Channel Operating Margin Tutorial

Richard Mellitz, Intel Corporation

March 2016 IEEE Plenary, Macau China

The Channel Operating Margin (COM) is a Signal to Noise Ratio (SNR)

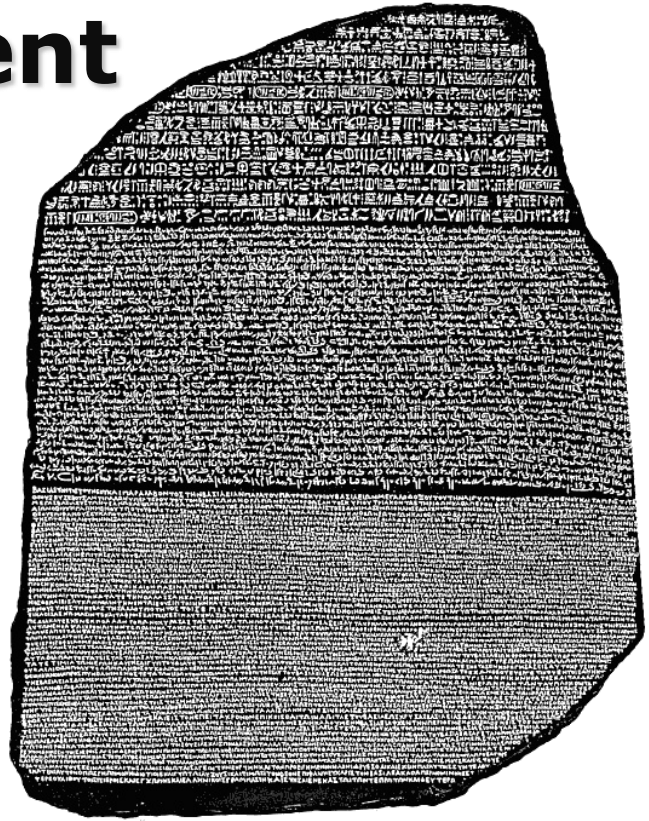
$$COM = 20 * log10\left(\frac{A_s}{N}\right)$$

- $N = Peak\ BER\ noise$
- $As = Peak\ Signal$
- In the Context of a Signaling Architecture!

For More Comprehensive Technology Development

COM is

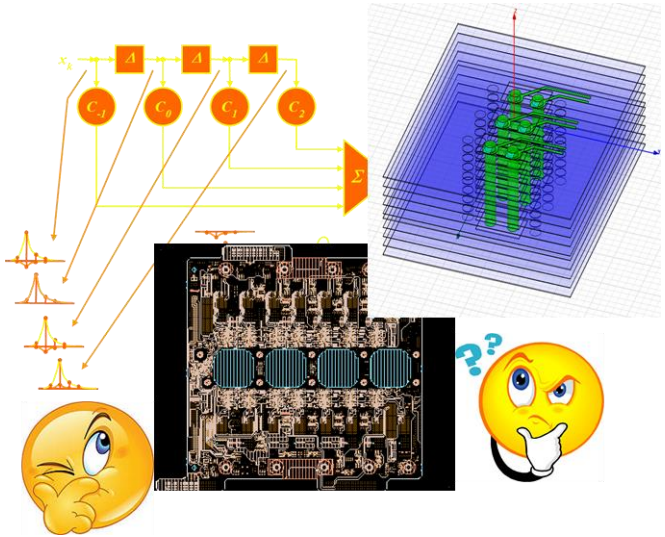
- The 'Rosetta Stone' for a unified budget which ties transmitter, receiver, and channel specifications together.



For Standards Development COM Provides

- An open and fair instrument to evaluate proposals
- A vehicle for technical advocacy
- A common vehicle for achieving consensus between
  - PHY circuit (architecture) interests
  - Interconnect - platform (architecture) interests
- Clear goals for silicon and interconnect designs

Interlocked Views



For a Serdes engineer COM is

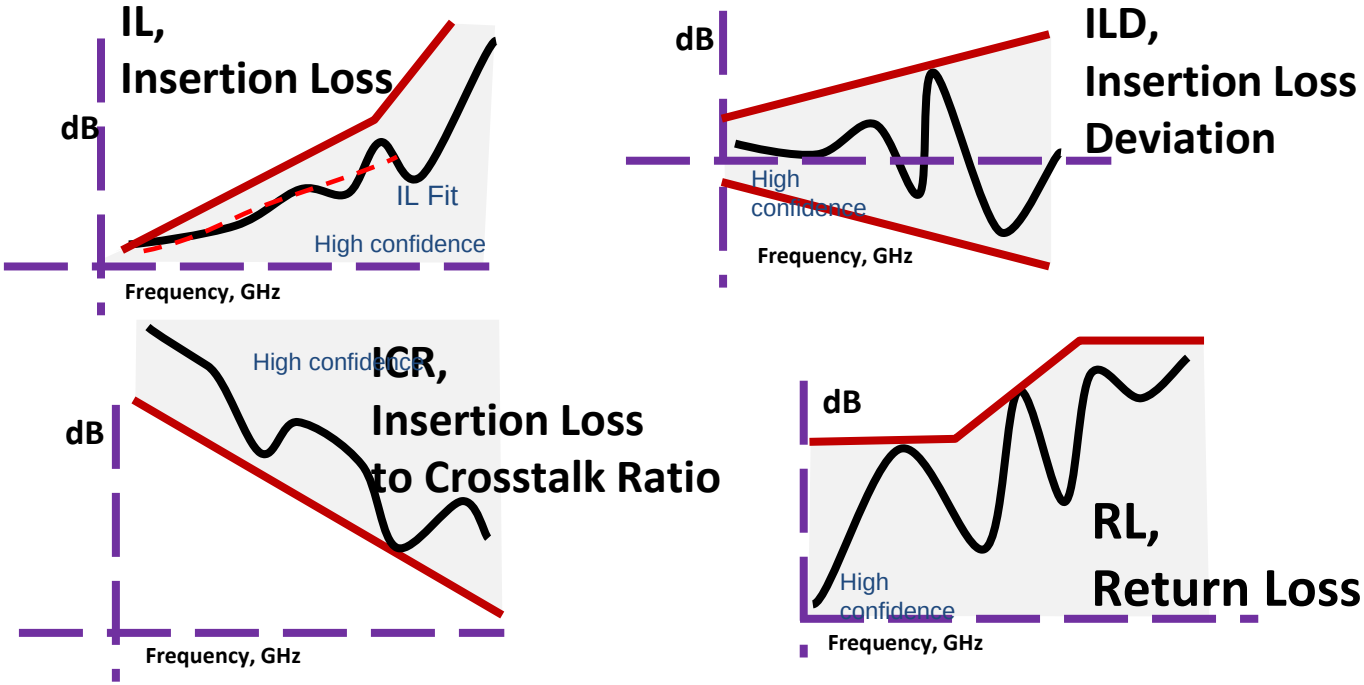
A reference chip capability

the SNR budget for a receiver

For a channel engineer COM is a

- Budget between insertion loss, return loss, reflections, and crosstalk.
- Management tool for trade offs between via stub, material selection, PWB constructions, connector choice.

In 10GBASE-KR channel compliance defined useful new metrics but limited trade-off possibilities



More Background

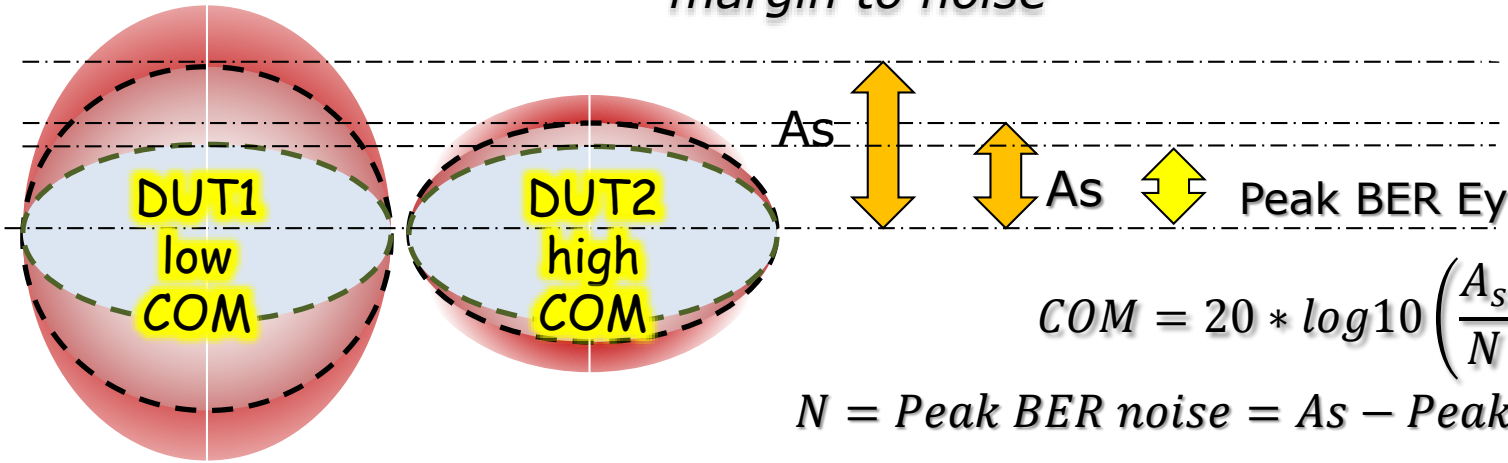
- Frequency domain channel requirements were shown to surrender too little margin for manufacturing at the required 42dB die to die loss at 13Ghz the project that developed Std. IEEE-802.3bj-2014
- COM is a time domain specification proposal which emerged from collaboration between silicon and platform engineers involved with Ethernet standards development.

Terminology: SBR

- Single Bit Response
- A.K.A Pulse Response

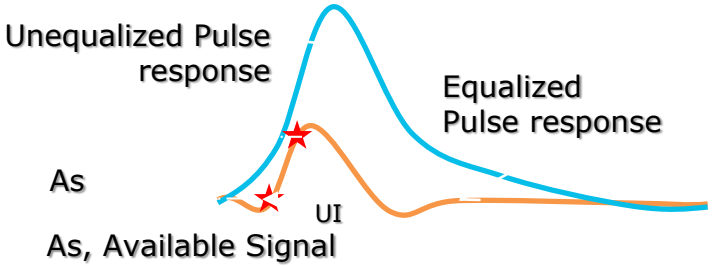
Pictograph Of COM Draws From Familiar Themes

2 DUTs with same reference receiver eye opening can have a very margin to noise



$$COM = 20 * log10\left(\frac{A_s}{N}\right)$$

$$N = Peak\ BER\ noise = As - Peak\ BER\ Height$$



- COM is the available signal to noise ratio
- Noise outside the reference receiver is expected to scale with COM
- Higher COM suggests more immunity
- AGC is a implementation choice so is not included
- It is expected that noise outside the receiver will scale with the SNR or COM

Parameters for COM computation are tied to transmitter and receiver specifications

Transmitter spec parameters

COM algorithm & spec

Receiver spec parameters

PMD Transmitter | **Channel** | **PMD Receiver**

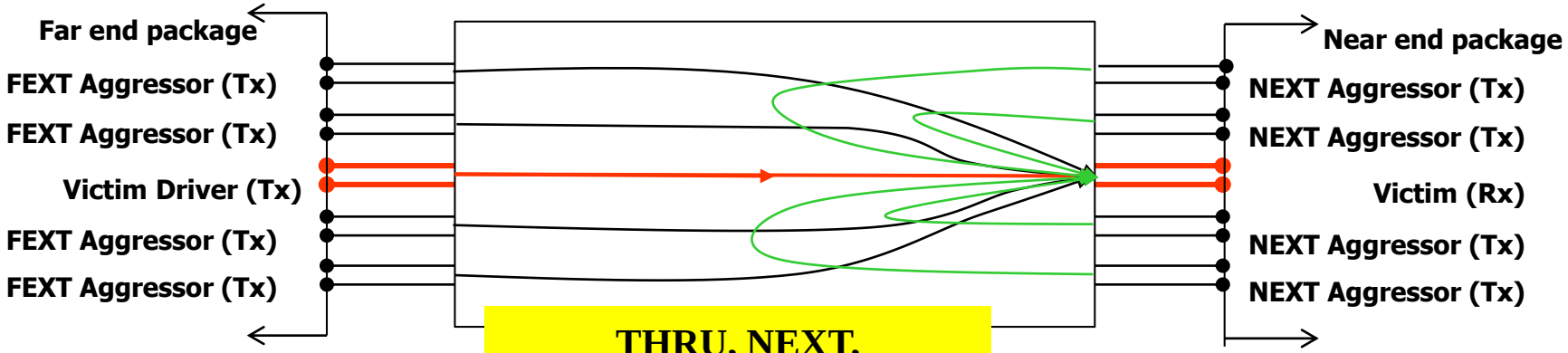
Single Transmitter to Single Receiver with Disturbers (Aggressors)

- Boards
- Connectors
- Cables

Relation to device parameters are discussed in a later slide.

