# Study of Channel Operating Margin for Backplane and Direct Attach Cable Channels

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# Presentation overview

- Continuation of the work from kareti_50GE_NGOATH_01b_0316
- Identify major barriers to improved Channel Operating Margin (COM)
  - Begin with the parameter set from the previous presentation
  - Consider possible enhancements
    - Improve package and device termination
    - Optimize equalization
    - Reduce Gaussian noise contributors
  - Observe impact of these enhancements on COM for backplane and direct attach copper cable channels
    - Include channels in the vicinity of the 30 dB insertion loss objective

# Initial COM parameters

| 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 | [2.3e-4 2.3e-4] | nF | [TX RX] |
| z_p select | [1] | | [test cases to run] |
| z_p (TX) | [30] | mm | [test cases] |
| z_p (NEXT) | [12] | mm | [test cases] |
| z_p (FEXT) | [30] | mm | [test cases] |
| z_p (RX) | [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(-2) | [-0.15:0.05:0] | | [min:step:max] |
| c(1) | [-0.35:0.05:0] | | [min:step:max] |
| g_DC | [-20:1:0] | 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 | 15 | 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-04 | | |
| **Operational control** | | | |
| COM Pass threshold | 3 | dB | |
| Include PCB | 0 | Value | 0, 1, 2 |

| | | | |
|---|---|---|---|
| g_DC_HP | [-7:1:0] | | [min:step:max] |
| f_HP_PZ | 0.6640625 | GHz | |

| I/O control | | |
|---|---|---|
| DIAGNOSTICS | 1 | logical |
| DISPLAY_WINDOW | 1 | logical |
| Display frequency domain | 1 | logical |
| CSV_REPORT | 1 | logical |
| RESULT_DIR | .\results\COM50_{date}\ | |
| SAVE_FIGURES | 0 | logical |
| Port Order | [1 2 3 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 |

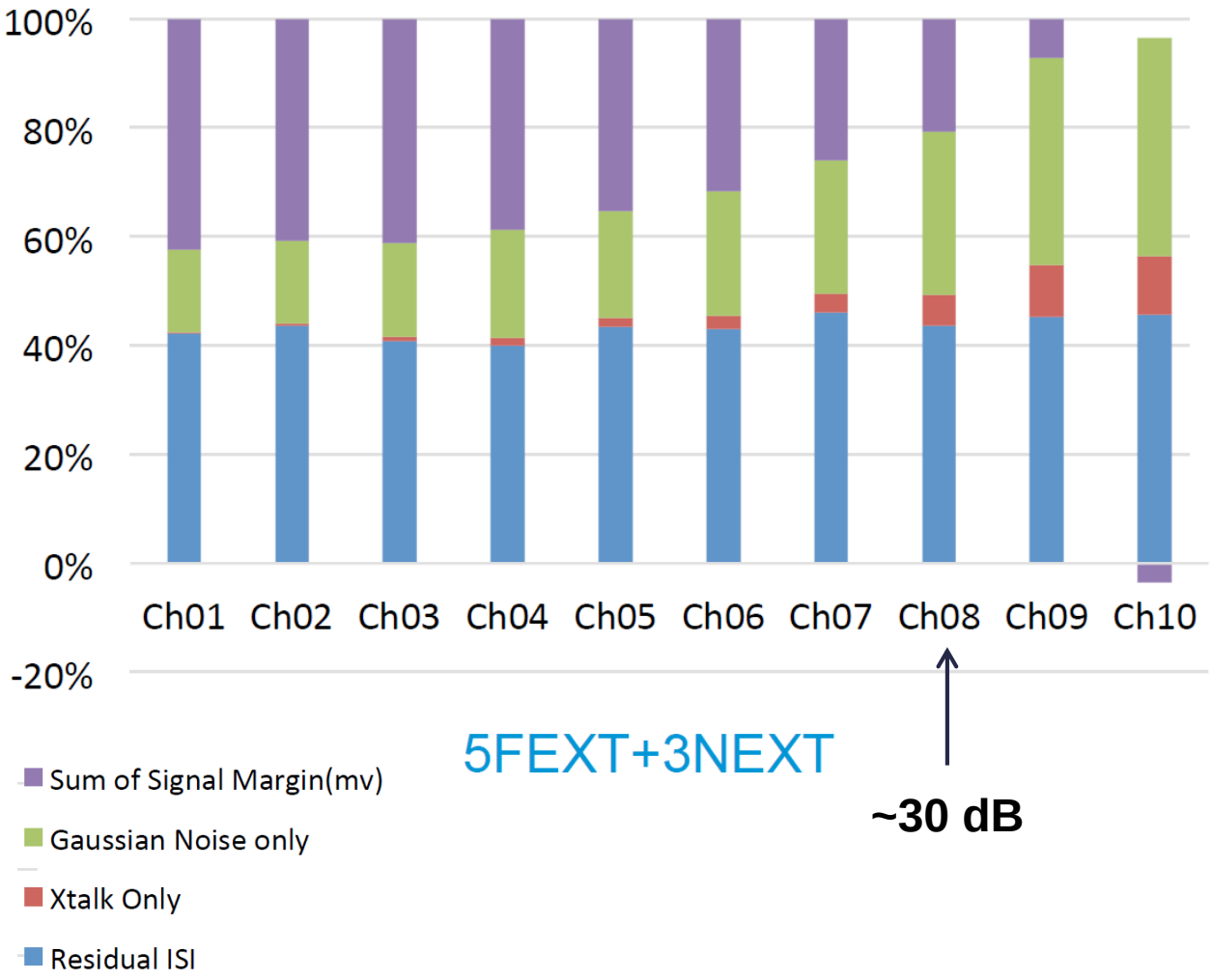
| Non standard control options | | |
|---|---|---|
| INC_PACKAGE | 1 | logical |
| IDEAL_RX_TERM | 0 | logical |
| INCLUDE_CTLE | 1 | logical |
| INCLUDE_TX_RX_FILTER | 1 | logical |
| COM_CONTRIBUTION | 0 | logical |
| CDR_OVERSAMPLED | 0 | logical |

