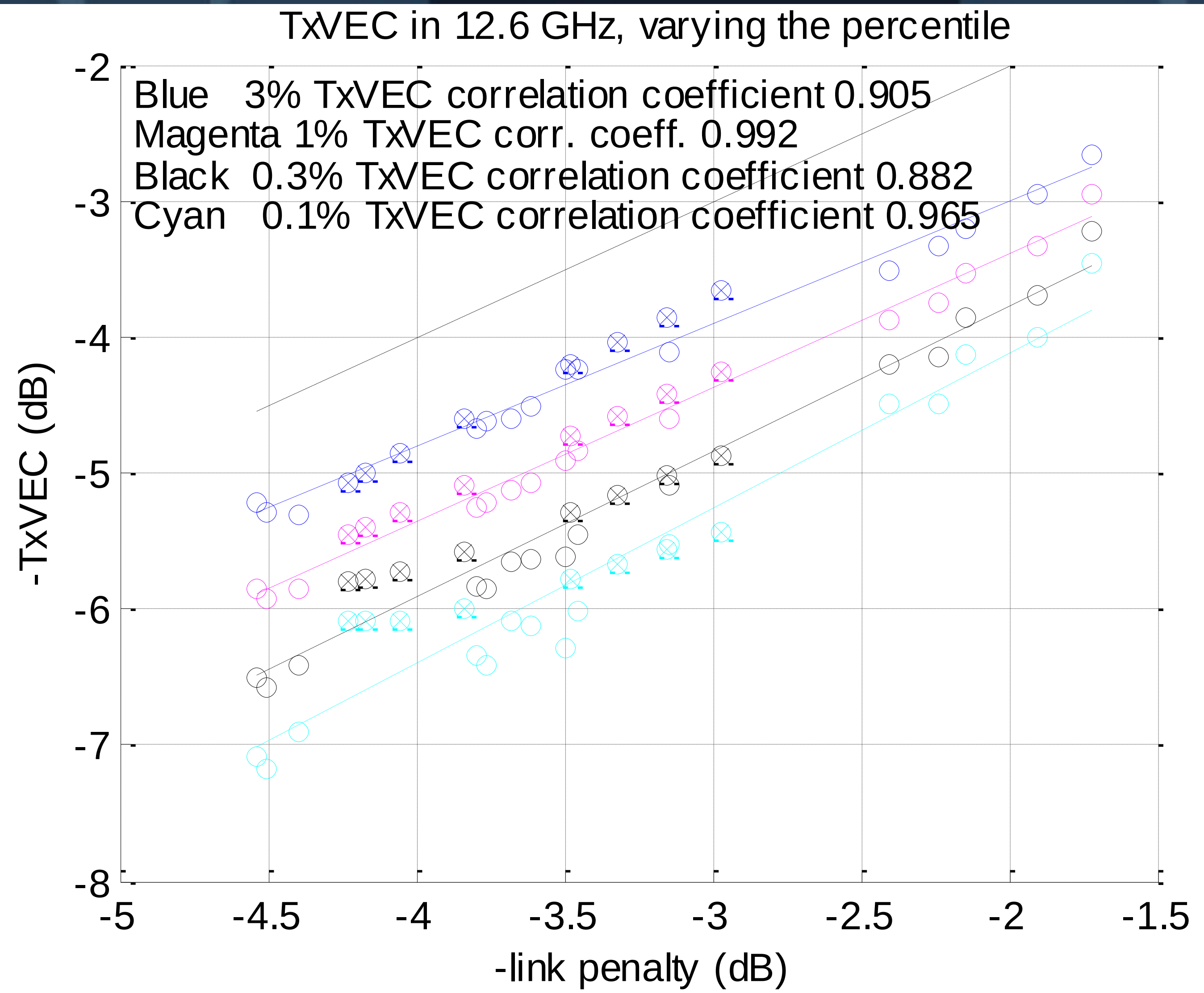
Percentile method's correlation slightly better with scope noise