Channel Model

- A **collection of 4 port s-parameters** of sufficient bandwidth and resolution which are converted into 2 port differential mode
- A channel set contains a
  - A victim channel response called **THRU**
  - Some number of far end crosstalk aggressor responses (**FEXT**)
    - Same Tx as victim
  - Some number of near end aggressor responses (**NEXT**)
    - Not same Tx as victim



COM is Computed Between Test Points TP0 and TP5

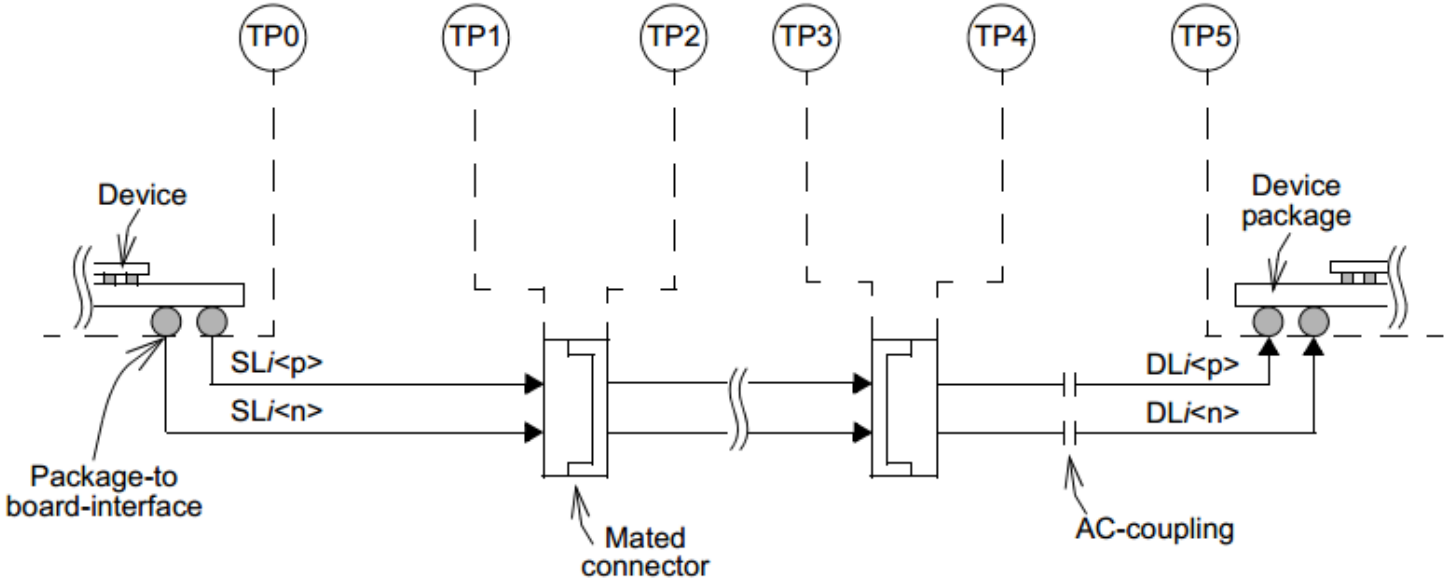
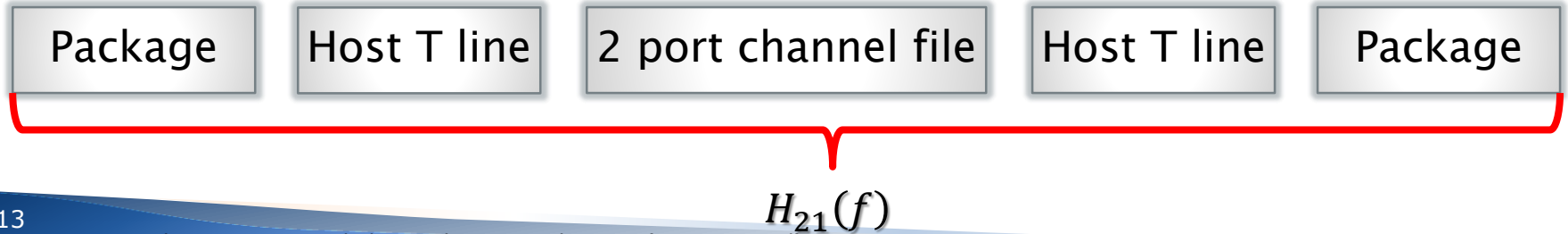


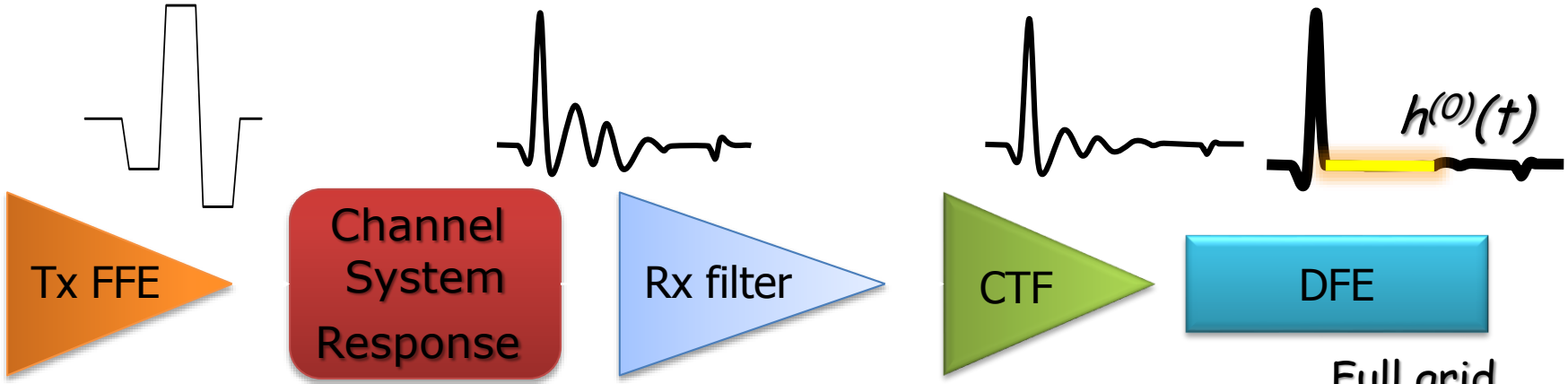
Figure 93B–1—Reference model (one direction from one lane is illustrated)

The Channel Response, $H_{21}(f)$

- First convert 4 port frequency domain s-parameters (S4P files) for victim (Thru) and aggressor (NEXT & FEXT) channels to a 2 port differential to differential mode s parameter representation
- For Cable testing, cascade a 2 port host transmission line s-parameter.
- Cascade a reverence package s parameter model
  - Transmitter parameters and target return loss limit (not normative)



Reference Signaling Architecture



Full grid equalization search is used to find best settings

$$H(f) = H_{ffe}(f)H_{21}(f)H_r(f)H_{ctf}(f)H_{bit}(f) \xrightarrow{ifft} h^{(0)}(t)$$

COM Model Annex 93A

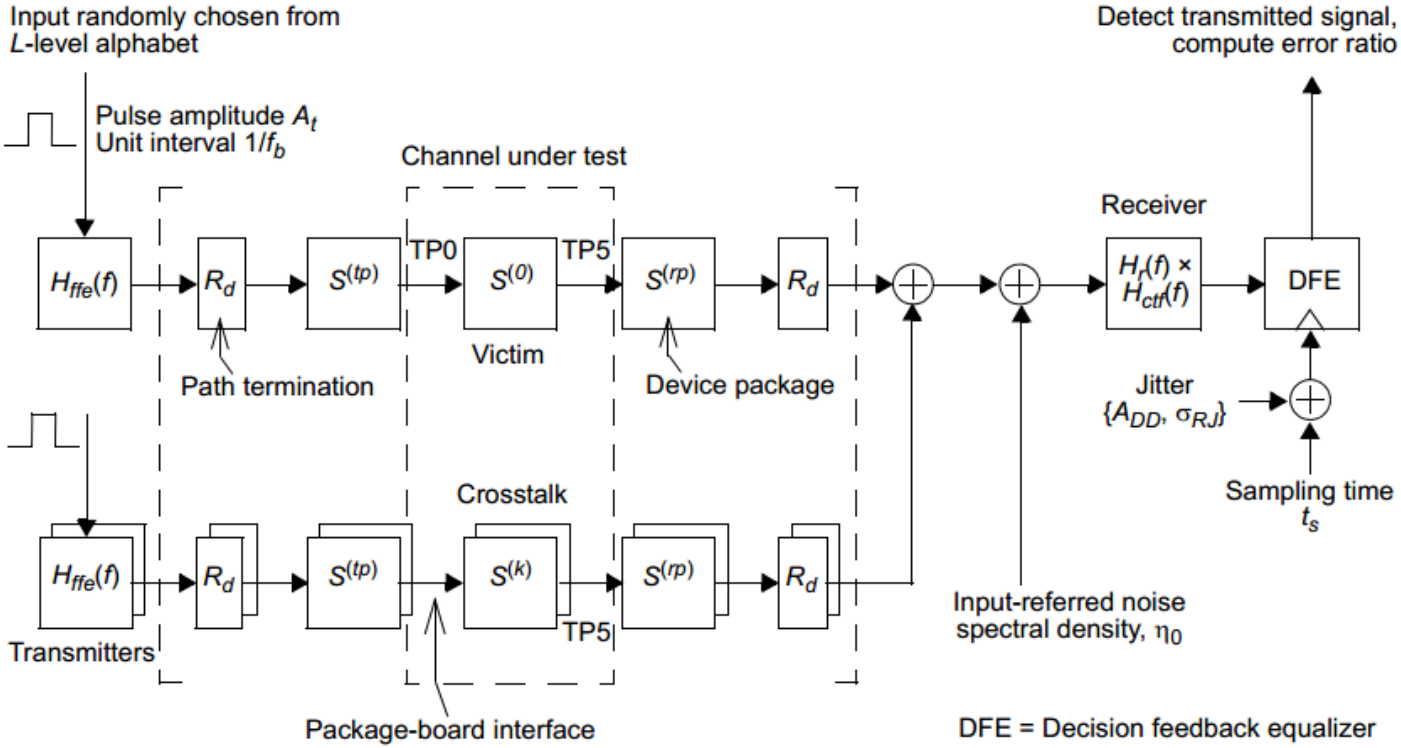
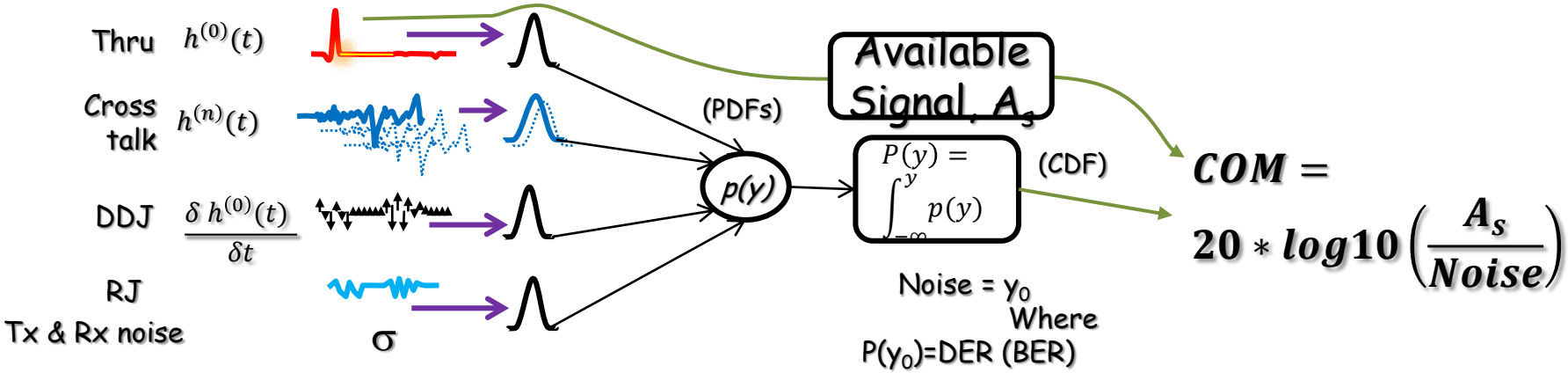