| 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 | 90 | 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 |

# Observations from kareti_50GE_NGOATH_01b_0316

- Residual ISI is consistently the largest impairment
- As loss increases, the Gaussian noise terms become significant



# Improve package and device termination

- Consider reducing device capacitance C_d to 180 fF
- Note the package transmission line impedance package_Z_c is 90 Ohms in the initial parameters
- Note that the initial parameters do not include the transmitter rise time filter added by IEEE Std 802.3by-2016 and subsequently employed by CDAUI-8 chip-to-chip

# Optimize equalization

- Considerations for the transmitter
  - Change c(−2) sweep so that is that it has higher resolution (2.5%) and sign opposite to c(−1)
- Considerations for the receiver
  - Extend range of g_DC (to −22 dB) and g_DC_HP (to −8 dB)
  - Consider finer resolution for g_DC and g_DC_HP (0.5 dB steps)
  - Increase the range of the first DFE tap b_max(1) but leave b_max(2..N_b) at 0.2 (this is consistent with “dominant 1st tap” assumption used for precoding analysis)
  - Optimize the DFE length N_b to the smallest value that provides the majority of the benefit (12)

# Reduce Gaussian noise contributors

- Consider increasing transmitter signal-to-noise ratio SNR_TX and/or reducing one-sided noise spectral density eta_0
- Sweep SNR_TX across the values 31.1 dB, 32.5 dB, and 33.4 dB
- Sweep eta_0 from 1.3 x $10^{-8}$ to 2.6 x $10^{-8}$ $V^2$/GHz in 0.5 dB steps
- Jitter parameters are unchanged

