Using IBIS-AMI in COM Analysis

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Agenda:

- Motivation
- Background
- Using AMI in COM Flow
- Results
- Summary
- Q & A

Motivation

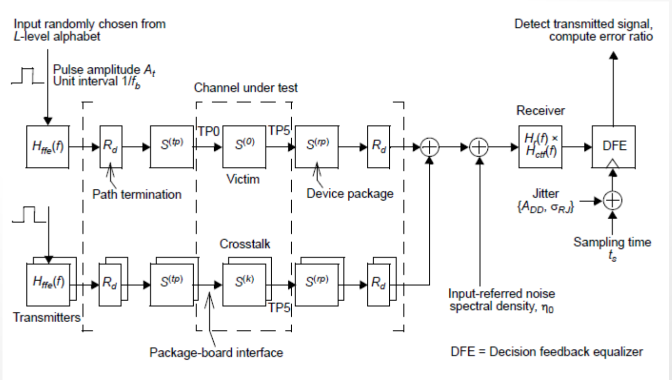
- **AMI model development :**
  - Model is not an executable, it needs driver
  - Spawn child (simulation) processes is tricky to debug
  - Optimization/flow is beyond model developer's control

- **Open source link-analysis platforms**
  - Includes useful building blocks (e.g. Figure of Merits, BER)
  - Mostly use generic Tx/Rx EQ blocks/algorithms
  - Can be adapted to use IBIS-AMI models
  - Can shorten AMI modeling design cycle
  - E.g. COM (1), (2) & PyBERT (3)

Background 1/3

- COM (Channel operating Margin)
  - Is a IEEE 802.3bj Spec (Annex 93A)
  - Published codes, well documented and maintained
  - Is a simplified version of BER analysis
  - Figure of merit based channel optimization and analysis
  - Jitter, Noise etc are also included

$$\boxed{COM = 20\log_{10}(A_s/A_{ni})}$$

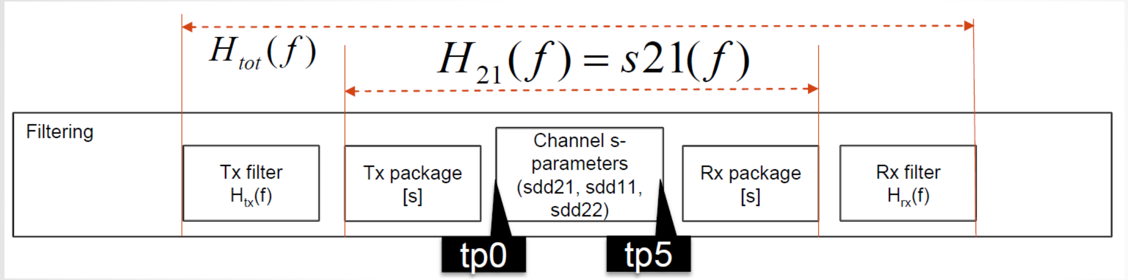


Input randomly chosen from L-level alphabet
Pulse amplitude A_t Unit interval $1/f_b$
Channel under test
Detect transmitted signal, compute error ratio
Receiver
$H_{ffe}(f)$
R_d
$S^{(tp)}$
TP0
$S^{(0)}$
TP5
$S^{(rp)}$
$H_r(f) \times H_{ctf}(f)$
DFE
Path termination
Victim
Device package
Jitter $\{A_{DD}, \sigma_{RJ}\}$
Sampling time t_s
Crosstalk
$S^{(k)}$
Transmitters
Input-referred noise spectral density, η_0
Package-board interface
DFE = Decision feedback equalizer

