802.3dj D1.1 Comment Resolution Electrical Topics

Adee Ran (Cisco), 802.3dj Electrical Lead Editor
<others>

Eta0, Reference Rx FFE parameters

eta0
Comments 377, 35

Cl **178**	*SC* **178.10.1**	*P* **311**	*L* **46**	# 377

Ran, Adee — Cisco Systems, Inc.

Comment Type **TR** *Comment Status* **D** *eta0*

eta0 is TBD in Table 178-13.
A value of 1e-8 has been adopted for C2M in Table 176E-6 (in the resolution of comment #72 against D1.0).
There is no reason to have different values in other interfaces; eta0 represents physical noise that comes from the same sources in all interfaces.

Also applies to eta0 in 179.11.7, Table 179-16, and in 176D.4.1, Table 176D-7.

SuggestedRemedy

Change the TBDs for eta0 to 1e-8 in Table 178-13, Table 179-16, and Table 176D-7.

The same value of eta0 is suggested by

- Comments 377 and 35
- Comments 545, 546, and 547 (which also address reference Rx FFE parameters)
- Comments 1, 2, 37, and 142 (by reference to heck_3dj_01a_2407 and lusted_3dj_06b_2407)

Straw Poll #TF-3 from July 2024 shows support for this value:
I would support putting the COM parameter values and the editors note for CR and KR (per lusted_3dj_06b_2407, slides 6-7) into the P802.3dj draft specification
Results (all): Y: 73, N: 2, A: 20

Note that eta0 appears twice in Table 176D–7.

Editors' recommendation: ACCEPT IN PRINCIPLE, Implement the suggested remedy, and remove the duplicate row in Table 176D–7.
(include a reference to this slide)

Reference Rx FFE parameters
Comments 2, 1, 545, 546, 547, 37, 142

Cl 178 SC 178.10.1 P 311 L 46 # 2

Lusted, Kent — Intel Corporation

Comment Type **TR** *Comment Status* **D** *Reference FFE*

The COM parameter values for the 200GBASE-KR1, 400GBASE-KR2, 800GBASE-KR4 and 1.6TBASE-KR8 PMDs are TBDs

SuggestedRemedy

In table 178-12, use the COM parameter values and the editors note for KR (per lusted_3dj_06b_2407, slides 6-7) , which are:

d_w = 6
Nfix = 15
N_g = 2
N_f = 4
N_max = 80

Use MLSE per Annex 178A.1.11
the MLSD implementation allowance is TBD

Set COM = 3dB

The values in the suggested remedy are also suggested by

- Comments 1 (clause 179) and 2 (clause 178)
- Comments 546 (clause 179) and 545 (clause 178), which also address eta0, and reference lit_3dj_01a_2407

Comment 547 and comments 37 and 142 (by reference to heck_3dj_01a_2407) suggest similar values for AUI-C2C except for

- N_fix=14 and d_w=5 (5 pre, 8 post instead of 6 pre, 8 post)
- N_max=50

Straw Poll #TF-3 from July 2024 (see previous slide) indicates support for the d_w and N_fix values, while other values were TBD.

Editors' recommendation: ACCEPT IN PRINCIPLE

- Use the proposed values in comment #2 for clause 178 for clause 179.
- Use the proposed values in comment 547 for annex 176D.
- Add editor's notes below the COM tables in 178, 179, 176D, and 176E: "The parameters values in this table are to be confirmed and may change based on further analysis. Contributions in this area are encouraged."

(include a reference to this slide)

eta0
Comments 377, 35

Cl **178** *SC* **178.10.1** *P* **311** *L* **46** # 377

Ran, Adee — Cisco Systems, Inc.

Comment Type **TR** *Comment Status* **D** *eta0*

eta0 is TBD in Table 178-13.
A value of 1e-8 has been adopted for C2M in Table 176E-6 (in the resolution of comment #72 against D1.0).
There is no reason to have different values in other interfaces; eta0 represents physical noise that comes from the same sources in all interfaces.

Also applies to eta0 in 179.11.7, Table 179-16, and in 176D.4.1, Table 176D-7.

SuggestedRemedy

Change the TBDs for eta0 to 1e-8 in Table 178-13, Table 179-16, and Table 176D-7.