# Results for backplane channels

| | | CISCO Channels | | | | | | | | | | TE Connectivity Channels | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ch1 | Ch2 | Ch3 | Ch4 | Ch5 | Ch6 | Ch7 | Ch8 | Ch9 | Ch10 | Ch1 | Ch2 | Ch3 | Ch4 |
| | Insertion Loss @ NQ, dB | 10.7876 | 12.4579 | 17.3145 | 20.874 | 22.3474 | 25.3573 | 27.6685 | 30.1441 | 32.859 | 34.9828 | 32.0325 | 31.1419 | 31.9702 | 33.173 |
| | FOM_ILD | 0.31042 | 0.30047 | 0.28196 | 0.31335 | 0.28224 | 0.3028 | 0.31005 | 0.30382 | 0.31247 | 0.34579 | 0.27181 | 0.14762 | 0.26931 | 0.27802 |
| | ICN, mV | 1.2534 | 1.1147 | 0.81725 | 0.72664 | 0.69128 | 0.64907 | 0.60807 | 0.57276 | 0.55667 | 0.54711 | 0.77071 | 0.77071 | 0.77071 | 0.77071 |
| | Change Log | COM @ DER_0 = 1e-4 | | | | | | | | | | | | | |
| 1 | Initial COM parameters | 4.7856 | 4.5463 | 4.5937 | 4.259 | 3.7685 | 3.3116 | 2.6154 | 2.0145 | 0.63969 | -0.32395 | 1.0317 | 1.9057 | 0.88624 | 0.89587 |
| 2 | + T_r filter : 13 ps Gaussian w/ beta = 2 | 4.4121 | 4.1437 | 4.0116 | 3.8358 | 3.1353 | 2.7217 | 2.1248 | 1.0906 | -0.21448 | -1.229 | 0.3365 | 1.0513 | 0.15777 | 0.1401 |
| 3 | + C_d = 180 fF; c(-2) = [0:0.025:0.1]; g_DC(min) = -22; g_DC_HP(min) = -8 | 5.2627 | 4.9626 | 5.0527 | 4.8218 | 4.1382 | 3.7551 | 2.926 | 2.0915 | 0.88624 | -0.41551 | 1.2999 | 2.0145 | 1.0808 | 1.0024 |
| 4 | + eta_0 = 1.3e-08; N_b = 12; b_max(1) = 1; b_max(2..N_b) = 0.2 | 5.2627 | 4.9929 | 5.1211 | 5.0829 | 4.3937 | 4.2225 | 3.5828 | 3.0733 | 2.3381 | 1.6499 | 3.0856 | 3.596 | 2.7932 | 2.9626 |
| 5 | + g_DC(min) = -20; g_DC_HP(min) = -6; 0.5 dB step size; b_max(2..N_b) = 1 | 5.2558 | 5.0205 | 5.1211 | 5.0829 | 4.4515 | 4.2225 | 3.6223 | 3.1105 | 2.3609 | 1.6709 | 3.1353 | 3.6223 | 2.8534 | 2.9748 |
| 6 | + eta_0 = 1.64e-08; SNR_TX = 32.5; b_max(1)=0.7; b_max(2..N_b)=0.2 | 5.6924 | 5.4024 | 5.519 | 5.4329 | 4.7314 | 4.4081 | 3.7551 | 3.1229 | 2.2589 | 1.4116 | 2.9139 | 3.5697 | 2.5336 | 2.7454 |
| 7 | + eta_0 = 1.84e-08; SNR_TX = 33.4; | 5.9294 | 5.6212 | 5.725 | 5.5968 | 4.8673 | 4.4951 | 3.8088 | 3.1105 | 2.1916 | 1.2899 | 2.8413 | 3.5305 | 2.5104 | 2.6861 |

