Time-Domain Channel Specification: Proposal for Backplane Channel Characteristic Sections

IEEE802.3bj

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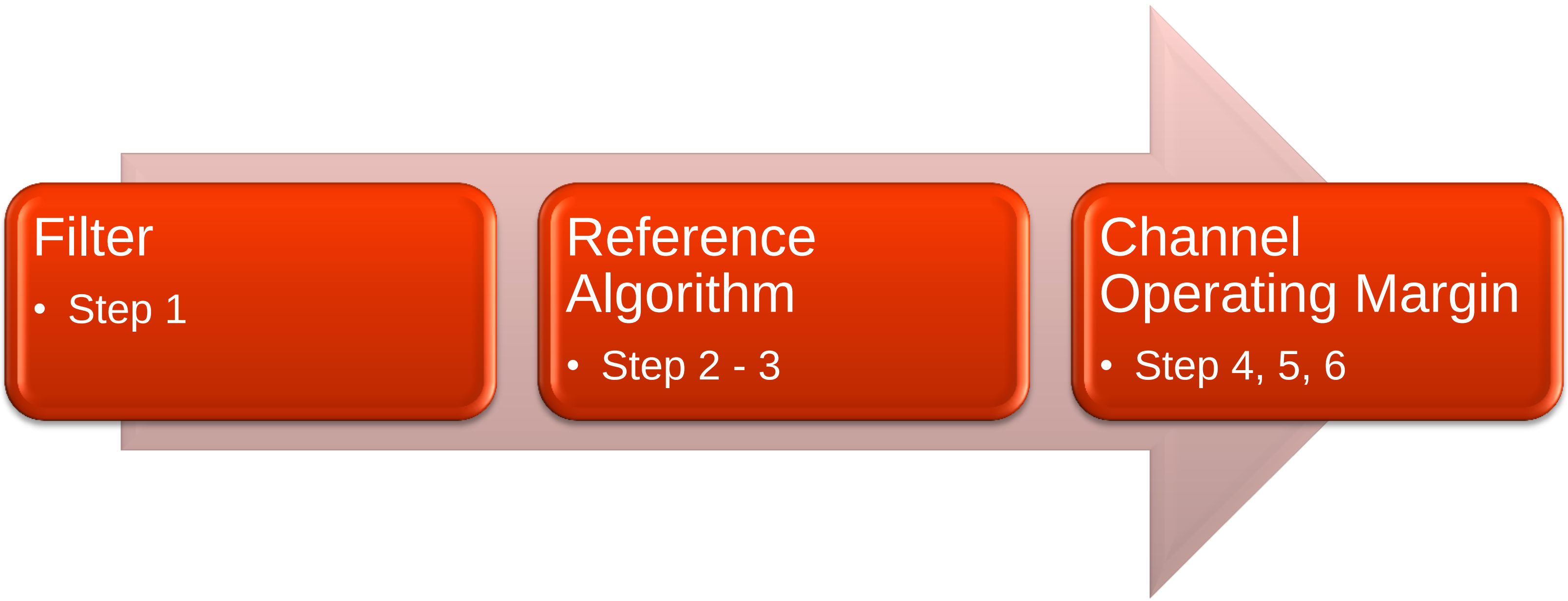
Agenda

- Channel Specification Steps
- Flow Diagram
- Technical Description
- Tables
- Proposal

Channel Operating Margin (COM)