The same value of eta0 is suggested by

- Comment 35
- Comments 545, 546, and 547 (which also address several other parameters)
- Comments 1, 2, 37, and 142 (by reference to heck_3dj_01a_2407 and lusted_3dj_06b_2407)

Straw Poll #TF-3 from July 2024 shows support for this value:
I would support putting the COM parameter values and the editors note for CR and KR (per lusted_3dj_06b_2407, slides 6-7) into the P802.3dj draft specification
Results (all): Y: 73, N: 2, A: 20

Editors' recommendation: ACCEPT IN PRINCIPLE, Implement the suggested remedy (include a reference to this slide)

ERL

Comments 540, 531, 541, 539, 444, 543

Nbx
Comments 540, 531, 541, 539, 444

Cl **178**	*SC* **178.9.2.2**	*P* **304**	*L* **14**	# 540

Li, Mike — Intel

Comment Type **TR** *Comment Status* **D** *ERL*

Nbx TBD

SuggestedRemedy

Based on the 8 post tap, and 2x4 floating per straw-polls (#TF-3, #TF-4, https://www.ieee802.org/3/dj/public/24_07/motions_3dj_2407.pdf), change it to 16.

Cl **179B**	*SC* **179B.4.2**	*P* **749**	*L* **20**	# 444

Ran, Adee — Cisco Systems, Inc.

Comment Type **TR** *Comment Status* **D** *ERL*

Reflections in the mated test fixtures should not be eliminated from the measurement.

Thus, in Table 179B-1, N_bx and T_fx should both be set to 0, consistent with Table 162B-1 (802.3ck) and the NOTE in this table.

The note is not TBD.

SuggestedRemedy

Replace both TBDs with value 0.

Delete "(TBD)" from the NOTE.

The value 16 is suggested by:
- Comment #540 for Table 178–8—Transmitter and receiver
- Comment #531 for Table 178–14—Channel
- Comment #541 for both tables above
- Comment #539 for Table 176D–8—Channel

The value 0 is suggested by:
- Comment #444 for Table 179B–1—Mated test fixture

For reference, the corresponding values in 802.3ck are:
- 21 in Clause 163 (Tx, Rx, and channel)
- 6 in Annex 120F (Tx, Rx, and channel)
  [These numbers are equal to the total (fixed+floating) number of DFE taps in the reference receiver for each case]
- 0 in Annex 162B (Mated test fixture)

There has been no discussion of Nbx in 802.3dj so far. However, based on precedence, we may be able to adopt these values.

Editors' recommendation: ACCEPT IN PRINCIPLE
Use Nbx=16 in all ERL tables in Clause 178 and Annex 176D. Add/change editorial notes to state that the value of Nbx is to be confirmed and contributions in this area are encouraged.
Use Nbx=0 in Table 179B–1.
(include a reference to this slide)

Min channel ERL
Comment 543

Cl **178**	*SC* **178.10**	*P* **309**	*L* **21**	# 543

Li, Tobey — MediaTek

Comment Type **TR** *Comment Status* **D** *ERL*

Minimum channel ERL is TBD

SuggestedRemedy

Replace TBD with 11dB, see response to comment #29, 8023dj_D1p0_closedcomments_id_240612.

The suggested remedy refers to closed comment #29 against D1.0.
The response (see Final comment report) indicates that the value of 11 dB was indeed accepted.
However, in D1.1 it still appears as TBD.

Editors' recommendation: ACCEPT.

dERL
Comment 526, 542

Cl **178**	*SC* **178.9.3**	*P* **305**	*L* **25**	# 526

Li, Mike — Intel

Comment Type **TR** *Comment Status* **D** *ERL*

dERL (min) is TBD

SuggestedRemedy

change it to -3 dB, same as TX

Proposed Response *Response Status* **W**

PROPOSED ACCEPT.
[Editor's note: TBD, P305 L25]

Cl **178**	*SC* **178.9.3**	*P* **305**	*L* **26**	# 542

Li, Tobey — MediaTek

Comment Type **TR** *Comment Status* **D** *ERL*

dERL is TBD

SuggestedRemedy

Replace TBD with -3 dB to be consistent with TX ERL spec.

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: TBD, P305 L25]
Resolve using the response to comment #526.

Both comments propose a value of -3 dB, which is consistent with the transmit dERL requirement on D1.1. It is also consistent with the requirement in P802.3ck.

Editors' recommendation: ACCEPT.

MLSD

Comments 327, 4, 529, 530, 3, 535, 536

MLSD receiver noise
Comment 327

Cl **178A** SC **178A.1.11** P **737** L **4** # **327**

Healey, Adam — Broadcom Inc.

Comment Type **T** *Comment Status* **D** *MLSD*

For the calculation of COM using the MLSD-based reference receiver, COM_DFE and the noise at the output of the feed-forward filter should be adjusted to account for impairments not explicitly included in the calculation of COM but considered to be consumed by the margin represented by the minimum COM limit.

SuggestedRemedy

Implement the "scale receiver noise" option from <https://www.ieee802.org/3/dj/public/24_07/healey_3dj_01a_2407.pdf>. Specific changes to 178A.1.11 will be provided in a separate contribution.

The presentation referenced in the comment is healey_3dj_01a_2407.