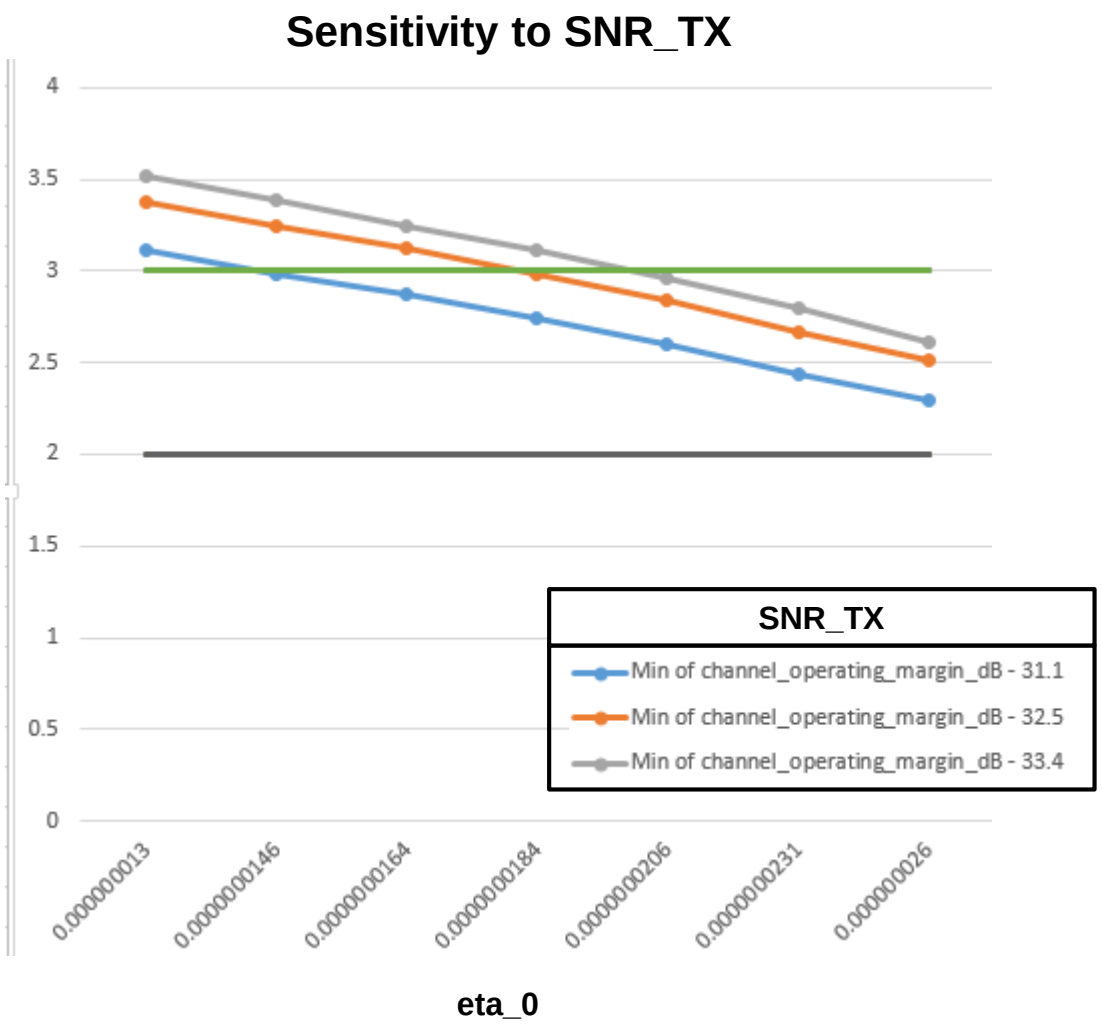
Acknowledgement: Thanks to TE Connectivity for providing available measured channels for this analysis