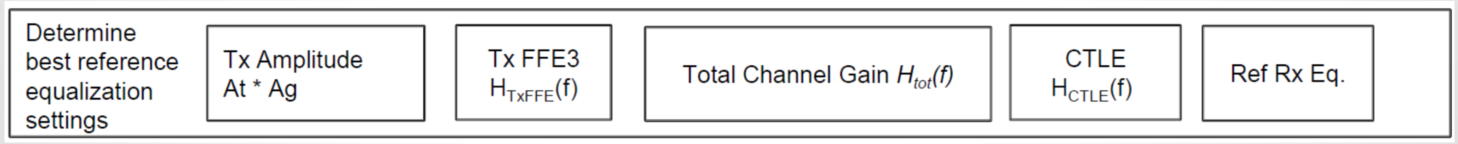
Figure 93A–1—COM reference model

Background 2/3

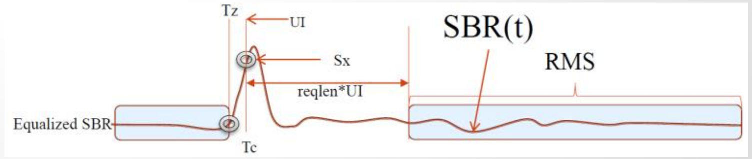
- COM has channel components and conditioning algorithms



- Use FOM to find FFE, CTLE settings, then apply DFE for BER

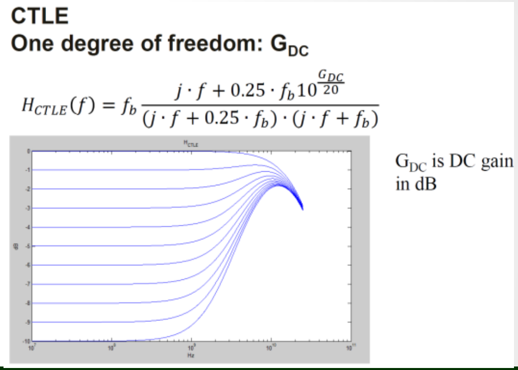

Determine best reference equalization settings
Tx Amplitude At * Ag
Tx FFE3 $H_{TxFFE}(f)$
Total Channel Gain $H_{tot}(f)$
CTLE $H_{CTLE}(f)$
Ref Rx Eq.

- Single-bit-response based



Background 3/3

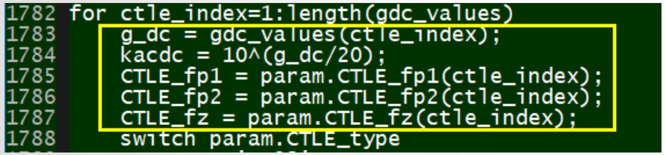
- COM use exhaustic search for FFE + CTLE (4)
  - Generic implementations
  - CTLE is gdc only
  - DFE is not optimized together