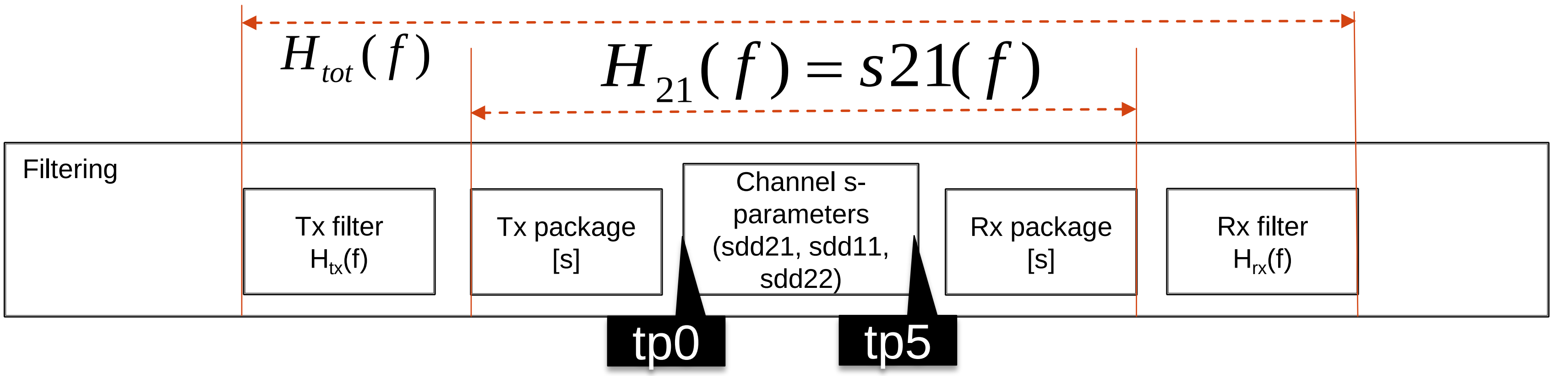
- The channel operating margin (COM) is a figure of merit for a channel utilizing reference transmitter/receiver performance characteristics. The reference transmitter/receiver block represents a minimum expected capability.
- This method shall be complemented by appropriate TX and RX compliance tests.
  - It is expected that compliant receivers will cope with ISI in the first 16 UI or so in some way and that COM may have computational differences between PAM4, NRZ/FEC, and NRZ.
- A channel with positive COM is expected to operate with a minimally compliant transmitter and receiver.
- COM effectiveness is presented in *adee_01_0712.pdf*

Top Level Flow:
Starting with channel s-parameters



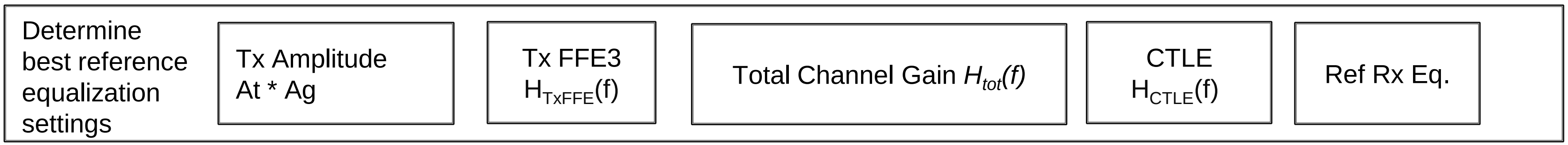
Glossary,
SBR – single bit response aka pulse response
PDF – Probability Density Function
CDF – Cumulative Distribution Function
CTLE – Continuous Time Linear Equalizer
FFE3 – 3 tap Feed Forward Linear Equalizer