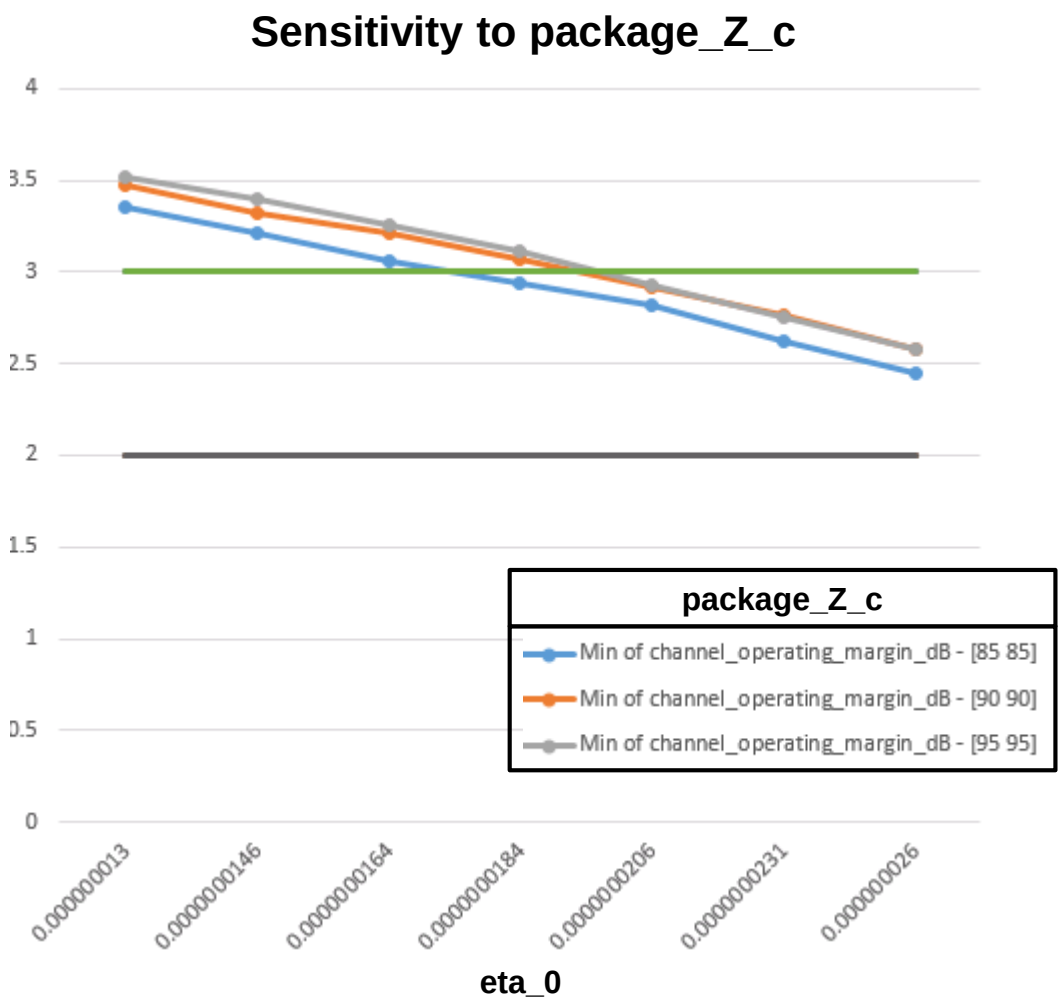
# Results for direct attach cable channels

| | | 3 m Cables | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | TE Connectivity | | | Amphenol | Generic | Molex | FCI |
| Cable Gauge | | 26 AWG | 28 AWG | 30 AWG | 26 AWG | 26 AWG | 26 AWG | 26 AWG |
| | Insertion Loss @ NQ, dB | 27.5009 | 30.0043 | 32.1525 | 28.8481 | 28.8481 | 27.2336 | 27.9278 |
| | FOM_ILD | 0.19026 | 0.27513 | 0.23573 | 0.2976 | 0.2976 | 0.1363 | 0.18498 |
| | ICN, mV | 0.62665 | 0.46826 | 0.42365 | 0.86665 | 1.5935 | 0.86358 | 0.49285 |
| | Change Log | COM @ DER_0 = 1e-4 | | | | | | |
| 1 | Initial COM parameters | 4.1242 | 2.926 | 1.841 | 2.6743 | 2.1026 | 3.9309 | 4.0685 |
| 2 | + T_r filter : 13 ps Gaussian w/ beta = 2 | 3.2735 | 2.0915 | 0.87663 | 1.9057 | 1.4116 | 3.223 | 3.2609 |
| 3 | + C_d = 180 fF; c(-2) = [0:0.025:0.1]; g_DC(min) = -22; g_DC_HP(min) = -8 | 4.1662 | 2.8413 | 1.841 | 2.7693 | 2.1359 | 4.0408 | 4.027 |
| 4 | + eta_0 = 1.3e-08; N_b = 12; b_max(1) = 1; b_max(2..N_b) = 0.2 | 5.0673 | 4.1102 | 3.5305 | 3.8358 | 3.098 | 4.8978 | 4.8978 |
| 5 | + g_DC(min) = -20; g_DC_HP(min) = -6; 0.5 dB step size; b_max(2..N_b) = 1 | 5.0673 | 4.1522 | 3.5436 | 3.8358 | 3.1105 | 5.0053 | 4.9283 |
| 6 | + eta_0 = 1.64e-08; SNR_TX = 32.5; b_max(1)=0.7; b_max(2..N_b)=0.2 | 5.1927 | 4.1943 | 3.4139 | 3.8764 | 3.1353 | 5.1927 | 5.0829 |
| 7 | + eta_0 = 1.84e-08; SNR_TX = 33.4; | 5.2561 | 4.1802 | 3.3116 | 3.89 | 3.1478 | 5.2561 | 5.1612 |

