Reference Architecture Proposals and Channel Data

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IEEE802.3 Plenary July 2018, San Diego, Ca

Outline

- ❑ 4 COM architectures
- ❑ Data for each architecture vs a collection of channels
- ❑ Next steps

4 Signal Architecture Approaches

1. Zero Forced DFE
2. Quantized Forced DFE
3. One DFE tap and a number of (Rx)FFE taps
4. One DFE tap and a number of (Rx)FFE taps with gain at cursor

COM is based on the pulse response (Annex 93A)

- Thru (ISI) channel response is $h^{(0)}(t)$ i.e. the pulse response

The pulse response $h^{(k)}(t)$ is derived from the voltage transfer function $H^{(k)}(f)$ (see 93A.1.4) using Equation (93A–24).

$$h^{(k)}(t) = \int_{-\infty}^{\infty} X(f)H^{(k)}(f)\exp(j2\pi ft)dt \qquad (93A\text{–}24)$$

- The following uses pulse response plots to describe COM equalization

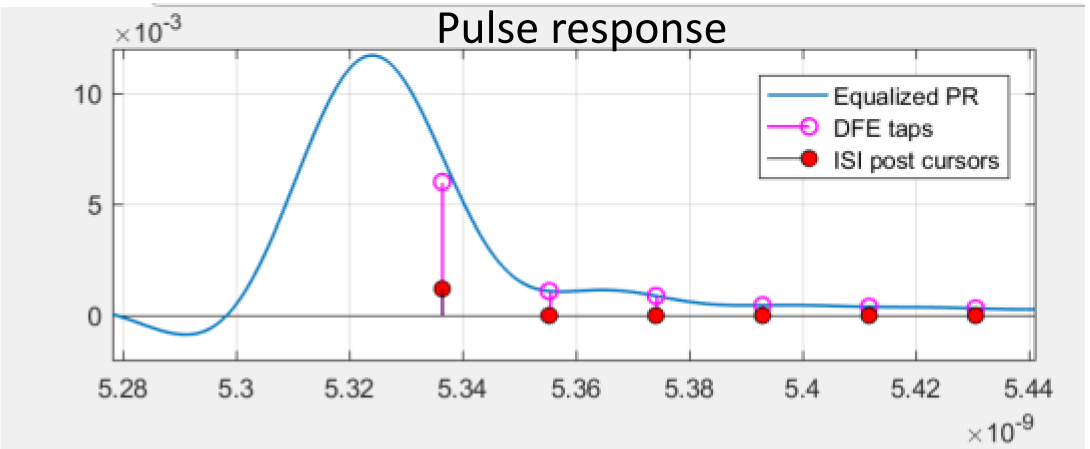
Zero Forced (ZF) DFE

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

The FOM is calculated for each permitted combination of $c(-1)$, $c(1)$, and g_{DC} values per Table 93A–1. The combination of values that maximizes the FOM, including the corresponding value of t_s, is used for the calculation of the interference and noise amplitude in 93A.1.7 and the calculation of COM in 93A.1.

- All legal Tx FFE and CTF (continuous time function) settings are considered
  - Called a full grid search
  - Caveat: Very often CTF settings dominate over the Tx FFE post cursor.
- Exception: Samples corresponding to DFE cursor of is $h^{(0)}(t)$ greater than certain values (b_{max}) are converted in to ISI noise

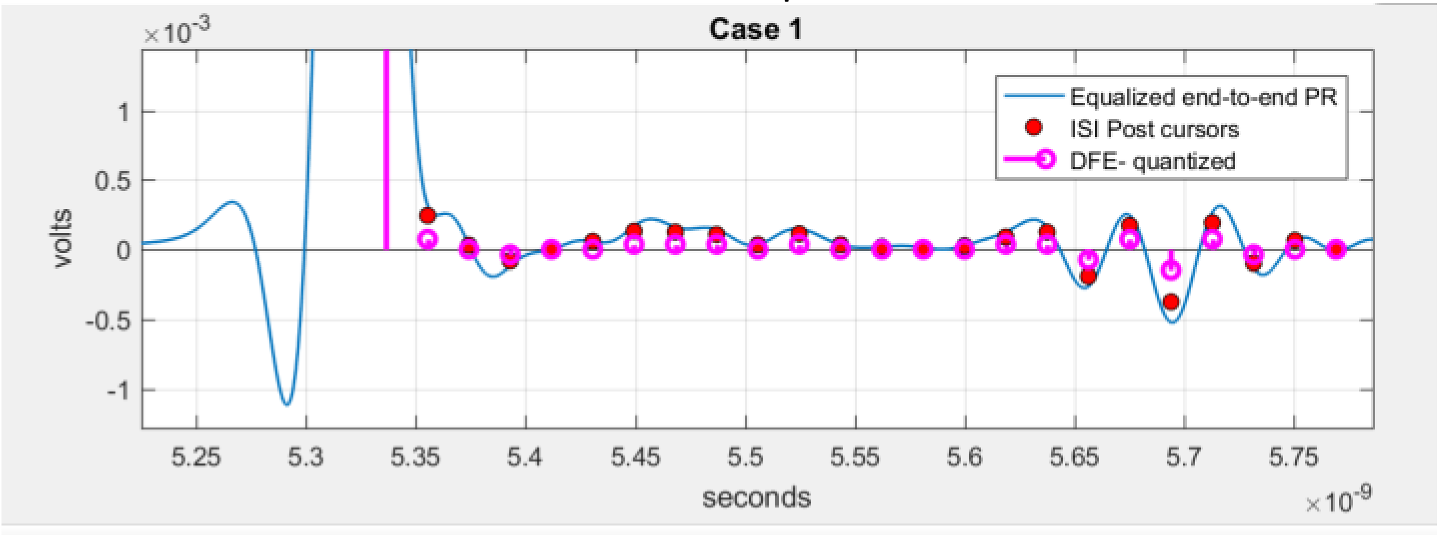
Example where 1st DFE tap reach limit creating ISI noise



Quantized DFE

- ❑ Same as Zero force except:
  - Samples corresponding to a DFE cursor $h^{(0)}(t_n)$ greater than the DFE quantization step size are also converted into ISI noise

Pulse response



One DFE tap + (Rx)FFE

- Same full grid as for zero forced DFE except
  - 1 tap of DFE w/ an Rx FFE of a specified number and resolution of pre-cursors and post-cursors are determined from a vector forced optimization.
    - The cursor for the vector forcing is $h^{(0)}(t_s)$ *where* t_s is the sample point and
    - The first post cursor is set the maximum allowed setting (b_{max})
  - `C=((HH'*HH)^-1*HH')'*FV';`
    - C are the Rx FFE taps HH is derived from $h^{(0)}(t)$
    - FV is the forcing vector , FV = `[... 0, 0, As, bmax(1)*As, 0, 0, 0, 0...]`
  - FOM is computed from each CTF and Tx FFE setting with
  - $h_{fferx}(f)$ is computed from the C found as in eq 93A-32

$$H_{ffe}(f) = \sum_{i=-1}^{1} c(i)\exp(-j2\pi(i+1)(f/f_b)) \qquad (93A\text{–}21)$$