Process consisting of: Step 1



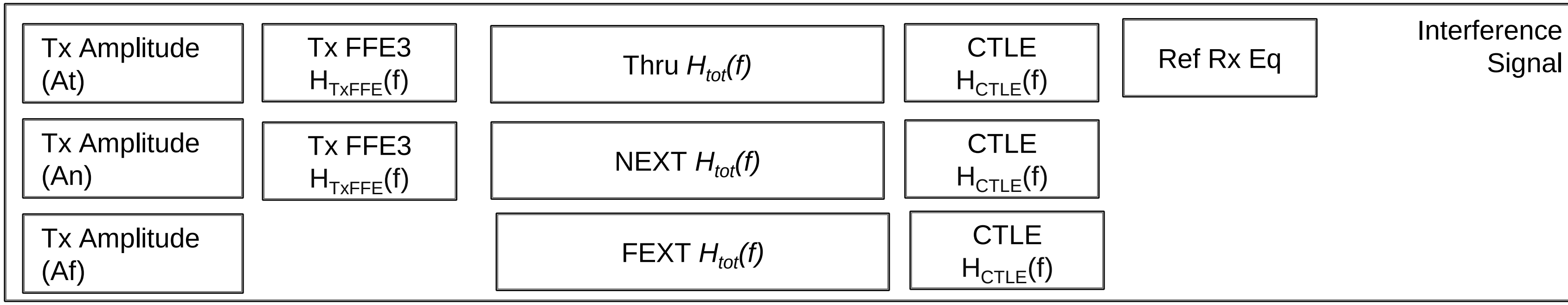
1. Computation of total channel gain $H_{tot}(f)$ from linear filters and channels s-parameters
   - Combine channel S-parameters (sdd21…) with reference Tx and Rx package S-parameters to get S-parameters of complete channel, H_{21}(f).
   - Tx/Rx low pass filters

Process cont'd: Steps 2-3



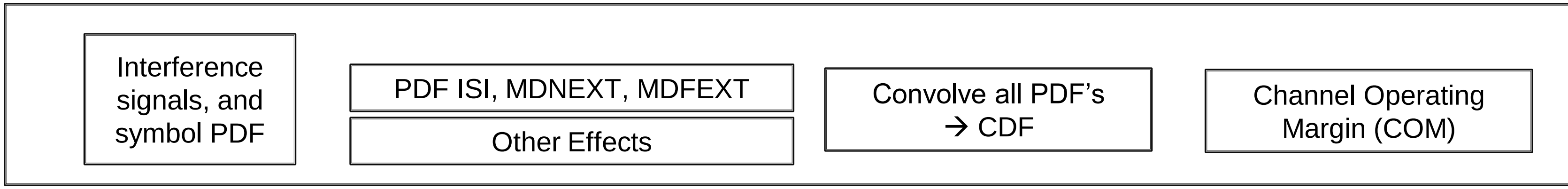
2. Compute SBRs (single bit responses) from convolution of a
   - 1 UI wide source of appropriate amplitude
   - the 3 tap Tx FFE filter $H_{TxFFE}(f)$
   - the pole/zero CTLE filter $H_{CTLE}(f)$
   - and the through channel $H_{tot}(f)$
3. Compute available single amplitude(Sx), Tx FFE setting, and CTLE setting (NRZ/wo FEC example)
   - For each SBR of every Tx FFE and CTLE setting: (exhaustive search)
     - Determine the signal amplitude using a main cursor sample point 1 UI after the first positive zero crossing
     - Determine the RMS of the residual ISI (interference signal) after accounting for reference UI Gating
     - Combine the RMS with a fixed white noise source before the CTLE
   - Determine the Tx FFE taps setting and CTLE setting that produces the largest signal amplitude (Sx) to adjusted ISI RMS ratio.
     - The settings are used in following steps.
     - Also the main cursor sample point is also recorded for following steps.

Process cont'd: Steps 4



4. **Determine interference signals** (without symbol gain)
   - Create SBRs for Thru, NEXT, FEXT
     - For all channels, perform a linear transformation on H_{tot} (step 1) with $H_{CTLE}(f)$ CTLE setting found in step 3.
     - For Thru and FEXT, additionally perform a linear transformation with $H_{TxFFE}(f)$
   - FEXT, and NEXT interference signals are the above SBRs
   - The Thru interference signal is the Thru SBR accounting for "Ref Rx Equalizer"