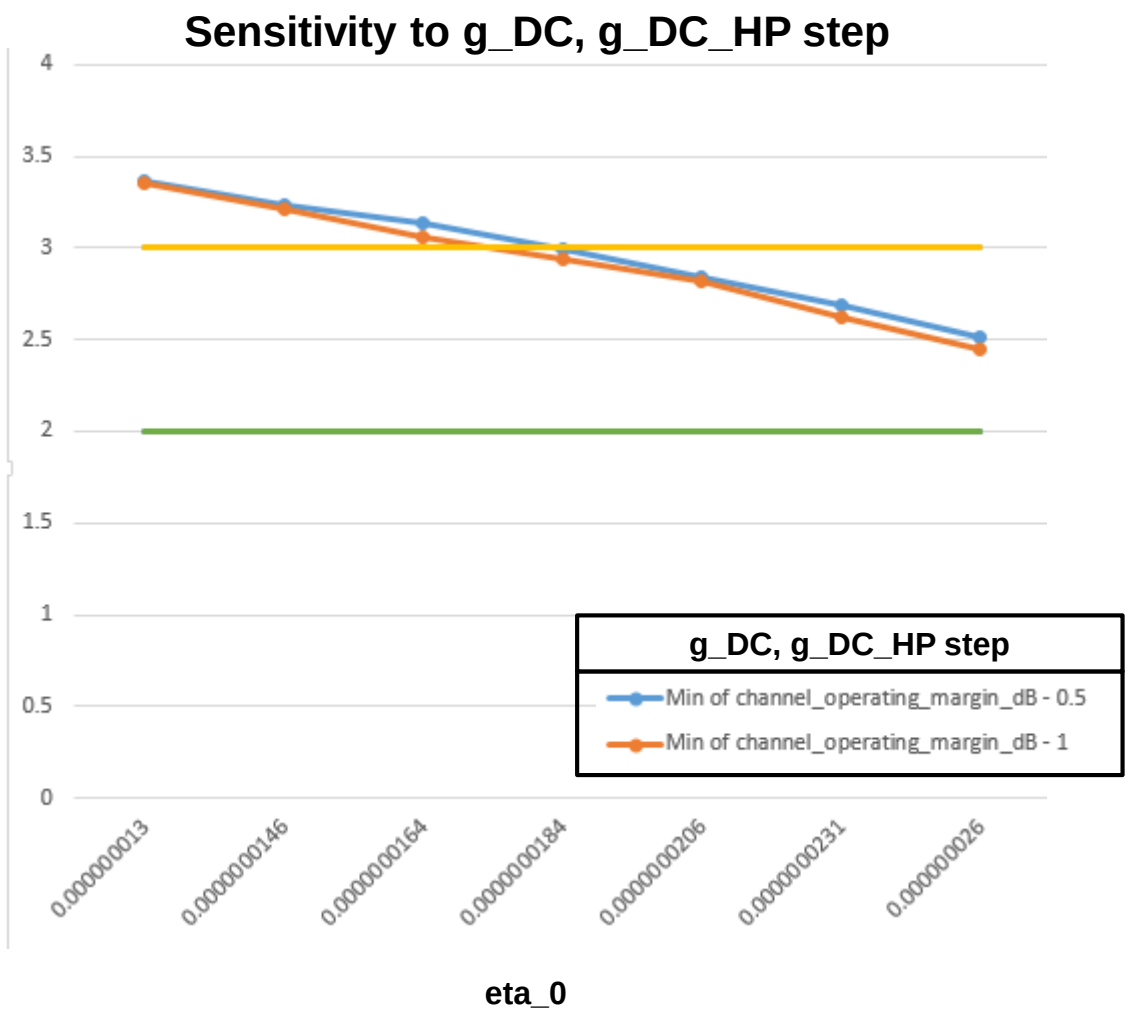
TE Connetivity, Amphenol and FCI data from their respective contributions to IEEE P802.3by Task Force. Molex data from their contribution to IEEE 802.3 50G/NGOATH Ethernet Study Groups. Results include transmitter and receiver host board models.