- FFE(3,32) used here for now
  - 3 precursors and 32 post cursors

One DFE tap + (Rx) FFE w/ Cursor Gain

- Same as one DFE tap and a number of Rx FFE taps (pre and post cursor) except:
  - The cursor for the vector forcing ($h^{(0)}$ (t_s) *where* t_s is the sample point) has some gain
  - `C=((HH'*HH)^-1*HH')'*FV';`
    - C are the Rx FFE taps HH is derived from $h^{(0)}$ *(t)*
    - FV is the forcing vector , FV = $[\ldots\ 0,\ 0,\ As*10^{\frac{gain}{20}},\ b_{max}(1)*As,\ 0,\ 0,\ 0,\ 0\ldots]$
    - 3 dB gain seems to work best

Table 93A-1 parameters			
Parameter	Setting	Units	Information
f_b	53.125	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[1.3e-4 1.3e-4]	nF	[TX RX]
z_p select	[2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 30]	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	[50 50]	Ohm	[TX RX] or selected
f_r	0.75	*fb	
c(0)	0.6		min
c(-1)	[-0.28:0.025:0]		[min:step:max]
c(-2)	[0:0.05:0.1]		[min:step:max]
c(-3)	[-0.1:0.025:0]		[min:step:max]
c(-4)	0		[min:step:max]
c(1)	[-0.05:.025:0]		[min:step:max]
g_DC	[-20:1:10]	dB	[min:step:max]
f_z	21.25	GHz	
f_p1	21.25	GHz	
f_p2	53.125	GHz	
A_v	0.41	V	tdr selected
A_fe	0.41	V	tdr selected
A_ne	0.6	V	tdr selected
L	4		
M	32		
N_b	32	UI	
N_b_step	0		normailized
b_max(1)	0.7		
b_max(2..N_b)	0.2		
sigma_RJ	0.01	UI	
A_DD	0.02	UI	
eta_0	8.20E-09	V^2/GHz	
SNR_TX	32.5	dB	tdr selected
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
CSV_REPORT	1	logical
RESULT_DIR	.\results\100G_Study_Group_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	KR_Study_Group	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
IDEAL_TX_TERM	0	logical
T_r	6.16E-03	ns
FORCE_TR	1	logical

Non standard control options		
COM_CONTRIBUTION	0	logical
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.0189	ns
N	1000	
TDR_Butterworth	1	logical
beta_x	1.70E+09	
rho_x	**0.18**	
fixture delay time	0	
Rx FFE		
ffe_pre_tap_len	**0**	UI
ffe_post_tap_len	0	UI
ffe_tap_step_size	0.01	
ffe_main_cursor_min	0.7	
ffe_pre_tap1_max	0.3	
ffe_post_tap1_max	0.3	
ffe_tapn_max	0.1	

Set to zero

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 (tdr sel)

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

COM config sheet for ZF or Q DFE

N_b	32	UI	
N_b_step	0.0115		normailized

Q DFE

For reference

COM config sheet for FFE and w/wo gain

Table 93A-1 parameters			
Parameter	**Setting**	**Units**	**Information**
f_b	53.125	GBd	
f_min	0.05	GHz	
Delta_f	0.01	GHz	
C_d	[1.3e-4 1.3e-4]	nF	[TX RX]
z_p select	[2]		[test cases to run]
z_p (TX)	[12 30]	mm	[test cases]
z_p (NEXT)	[12 30]	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	[50 50]	Ohm	[TX RX] or selected
f_r	0.75	*fb	
c(0)	0.6		min
c(-1)	[-0.28:0.025:0]		[min:step:max]
c(-2)	[0:0.05:0.1]		[min:step:max]
c(-3)	0		[min:step:max]
c(-4)	0		[min:step:max]
c(1)	[-0.05:.025:0]		[min:step:max]
g_DC	[-20:1:10]	dB	[min:step:max]
f_z	21.25	GHz	
f_p1	21.25	GHz	
f_p2	53.125	GHz	
A_v	0.41	V	tdr selected
A_fe	0.41	V	tdr selected
A_ne	0.6	V	tdr selected
L	4		
M	32		
N_b	1	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	8.20E-09	V^2/GHz	
SNR_TX	32.5	dB	tdr selected
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
CSV_REPORT	1	logical
RESULT_DIR	.\results\100G_Study_Group_{date}\	
SAVE_FIGURES	0	logical
Port Order	[1 3 2 4]	
RUNTAG	CK_100GEL	
Receiver testing		
RX_CALIBRATION	0	logical
Sigma BBN step	5.00E-03	V
IDEAL_TX_TERM	0	logical
T_r	6.16E-03	ns
FORCE_TR	1	logical

Non standard control options		
COM_CONTRIBUTION	0	logical
TDR	1	logical
ERL	1	logical
ERL_ONLY	0	logical
TR_TDR	0.0189	ns
N	1000	
TDR_Butterworth	1	logical
beta_x	1.70E+09	
rho_x	**0.18**	
fixture delay time	0	

Rx FFE		
ffe_pre_tap_len	**3**	**UI**
ffe_post_tap_len	**32**	**UI**
ffe_tap_step_size	0.01	
ffe_main_cursor_min	0.7	
ffe_pre_tap1_max	0.3	
ffe_post_tap1_max	0.3	
ffe_tapn_max	0.1	
crusor_gain	0:1:4	dB

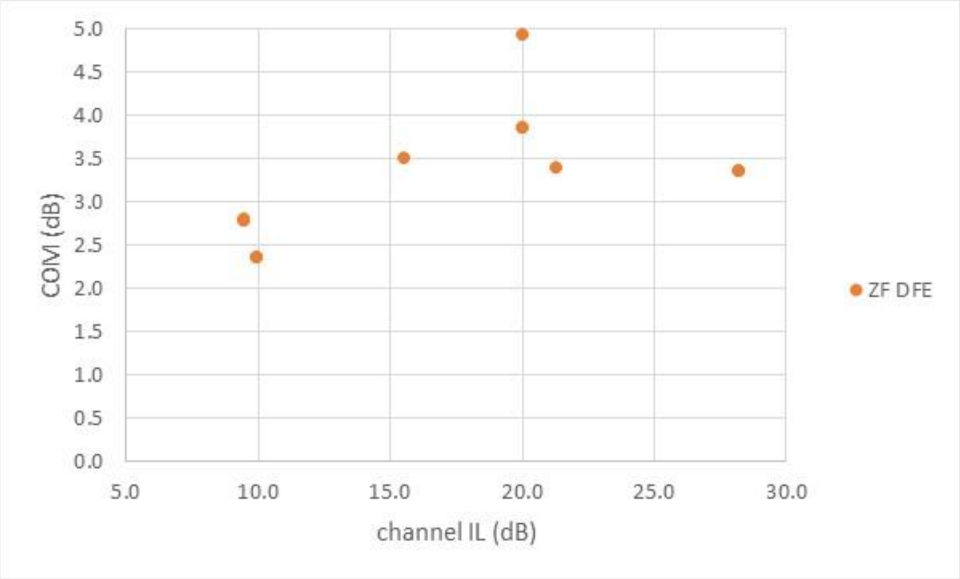
Set to zero for no gain

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 (tdr sel)