Process cont'd: Steps 5 and 6

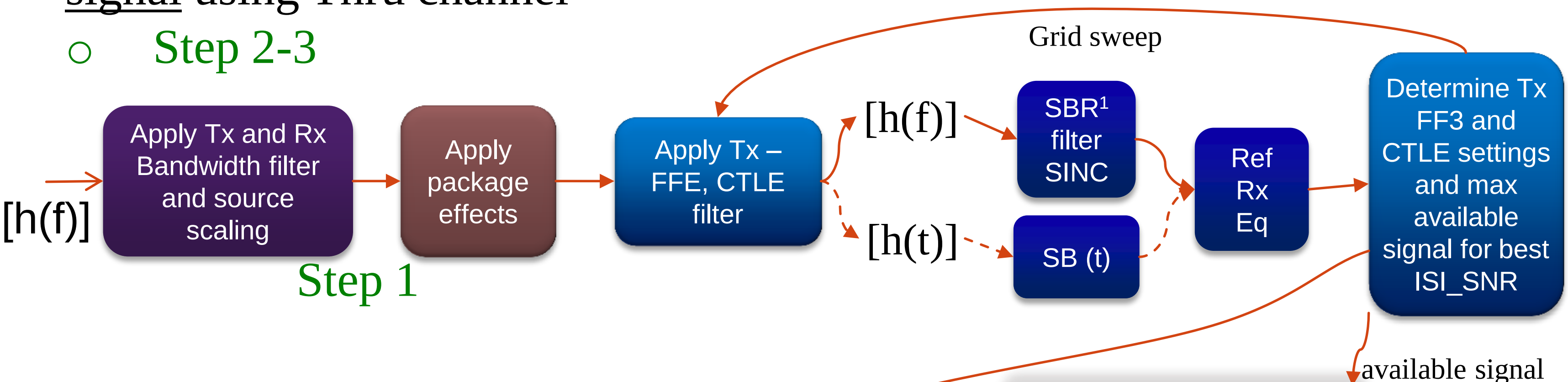


5. Compute interference PDFs for some number of sampling phases (32) and select the PDF for the worst variance and then compute a CDF.
   - PDFs for the Thru, all NEXT, and all FEXT channels are created using convolution with the PDF of a symbol for the port type and sampled interference signals.
   - Allowance for other effects are also joined with the joint PDF created from all channel PDFs
   - A CDF (cumulative distribution function) is computed using the cumulative sum of the joint PDF.
6. Computation of channel operating margin (COM) is dB ratio of the available signal amplitude (Sx) to the CDF voltage at the specified raw BER probability.

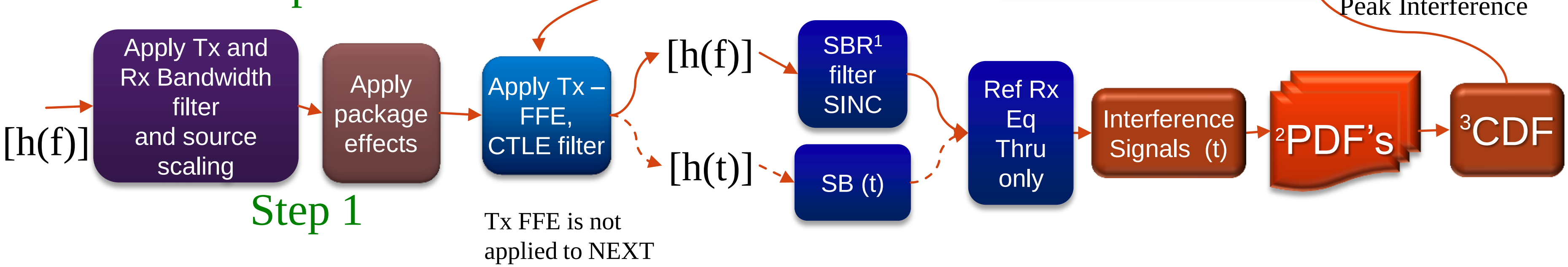
Twofold Flow

SBR[1] – single bit response aka pulse response
PDF[2] – Probability Density Function
CDF[3] – Cumulative Distribution Function
CTLE – Continuous Time Linear Equalizer