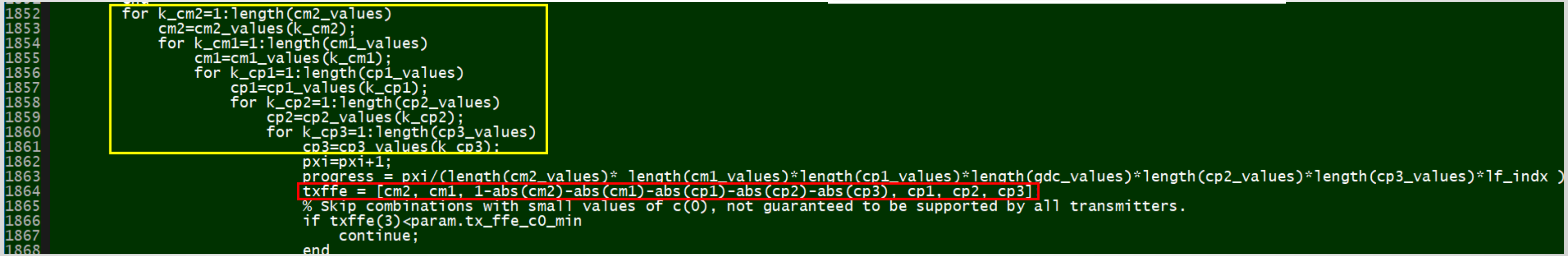
CTLE
One degree of freedom: G_{DC}

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

G_{DC} is DC gain in dB

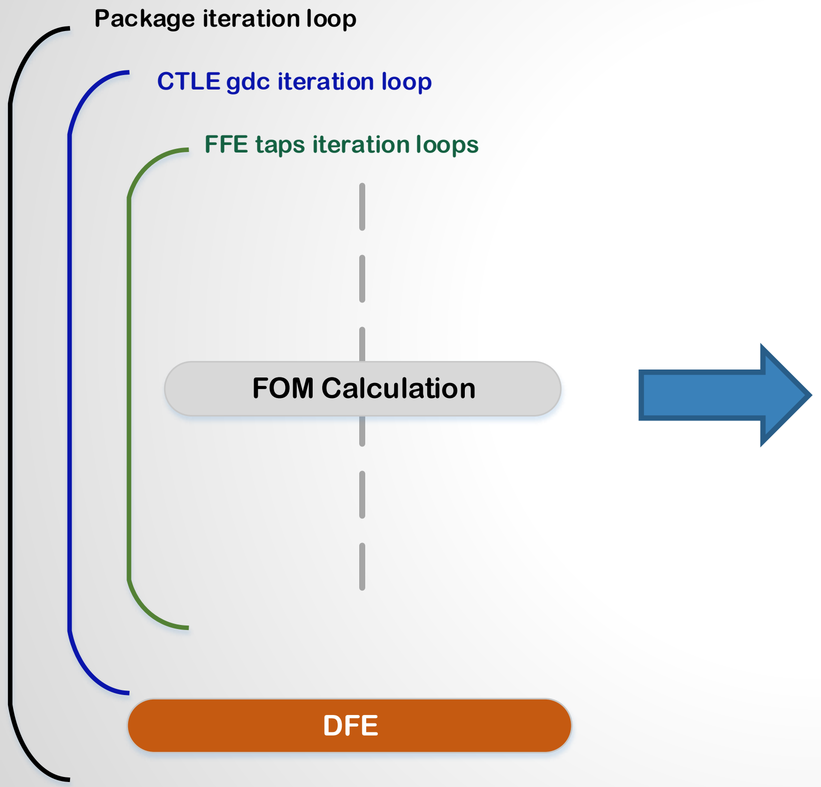


```
for ctle_index=1:length(gdc_values)
    g_dc = gdc_values(ctle_index);
    kacdc = 10^(g_dc/20);
    CTLE_fp1 = param.CTLE_fp1(ctle_index);
    CTLE_fp2 = param.CTLE_fp2(ctle_index);
    CTLE_fz = param.CTLE_fz(ctle_index);
    switch param.CTLE_type
```