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

For reference

Reference: ZF DFE



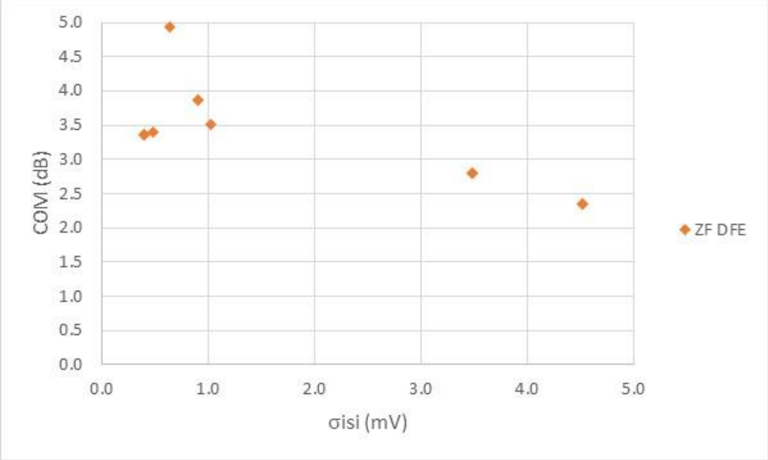
Channels:

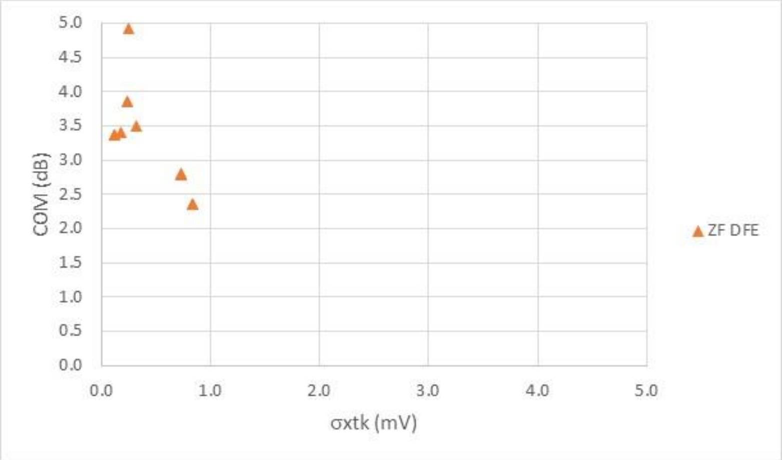
- Cabled backplane (2)
- Cabled fabric switch (12)

Used channels with COM≥2.3dB

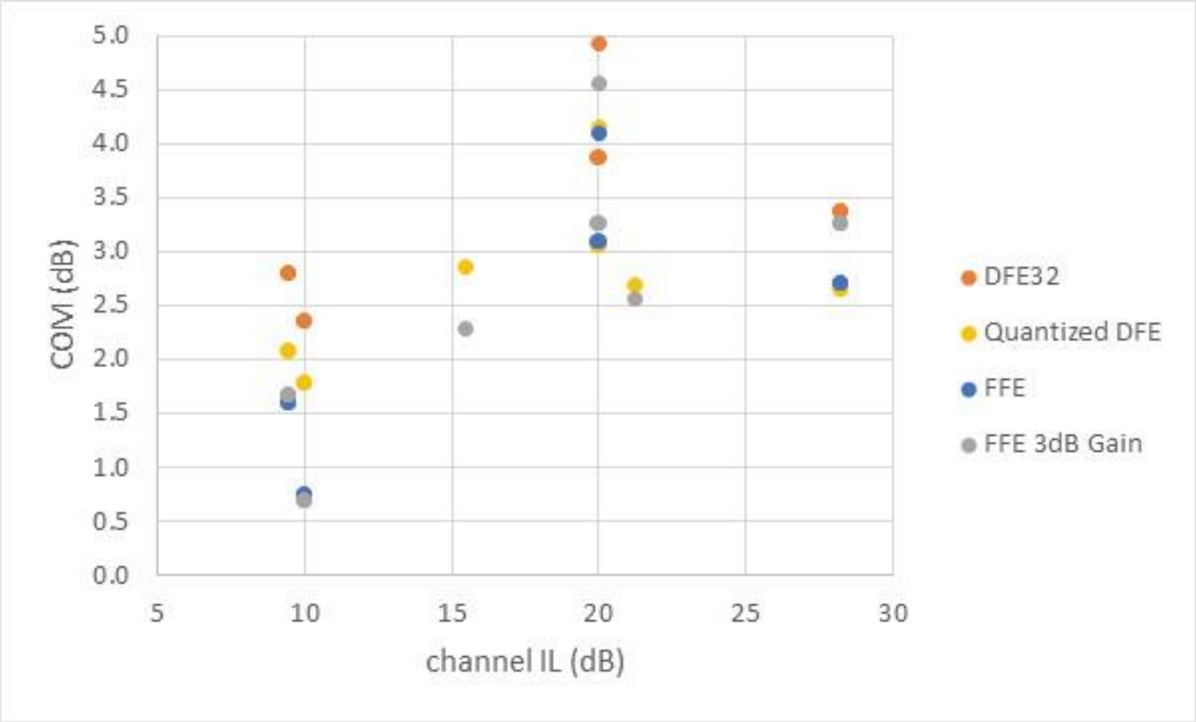
Analysis used 32 taps total (DFE+FFE or DFE-only)

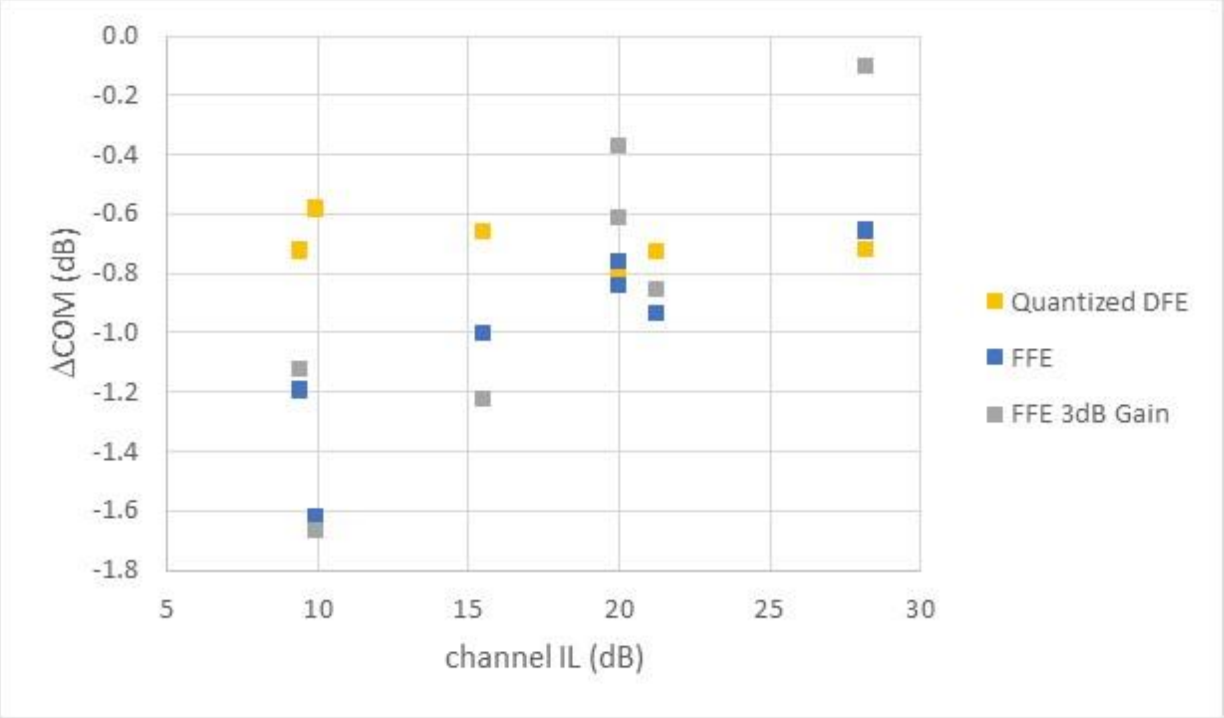
- Is the ZF DFE too optimistic
- Does the implication of the ZF DFE require too much power