1. Determine Tx FF3 and CTLE settings and available signal using Thru channel
   - Step 2-3



2. Determine peak interference for Thru, FEXT, NEXT channels
   - Steps 4-6



Total Channel Gain, H_{tot} w/o equalization (from step 1)

$$H_{tot}(f) = H_{tx}(f) * H_{21}(f) * H_{rx}(f)$$

Tx/Rx Filter

- Tx Filter
  - $H_{tx}(f) = \dfrac{1}{1+\sqrt{2}\cdot\left(\frac{j\cdot f}{f_t}\right)+\left(\frac{j\cdot f}{f_t}\right)^2}$
- Rx Filter
  - $H_{rx}(f) = \dfrac{1}{1+bw1\cdot\left(\frac{j\cdot f}{f_r}\right)+bw2\cdot\left(\frac{j\cdot f}{f_r}\right)^2+bw1\cdot\left(\frac{j\cdot f}{f_r}\right)^3+\left(\frac{j\cdot f}{f_r}\right)^4}$

$bw1=2.613126,\ \ bw2=3.4142136$

Tx/Rx Package Modeling

return loss and channel s-parameters , H_{21}

$$\text{Tx}, \Gamma_1(f) = \frac{\Gamma_{01} - j\frac{f}{f_1}}{1 + j\frac{f}{f_1}}$$

$$\text{Rx}, \Gamma_2(f) = \frac{\Gamma_{02} - j\frac{f}{f_2}}{1 + j\frac{f}{f_2}}$$