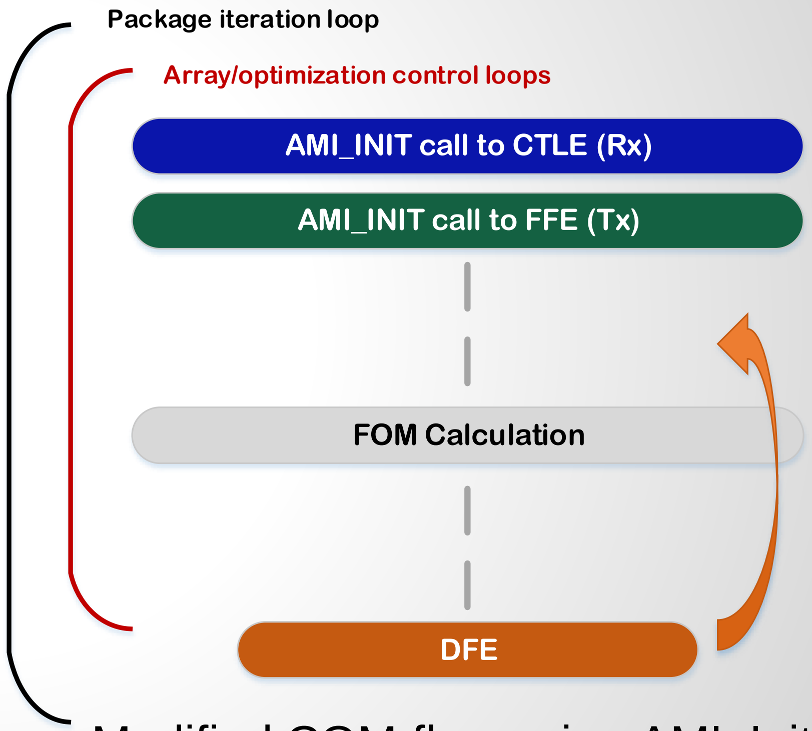


```
        for k_cm2=1:length(cm2_values)
            cm2=cm2_values(k_cm2);
            for k_cm1=1:length(cm1_values)
                cm1=cm1_values(k_cm1);
                for k_cp1=1:length(cp1_values)
                    cp1=cp1_values(k_cp1);
                    for k_cp2=1:length(cp2_values)
                        cp2=cp2_values(k_cp2);
                        for k_cp3=1:length(cp3_values)
                            cp3=cp3_values(k_cp3);
                            pxi=pxi+1;
                            progress = pxi/(length(cm2_values)* length(cm1_values)*length(cp1_values)*length(gdc_values)*length(cp2_values)*length(cp3_values)*lf_indx )
                            txffe = [cm2, cm1, 1-abs(cm2)-abs(cm1)-abs(cp1)-abs(cp2)-abs(cp3), cp1, cp2, cp3]
                            % Skip combinations with small values of c(0), not guaranteed to be supported by all transmitters.
                            if txffe(3)<param.tx_ffe_c0_min
                                continue;
                            end
```

Use AMI models in COM 1/2 (5)

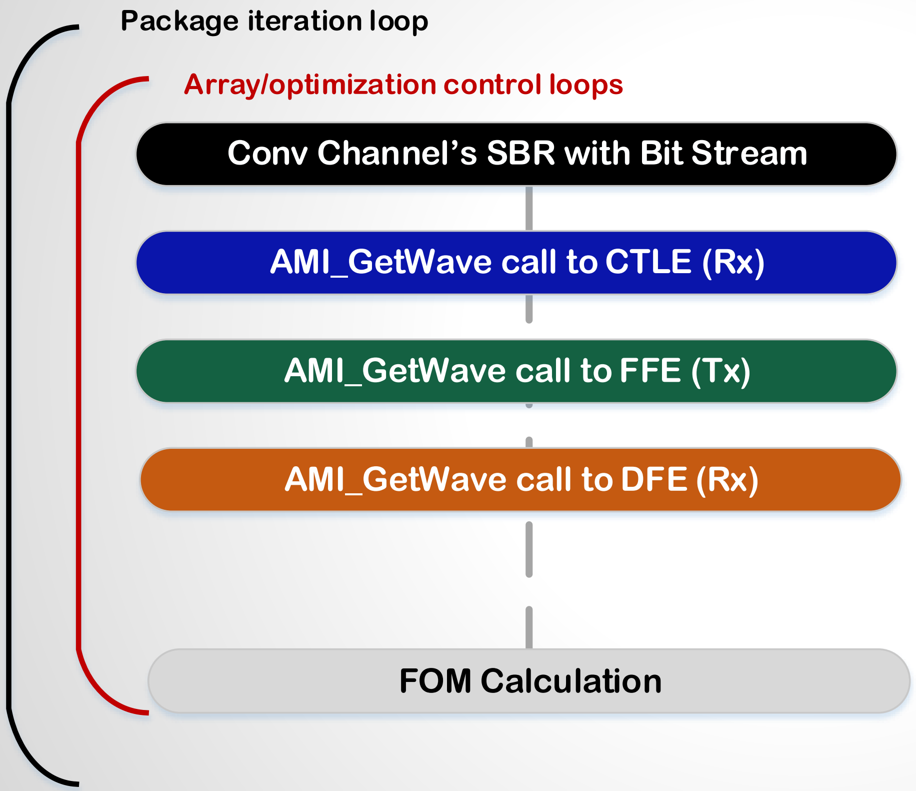


Original COM flow


Package iteration loop
Array/optimization control loops
AMI_INIT call to CTLE (Rx)
AMI_INIT call to FFE (Tx)
FOM Calculation
DFE