Figure 93A–1—COM reference model

The COM Simplification[2]

- Starts with converting filtered s-parameters into a SBRs $h^{(0)}(t)$, $h^{(n)}(t)$
- Convolution converts ISI and crosstalk into voltage PDFs.
- The derivative of the Thru SBR is used to compute the jitter PDF
- Tx and Rx noise determine another PDF
- *Noise* at BER is determined from the noise cumulative distribution function (CDF) created from the combined PDF's
- COM is defined as the ratio of available signal to noise



[2]R Mellitz, C Moore, M Dudek, M Li, A Ran, "Time-Domain Channel Specification: Proposal for Backplane Channel Characteristic Sections July 2012 Meeting, San Diego, CA (http://www.ieee802.org/3/bj/public/jul12/mellitz_01_0712.pdf)

Package is represented as a single ended 50 ohm referenced model IEEE802.3bj example

Parameter	Setting	Units
f_b	25.78125	GBd
f_min	0.05	GHz
Delta_f	0.01	GHz
C_d	[2.5e-4 2.5e-4]	nF
z_p select	[1 2]	
z_p (TX)	[12 30]	mm
z_p (NEXT)	[12 12]	mm
z_p (FEXT)	[12 30]	mm
z_p (RX)	[12 30]	mm
C_p	[1.8e-4 1.8e-4]	nF
R_0	50	Ohm
R_d	[55 55]	Ohm

- 250 ff die pad & 55 ohm termination
- 78 ohm package
- Two package trace lengths
  - 0.88dB loss package
    - 12mm with 38μm trace width
    - ~13Ghz destructive resonance
  - 2.2dB package
    - 30mm with 38μm trace width
- 180 ff BGA ball capacitance
- Usually a very strong performance impact

Details of Package S-parameters Concatenated with Differential Channels

93A.1.2.2 Two-port network for a shunt capacitance

The scattering parameters for a shunt capacitance with value C are defined by Equation (93A–8) where $j = \sqrt{-1}$ and $\omega = 2\pi f$.

$$S(C) = \frac{1}{2 + j\omega CR_0}\begin{bmatrix} -j\omega CR_0 & 2 \\ 2 & -j\omega CR_0 \end{bmatrix} \quad (93A–8)$$

The scattering parameters for the device capacitance C_d are denoted as $S^{(d)} = S(C_d)$ and the scattering parameters for the board capacitance C_p are denoted as $S^{(p)} = S(C_p)$.

93A.1.2.3 Two-port network for the package transmission line

The scattering parameters for the package transmission line model are a function of the complex propagation coefficient defined by Equation (93A–9), Equation (93A–10), and Equation (93A–11) and the reflection coefficient defined by Equation (93A–12). The values of the parameters that appear in these equations are defined in Table 93A–3. The units of f are GHz.

$$\gamma(f) = \begin{cases} \gamma_0 & f = 0 \\ \gamma_0 + \gamma_1\sqrt{f} + \gamma_2(f)f & f > 0 \end{cases} \quad (93A–9)$$

$$\gamma_1 = a_1(1 + j) \quad (93A–10)$$

$$\gamma_2(f) = a_2(1 - j(2/\pi)\log_e(f/1\ \text{GHz})) + j2\pi\tau \quad (93A–11)$$

$$\rho = \frac{Z_c - 2R_0}{Z_c + 2R_0} \quad (93A–12)$$

Table 93A–3—Transmission line model parameters and values

Parameter	Value	Units
γ_0	0	1/mm
a_1	1.734×10^{-3}	$ns^{1/2}$/mm
a_2	1.455×10^{-4}	ns/mm
τ	6.141×10^{-3}	ns/mm
Z_c	78.2	Ω

The scattering parameters for a package transmission line of length z_p are defined by Equation (93A–13) and Equation (93A–14). The units of z_p are mm.

$$s_{11}^{(l)}(f) = s_{22}^{(l)}(f) = \frac{\rho(1 - \exp(-\gamma(f)2z_p))}{1 - \rho^2\exp(-\gamma(f)2z_p)} \quad (93A–13)$$

$$s_{21}^{(l)}(f) = s_{12}^{(l)}(f) = \frac{(1 - \rho^2)\exp(-\gamma(f)z_p)}{1 - \rho^2\exp(-\gamma(f)2z_p)} \quad (93A–14)$$

The transmission line scattering parameter matrix is then denoted as $S^{(l)}$

Transmission line s- parameters

The Voltage Transfer Function (VTF) is the Unequalized System Response

The reflection coefficients Γ_1 and Γ_2 are defined by Equation (93A–17).

$$\Gamma_1 = \Gamma_2 = \frac{R_d - R_0}{R_d + R_0} \qquad (93A–17)$$

The voltage transfer function of the terminated signal path is defined by Equation (93A–18) where $\Delta S(f) = s_{11}(f)s_{22}(f) - s_{12}(f)s_{21}(f)$.

$$H_{21}(f) = \frac{s_{21}(f)(1-\Gamma_1)(1+\Gamma_2)}{1 - s_{11}(f)\Gamma_1 - s_{22}(f)\Gamma_2 + \Gamma_1\Gamma_2\Delta S(f)} \qquad (93A–18)$$

The voltage transfer function for the signal path represented by $S_p^{(k)}(f)$ is denoted $H_{21}^{(k)}(f)$.

This is used to create the unequalized single bit response $h^{(k)}(t)$ *for thru and all crosstalk channels*

filters

Parameter	Setting	Units
f_b	25.78125	GBd
f_r	0.75	*fb
c(0)	0.62	
c(-1)	[-0.18:0.02:0]	
c(1)	[-0.38:0.02:0]	
g_DC	[-12:1:0]	dB
f_z	6.4453125	GHz
f_p1	6.4453125	GHz
f_p2	25.78125	GHz

Bessel
Thomsen
- ~19Ghz

93A.1.4.1 Receiver noise filter

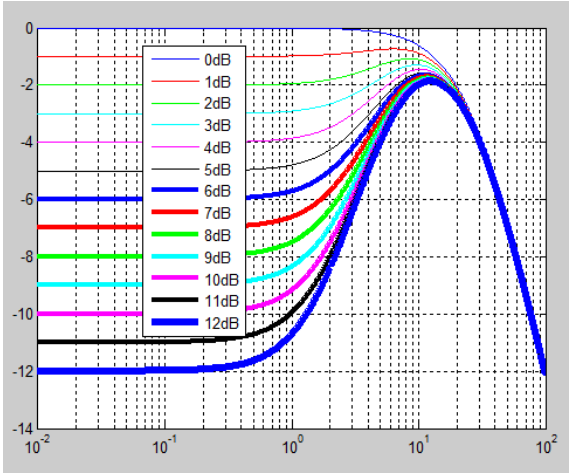
$H_r(f)$ is a noise filter defined by Equation (93A–20).

$$H_r(f) = \frac{1}{1 - 3.414214(f/f_r)^2 + (f/f_r)^4 + j2.613126(f/f_r - (f/f_r)^3)}$$

93A.1.4.3 Receiver equalizer

$H_{ctf}(f)$ is defined by Equation (93A–22)

$$H_{ctf}(f) = \frac{10^{g_{DC}/20} + jf/f_z}{(1 + jf/f_{p1})(1 + jf/f_{p2})}$$



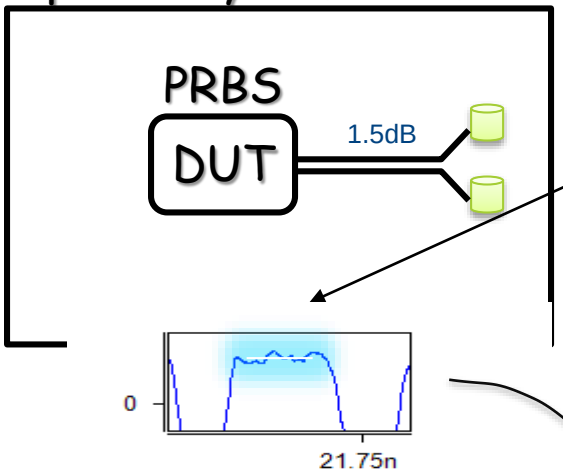
Transmitter Specifications

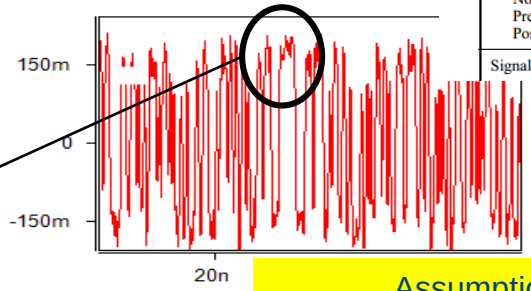
Parameter	Setting	Units
f_b	25.78125	GBd
A_v	0.4	V
A_fe	0.4	V
A_ne	0.6	V
SNR_TX	27	dB

Table 93–4—Summary of transmitter characteristics at TP0a

Parameter	Subclause reference	Value	Units
Signaling rate	93.8.1.2	25.78125±100 ppm	GBd
Differential peak-to-peak output voltage (max.) Transmitter disabled Transmitter enabled	93.8.1.3	 30 1200	 mV mV
DC common-mode output voltage (max.)	93.8.1.3	1.9	V
DC common-mode output voltage (min.)	93.8.1.3	0	V
AC common-mode output voltage (RMS, max.)	93.8.1.3	12	mV
Differential output return loss (min.)	93.8.1.4	Equation (93–3)	dB
Common-mode output return loss (min.)	93.8.1.4	Equation (93–4)	dB
Output waveform Steady-state voltage v_f (max.) Steady-state voltage v_f (min.) Linear fit pulse peak (min.) Normalized coefficient step size (min.) Normalized coefficient step size (max.) Pre-cursor full-scale range (min.) Post-cursor full-scale range (min.)	 93.8.1.5.2 93.8.1.5.2 93.8.1.5.2 93.8.1.5.4 93.8.1.5.4 93.8.1.5.5 93.8.1.5.5	 0.6 0.4 0.71 × v_f 0.0083 0.05 1.54 4	 V V V — — — —
Signal-to-noise-and-distortion ratio (min.)	93.8.1.6	27	dB

precisely defined fixture





Assumption:
unbounded Gaussian noise

$$SNDR = 10\log_{10}\left(\frac{p_{max}^2}{\sigma_e^2 + \sigma_n^2}\right) \text{ (dB)}$$