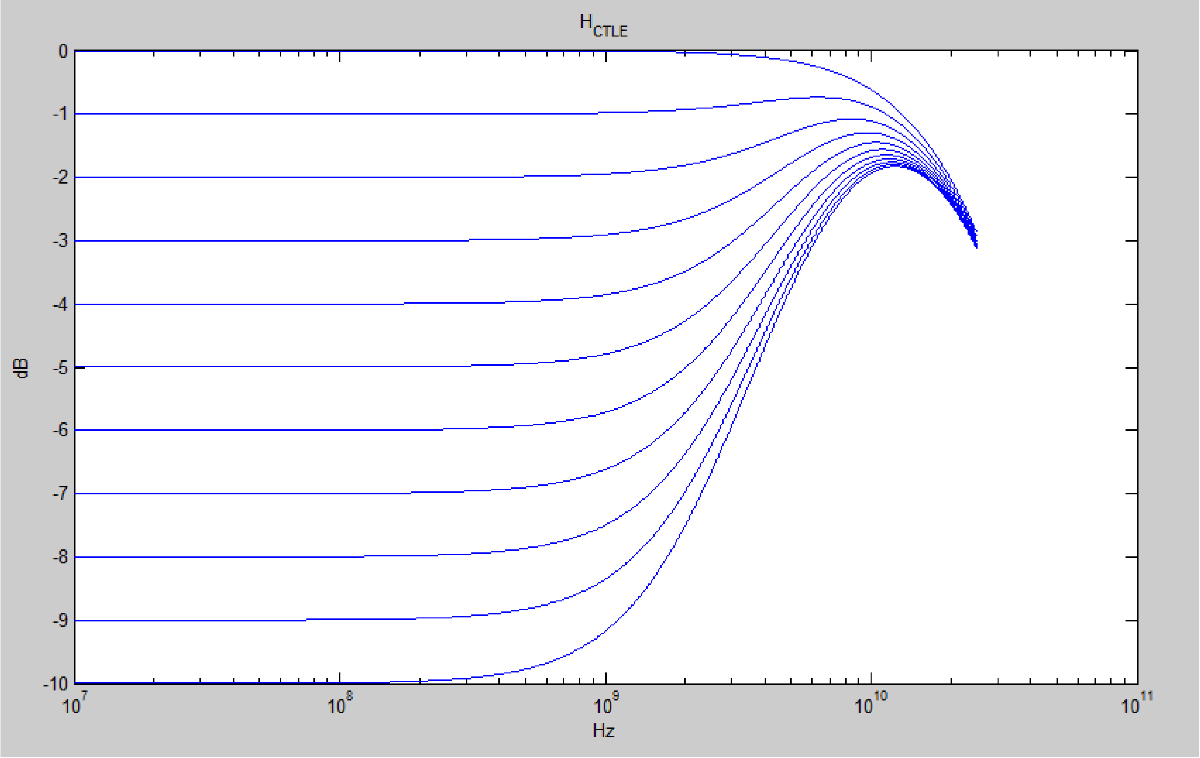
TBD

$$H_{21} = \frac{S_{21}}{1 - S_{11}\Gamma_{TX} - S_{22}\Gamma_{rX} - S_{21}S_{12}\Gamma_{TX}\Gamma_{RX} + S_{11}\Gamma_{TX}S_{22}\Gamma_{RX}}$$

$H, S\ and, \Gamma\ are\ all\ function\ of\ f$

CTLE
One degree of freedom: G_{DC}

$$H_{CTLE}(f) = f_b \frac{j \cdot f + 0.25 \cdot f_b 10^{\frac{G_{DC}}{20}}}{(j \cdot f + 0.25 \cdot f_b) \cdot (j \cdot f + f_b)}$$



G_{DC} is DC gain in dB

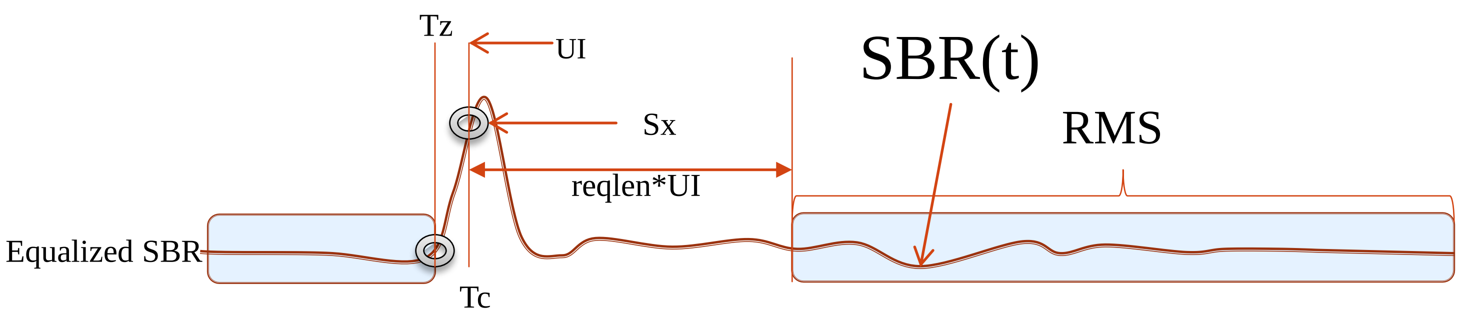
SBR(t) from H_{tot}(f) example

(as in step 2ff)