Modified COM flow using AMI_Init

Use AMI model in COM 2/2


Package iteration loop
Array/optimization control loops
Conv Channel’s SBR with Bit Stream
AMI_GetWave call to CTLE (Rx)
AMI_GetWave call to FFE (Tx)
AMI_GetWave call to DFE (Rx)
FOM Calculation

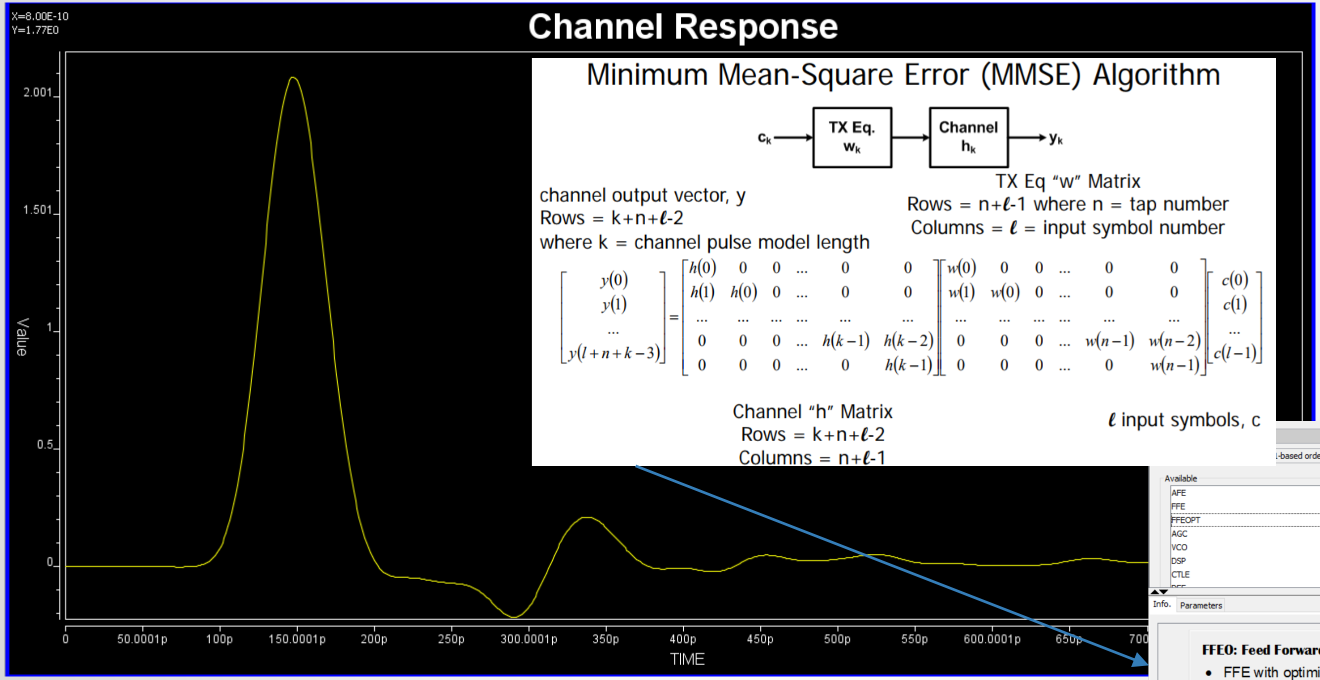
Modified COM flow using AMI_GetWave (Bit-by-bit)