Tap Coefficients
Peak Voltage
Fits error

Jitter

Parameter	Setting	Units	Information
sigma_RJ	0.01	UI	
A_DD	0.05	UI	
eta_0	5.20E-08	V^2/GHz	
SNR_TX	27	dB	

- EOJ is assumed to be removed by Rx
- A_dd =EBUJ/2
  - Converted to dual Dirac PDF convolved with derivative of single bit response
- Sigma_RJ=ETUJ/18
  - somewhat smaller that divide by 14.
  - RJ rms
- Eta_0 converted to rms
- PDF for rms component convolved together

Output jitter (max.)	93.8.1.7		
Even-odd jitter		0.035	UI
Effective bounded uncorrelated jitter, peak-to-peak		0.1	UI
Effective total uncorrelated jitter, peak-to-peak		0.18	UI

DFE, Sample Points, and Single Bit Responses

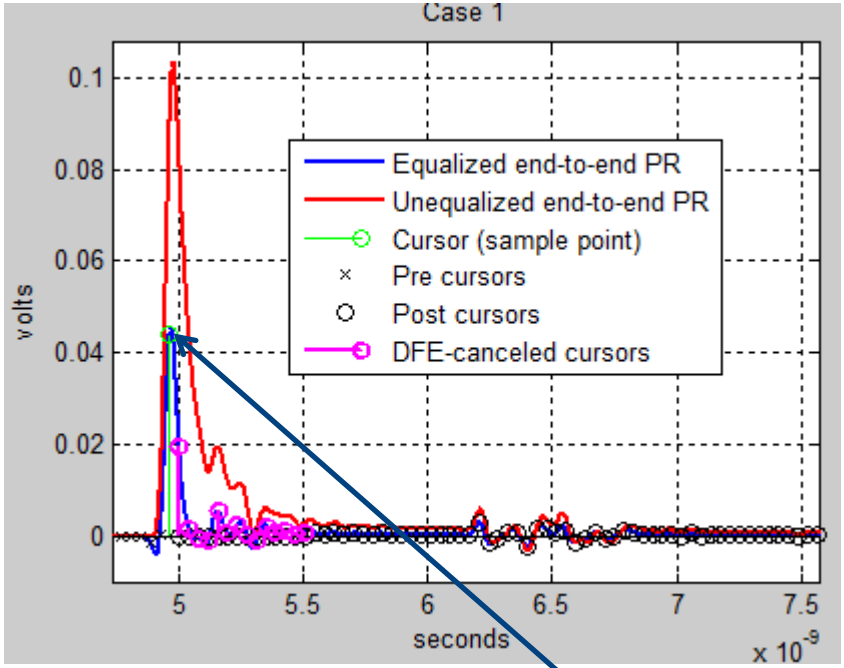


Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
N_b	14	UI	
b_max(1)	1		
b_max(2..N_b)	1		

- 14 Ideal DFE taps
- Max normalized tap is 1
  - (different for CAUI)
  - "b" or "b_max"
- $h^{(0)}(t)$ is the single bit response
  - Full grid for CTLE and Tx FFE examined
- Approximate Mueller-Muller algorithm used to determine sample point, t_s. T_b is the unit interval.

$$h^{(0)}(t_s - T_b) = h^{(0)}(t_s + T_b) - h^{(0)}(t_s)b(1)$$

Optimize SNR As FOM Determines Best Equalization Settings

$$FOM = 10\log_{10}\left(\frac{A_s^2}{\sigma_{TX}^2 + \sigma_{ISI}^2 + \sigma_J^2 + \sigma_{XT}^2 + \sigma_N^2}\right) \quad (93A\text{–}36)$$

- Transmitter RMS noise - σ_{TX}
- RMS of ISI cursors - σ_{ISI}
- Jitter converted RMS voltage - σ_J
- Coding RMS noise voltage - σ_{XT}
  - Zero for NRZ
- Receiver noise from eta_0 - σ_N
- Setting from best FOM are used for statically computation of COM

The example Matlab computation parameters tables are represented in a config spreadsheet

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	5.15625	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[1e-3 1e-3]	nF	[TX RX]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 12]	mm	[test cases]
z_p (FEXT)	[12 30]	mm	[test cases]
z_p (RX)	[12 30]	mm	[test cases]
C_p	[3e-4 3e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[55 55]	Ohm	[TX RX]
f_r	0.75	*fb	
c(0)	0.62		min
c(-1)	[-.1:0.05:0]		[min:step:max]
c(1)	[-0.25:0.125:0]		[min:step:max]
g_DC	[-12:1:0]	dB	[min:step:max]
f_z	1.2890625	GHz	
f_p1	1.2890625	GHz	
f_p2	5.16E+00	GHz	
A_v	0.4	V	
A_fe	0.4	V	
A_ne	0.6	V	
L	2		
M	32		
N_b	6	UI	
b_max(1)	0.35		
b_max(2..N_b)	0.2		
sigma_RJ	0.010	UI	1.9
A_DD	0.06	UI	23.3
eta_0	5.20E-08	V^2/GHz	
SNR_TX	30	dB	12.6
R_LM	1		
DER_0	1.00E-12		
Operational control			
COM Pass threshold	3	dB	

ps

ps

mV RMS

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
Display frequency domain	1	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\COM_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
IDEAL_TX_TERM	0	logical
T_r	8.00E-02	ns
T_r_filter_type	0	logical
T_r_meas_point	0	logical

Non standard control options		
INC_PACKAGE	1	logical
IDEAL_RX_TERM	0	logical
INCLUDE_CTLE	1	logical
INCLUDE_TX_RX_FILTER	1	logical

COM_CONTRIBUTION	1	logical

Table 93A–2 parameters		
Parameter	**Setting**	**Units**
package_tl_tau	6.141E-03	ns
package_tl_gamma0_a1_a2	[0 1.734e-3 1.455e-4]	
package_Z_c	78.2	Ohm [Tx Rx]

Table 92–12 parameters		
Parameter	**Setting**	
board_tl_tau	6.191E-03	ns
board_tl_gamma0_a1_a2	[0 4.114e-4 2.547e-4]	
board_Z_c	90	Ohm
z_bp (TX)	151	mm
z_bp (NEXT)	72	mm
z_bp (FEXT)	72	mm
z_bp (RX)	151	mm

o

cd

This is good place to start

Example of starting point for package and die load

5GBASE KR

C_d	[1e-3 1e-3]	nF	[TX RX]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 12]	mm	[test cases]
z_p (FEXT)	[12 30]	mm	[test cases]
z_p (RX)	[12 30]	mm	[test cases]
C_p	[3e-4 3e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[55 55]	Ohm	[TX RX]

2.5GBASE KR

C_d	[1e-3 1e-3]	nF	[TX RX]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 12]	mm	[test cases]
z_p (FEXT)	[12 30]	mm	[test cases]
z_p (RX)	[12 50]	mm	[test cases]
C_p	[3e-4 3e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[55 55]	Ohm	[TX RX]

- Cpad
  - 5G – 1pF
  - 2.5G 1pf (could go higher)
- 500 ff BGA to package load (another trade off parameter)
- Hi Termination resistance 55 ohms
- Package length
  - Short
    - 12mm
  - Long
    - 50mm 5G & 3G
    - Could consider asymetric budget
- Drives return loss specs
- May impact transition time specs and questions

Example of starting point for linear equalization

5GBASE KR

f_r	0.75	*fb	
c(0)	0.62		min
c(-1)	[-.1:0.05:0]		[min:step:max]
c(1)	[-0.25:0.125:0]		[min:step:max]
g_DC	[-12:1:0]	dB	[min:step:max]
f_z	1.2890625	GHz	
f_p1	1.2890625	GHz	
f_p2	5.15625	GHz	

2.5GBASE KR

f_r	0.75	*fb	
c(0)	0.62		min
c(-1)	[0]		[min:step:max]
c(1)	[0]		[min:step:max]
g_DC	[-10:1:0]	dB	[min:step:max]
f_z	0.78125	GHz	
f_p1	0.78125	GHz	
f_p2	3.125	GHz	

- CTLE
  - 2 poles, 1 zero
  - AC-DC gain
    - 5G: 0 to 12 dB, 1dB step
    - 2.5G: 0 to 10 dB, 1dB step
- Tx FFE (normalized)
  - 5G:
    - pre: -0.1,0.05,0
    - Post: -0.25,-0.125,0
  - 2.5G: none
- Butterworth Receiver filter
  - 0.75 f_b

Example of starting point for DFE and clocking

5GBASE KR

N_b	6
b_max(1)	1
b_max(2..N_b)	1

- 5G DFE6
  - Coefficients (normalized) and limited to 1
    - Driven by MTTFPA
  - Approximate: Mueller-Muller
  - DFE may be eliminated by trading off other parameters and channels
- 2.5G none
  - Approximate Bang-Bang

Example of starting point for jitter, noise, and DER (BER)

5GBASE KR

sigma_RJ	0.010	UI	1.9	ps
A_DD	0.06	UI	23.3	ps
eta_0	5.20E-08	V^2/GHz		
SNR_TX	30	dB	8.0	mV RMS

2.5GBASE KR

sigma_RJ	0.010	UI	3.1	ps
A_DD	0.085	UI	54.4	ps
eta_0	5.20E-08	V^2/GHz		
SNR_TX	30	dB	17.9	mV RMS

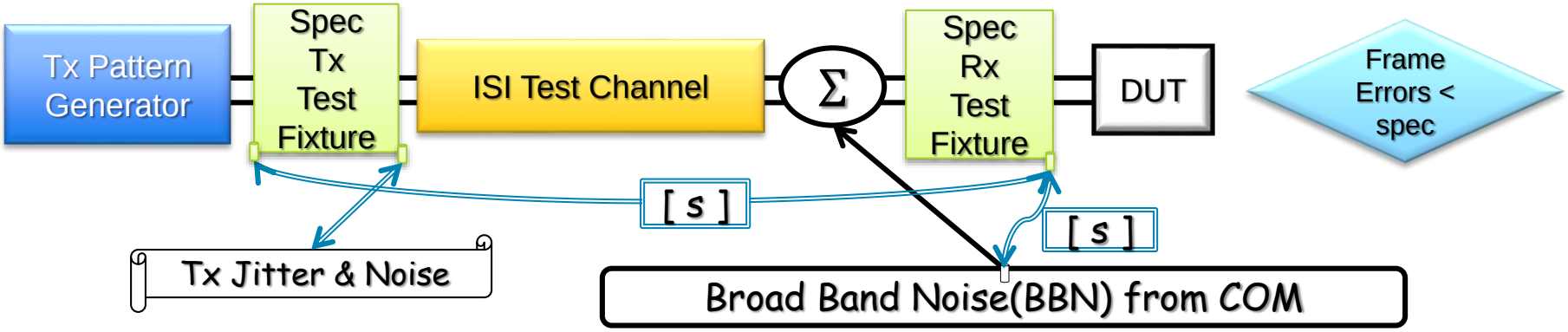
- Jitter
  - Rj
    - 5G: 1.9 ps RMS
    - 2.5G: 3.1 ps RMS
  - Dj
    - 5G: 23.3 ps
    - 2.5G: 54.4 ps
- EOJ – not in COM computation
  - Part of COM Rx budget
  - Implementation dependent
- Eta_0 taken from -155dBm/Hz + 1 mV alien system noise at RX pin
- SNR_Tx can tolerate
  - 12.5mV RMS
  - Trade off parameter

Example of starting point for COM passing threshold i.e. receiver budget.