- Peak Amplitude (per port type) for a 1 UI wide 100 Ω differential ideal data source whose voltage swings between +/- peak amplitude
  - Amplitude, A, is assign per channel type
    - Thru channel and FEXT channels will have the same amplitude but NEXT will be larger
    - A_t ,A_{ft} , and A_{nt}
    - Symbol gain scale is applied during PDF generation for NRZ and PAM4 and during the algorithm to determine Sx.
- Reference termination is 100 Ω differential.
- Example:
    - $\mathrm{SBR(t)} = \mathrm{inverseDFT}(\mathrm{A} \cdot H_{tot}(t) \cdot H_{CTLE}(f) \cdot \left(c(-1) \cdot e^{j \cdot 2 \cdot \pi \cdot f \cdot UI} \; + c(o) + c(1) \cdot e^{j \cdot 2 \cdot \pi \cdot f \cdot UI}\right))$
  - SBR extraction using convolution in the time domain is also acceptable.
- Inverse DFT must be applied prior to UI gating if a Thru channel. Time domain data is sampled OVERSAMPLING times per UI. Data should be available from 50MHz to 40GHz at 10MHz intervals:
  - LMS linear fit "unwrapped" phase and log amplitude from 10MHz to 100MHz. Modify phase fit by changing y intercept to give integer multiple of pi at DC and slope to give best LMS fit from 50MHz to 100MHz. Use these linear fits to extrapolate down to DC
  - May use other methods known by the implementer to give a better fit.
  - Zero pad data from 40GHz to 0.5*OVERSAMPLING/UI

Finding available signal (Sx) and equalization settings from SBR(t) is an exhaustive search: NRZ /wo FEC example
(as in step 3)

- For each CTLE G_{DC} gain setting, c(-1) setting, and c(1) setting
  - c(0)= 1 - |c(-1)| - |c(1)|
  - Determine SBR(t) as in previous slide
  - Determine first zero positive crossing, Tz (precursor sample point)
    - Main cursor Tc = Tz+UI
  - Determine voltage Sx one UI after first zero positive crossing (Tz+UI)
  - Determine RMS for region out side equalizers' reach, $residual\_ISI$
  - $Noise = \sqrt{residual\_ISI^2 + (G_{\sigma\_noise} \cdot S_x)^2}$
  - Determine $\mathrm{ISI\_SNR} = 20 * log10(\frac{S_x}{Noise})$
  - If ISI_SNR > best ISI_SNR, best ISI_SNR=ISI_SNR, record, S_x, c(-1), c(1), G_{dc} and SBR(t), and main cursor sample point, Tz+1UI



PDF generation

(as in step 5)

- Interference consists of residual ISI, several NEXT, and several FEXT signals.
  - Interference signal for ISI, aka Thru channel, is the Thru SBR after gateing by “reqlen” Uis. (NRZ example)
  - Interference signal for XTALK is all of SBR for each NEXT or FEXT.
- Each interference signal is sampled at UI intervals into OVERSAMPLING vectors, representing sampling phases that are UI/OVERSAMPLING apart.
- For each interference pattern
  - Using the specified “binsize”, Convolve the PDF of a single cursor specified per port type with cursor values for all UI for each OVERVERSAMPLING vector
  - Select the PDF of the OVERSAMPLING vector that has maximum variance for each Thru, NEXT, and FEXT
- Convolve PDFs of all selected FEXT and NEXT together with the PDF for the ISI to create an interference PDF.

Allowances:

- Some sources considered
  - Jitter
  - Non-ideal performance of real circuits due to non-linearity, bandwidth limitations, etc.
  - Manufacturing tolerance of PHY
  - Manufacturing tolerance of channel
- Binary (Dual Dirac) noise = +/- $G_{dd\_noise} * S_x$
- Gaussian Noise: RMS= $G_{\sigma\_noise} * S_x$
- These allowances convolve with the interference PDF creating a total interference PDF.

COM Computation

- A CDF is created from the total interference PDF. A total peak interference is created when the CDF probability achieves the raw BER for the specified port type
  - $CDF(i) = \sum_{k=1}^{i} \text{Total\_PDF}.y(k)$
  - The peak total interference, Total_PDF.x(spec_i), is when the when CDF(spec_i) = “raw BER”
    - Where Total_PDF.y are probabilities and Total_PDF.x are respective voltage values in the bins of “binsize”.
- COM is the dB ratio of the available signal to total peak interference.
  - $COM = 20\log10\left(\frac{S_x}{\text{Total\_PDF.x(spec\_i)}}\right)$