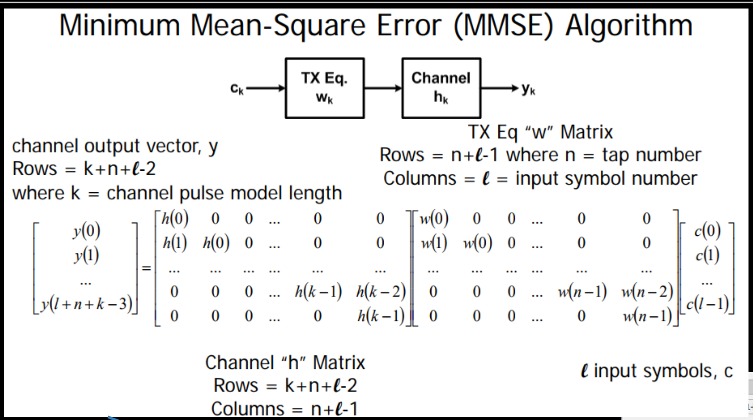
- Use loadlibrary mechanism
- AMI parameters can be pre-assembled
- Example library loading/calling in COM

```
mex -setup
load('SPISimAMI_WIN64.dll', 'ami.h')
libisloaded('SPISimAMI_WIN64')
libfunctions('SPISimAMI_WIN64')
calllib('SPISimAMI_WIN64','ami_init', htInput, rowSize, numAggr...)
unloadlibrary('SPISimAMI_WIN64')
```

Example Results 1 (6), (7)

- Replace COM's FFE with self-optimization FFE




Minimum Mean-Square Error (MMSE) Algorithm

$$\begin{tikzcd} c_k \arrow[r] & \boxed{\begin{matrix}\text{TX Eq.}\\ w_k\end{matrix}} \arrow[r] & \boxed{\begin{matrix}\text{Channel}\\ h_k\end{matrix}} \arrow[r] & y_k \end{tikzcd}$$

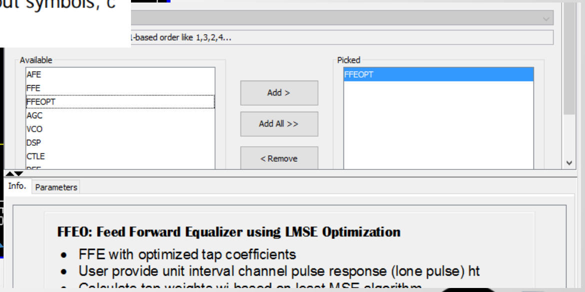
channel output vector, y
Rows = k+n+ℓ-2
where k = channel pulse model length

TX Eq "w" Matrix
Rows = n+ℓ-1 where n = tap number
Columns = ℓ = input symbol number

$$\begin{bmatrix} y(0) \\ y(1) \\ \ldots \\ y(l+n+k-3) \end{bmatrix} = \begin{bmatrix} h(0) & 0 & 0 & \ldots & 0 & 0 \\ h(1) & h(0) & 0 & \ldots & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & 0 & \ldots & h(k-1) & h(k-2) \\ 0 & 0 & 0 & \ldots & 0 & h(k-1) \end{bmatrix} \begin{bmatrix} w(0) & 0 & 0 & \ldots & 0 & 0 \\ w(1) & w(0) & 0 & \ldots & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & 0 & \ldots & w(n-1) & w(n-2) \\ 0 & 0 & 0 & \ldots & 0 & w(n-1) \end{bmatrix} \begin{bmatrix} c(0) \\ c(1) \\ \ldots \\ c(l-1) \end{bmatrix}$$