- 3 dB
- Really need to agreed upon by SerDes folks

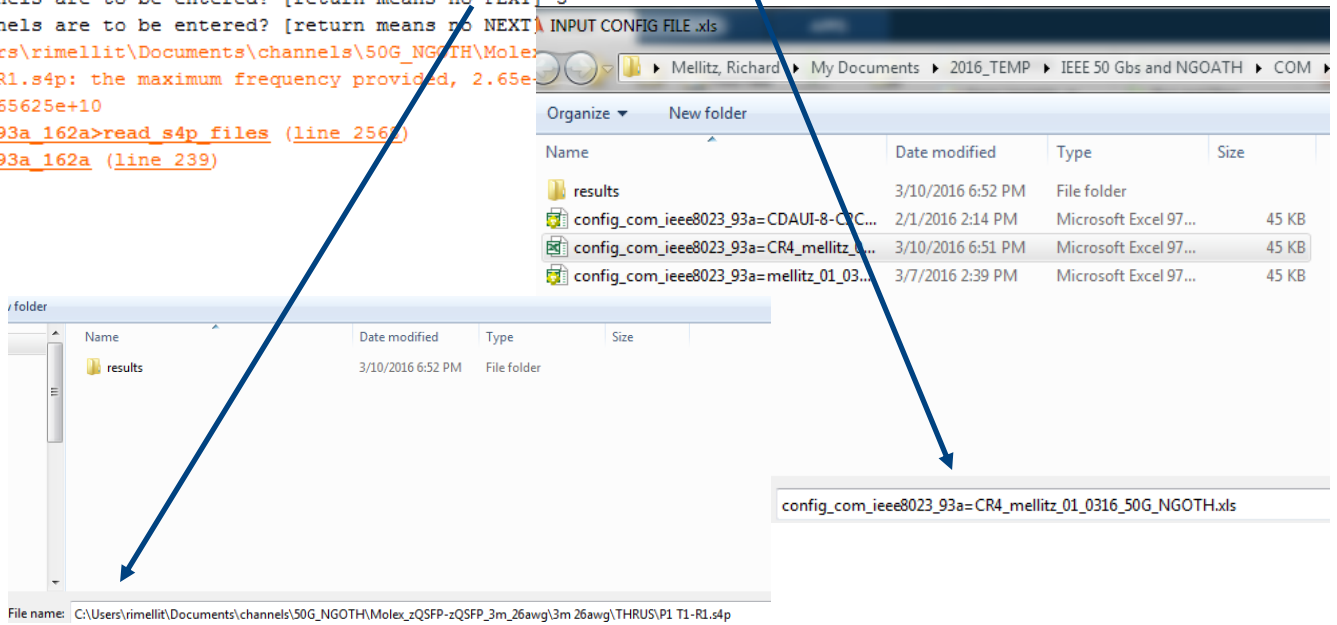
Determine Rx Noise Tolerance ties together COM, Validation and Operation.

- Acquire data for COM calculation
  - Measure Tx jitter and noise for input
  - Measure 2 sets of S-parameter
    - channel and noise path S parameters
- Acquire BBN noise from COM calculation
- The BBM is the physical tie in between COM (or simulation) and device performance in a system



Running the COM Matlab code. Interactively

```
>> com_ieee8023_93a_162a
This is not an official IEEE document.
This is a computation example for exploring COM for projects like P802.3bs development and P802.3by D2.1 ($Revision: 1.62 $)
Annex 93A is normative for some implementations
This code is a sample implementation of Annex 93A with some exploratory extensions and is not normative or official
Enter config XLS file or return will just pop a window to ask for the XLS file]:
How many FEXT channels are to be entered? [return means no FEXT] 3
How many NEXT channels are to be entered? [return means no NEXT
Warning: In C:\Users\rimellit\Documents\channels\50G_NGOTH\Molex
26awg\THRUS\P1 T1-R1.s4p: the maximum frequency provided, 2.65e
signaling rate: 2.65625e+10
> In com_ieee8023_93a_162a>read_s4p_files (line 2562)
  In com_ieee8023_93a_162a (line 239)
```



Running the example Matlab code from a command line

```
>> cable_1_dir='..\..\..\channels\ieee802p3bj\bugg_02_0511\5m_26awg\5m 26AWG Leoni\P1 RX1';
com_ieee8023_93a('config_com_ieee8023_93a=100GBASE-CR4.xls',    3,  4,...
    [cable_1_dir '\IL\TX1.s4p'],...
    [cable_1_dir '\FEXT\TX2.s4p'],'TX3.s4p','TX4.s4p',...
    [cable_1_dir '\NEXT\TX1.s4p'],'TX2.s4p','TX3.s4p','TX4.s4p')
COM tool for P802.3bj Draft 3.2/P802.3bm Draft 2.2 ($Revision: 1.54 $)
This is not an official IEEE document.
Annex 93A is normative for some implementations. This code is a sample implementation of Annex 93A and is not normative.
Warning: In ..\..\..\channels\ieee802p3bj\bugg_02_0511\5m_26awg\5m 26AWG Leoni\P1
RX1\IL\TX1.s4p: frequency step, 0.01 GHz, is larger than the recommended 0.005 GHz
> In com_ieee8023_93a>read_s4p_files at 2416
  In com_ieee8023_93a at 220
Warning: In ..\..\..\channels\ieee802p3bj\bugg_02_0511\5m_26awg\5m 26AWG Leoni\P1
RX1\FEXT\TX2.s4p: frequency step, 0.01 GHz, is larger than the recommended 0.005
GHz
> In com_ieee8023_93a>read_s4p_files at 2416
  In com_ieee8023_93a at 220
Warning: In ..\..\..\channels\ieee802p3bj\bugg_02_0511\5m_26awg\5m 26AWG Leoni\P1
RX1\FEXT\TX3.s4p: frequency step, 0.01 GHz, is larger than the recommended 0.005
```

Specify a variable with the base directory for channel files

Concatenate directories and file name and sub directories,

This is some what normal because of test equipment limitations

Simple Organization Hint

- You can use the results directory to organize data

I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
Display frequency domain	0	logical
CSV_REPORT	1	logical
SAVE_FIGURE_to_CSV	0	logical
RESULT_DIR	.\C93_test_results\	
SAVE_FIGURES	0	logical
SAVE_RESP	0	logical
Port Order	[1 3 2 4]	

- Copy “config” spread sheet and rename according to data or DUT organization
- Script in done with Matlab®
- New feature: todays date replaces the string {date} in RESULTS_DIR string.

Running COM without the display windows yields faster execution

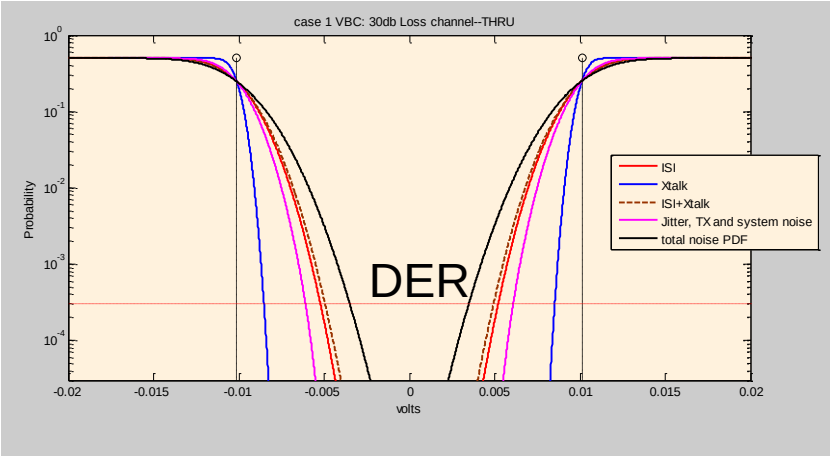
I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
Display frequency domain	0	logical

Running COM with the display windows

I/O control		
DIAGNOSTICS	1	logical
DISPLAY_WINDOW	1	logical
Display frequency domain	1	logical

A Wealth Of Assessment Data is Available in the Overlaid COM Bathtub Curves.

- COM may be used for PAM signals
- COM may be used for error correction code by adjusting the detector error ratio (DER)
- COM may be use for a variety of data rates. I.e. the concept is not bandwidth limited.

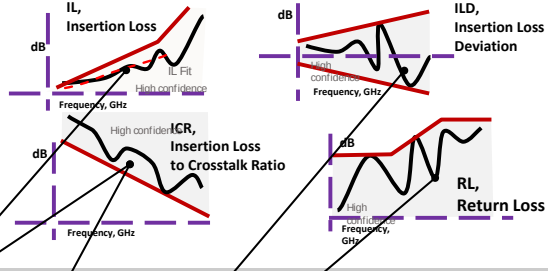


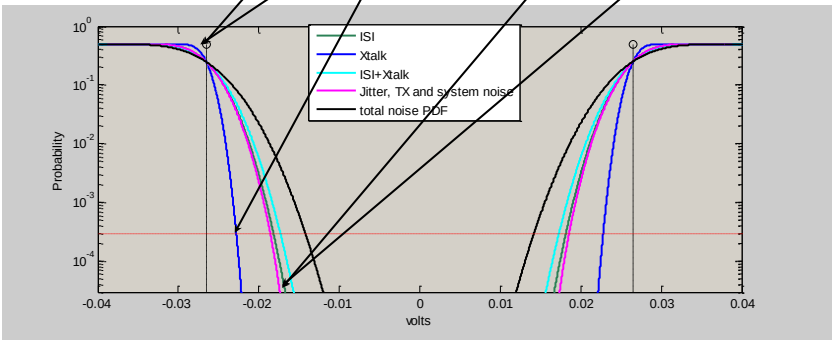
40 Gb/s PAM4 example

Interim computation results are use to

- *Diagnose channel problems*
- *Identify interesting worst case channels for Si Design*

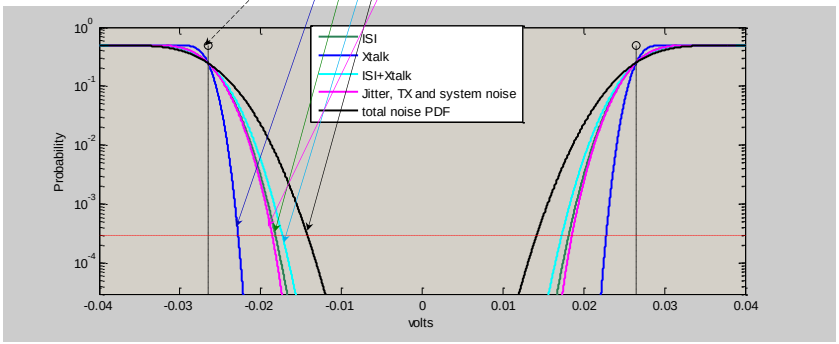
COM Diagnoses Bathtub Key



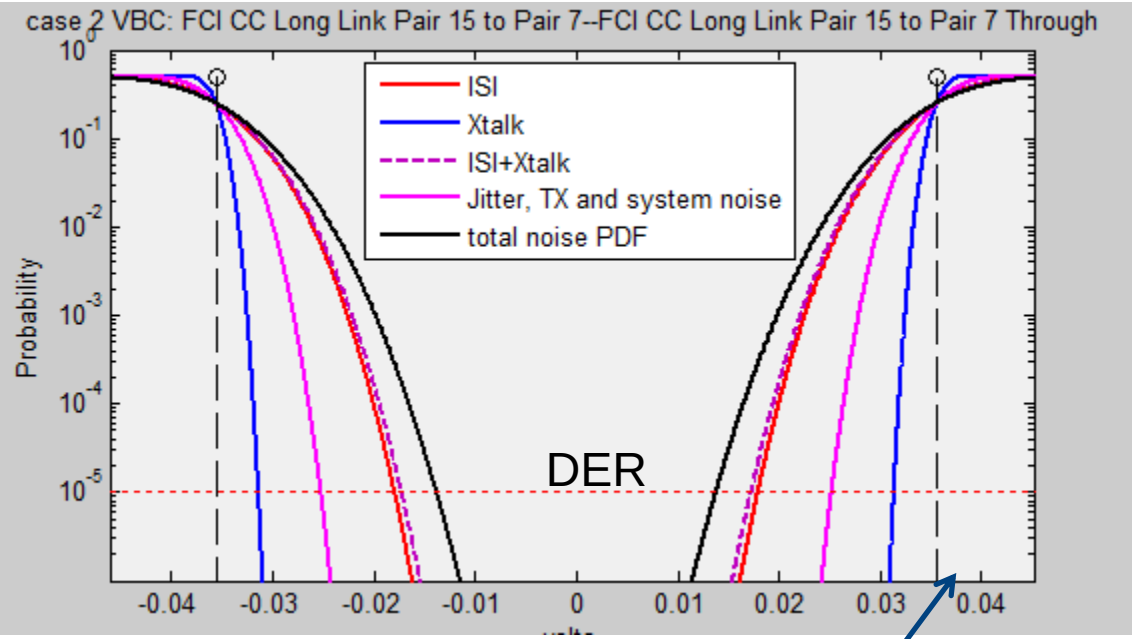


COM Diagnoses Bathtub vs Report Key

- peak_MDXTK_interference_mV
- peak_ISI_mV
- available_signal_after_eq_mV
- peak_channel_interference_mV
- peak_interference_mV:
- Device jitter and noise