Data Summary



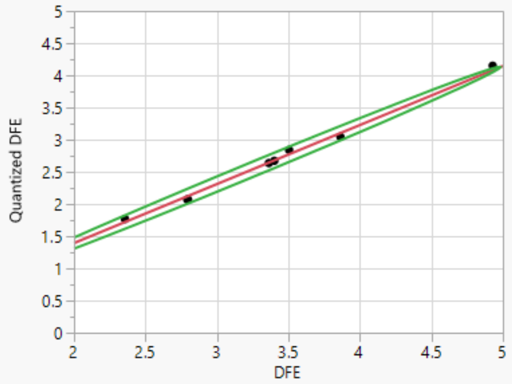


- Quantized DFE seems like just derating COM of the ZF DFE
- FFE with gain seems to get closer to ZF DFE for high loss

COM Correlations to DFE-based COM

More variability for the FFE based COM

Bivariate Fit of Quantized DFE By DFE



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

Quantized DFE = -0.4393 + 0.9172272*DFE

Summary of Fit

RSquare	0.994505
RSquare Adj	0.994047
Root Mean Square Error	0.051023
Mean of Response	2.51465
Observations (or Sum Wgts)	14

Lack Of Fit

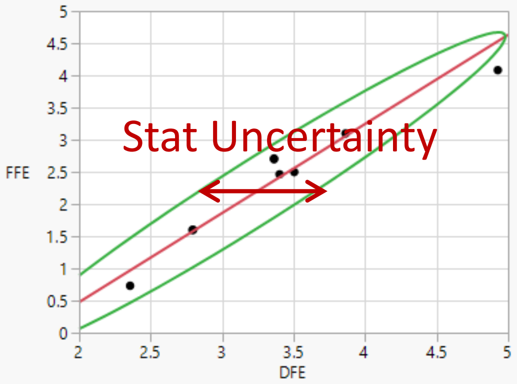
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5.6535462	5.65355	2171.621
Error	12	0.0312405	0.00260	Prob > F
C. Total	13	5.6847867		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.4393	0.064839	-6.78	<.0001*
DFE	0.9172272	0.019683	46.60	<.0001*

Bivariate Fit of FFE By DFE



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

FFE = -2.291455 + 1.3845124*DFE

Summary of Fit

RSquare	0.947029
RSquare Adj	0.942615
Root Mean Square Error	0.245034
Mean of Response	2.167397
Observations (or Sum Wgts)	14

Lack Of Fit

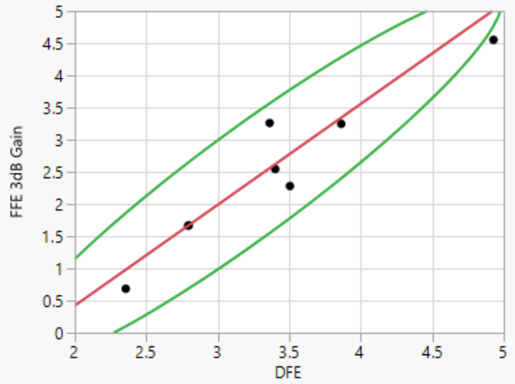
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	12.881333	12.8813	214.5404
Error	12	0.720498	0.0600	Prob > F
C. Total	13	13.601831		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2.291455	0.311381	-7.36	<.0001*
DFE	1.3845124	0.094524	14.65	<.0001*

Bivariate Fit of FFE 3dB Gain By DFE



Linear Fit
Bivariate Normal Ellipse P=0.950

Linear Fit

FFE 3dB Gain = -2.710912 + 1.567303*DFE

Summary of Fit

RSquare	0.881475
RSquare Adj	0.871597
Root Mean Square Error	0.430078
Mean of Response	2.336621
Observations (or Sum Wgts)	14

Lack Of Fit

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	16.507187	16.5072	89.2441
Error	12	2.219600	0.1850	Prob > F
C. Total	13	18.726787		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2.710912	0.546529	-4.96	0.0003*
DFE	1.567303	0.165906	9.45	<.0001*

X and Y axis are dB of COM

Summary & Next Steps

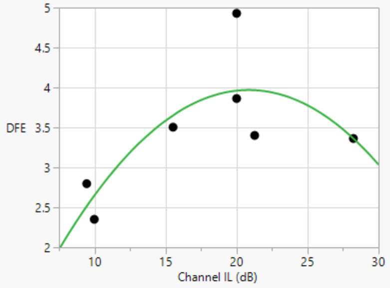
- ❑ Reference EQ architecture choices impact on COM results
- ❑ More variability in results with DFE+FFE-based reference EQ
- ❑ Is a quantized DFE good enough?
  - It seems like it is the same as raising the COM threshold
- ❑ Follow-on work
  - Assess the sensitivity to # of taps in the Rx Equalizer
  - Look at algorithm to better optimize gain in FFE; goal being to reduce uncertainty in results
- ❑ Follow-work for channels: Address PCB manufacturing to further reduce the channel ISI.

Backup

COM vs Channel IL

ZF DFE

Bivariate Fit of DFE By Channel IL (dB)



Polynomial Fit Degree=2

Polynomial Fit Degree=2

DFE = 2.3865973 + 0.0833732*Channel IL (dB) - 0.0111806*(Channel IL (dB)-17.128)^2

Summary of Fit

RSquare	0.733594
RSquare Adj	0.685157
Root Mean Square Error	0.403421
Mean of Response	3.220521
Observations (or Sum Wgts)	14

Lack Of Fit

Analysis of Variance

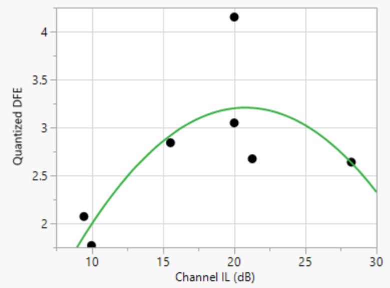
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	4.9297291	2.46486	15.1452
Error	11	1.7902375	0.16275	Prob > F
C. Total	13	6.7199666		0.0007*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3865973	0.277421	8.60	<.0001*
Channel IL (dB)	0.0833732	0.016269	5.12	0.0003*
(Channel IL (dB)-17.128)^2	-0.011181	0.002824	-3.96	0.0022*

Quantized ZF DFE

Bivariate Fit of Quantized DFE By Channel IL (dB)



Polynomial Fit Degree=2

Polynomial Fit Degree=2

Quantized DFE = 1.7594858 + 0.0763623*Channel IL (dB) - 0.0104029*(Channel IL (dB)-17.128)^2

Summary of Fit

RSquare	0.734246
RSquare Adj	0.685927
Root Mean Square Error	0.370596
Mean of Response	2.51465
Observations (or Sum Wgts)	14