Channel "h" Matrix
Rows = k+n+ℓ-2
Columns = n+ℓ-1

ℓ input symbols, c

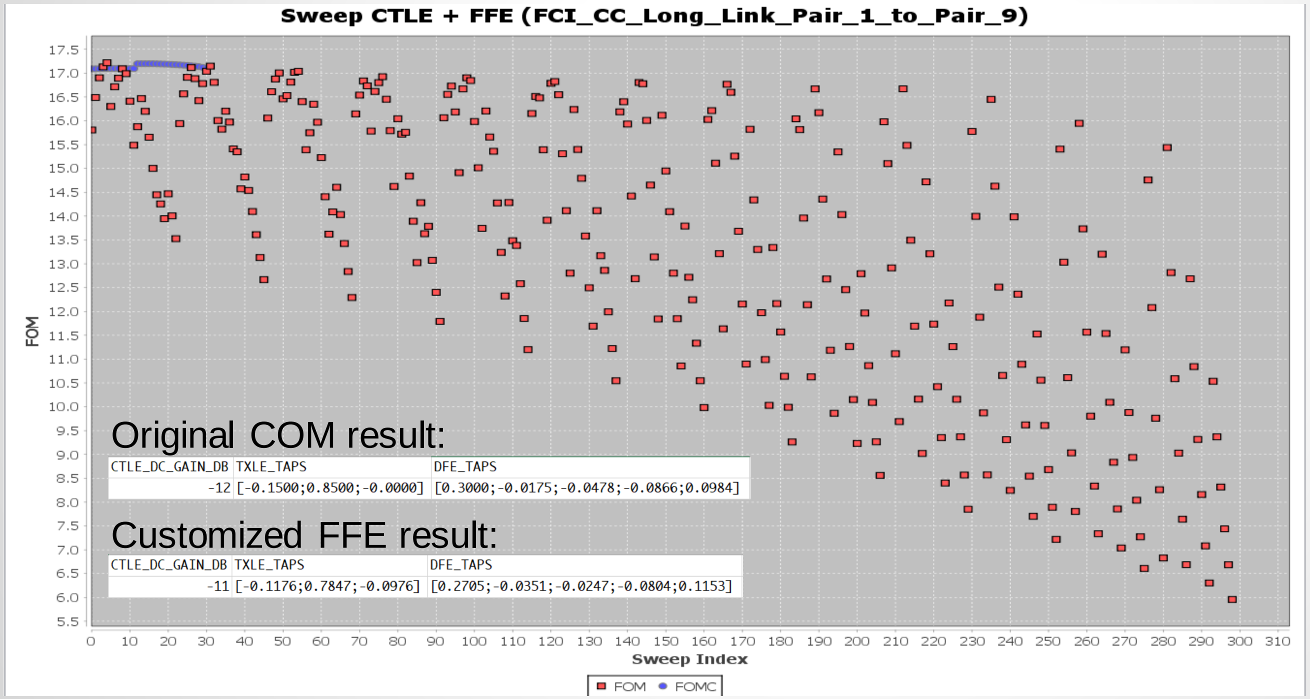


FFEO: Feed Forward Equalizer using LMSE Optimization

- FFE with optimized tap coefficients
- User provide unit interval channel pulse response (lone pulse) ht

Example Results 1

- 13 gdc * 24 FFE sweep **(red)** vs customized FFE **(blue)**



Original COM result:

