Cable Qualification for 2.5G and 5GBASE-T

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July 2015

Why Cable Qualification Needed?

- Various channels in a cable plant have to meet certain conditions in order for a PHY to operate at its target link performance
- A qualification criterion is needed to determine whether a cable plant meet the required conditions
- A PHY has to guarantee target performance if the cable passes the qualification

Cable Qualification vs Certification

- Cables may be certified to meet specification of a particular type or category (e.g. Cat5e, Cat6a, etc.)
  - Based on physical models of various channels in the cable and expressed as limit-lines in frequency
  - Defined independent of considerations for PHY performance
- Qualification is related to factors that directly impact the PHY receiver performance:
  - Signal type: echo, internal and alien crosstalk, noise, etc.
  - Signal characteristics: PSD, PDF, etc.
- These 2 are highly correlated but not identical
  - Qualified cable space is ideally a superset of certified space and certification is often used in lieu of qualification

Qualification for 2.5G and 5G

- Cat5e/Cat6 certification puts limits on the main intra-cable channels: IL, RL, NEXT, FEXT
  - Frequency extension to 250 MHz for Cat5e may be needed
- Cat5e/Cat6 certification does not limit alien crosstalk
  - Alien crosstalk is a qualification hole!
- Need a qualification criterion for alien crosstalk
  - Option 1: Define new limit lines for alien crosstalk channels, perhaps by extending the ones from Cat6a and 10GBASE-T
  - Option 2: Use Salz SNR as a criterion that correlates more directly to PHY operation

Alien Crosstalk Certifications in 10G

- Limit lines are defined based on some physical models for alien crosstalk channels
- Independent limit lines are defined for ANEXT and AFEXT

$$ANEXT_{PS} = \begin{cases} X_n - 10 \times log(f/100) & f < 100\ \text{MHz} \\ X_n - 15 \times log(f/100) & f \geq 100\ \text{MHz} \end{cases}$$

$$AELFEXT_{PS} = X_f - 20 \times log(f/100) - 10 \times log(L/100)$$

- X_f and X_n are alien crosstalk loss of Cat6a at 100 MHz

Alien Crosstalk Qualification in 10G

- PHY can tolerate more noise when IL is lower, hence IL adjustment is incorporated (55.7.3)

$$X_f \rightarrow X_f \; - \frac{IL_{LimitLine}(250\ MHz) - IL(250\ MHz)}{2.29}$$

$$X_n \rightarrow X_n \; - \frac{IL_{LimitLine}(250\ MHz) - IL(250\ MHz)}{1.04}$$

- PHY is sensitive to total alien crosstalk
  - A cable plant may violate one limit line and pass the other but still qualify for 10GBASE-T
  - To allow a trade-off between ANEXT and AFEXT, the concept of ACMC is introduced (55.7.3.3)
- Additional averaging factors to account for peaks and valleys of alien crosstalk channels across frequency

Additional Difficulties to Use Limit Line in 5G and 2.5G

- There is no widely accepted model for alien crosstalk limit lines for Cat6/Cat5e
- Aggressors may be mixtures of various rates (1G, 2.5G, 5G and 10G) with very different transmit PSD
- Aggressors and victim may have different cable lengths
  - Bottleneck is not necessary 100m aggressor
- While 5G and 2.5G have PBO, there is no PBO for 1G

Salz SNR as Qualification Metric

- Salz SNR correlates well with real link performance with PHYs that include THP and typical 10G equalizer
- It provides an unambiguous pass/fail criterion and also a measure of margin or degree of goodness
- It is based on measurements of the following channels:
  - IL: for all pairs of the victim and aggressors
  - AFEXT and ANEXT: from any pair of every aggressor to any pair of the victim
- Unlike other metrics, including ACMC, Salz SNR does not rely on a definition for limit lines

Qualification Procedure

- Using IL, identify the PBO for each link at each rate
- For all possible combination of aggressor rates, find the PSD of signal and noise at victim receiver over the bandwidth (W) relevant to the victim rate:
  a) Find the transmit PSD by subtracting the PBO from the nominal PSD of the corresponding rate
  b) Find the desired receive signal by subtracting the IL of victim for lane l from transmit PSD of victim : $S_l(f)$
  c) Calculate ANEXT and AFEXT PSD at any lane of victim receiver from any lane of aggressors by subtracting the corresponding loss from the transmit PSD of the aggressor
  d) Power-sum the ANEXT and AFEXT PSDs to find the total alien crosstalk PSD at each lane of victim receiver
  e) Add background noise to get total noise PSD for lane l : $N_l(f)$

Salz SNR Margin

- Calculate Salz SNR for each lane l as

$$SNR_{Salz}(l) = e^{\frac{\int_0^W log\left(1+\frac{S_l(f)}{N_l(f)}\right)\cdot df}{W}} - 1$$

- Denote SNR_{Salz}^{min} as the minimum SNR over 4 victim lanes and all combination of the aggressor rates

- Qualification metric: $Margin_{Salz} = SNR_{Salz}^{min} - SNR_{target}$

- Qualification criterion: $Margin_{Salz} > 0$

Salz SNR Calculation
finite number of discrete frequency bands

- Partition the overall bandwidth into B frequency bands and calculate the power of signal and noise within each band
- Salz SNR is calculated as

$$SNR_{Salz}(l) = e^{\frac{\sum_{b=1}^{B}\left(w_b \times log\left(1+\frac{S_{lb}}{N_{lb}}\right)\right)}{W}} - 1$$

W is the overall bandwidth $W = \sum_{b=1}^{B} w_b$

w_b is the bandwidth of the b^{th} frequency band

S_{lb} and N_{lb} are the signal and noise power on l^{th} lane b^{th} band

TBDs

- Nominal (template) transmit PSDs
- Target SNR – need margin to cover for ambiguities in
  - Nominal transmit power level (e.g. 2 dB range for 2.5G/5G)
  - PBO setting (2 dB steps)
- Salz integration parameters:
  - Minimum number of frequency points
  - Frequency resolution
  - Uniform or logarithmic frequency steps
- Background noise level
- Required accuracy and minimum sensitivity of test measurements
- Fortunately, there is lots of source work on this, we are not on completely new ground, examples include:
  - TIA TSB-155-A, IEEE Std. 802.3 (55.7.3.3) for 10GBASE-T
  - ANSI T1.417-2001 & 2003 for DSL crosstalk

Summary

- Cat6/5e cables need alien crosstalk qualification for their use in 5G and 2.5G systems

- Salz SNR can be used as a qualifying metric which correlates closely with PHY performance
  - It takes into account transmit PSDs of various operating rates
  - It takes into account of different PBO schedules for various operating rates
  - It works well when victim and aggressors have different lengths
  - It is a clear pass/fail criterion
  - It provides a sense of margin and measure of goodness
  - It is based on familiar channel measurements