Lack Of Fit

Analysis of Variance

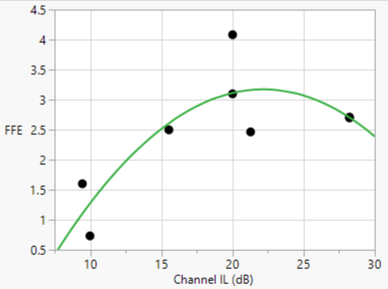
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	4.1740291	2.08701	15.1958
Error	11	1.5107576	0.13734	Prob > F
C. Total	13	5.6847867		0.0007*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.7594858	0.254848	6.90	<.0001*
Channel IL (dB)	0.0763623	0.014946	5.11	0.0003*
(Channel IL (dB)-17.128)^2	-0.010403	0.002594	-4.01	0.0021*

DFE+FFE

Bivariate Fit of FFE By Channel IL (dB)



Polynomial Fit Degree=2

Polynomial Fit Degree=2

FFE = 0.6362071 + 0.1290896*Channel IL (dB) - 0.0127946*(Channel IL (dB)-17.128)^2

Summary of Fit

RSquare	0.775052
RSquare Adj	0.734152
Root Mean Square Error	0.527405
Mean of Response	2.167397
Observations (or Sum Wgts)	14

Lack Of Fit

Analysis of Variance

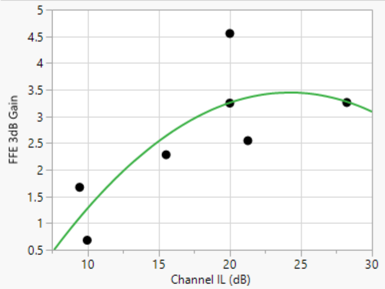
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	10.542120	5.27106	18.9500
Error	11	3.059711	0.27816	Prob > F
C. Total	13	13.601831		0.0003*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6362071	0.36268	1.75	0.1072
Channel IL (dB)	0.1290896	0.021269	6.07	<.0001*
(Channel IL (dB)-17.128)^2	-0.012795	0.003692	-3.47	0.0053*

DFE+FFE w/ Gain

Bivariate Fit of FFE 3dB Gain By Channel IL (dB)



Polynomial Fit Degree=2

Polynomial Fit Degree=2

FFE 3dB Gain = 0.2971603 + 0.1523966*Channel IL (dB) - 0.010742*(Channel IL (dB)-17.128)^2

Summary of Fit

RSquare	0.762638
RSquare Adj	0.719482
Root Mean Square Error	0.635683
Mean of Response	2.336621
Observations (or Sum Wgts)	14

Lack Of Fit

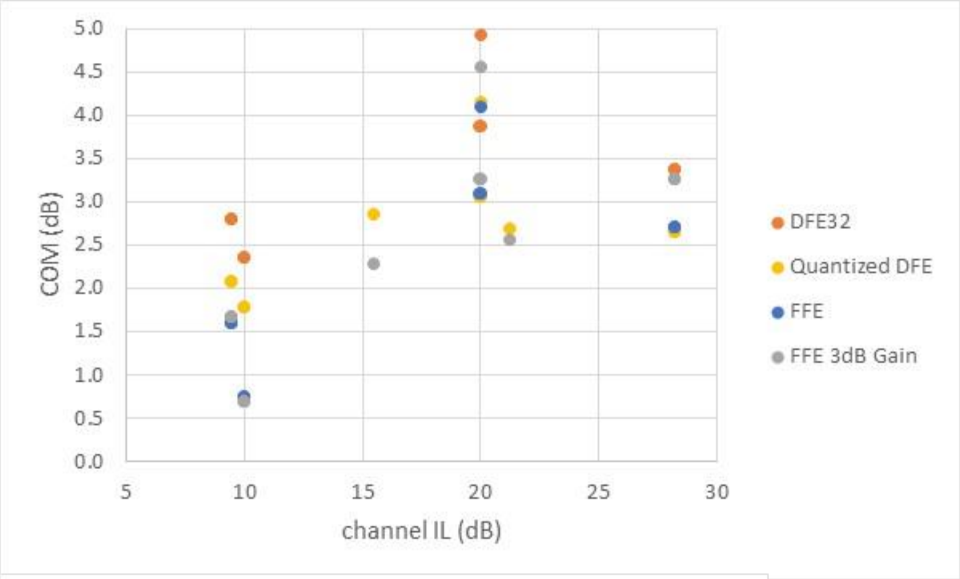
Analysis of Variance

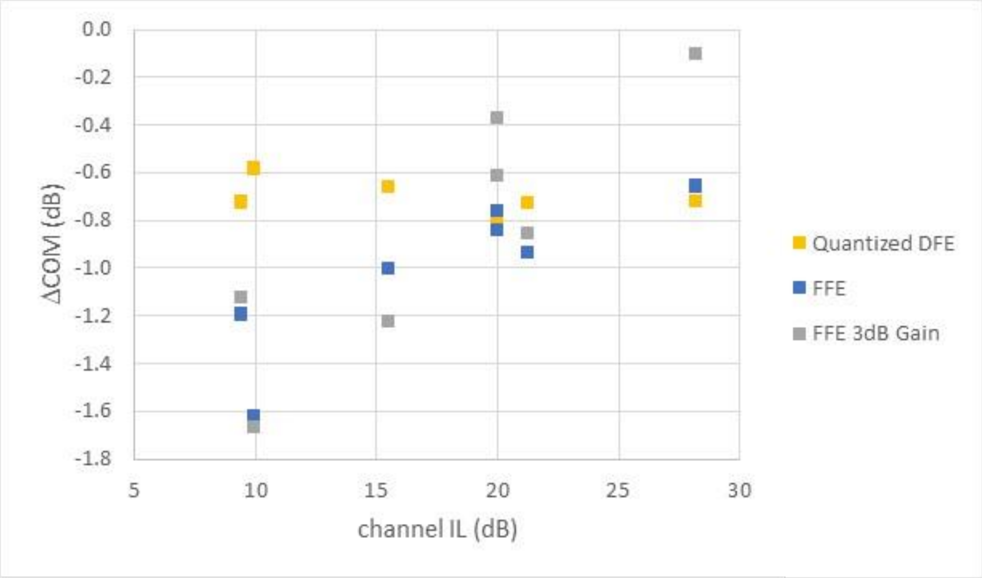
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	14.281764	7.14088	17.6714
Error	11	4.445023	0.40409	Prob > F
C. Total	13	18.726787		0.0004*