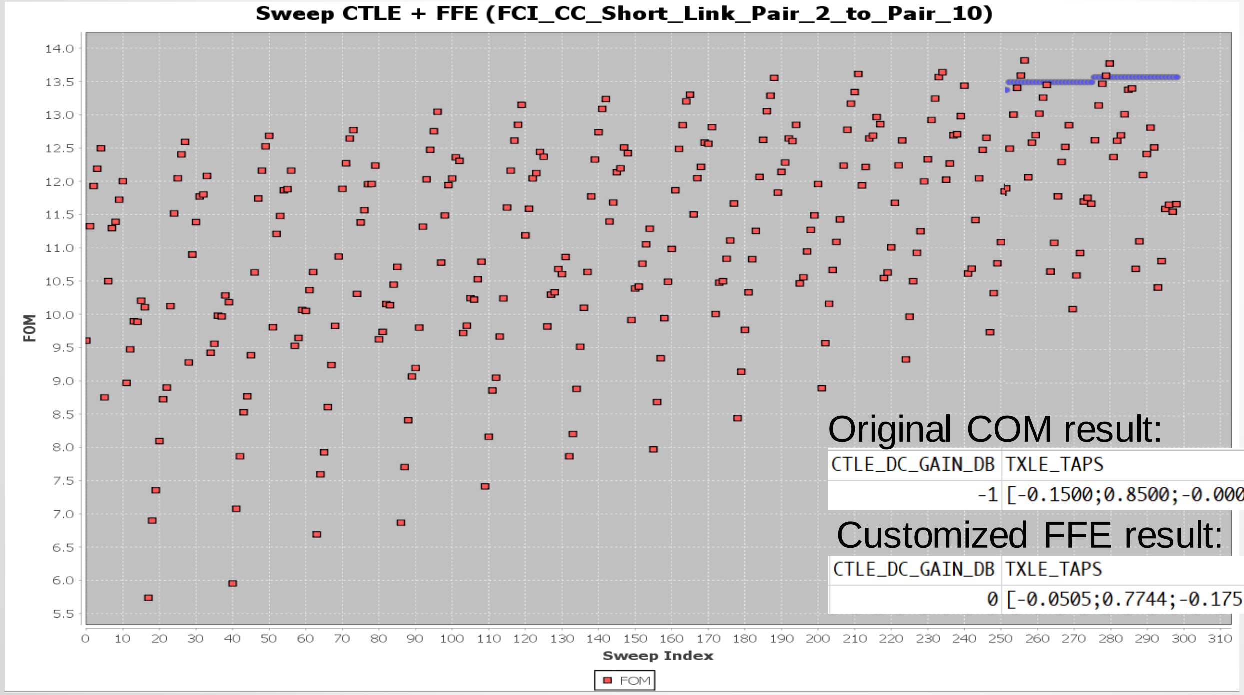
CTLE_DC_GAIN_DB	TXLE_TAPS	DFE_TAPS
-12	[-0.1500;0.8500;-0.0000]	[0.3000;-0.0175;-0.0478;-0.0866;0.0984]

Customized FFE result:

CTLE_DC_GAIN_DB	TXLE_TAPS	DFE_TAPS
-11	[-0.1176;0.7847;-0.0976]	[0.2705;-0.0351;-0.0247;-0.0804;0.1153]

Example Results 2

- 13 gdc * 24 FFE sweep **(red)** vs customized FFE **(blue)**



Original COM result:

CTLE_DC_GAIN_DB	TXLE_TAPS	DFE_TAPS
-1	[-0.1500;0.8500;-0.0000]	[0.3000;0.1017;0.0660;0.0171;0.0480]

Customized FFE result:

CTLE_DC_GAIN_DB	TXLE_TAPS	DFE_TAPS
0	[-0.0505;0.7744;-0.1751]	[0.3000;0.0591;0.0395;0.0322;0.0224]

Summary:

- AMI model can be used in COM analysis:
    - COM is a great open platform for link analysis/AMI development
    - Replaces multi-level CTLE and FFE loops with AMI call
    - Can pull-in DFE for co-optimization

- Considerations:
    - Original COM flow supports AMI_Init type LTI only
        - AMI_GetWave based flow needs SBR $\otimes$ BitStream first
    - AMI parser is not necessarily needed
        - Parameters can be pre-assembed as strings
    - Can be used for back-channel analysis development

References:

1. **IEEE Std 802.3bj-2014, Specification**, Annex 93A
2. **Channel Operating Margin (COM)**, Richard Mellitz, DesignCon 2013
3. **PyBERT:** https://pypi.python.org/pypi/PyBERT
4. **COM tools:** http://www.ieee802.org/3/bj/public/tools.html
5. **IBIS V6.1 Spec. Section 10** http://ibis.org/ver6.1/
6. **New SI Techniques for Large System Performance Tuning**, Donald Telian, DesignCon 2016
7. **Sam Palermo, ECEN 720, High-Speed Link Circuits & Systems, Texas A&M**

Q & A

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