The following straw poll from the July 2024 meeting indicates support for the suggested remedy:
Straw Poll #E-2
I would support the direction of modifying the calculation of COM for an MLSD reference receiver to add a method of receiver impairments per healey_3dj_01a_2407
Results (all): Y: 36, , N: 7 , A: 15

The detailed contribution for implementing the proposed changes is healey_3dj_01_2409.

Editors' recommendation:
Implement the changes on slides 11-15 of healey_3dj_01_2409.

MLSD and its Q
Comments 529, 530, 4, 535, 546, 3, 208

Cl 178 SC 178.10.1 P 312 L 17 # 529

Li, Mike Intel

Comment Type **TR** *Comment Status* **D** *MLSD*

MLSD is not enabled

SuggestedRemedy

Add MLSD usage parameter, and set it to 1

Cl 178 SC 178.10.1 P 312 L 17 # 530

Li, Mike Intel

Comment Type **TR** *Comment Status* **D** *MLSD*

MLSD implementation penalty Q is missing

SuggestedRemedy

Add MLSD implemtentation penalty Q parameter and set it as zero in magenta or TBD.

Comment #4 is similar to #529. #535, #536, and #3 are the corresponding comments for Clause 179.

Based on straw poll #TF-3 from the July 2024 plenary (which addressed slides 6-7 of lusted_3dj_06b_2407) there is consensus to add MLSD implementation allowance parameter Q, and the value in the slide is TBD (as in the suggested remedy).

Note that in healey_3dj_01_2409 it is suggested to remove the parameter Q, in conjunction with using a more detailed calculation of the expected MLSE effect.

Also note that there is no "MLSD usage" parameter defined in Annex 178A. The reference receiver can be specified by either referring to the subclause that defines it or by defining the new parameter and subclause mapping in Annex 178A. It seems more efficient to point directly to the subclause.

Comment #208 suggests adding MLSD to the recommendation for CR TP0d-TP5d COM (179A.7). However, 179A.7 refers to Table 178–13, and if this table specifies using MLSD then no additional change is required.

Editors' recommendation:

- In 178.10.1 and 179.11.7, specify that the maximum likelihood sequence detection defined in 178A.1.11 is to be used for the calculation of COM.
- In 176D.4.1 and 176E.5.2., specify that the maximum likelihood sequence detection defined in 178A.1.11 is not included in the calculation of COM.
- Implement with editorial license

(include a reference to this slide)

RX Test

Comments 334, 371, 372

RX Test
Comment 334

Cl **178** SC **178.9.3.3** P **306** L **6** # 334

Healey, Adam Broadcom Inc.

Comment Type **T** *Comment Status* **D** *Rx tests, multi-lane*

The following note is included in 179.9.5.4.2 and 176E.6.12. "NOTE--If noise is applied to each of the n lanes one at a time, results of the n measurements are summed to yield the block error ratio. The result may need to be corrected based on the block error ratio with no noise added on any lane." This statement should be true for any interference (or jitter) tolerance test but it only appears in Clause 179 and Annex 176E. This consideration should be repeated here, or moved to a centralized location (which is referenced from here).

SuggestedRemedy

Add this note, or equivalent content, to 178.9.3.3. Alternatively, define considerations for lane-by-lane testing in a central location (Annex 174A?) and ensure it is referenced by these test procedures. See also 176D.3.4.4.

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: technically incomplete, missing required note in 178]
Add this note quoted in the comment to 178.9.3.3.
Implement the suggested remedy with editorial license.

Editors' recommendation: ACCEPT IN PRINCIPLE.
Implement the suggested remedy with editorial license.

D1.1, 179.9.5.4.2

Table 179–12—Receiver jitter tolerance parameters

Parameter	Case A	Case B	Case C	Case D	Case E	Case F	Units
Jitter frequency	0.04	0.4	1.333	4	12	40	MHz
Jitter amplitude (pk-pk)	5	0.5	0.15	0.05	0.05	0.05	UI

NOTE 1—If jitter is applied to each of the *n* lanes one at a time, results of the *n* measurements are summed to yield the block error ratio. The result may need to be corrected based on the block error ratio with no jitter applied on any lane.

D1.1, 178.9.3.3, p. 307

Table 178–10—Receiver interference tolerance parameters

Parameter	Test 1 (low loss) Min	Test 1 (low loss) Max	Test 1 (low loss) Target	Test 2 (high loss) Min	Test 2 (high loss) Max	Test 2 (high loss) Target	Units
Block error ratio[a]			$< 1.45 \times 10^{-11}$				—
Insertion loss, *ILdd*, at 53.125 GHz[b]			—			—	dB
Receiver package class A	14.5	15.5		33.5	34.5		
Receiver package class B	14.5	15.5		30	31		
COM including effects of broadband noise[c]	—	—	3	—	—	3	dB

[a] The block error ratio (see 178.2) is measured instead of the FEC symbol error ratio in step 10) of the receiver interference tolerance method defined in 93C.2.
[b] ILdd measured between TPt and TP5 (see Figure 93C–4) minus ILdd of the specific package used by the test transmitter.
[c] The COM value is the target for the receiver noise level calibration defined in 93C.2 step 7). The channel noise voltage applied in 93C.2 step 8) should be as close as practical to the value needed to produce the target COM. If higher amplitude values are used, this would demonstrate margin to the specification but this is not required for compliance.