Bathtub Curvers and DER

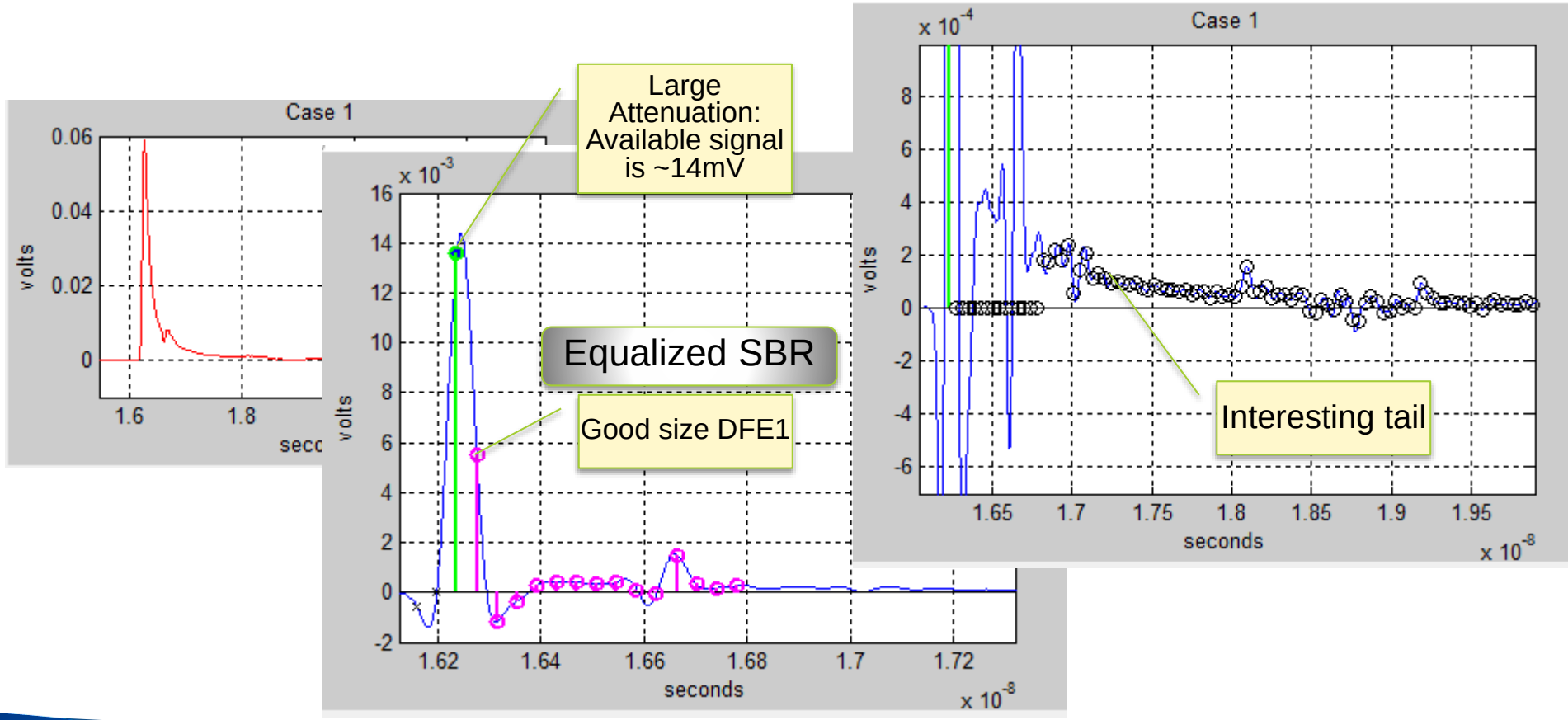


Available signal

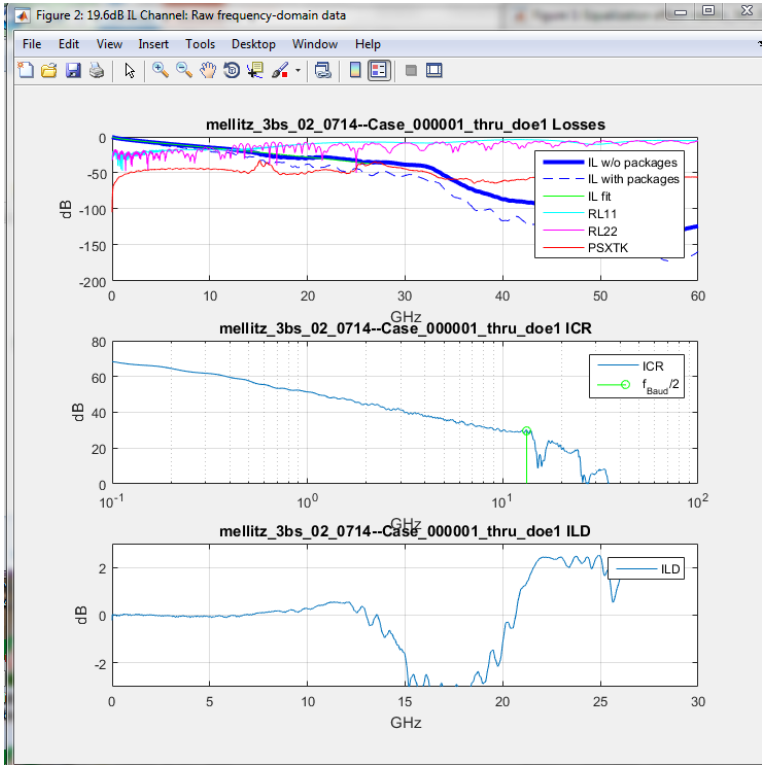
- Detector Error Ratio
- w/RS FEC : 1e-5
- wo/RS FEC : 1e-12
- Minimum COM = 3dB
  - 30% eye opening of nominal or available signal
  - COM margin left to the receiver over the reference

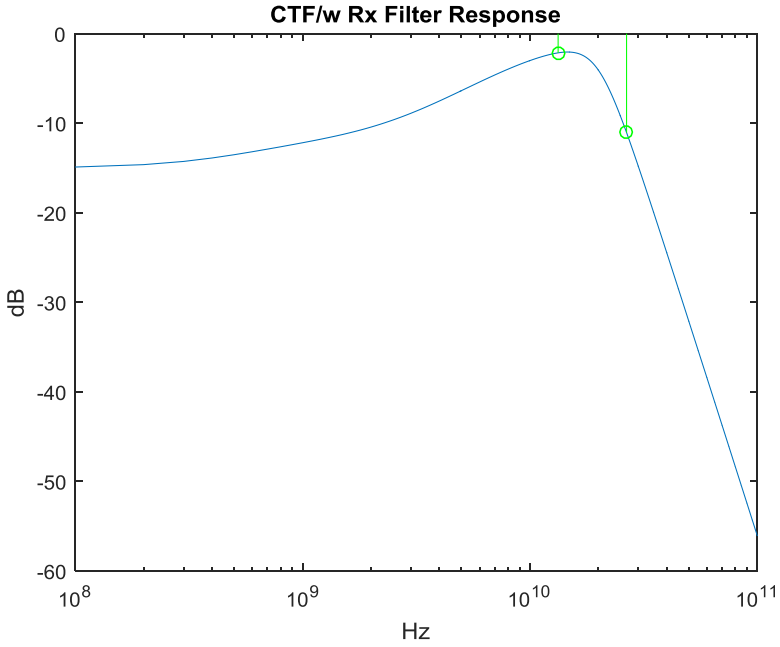
Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
DER_0	1.00E-05		
Operational control			
COM Pass threshold	3	dB	
Include PCB	0	logical	

SBR is good place to start evaluations



Other Plots Provide Frequency Domain Information and CTL Response





Rx Testing with COM: Hints

- Syntax
  - ```
    com_ieee8023_93a…
    ('config_com_ieee8023_93a=100GBASEKR4_CAL.xls',…
        1,  0,'TEC_Whisper42p8in_Meg6_THRU_C8C9.s4p','TPn to TP5 replica.s4p')
    ```
- Modify configuration Spreadsheet
  - Measured data
  - Rx noise source capability
  - Set Tx termination to Idea if Instrument is used

sigma_RJ	0.01	UI
A_DD	0.05	UI
eta_0	5.20E-08	V^2/GHz
SNR_TX	27	dB

Receiver testing		
RX_CALIBRATION	1	logical
Sigma BBN step	5.00E-04	V
BBN Q factor	5	
Force BBN Q factor	0	logical

Non standard control - Tx package control used for Rx testing		
INC_PACKAGE	1	logical
IDEAL_RX_TERM	0	logical
IDEAL_TX_TERM	1	logical
    ```

Script example

```
config_file='config_com_ieee8023_93a=CDAUI-8-C2C_D1p1_proposetemp.xls';

run_tag='_ref40';

%  'param.C_diepad','[.28 .12 ]*1e-12', 'param.C_pkg_board','[.14 .14 ]*1e-12','param.R_diepad','[60 54]','param.pkg_Z_c','[120 105
]',...

%     'OP.BREAD_CRUMBS','1','param.z_p_next_cases','[30 30]',...

ch_dir='..\..\..\channels\ieee802p3bs\50+Gbps\mellitz_3bs_02_0714\';

E(1)=com_ieee8023_93a_162(config_file,        3,4,[ch_dir 'Case_000001_thru.s4p'], ...

    'Case_000001_xtalk1.s4p','Case_000001_xtalk2.s4p','Case_000001_xtalk3.s4p', ...

    'Case_000001_xtalk4.s4p','Case_000001_xtalk5.s4p','Case_000001_xtalk6.s4p','Case_000001_xtalk7.s4p',...

    'OP.pkg_len_select','2','OP.RUNTAG',run_tag);

ch_dir='..\..\..\channels\ieee802p3bs\50+Gbps\mellitz_3bs_03_0714\';

E(2)=com_ieee8023_93a_162(config_file,        3,4,[ch_dir 'Case_000002_thru.s4p'], ...

    'Case_000002_xtalk1.s4p','Case_000002_xtalk2.s4p','Case_000002_xtalk3.s4p', ...

    'Case_000002_xtalk4.s4p','Case_000002_xtalk5.s4p','Case_000002_xtalk6.s4p','Case_000002_xtalk7.s4p',...

    'OP.pkg_len_select','2','OP.RUNTAG',run_tag);…

ch_dir='..\..\..\channels\ieee802p3bs\50+Gbps\mellitz_3bs_06a_0315\';

E(10)=com_ieee8023_93a_162(config_file,       3,4,[ch_dir 'Case_000005a_thru.s4p'], ...

    'Case_000005a_xtalk1.s4p','Case_000005a_xtalk2.s4p','Case_000005a_xtalk3.s4p', ...

    'Case_000005a_xtalk4.s4p','Case_000005a_xtalk5.s4p','Case_000005a_xtalk6.s4p','Case_000005a_xtalk7.s4p',...