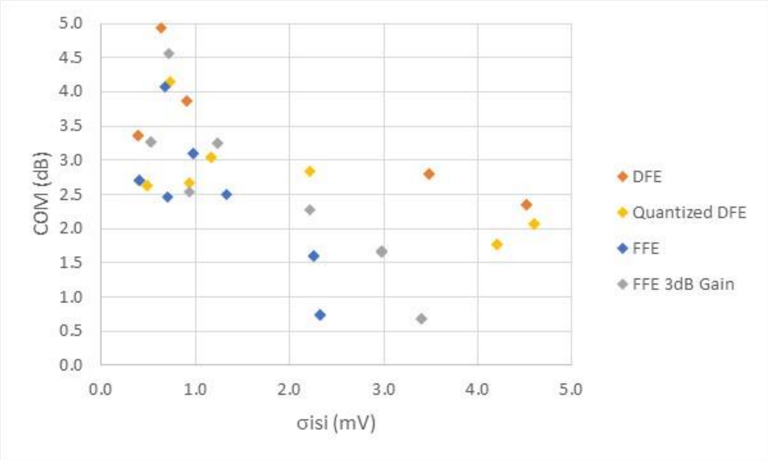
Parameter Estimates

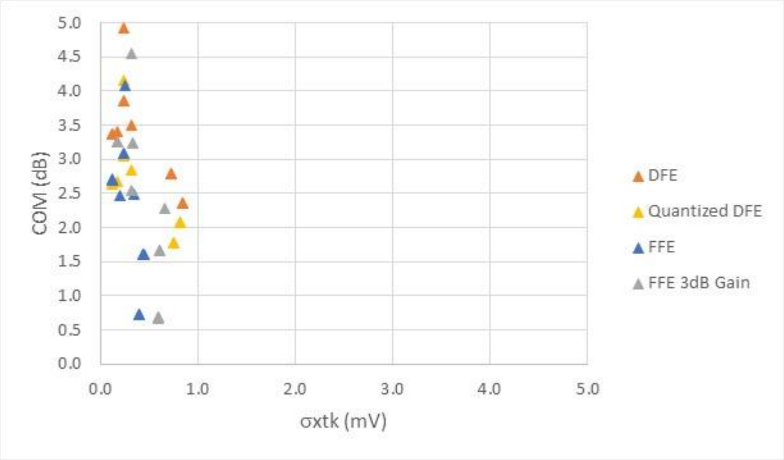
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2971603	0.43714	0.68	0.5107
Channel IL (dB)	0.1523966	0.025636	5.94	<.0001*
(Channel IL (dB)-17.128)^2	-0.010742	0.00445	-2.41	0.0344*