As before with scope noise



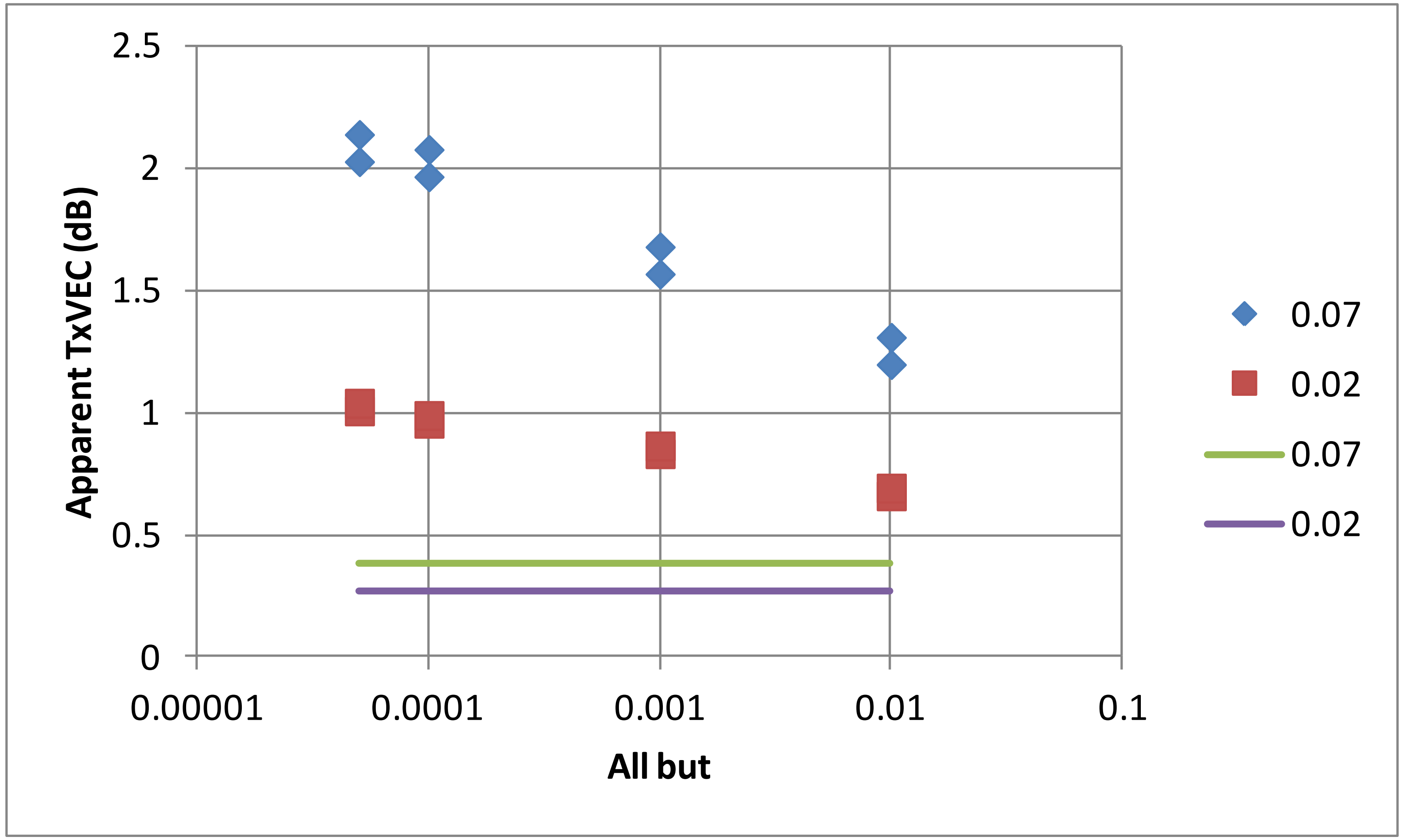
- Repeat of slide 7 left with 10 uW scope noise

Trying different percentiles around 1%



- With scope noise
- 1% to 3% looks like the best

Percentile TxVEC is affected by scope noise



- Allowed range of Tx powers is much more than 4.5 dB
- Scope noise for 100GBASE-SR4 is more than for 40GBASE-SR4

- Experimental results
- DUT was a 40GBASE-SR4 eye measured with 10G scope
- Eye had virtually no ISI at the histogram sampling times
- Signal was measured straight from the transmitter (0.02: red, purple) and after 4.5 dB attenuation (0.07: blue, green)
- Histograms were measured according to proposed method
- Histograms were analysed with percentiles method (two algorithms) and with noise adding method (aka improved TxVEC, soft TDP)

Oscilloscope noise

- Oscilloscope at 19 GHz setting might have 17 uW RMS noise
- Same scope at 12.6 GHz setting might have 10 uW RMS noise
- Minimum signal at maximum OMA -3 dBm
- Signals with better TDP/TxVEC/whatever could be up to 4 to 5 dB weaker
- Pass-through CDR in scope may take 1.6 dB
- VOA and/or optical switch in test rig might take another 2 dB (say)
- -3-4.3-1.6-2 = -10.9 dBm OMA/y = 40.6 uW, RN = RMS noise / (OMA/2) = 0.246 !
- We could define percentile TxVEC for a particular RMS noise, referred to TP2
  - Implementers could use loss to get to that noise point or process the histograms to account for the noise in software
- We can use noise adding TxVEC = soft TDP without requiring a particular RMS noise, referred to TP2
  - Calculation already accounts for scope noise

Simplified transmitter testing: why it's good

- Histograms can be measured with a sampling scope and processed to give a result, all in a reasonable time
  - Whichever algorithm is used
- Scope noise is important
  - Is included (corrected for) very easily with noise adding algorithm ("improved TxVEC")
- Same scope measurement can find apparent OMA (as seen by the scope) and average power
  - Don't need to know what they really are, for finding Tx quality metric
  - Method still works if there is attenuation such as CDR plug-in, VOA, optical switch
- So everything is relative, from the same instrument
  - **No reference transmitter needed! No reference transmitter calibration**
  - Errors caused by variable connector loss are eliminated