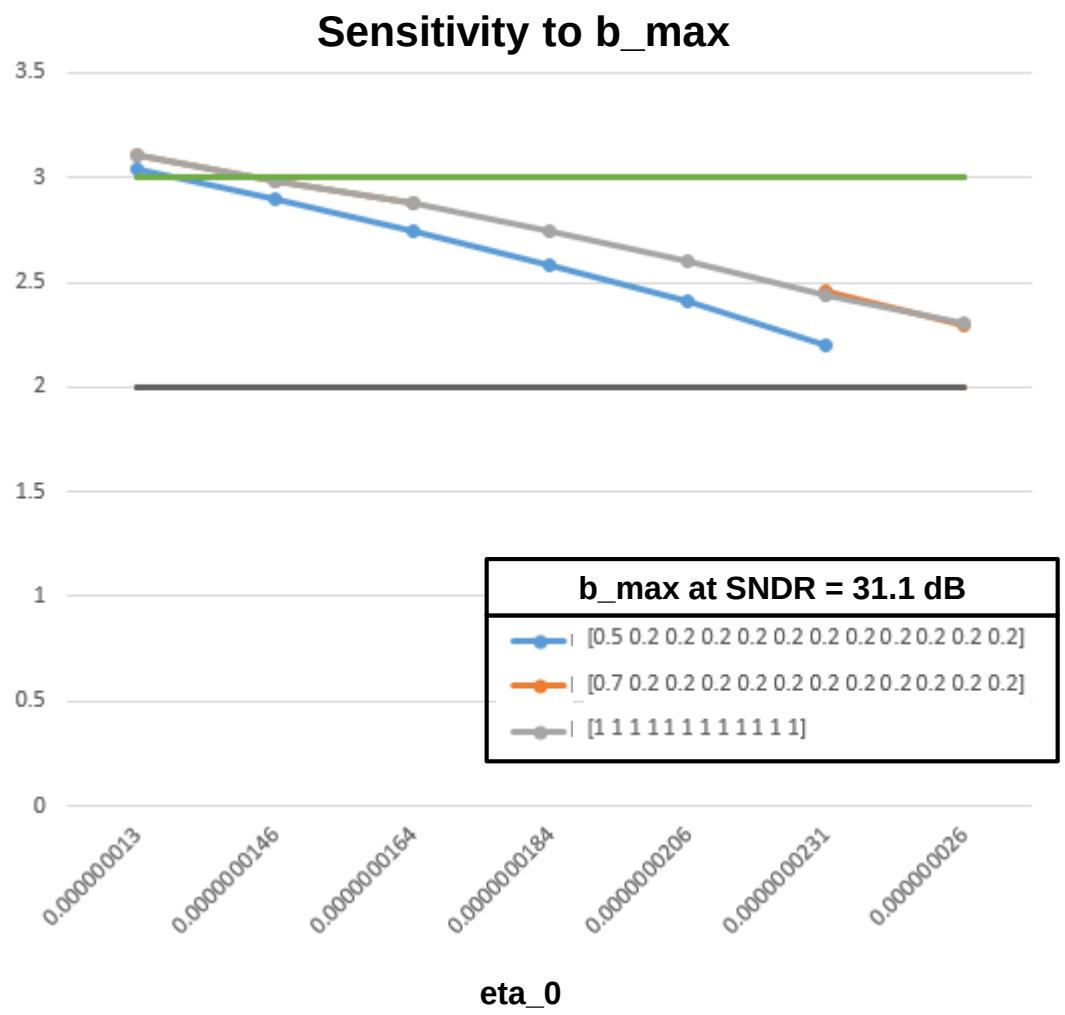
# Sensitivity analysis for Ch8 (~30 dB)