Consolidated Data

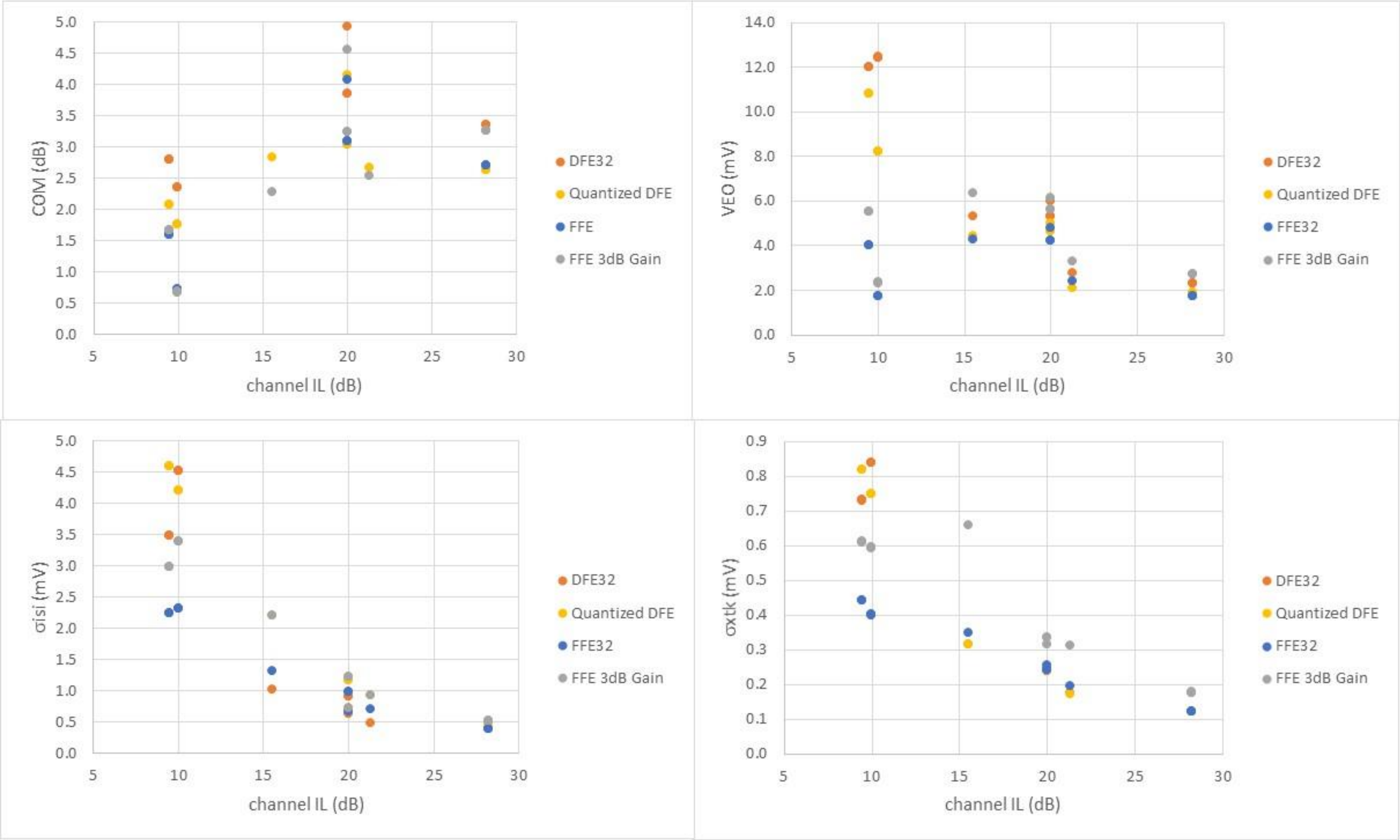






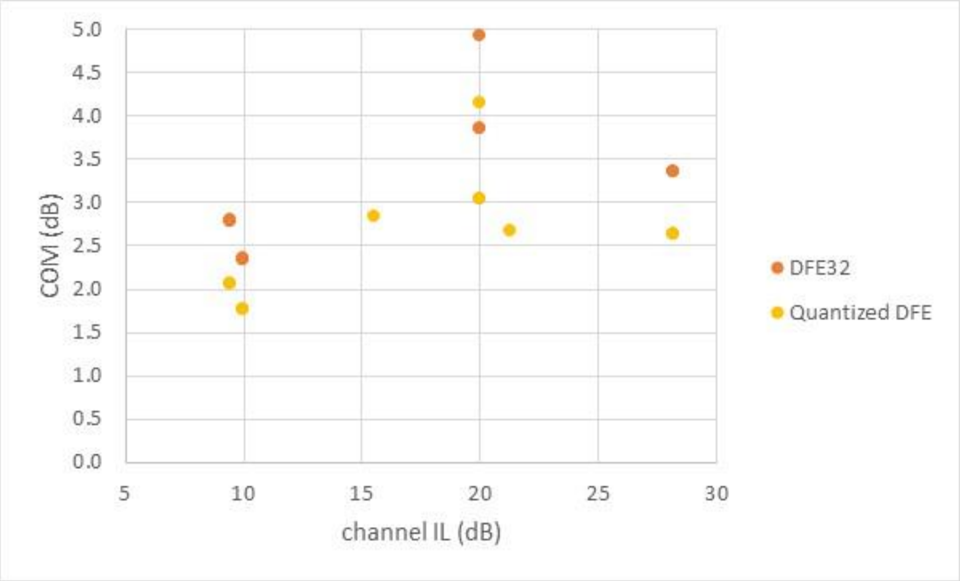


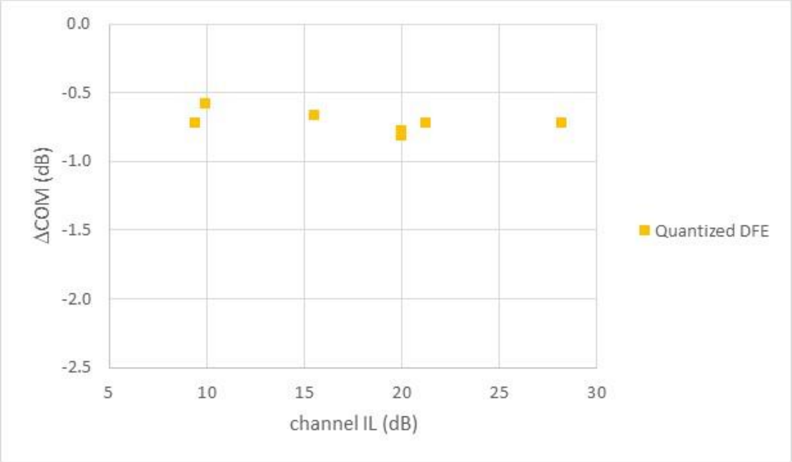
Consolidated Data #2

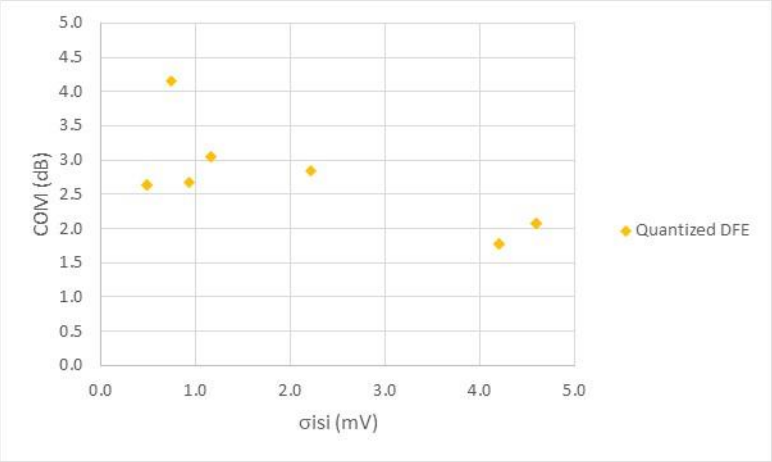


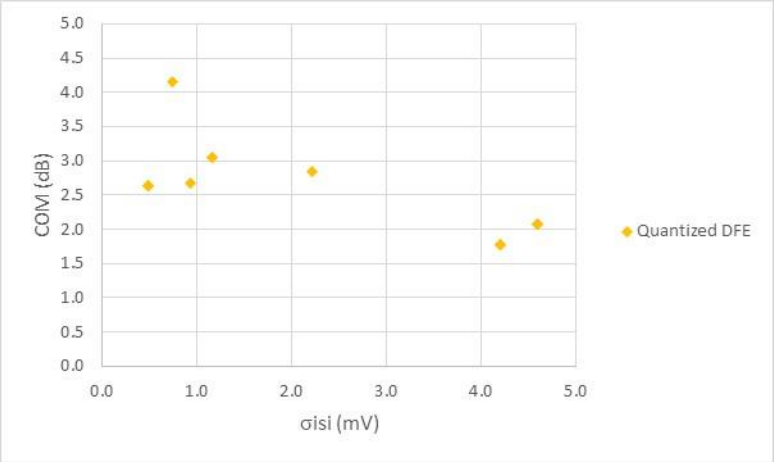
Quantized DFE

Delta calculated relative to ZF-DFE.