Table: Channel Electrical Characteristics

Parameters	Type	Description
COM	Figure of merit	Channel Operating Margin
ILfit at *f*b/2	dB loss	Insertion loss fit at the Port Nyquist frequency
IL at *f*b/2	dB loss	Insertion fit at the Port Nyquist frequency
Amax/IL	Mask/graph	Maximum Attenuation
RL	Mask/graph	Maximum Common Mode and Differential Return Loss
PTI	Interim Peak V	Peak[1] Total Interference at raw BER including ISI, crosstalk, and system "allowance"
PJI	Interim Peak V	Peak[1] joint ISI and crosstalk interference voltage at raw BER
PISI	Interim Peak V	Peak[1] ISI interference voltage at raw BER
Sx	Interim V	Available signal amplitude
PMXI	Interim Peak V	Peak[1] Multi-aggressor crosstalk interference voltage at raw BER
PMFEXTI	Interim Peak V	Peak[1] Multi-aggressor FEXT interference voltage at raw BER
PMNEXTI	Interim Peak V	Peak [1]Multi-aggressor NEXT interference voltage at raw BER

Peak[1] is the cumulative peak a raw BER

Table: Channel Parameters

Moore_01_0311

Parameter	Symbol	100GBASE-KP4	100GBASE-KR4	
Symbol rate, GH	fb	13.5938	25.7813	GHz
Victim differential output amplitude, mV peak	A_t	400	400	mV
Victim transmitter 3 dB bandwidth, GHz	f_t	0.55 x fb	0.55 x fb	GHz
Far-end disturber differential output amplitude, mV peak	A_{ft}	400	400	mV
Far-end disturber 3 dB bandwidth, GHz	f_{ft}	0.55 x fb	0.55 x fb	GHz
Near-end disturber differential output amplitude, mV peak	Ant	600	600	mV
Near-end disturber 3 dB bandwidth, GHz	f_{nt}	1.00 x fb	1.00 x fb	GHz
Receiver 3 dB bandwidth GH	f_r	0.75x fb	0.75x fb	GHz
Maximum frequency for transfer function fit, GHz	fmax	0.75 x fb	0.75 x fb	GHz
Symbol gain	Ag	1/3	1	
Interference Symbol Gain (X values of a PDF)	ISG	PDF.x = [-1 -1/3 1/3 1]	[-1 1]	-
Interference Symbol probability. (Y probabilities of a PDF)	ISP	PDF.y= [.25 .25 .25 .25]	[.5 .5]	-
Probability bin size for probability density	binsize	100	100	µV
Oversampling	OVERSAMPLING	32	32	

Table: Channel Parameters

Parameters	symbol	100GBASE-KP4	100GBASE-KR4	
Transmitter DC reflection coefficient, V/V	Γ_{01}	.161	.161	
Transmitter return loss reference frequency, GHz	f_1	1.25*f_b	1.25*f_b	Hz
Receiver DC reflection coefficient, V/V	Γ_{02}	.161	.161	
Receiver return loss reference frequency, GHz	f_2	1.25*f_b	1.25*f_b	Hz
Tx FFE3 pre cursor tap	c(-1)	[0.0, -.02, … -0.1]	[0.0 , -0.02, … -0.1]	
TX FFE3, post cursor tap	c(1)	[0.0, -.02, … -0.4]	[0.0, -0.02, … -0.4]	
CTLE ac gain	Gdc	0, 1, … 10	0, 1, … 10	dB
Reference Rx equalizer length	reqlen	TBD	TBD	
Raw Probability Target	rawBER	1e-5	1e-5(FEC)/1e-12	
Reference equalizer Gaussian noise scale	G_{σ_noise}	0.01	0.01	
Reference equalizer Dual Dirac noise scale	G_{dd_noise}	0.1	0.1	

TBD

Proposal

Add sub clause after 93.9.2 and 94.4.2 entitled “Channel Operating Margin” based on this presentation.

Channel operating margin shall be normative for clause 93 and 94

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