# Sensitivity analysis for Ch8 (~30 dB), continued



# Place Holder for  further Sensitivity analysis

# Summary of observations

- Enhancements to equalization were considered
  - Biggest gains from new c(−2) range, increasing b_max(1) to 0.7, extending range for g_DC  and g_DC_HP (only to a point), and increasing N_b to 12 (mostly to curb residual package reflection)
  - Small (or no) benefit for further relaxation of DFE constraints, higher g_DC and g_DC_HP resolution, or higher N_b (unless N_b becomes large)
- Reductions in noise were considered and significant gains shown
  - SNR_TX reduction implies more stringent transmitter requirements
  - Reduction in eta_0 is no different than a reduction in the COM limit – they both imply large broadband noise amplitudes for the receiver interference tolerance test

# Summary of observations, continued

- Other factors
  - Changing package_Z_c from 85 to 90 Ohms shows a visible benefit
  - However, there is little value in pushing it further
  - Similarly observations made for C_p (not presented)
- A solution suitable for 30 dB backplane seems more than adequate for 3 m direct attach copper cables
- Results indicate a solution does exist
  - Trade-offs between transmitter, channel, and receiver requirements must be carefully considered as we work toward a baseline proposal

# New basis for further work?

| 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 | [1.8e-4 1.8e-4] | nF | [TX RX] |
| z_p select | [1] | | [test cases to run] |
| z_p (TX) | [30] | mm | [test cases] |
| z_p (NEXT) | [12] | mm | [test cases] |
| z_p (FEXT) | [30] | mm | [test cases] |
| z_p (RX) | [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) | [-0.25:0.05:0] | | [min:step:max] |
| c(-2) | [0:0.025:0.1] | | [min:step:max] |
| c(1) | [-0.25:0.05:0] | | [min:step:max] |
| g_DC | [-20:1:0] | 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 | 0.63 | V | |
| L | 4 | | |
| M | 32 | | |
| N_b | 12 | UI | |
| b_max(1) | 0.7 | | |
| b_max(2..N_b) | 0.2 | | |
| sigma_RJ | 0.01 | UI | |
| A_DD | 0.02 | UI | |
| eta_0 | TBD (2.60E-08) | V^2/GHz | |
| SNR_TX | TBD (31.1) | dB | |
| R_LM | 0.95 | | |
| DER_0 | 1.00E-04 | | |
| **Operational control** | | | |
| COM Pass threshold | 3 | dB | |
| Include PCB | 0 | Value | 0, 1, 2 |

| | | | |
|---|---|---|---|
| g_DC_HP | [-6:1:0] | | [min:step:max] |
| f_HP_PZ | 0.6640625 | GHz | |

| I/O control | | |
|---|---|---|
| DIAGNOSTICS | 1 | logical |
| DISPLAY_WINDOW | 1 | logical |
| Display frequency domain | 1 | logical |
| CSV_REPORT | 1 | logical |
| RESULT_DIR | .\results\COM50_{date}\ | |
| SAVE_FIGURES | 0 | logical |
| Port Order | [1 2 3 4] | |
| RUNTAG | _CDAUI-8 | |
| **Receiver testing** | | |
| RX_CALIBRATION | 0 | logical |
| Sigma BBN step | 5.00E-03 | V |
| IDEAL_TX_TERM | 0 | logical |
| T_r | 1.30E-02 | ns |
| T_r_filter_type | 1 | 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 | 0 | logical |
| CDR_OVERSAMPLED | 0 | 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 | 90 | 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 |

# Thanks !!