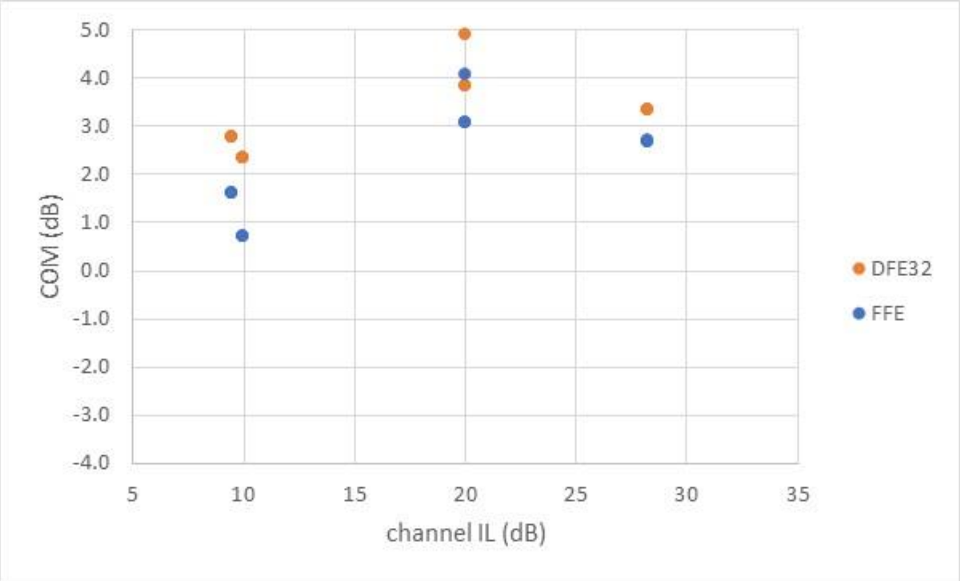




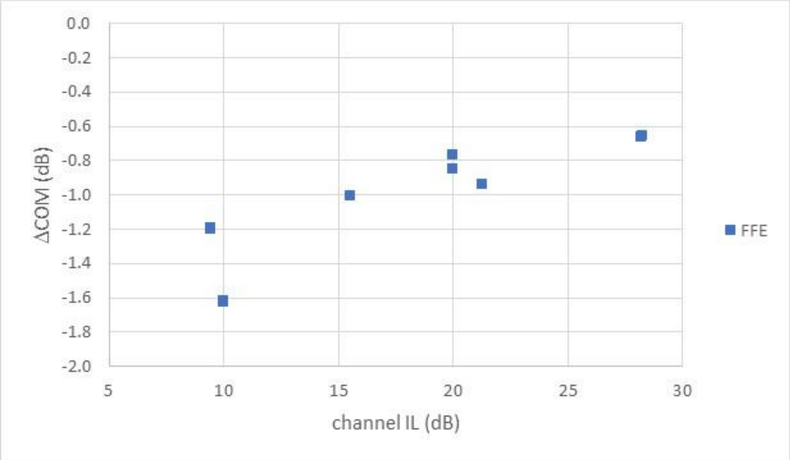




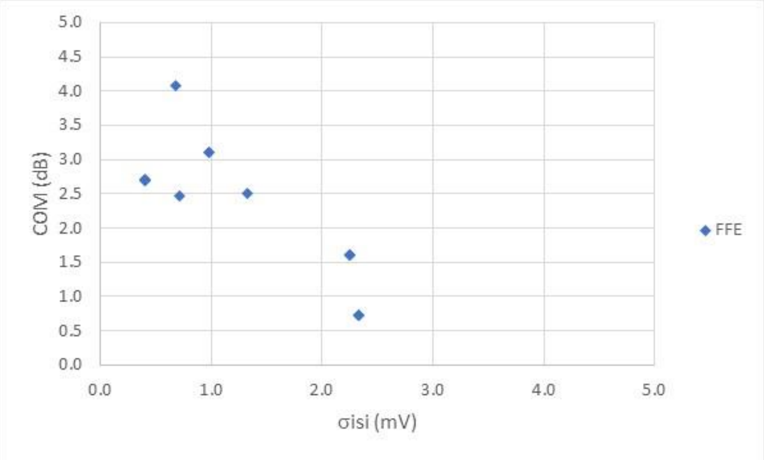
DFE + FFE



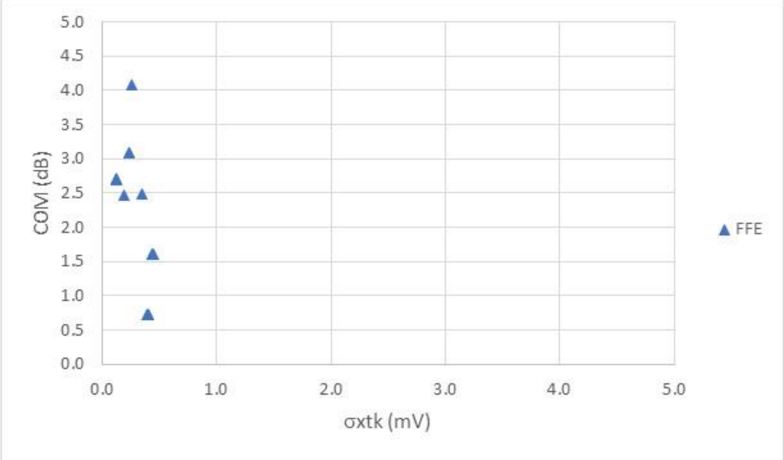
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
COM (dB)
5
10
15
20
25
30
35
channel IL (dB)
DFE32
FFE



0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
ΔCOM (dB)
5
10
15
20
25
30
channel IL (dB)
FFE

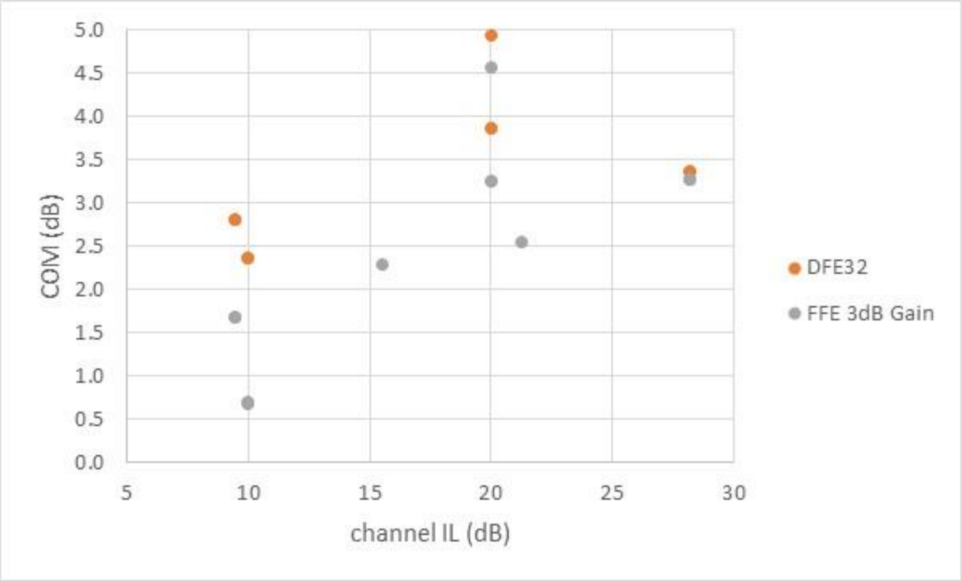


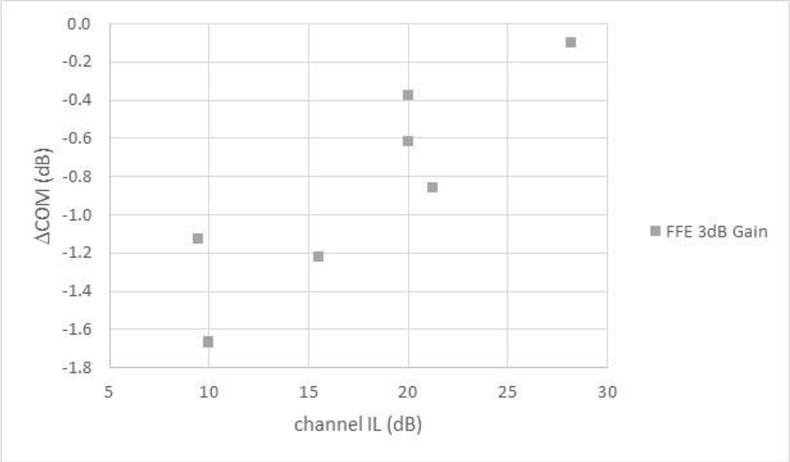
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
COM (dB)
0.0
1.0
2.0
3.0
4.0
5.0
σisi (mV)
FFE

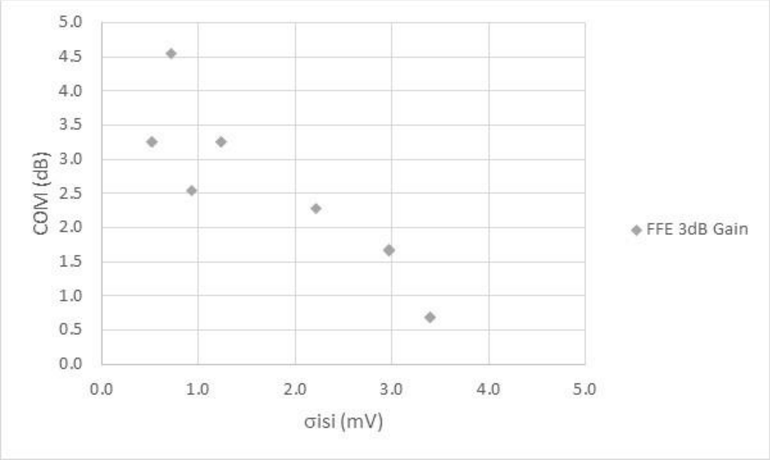


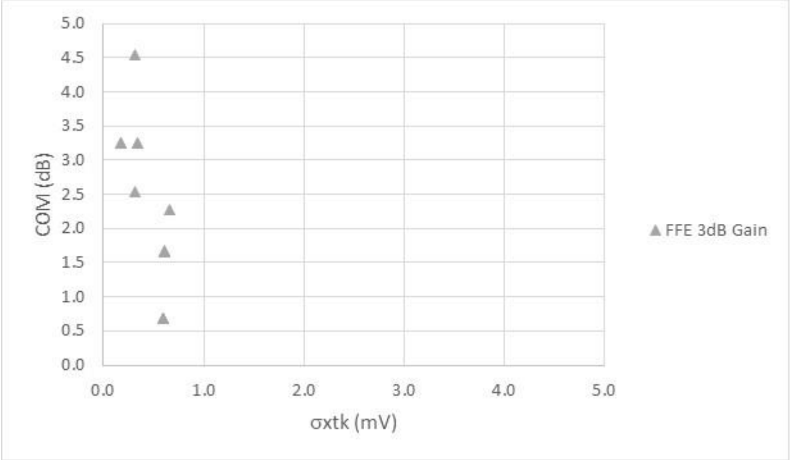
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
COM (dB)
0.0
1.0
2.0
3.0
4.0
5.0
σxtk (mV)
FFE

DFE + FFE w/ 3dB Cursor Gain









Correlation to COM with DFE