- To find OMA-TDP or OMA-TxVEC, need power meter to calibrate scope's apparent OMA

Improved 100GBASE-SR4 transmitter parameter

- High level summary

1. Find the eye of the signal under test in the right bandwidth
   - Find the apparent OMA and the apparent average power of the signal under test
   - Take histograms from the eye
   - Also find the scope's noise (measure with no input)
2. Find the amount of noise that a receiver could add, and still deliver the target BER, correcting for scope noise
3. Find the amount of noise that a receiver could add to an ideal eye with the same OMA, and still deliver the target BER
4. The ratio of the two noises is the "improved TxVEC" or "soft TDP"

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

Step 2: calculate soft TDP

- Step 1 produced histograms (probability distribution functions) of the signal with scope noise in the right bandwidth
- For the worse of the early and late histograms;
  - Assume scope noise, receiver noise, modal noise and mode partition noise are all Gaussian and additive (transmitter noise is in the measurement, not assumed)
  - Find *N*, the amount of Gaussian noise that could be added to this signal, for the target bit error ratio
    - Can do this with a Gaussian weighting function as in 8023-95-TxVECimpCMP.pdf
  - Estimate modal noise assuming that it is proportional to signal level (see e.g. dawe_04_0114_optx.pdf – scaling from 10GBASE-SR and 40GBASE-SR4)
    - See next slide
  - Estimate mode partition noise from worst case transmitter and channel spectral specifications, using established formulas e.g. in the 10 Gigabit Ethernet link model
    - See next slide
  - RSS the noises, giving the maximum tolerable receiver noise
    - See next slide
  - The “soft TDP” is proportional to OMA / this noise

Step 2 continued: finding the allowable receiver noise

- This Gaussian noise *N* is assumed to come from three (or four) sources
  - Receiver noise *R* – to be found
  - Mode partition noise from 10 Gigabit Ethernet link model
    - $\sigma_{MPN} = (k_{MPN}/\sqrt{2})*(1-e^{-(\pi B_{eff}.D.L.\sigma_W)^{\wedge}2}) = 0.0514 * OMA/2$
    - 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} 0.01 * average level of whole signal
    - By scaling from previous projects: see dawe_04_0114_optx.pdf
    - Find the apparent average power of the signal level from the same eye as used for the histograms
    - 0.0075 * mean 1, or e.g. 0.03 * OMA/2 depending on extinction ratio, simplified with very little error to 0.01 * average level of the signal
  - Baseline wander of receiver: not included
  - $M = \sqrt{(\sigma_{MPN}^2 + \sigma_{MN}^2)}$
- And the measurement already includes:
  - Oscilloscope noise: *S* = (0.01 to 0.1) * OMA/2
- RSS the noises to find *R*, the noise that could be added by a receiver:
  - $R = \sqrt{(N^2 + S^2 - M^2)}$

Steps 3, 4: final steps in calculating "improved TxVEC" / "soft TDP"

- Finding the amount of noise that a receiver after a worst case channel could add to an ideal eye with the same OMA, and still deliver the target BER
- σ_{Rx0} = OMA/(2*Qmin)
  - Where Qmin = 3.8905 for BER = 5e-5
- TxVEC (dB) = TDP (dB) = 10*log10(σ_{Rx0} / *R*)
  - This is a predicted penalty assuming worst case mode partition noise and modal noise but no receiver baseline wander

Conclusions

- An improved 100GBASE-SR4 transmitter specification is presented
  - Applies the physics in the link model but with full statistical calculation
- 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 percentile TxVEC and VECPq
- Suitable oscilloscopes are available
  - Direct measurement with "hardware bandwidth" is becoming available
  - Measurement with "software-adjusted bandwidth" can be used
  - Method has been trialled, is automatable, as fast as an eye mask measurement, and tolerant to optical loss in test rigs
- The definition in the standard should be the accurate metric
  - Right bandwidth
  - Right statistics
  - Right noise
  - Complete

References

- Draft text for noise-adding TxVEC 8023-95-TxVECimpCMP.pdf
- Draft text for percentile TxVEC Draft 8023-95-TxVEC_CMP.pdf
- Improved 100GBASE-SR4 transmitter testing, Piers Dawe, http://ieee802.org/3/bm/public/mmfadhoc/meetings/may15_14/Improved100GBASE-SR4txTestingV3.pdf
- 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
- TDP reference transmitter calibration
  - see http://ieee802.org/3/bm/public/mmfadhoc/meetings/aug22_13/king_01_0813_mmf_TDP.pdf
- 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
  - 100G SR4 TxVECUpdate, John Petrilla, http://ieee802.org/3/bm/public/mmfadhoc/meetings/may1_14/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