    'OP.pkg_len_select','2','OP.RUNTAG',run_tag);

for i=1:10

    COM(i)=E(i).channel_operating_margin_dB;

     IL(i)=E(i).IL_dB_at_Fnq;

end
```

appendix

Report (saved in csv file in row format)

--- Testcase xx results ---	This report is produced for each package case. These parameters are reported in the report mat and cvs files.
file_names:	This is the tag used for the channel run set - it contains the thru file name
config_file:	The configuration xls files used for the report
levels:	number of symbols levels (PAM-4 is 4, NRZ is 2)
Pkg_len_TX:	Victim transmitter package trace length in mm (integer only) cases
Pkg_len_NEXT:	NEXT aggressor transmitter package trace length in mm (integer only) for this cases
Pkg_len_FEXT:	FEXT aggressor transmitter package trace length in mm (integer only) for this cases
Pkg_len_RX:	victim receiver package trace length in mm (integer only) for this cases
baud_rate_GHz:	Baud (Signaling) rate (GHz) i.e. f_b
f_Nyquist_GHz:	f_b/2
channel_operating_margin_dB:	COM value in dB for this case
peak_interference_mV:	The total noise at probability DER_0 . This is used in COM calculation
peak_channel_interference_mV:	The noise at probability DER_0 for the combined uncompensated ISI and crosstalk. This is used in the diagnosis of a channel design.
peak_ISI_mV:	The noise at probability DER_0 for only uncompensated ISI. This is used in the diagnosis of a channel design.
peak_MDXTK_interference_mV:	The noise at probability DER_0 for only all the crosstalk. This is used in the diagnosis of a channel design.
peak_MDNEXT_interference_mV:	The noise at probability DER_0 for only all NEXT crosstalk. This is used in the diagnosis of a channel design.
peak_MDFEXT_interference_mV:	The noise at probability DER_0 for only all FEXT crosstalk. This is used in the diagnosis of a channel design.
available_signal_after_eq_mV:	The amplitude of the available signal (A_s). This is used in COM calculation and VEO calculations. It is essentially defined at the sample point.
steady_state_voltage_mV:	steady state voltage
VEO_mV:	vertical eye opening at the sample point.
VEO_normalized:	normalized vertical eye opening at the sample point.

Report (cont'd)

VEC_dB:	dB of normalized vertical eye opening at the sample point.
fit_loss_dB_at_Fnq:	fitted insertion loss at f_b/2. Not intended to couple with any particular standard or method.
IL_dB_at_Fnq:	insertion loss at f_b/2 of tp0-tp5 which includes host boards if applicable
FOM_ILD:	RMS over f_b/2 span of insertion loss deviation. This may used in the diagnosis of a channel design. Not intended to couple with any particular standard or method.
ICN_mV:	RMS over f_b/2 span of power sum of the crosstalk. This may used in the diagnosis of a channel design. Not intended to couple with any particular standard or method.
equivalent_ISI_ICN:	RMS over f_b/2 span of power sum of the crosstalk and ISI. This may used in the diagnosis of a channel design. Not intended to couple with any particular standard or method.
sci_noise_FD_RMS:	obsolete
CTLE_zero_poles:	List of zero pole1 and pole2 in Hz used for the CTLE in the COM calculations
CTLE_DC_gain_dB:	DC gain in DB used for the CTLE in the COM calculations
TXLE_taps:	List of transmitter FFE taps used for the CTLE in the COM calculations
DFE_taps:	List of transmitter DFE taps used for the CTLE in the COM calculations
cci_noise_TD_BER:	obsolete
peak_interference_at_BER:	same as peak_channel_interference_mV but in volts
FOM:	Best figure of merit result from the CTLE and Tx FFE optimization.
DFE2_RSS:	Root sum squared of DFE taps 2 to last DFE tap
DFE4_RSS:	Root sum squared of DFE taps 4 to last DFE tap
error_propagation_probability:	sequential list of error propagation probabilities for each DFE tap
burst_probabilities:	sequential list of burst error probabilities for each burst length.
peak_uneq_pulse_mV	peak value of the unequalized SBR
cable_loss	cable assemble loss report when include PCB" is not 0 in the config file

Implementation parameters

COM Pass threshold	the pass fail threshold for COM in dB
CSV_REPORT	When set to 1 a CSV report is created in the results directory. The name contains the name of the thru file and case number. 0 suppressed this .
DIAGNOSTICS	When set to 0 a limited set of results are reported. When set to 1 a fuller set of results are reported. This extra parameters can be useful for diagnosing contributions and other aspects of channel design. In addition a mat file is written to the result
Display frequency domain	When set to 1 a figure containing IL, RL, PST, ILD, and ICR is displayed. 0 suppresses this.
DISPLAY_WINDOW	When set to 0 the display window are suppressed. Set to 1 may be useful when running in a batch.
Enforce Causality	When set to 1 causality is enforced for the FD to TD conversion. If set to zero a IFFT using extrapolated low and high frequency data is used to convert to time domain. Look at the SBR in figure 100. If a small amount of precursor exists set to 1.
Enforce Causality DIFF_TOL	Tolerance parameter for causality, Hard enforcement, 1e-4,Soft enforcement, 1e-3
Enforce Causality pulse start tolerance	Tolerance parameter for causality, Hard enforcement, 0.05, Soft enforcement, .02
Enforce Causality REL_TOL	Tolerance parameter for causality, Hard enforcement, 1e-3, Soft enforcement, 1e-2
Error propagation COM margin	Unsupported. Set to 0
Force PDF bin size	Normally set to 0. This forces a PDF bin size when set to 1.

Implementation parameters, cont'd

IDEAL_RX_TERM	Normally set to 0. When set to 1 an ideal termination replaces the Tx package.
IDEAL_TX_TERM	Normally set to 0. When set to 1 an ideal termination replaces the Rx package.
T_r	Rise time of transmitter, converted to a TX filter per Equation 93A-46 if IDEAL_TX_TERM is true.
INC_PACKAGE	When set to 1 the package is added to the channel model. If the channel model contains a package set this to 0. When set to 0 C_d, z_p select, z_p (TX), z_p (NEXT),z_p (FEXT), z_p (RX), C_p, R_0, and R_d are ignored.
Include PCB	This is normally set to 0. Set to 1 for CR4. When set to 1 a PCB board is concatenated on both sides of the tested channel as specified in 92.10.7.1.1.
INCLUDE_CTLE	Normally set to 1. When set to 0 the CTLE is omitted from analysis.
INCLUDE_TX_RX_FILTER	Normally set to 1. If set to 0 the Tx and Rx filter are omitted. However Tx FFE and CTLE are no affect by this parameter.
Max burst length calculated	Used for calculation of probabilities of error bursts due to DFE error propagation.
PDF bin size	the value in volts which is the size of PDF voltage bins. Essentially can be used a noise filter as any value lower than this voltage is considered as 0 V.
Port Order	order for s-parameter ports [tx+, tx-, Rx+, Rx-]. Normally set to [1 3 2 4]
RESULT_DIR	The name of the results directory. May use relative references. If contains the string {date} todays date replaces {date}
RX_CALIBRATION	Set to 0 for regular channel analysis. Set to 1 for calibrating the noise source in RX compliance test (Annex 93C.2).
Sigma BBN step	Initial step used for noise adjustment in Rx calibration.
SAVE_FIGURE_to_CSV	Set to one to save figure contents in .csv files in RESULTS_DIR.
SAVE_FIGURES	Set to one to save .fig files in RESULTS_DIR.
COM_CONTRIBUTION	When set to 1 a rough approximation of COM contributions chart replaces the bathtub curves. When set to 0 the bathtub curves are displayed
BREAD_CRUMBS	BREAD_CRUMBS if 1 then a mat file with the structures "params" and "OP" is created in the results directory

COM parameters

Table 93A-1 parameters		
f_b		Baud (Signaling) rate
f_min		minimum required frequency start for s parameters
Delta_f		minimum required frequency step size s parameters
C_d		Device package model, Single-ended device capacitance (die pad)
z_p select		z_p test cases to run with correspond to respecive z_p (TX),z_p (NEXT),z_p (FEXT),z_p (RX) values
z_p (TX)		List of victim transmitter package trace lengths in mm, one per case
z_p (NEXT)		List of NEXT aggressor transmitter package trace lengths in mm, one per case
z_p (FEXT)		List of FEXT aggressor transmitter package trace lengths in mm, one per case
z_p (RX)		List of victim reciever package trace lengths in mm, one per case
C_p		Single-ended package-to-board capacitance (BGA ball)
R_0		reference single-ended impedance
R_d		Device package model, Single-ended termination resistance
f_r		Receiver 3 dB bandwidth for the 4th order Bessel-Thomson filter
c(0)		TX equalizer cursor minimum value (actual value is calculated as 1-c(-1)-c(1), skipped if smaller than the minimum)
c(-1)		TX equalizer pre cursor individual settings or range
c(1)		TX equalizer post cursor individual settings or range
g_DC		Continuous time filter DC gain settings or range as specified in clause 93A
f_z		Continuous time filter zero frequency. Can be either a single value or a vector of the same length as g_DC.
f_p1		Continuous time filter first pole frequency. Can be either a single value or a vector of the same length as g_DC.
f_p2		Continuous time filter second pole frequency. Can be either a single value or a vector of the same length as g_DC.
A_v		Victim differential peak output voltage (half of peak to peak)
A_fe		Transmitter differential peak output voltage for Far-end aggressor
A_ne		Transmitter differential peak output voltage for Near-end aggressor
L		number of symbols levels (PAM-4 is 4, NRZ is 2)
M		samples per UI
N_b		Decision feedback equalizer (DFE) length
b_max(1)		DFE magnitude limit, first coefficient(ignored if Nb=0)
b_max(2..N_b)		DFE magnitude limit, second coefficient and on (ignored if Nb<2)
sigma_RJ		voltage sensitivey RMS Gaussian noise
A_DD		Normalized peak dual-Dirac noise, this is half of the total bound uncorrelated jitter (BUJ) in UI
eta_0		One-sided noise spectral density
SNR_TX		transmitter SNR noise (RMS)
R_LM		Ratio of level separation mismatch. Relevant for PAM-4 only.
DER_0		Target detector error ratio

Package and board transmission line parameters

Below are parameters which represent model fit transmission line parameters		
Table 93A–3 parameters		The package trace lengths in mm are specified with z_p (TX), z_p (NEXT), z_p (FEXT), and z_p (RX). The package loads are specifed with C_d, C_p, R_0, and R_d.
package_tl_gamma0_a1_a2		Fitting parameters for package model per unit length. First element is in 1/mm and affects DC loss of package model . Second element is in $ns^{1/2}$/mm and affects loss proportional to sqrt(f). Third element is in ns/mm and affects loss proportional to f.
package_tl_tau		Represents propagation delay per unit length, for reflection effects
package_Z_c		Package model characteristic impedance
Table 92–12 parameters		The board trace lengths in mm are specified with z_bp (TX), z_bp (NEXT), z_bp (FEXT), and z_bp (RX).
board_tl_gamma0_a1_a2		Fitting parameters for board trace model per unit length. First element is in 1/mm and affects DC loss of package model . Second element is in $ns^{1/2}$/mm and affects loss proportional to sqrt(f). Third element is in ns/mm and affects loss proportional to f.
board_tl_tau		Represents propagation delay per unit length, for reflection effects
board_Z_c		Package model characteristic impedance

New Parameter in rev 162a

New		
c(-2)		TX equalizer pre cursor tap -2 individual settings or range .If not present ignored
c(2)		TX equalizer post cursor tap 2 individual settings or range. If not present ignored
c(3)		TX equalizer post cursor tap 3 individual settings or range. If not present ignored
g_DC_HP		Sweepable AC-DC gain
f_HP_PZ		pole-zero location

Param and OP matlab structure (output if Bread Crumbs is set)

param.

fb	specBER	z_p_rx_cases
max_start_freq	pass_threshold	pkg_gamma0_a1_a2
max_freq_step	sigma_RJ	pkg_tau
tx_ffe_c0_min	A_DD	pkg_Z_c
tx_ffe_cm1_values	eta_0	brd_gamma0_a1_a2
tx_ffe_cp1_values	SNDR	brd_tau
ndfe	R_LM	brd_Z_c
ctle_gdc_values	samples_per_ui	z_bp_tx
CTLE_fp1	bmax	z_bp_next
CTLE_fp2	C_pkg_board	z_bp_fext
CTLE_fz	C_diepad	z_bp_rx
a_thru	R_diepad	snpPortsOrder
a_fext	Z0	f_v
a_next	z_p_tx_cases	f_f
levels	z_p_next_cases	f_n
	z_p_fext_cases	f_r

OP.

include_pcb	BREAD_CRUMBS	PHY
INCLUDE_CTLE	ENFORCE_CAUSALITY	RUNTAG
INCLUDE_FILTER	EC_REL_TOL	use_simple_EP_model
force_pdf_bin_size	EC_DIFF_TOL	nburst
BinSize	EC_PULSE_TOL	COM_EP_margin
DEBUG	pkg_len_select	
DISPLAY_WINDOW	RX_CALIBRATION	
CSV_REPORT	sigma_bn_STEP	
SAVE_FIGURES	BBN_Q_factor	
SAVE_FIGURE_to_CSV	force_BBN_Q_factor	
GET_FD	transmitter_transition_time	
INC_PACKAGE	LIMIT_JITTER_CONTRIB_TO_DFE_SPAN	
IDEAL_RX_TERM	impulse_response_truncation_threshold	
IDEAL_TX_TERM	interp_sparam_mag	
EXTERNAL	interp_sparam_phase	
RESULT_DIR		

com_ieee8023_93a_162a revision document

Richard Mellitz

Intel Corporation

Added or Augmented Configuration File Commands

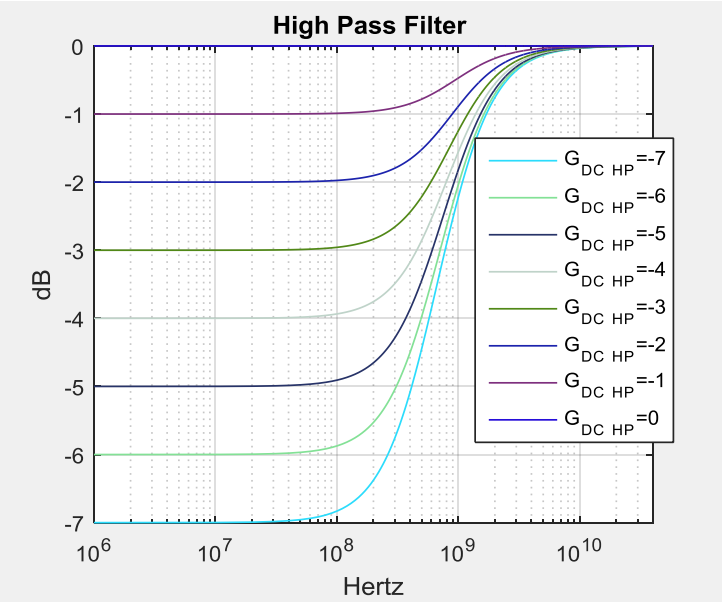
keyword	example		information	new actions
c(-2)	[0:0.01:0.1]		*[min:step:max]*	*no action if not present*
c(2)	[0:0.01:0.1]		*[min:step:max]*	*no action if not present*
c(3)	[-0.15:0.05:0]		*[min:step:max]*	*no action if not present*
g_DC_HP	[-7:1:0]	dB	*[min:step:max]*	*no action if not present*
f_HP_PZ	1	GHz		*no action if not present*
COM_CONTRIBUTION	1	logical	*COM bar graph comtribution estimates*	*revert to bathtub curves as in ran_com_3bj_3bm_01_1114 if 0 or not present*
T_r_filter_type	0	logical	*0 = 83a-36 Gaussian* *1 = fixed Gaussian*	*no action if not present*
T_r_meas_point	0	logical	*0 = meas. at tp0 or PGC* *1 = meas. at tp0a*	*Not implemented*
IDEAL_TX_TERM	0	logical	*0 = do not use H_t filter* *1= use B-T filter for H_t filter*	*same as ran_com_3bj_3bm_01_1114 if 0 or not present*
IDEAL_TX_TERM = 0 and T_r_filter_type = 1		logical	*use B-T filter for H_t filter in addtion to adding package*	*NA*
RESULT_DIR	.\results\COM_{date}\		*directory where results are written* *{date} is replace with current date*	*NA*
BREAD_CRUMBS	0		*0 or not present* *1= write mat file for internal param and OP controls*	*no action if 0 or not present*

Lower frequency pole-zero filter:

- Added: Lower frequency pole-zero filter: 2 keywords in config file

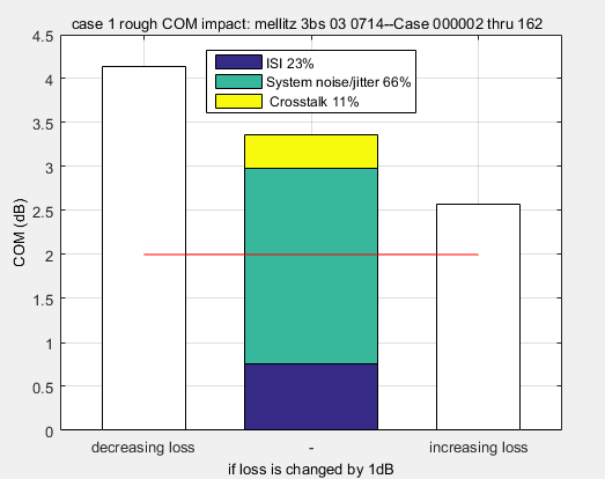
$$H_{ctf}(f) = \frac{(10^{\frac{g_{DC\_HP}}{20}} + \mathrm{j}\frac{f}{f_{HP\_PZ}})}{(1+\mathrm{j}\frac{f}{f_{HP\_PZ}})} \cdot \frac{(10^{\frac{g_{DC}}{20}} + \mathrm{j}\frac{f}{f_{z1}})}{(1+\mathrm{j}\frac{f}{f_{p1}})(1+\mathrm{j}\frac{f}{f_{p2}})}$$

- g_DC_HP
  - Sweepable AC-DC gain
- f_HP_PZ
  - pole-zero location



Added parameters and outputs

- Support for later Matlab 2015
- added output parameters
  - peak_uneq_pulse_mV – peak value of the unequalized SBR
  - cable_loss when "Include PCB" is not 0 in the config file
- added: tap c(-2) c(2) and c(3)
  - new value for "Include PCB" = 2 for cable Rx compliance test, Only the Rx host boards is added. Assumes test channels has proper loss. Can be achieve same by making z_bp (TX) and z_bp (FEXT) zero and Include PCB" = 1.
- Added
  - New keyword BREAD_CRUMBS if 1 then a mat file with the structures “params” and “OP” is created in the results directory
  - New keyword COM_CONTRIUBTION
    - When set to 1 a rough approximation of COM contributions chart replaces the bathtub curves
    - When set to 0 the bathtub curves are displayed



For RITT testing (potentially for IEEE802.3by)

Added: Keyword T_r_filter_type

- for RITT testing when IDEAL_TX_TERM is 1

0 is for is for Gaussian filter (eq 93a-46)

- $H_t(f) = \exp(-(\pi f T_r/1.6832)^2)$

1 is for fixed Gaussian filter

- $H_t(f) = \exp(-2(\pi f T_r/1.6832)^2)$

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	26.5625	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[2.8e-4 2.8e-4]	nF	[TX RX]
z_p select	[1 2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 12]	mm	[test cases]
z_p (FEXT)	[12 30]	mm	[test cases]
z_p (RX)	[12 30]	mm	[test cases]
C_p	[1.1e-4 1.1e-4]	nF	[TX RX]
R_0	50	Ohm	
R_d	[55 55]	Ohm	[TX RX]
f_r	0.75	*fb	
c(0)	0.6		min
c(-1)	[-0.15:0.05:0]		[min:step:max]
c(1)	[-0.35:0.05:0]		[min:step:max]
g_DC	[-15:1:0]	dB	[min:step:max]
f_z	10.625	GHz	
f_p1	10.625	GHz	
f_p2	1.00E+99	GHz	
A_v	0.45	V	
A_fe	0.45	V	
A_ne	0.65	V	
L	4		
M	32		
N_b	10	UI	
b_max(1)	0.5		
b_max(2..N_b)	0.2		
sigma_RJ	0.01	UI	
A_DD	0.02	UI	
eta_0	2.60E-08	V^2/GHz	
SNR_TX	31.1	dB	
R_LM	0.95		
DER_0	1.00E-05		
Operational control			
COM Pass threshold	3	dB	
Include PCB	0	Value	0, 1, 2

g_DC_HP	[-4:1:0]		[min:step:max]
f_HP_PZ	0.6640625	GHz	

I/O control		
DIAGNOSTICS	0	logical
DISPLAY_WINDOW	0	logical
Display frequency domain	1	logical
CSV_REPORT	1	logical
RESULT_DIR	.\results\COM50_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	_CDAUI-8	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
IDEAL_TX_TERM	0	logical
T_r	8.00E-03	ns
T_r_filter_type	0	logical
T_r_meas_point	0	logical

Non standard control options		
INC_PACKAGE	1	logical
IDEAL_RX_TERM	0	logical
INCLUDE_CTLE	1	logical
INCLUDE_TX_RX_FILTER	1	logical
COM_CONTRIBUTION	1	logical

Table 93A–3 parameters		
Parameter	**Setting**	**Units**
package_tl_gamma0_a1_a2	[0 1.734e-3 1.455e-4]	
package_tl_tau	6.141E-03	ns/mm
package_Z_c	85	Ohm

Table 92–12 parameters		
Parameter	**Setting**	
board_tl_gamma0_a1_a2	[0 4.114e-4 2.547e-4]	
board_tl_tau	6.191E-03	ns/mm
board_Z_c	110	Ohm
z_bp (TX)	151	mm
z_bp (NEXT)	72	mm
z_bp (FEXT)	72	mm
z_bp (RX)	151	mm

mellitz_bs_01_0116_elect Proposal example

References

- Original IEEE proposal. http://www.ieee802.org/3/bj/public/jul12/mellitz_01_0712.pdf
  - R Mellitz, C Moore, M Dudek, M Li, A Ran, "Time-Domain Channel Specification: Proposal for Backplane Channel Characteristic Sections July 2012 Meeting, San Diego, CA
- Technical detail in IEEE Std 802.3bj™-2014 Clause 93a.
- Brief overview to IEEE: IEEE. http://www.ieee802.org/3/25GSG/email/msg00130.html
- DesignCon 2014 Paper: http://www.ee.sc.edu/classes/Spring14/elct861/Class_Notes/8-TH6%20state%20of%20IEEE%20802%203bj%20100G%20Backplane%20Ethernet.pdf
  - M Brown, M Dudek, A Healey, E Kochuparambil, L Ben-Artsi, R Mellitz, C Moore, A Ran, P Zivny, "The state of IEEE 802.3bj 100 Gb/s Backplane Ethernet", DesignCon 2014, January 2014, Santa Clara, SC
- USC class lecture introducing COM. http://www.ee.sc.edu/classes/Spring14/elct861/Class_Notes/Developing%20Channel%20Operating%20Margin%20(COM).pdf
- A Healey, C Moore, R Mellitz, A Ran, L Ben-Artsi, "Proposal for a causal transmission line model" IEEE802 Plenary March 2014 Meeting, Beijing, China, http://www.ieee802.org/3/bj/public/mar14/healey_3bj_01_0314.pdf