NOTE 1---If jitter is applied to each of the *n* lanes one at a time, results of the *n* measurements are summed to yield the block error ratio. The result may need to be corrected based on the block error ratio with no jitter applied on any lane.

RX Test
Comment 371, 372

Comment 371 proposes to change “minus” to “plus” in footnote b).

- Doing so gives 40dB insertion loss from Tpt-to-Tp5 and the specific package used by the test transmitter for Test 2.

Cl **178** *SC* **178.9.3.3** *P* **307** *L* **30** # 371

Ran, Adee — Cisco Systems, Inc.

Comment Type **T** *Comment Status* **D** *Rx tests*

Footnote b of table 178-10 says "ILdd measured between TPt and TP5 (see Figure 93C–4) minus ILdd of the specific package used by the test transmitter." and the value of the "hight loss" is 40 dB minus the DUT's package loss.
If TPt is a measurable point then the test channel does not include the package used by test transmitter.
In order to calibrate the test channel to "40 dB minus the DUT package" the transmitter package's ILdd should be added to the measured ILdd, not subtracted from it.

The footnote is missing from the table in 176D.

SuggestedRemedy

Change "minus" to "plus".

Use the same footnote in 176D.

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: incomplete - incorrect calculation]
It is assumed that the goal of test 2 is to verify operation over an die-to-die channel with IL of 40 dB.
The table sets targets of 34 dB for receiver package class A and 30.5 dB for receiver package class B. These are effectively 40 dB minus the reference IL of the DUT (TP5 to TP5d). These values therefore represent the IL from the transmitter to TP5.
Figure 93C-4 shows the test channel from TPt to TP5 replica, including from TP0-to-TP0a replica, but not including a transmitter package. If a packaged transmitter is used, its IL (TP0d to TP0) should be added to that of the measured TPt to TP5 replica channel.
The existing footnote says "ILdd measured between TPt and TP5 (see Figure 93C–4) minus ILdd of the specific package used by the test transmitter" which seems contrary to the rationale above. The value in the table should be the IL of the combined TPt-TP5 (measured) and TP0d-TP0 (packaged transmitter) channel.

Implement the suggested remedy in alignment with comment #372.

Table 178–10—Receiver interference tolerance parameters

Parameter	Test 1 (low loss)			Test 2 (high loss)			Units
	Min	Max	Target	Min	Max	Target	
Block error ratio[a]			< 1.45 × 10^{-11}				—
Insertion loss, *ILdd*, at 53.125 GHz[b]			—			—	dB
Receiver package class A	14.5	15.5		33.5	34.5		
Receiver package class B	14.5	15.5		30	31		
COM including effects of broadband noise[c]	—	—	3	—	—	3	dB

[a] The block error ratio (see 178.2) is measured instead of the FEC symbol error ratio in step 10) of the receiver interference tolerance method defined in 93C.2.
[b] ILdd measured between TPt and TP5 (see Figure 93C–4) ~~minus~~ plus ILdd of the specific package used by the test transmitter.
[c] The COM value is the target for the receiver noise level calibration defined in 93C.2 step 7). The channel noise voltage applied in 93C.2 step 8) should be as close as practical to the value needed to produce the target COM. If higher amplitude values are used, this would demonstrate margin to the specification but this is not required for compliance.

Editors’ recommendation: ACCEPT IN PRINCIPLE
Implement the suggested remedy in alignment with comment #372.

RX Test
Comment 371, 372

Cl **178** SC **178.9.3.3** P **307** L **39** # 372

Ran, Adee — Cisco Systems, Inc.

Comment Type **T** *Comment Status* **D** *Rx tests*

The editor's note highlights a problem in footnote b that should be addressed.
The insertion loss of the test channel should be calculated differently for each of the cases listed in list item e).

SuggestedRemedy

Add an item to the list to address the calculation of the required test channel ILdd.
Change the "Parameter" in the second row of Table 178-10 to "Test channel ILdd at 53.125" and refer to the new list item in the footnote instead of the current footnote.

Also apply in 176D as appropriate.

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
The suggested remedy seems to refer to the dashed list in item e) of 178.9.3.3.
The test channel ILdd calculation are different for each of the cases in the dashed list:
- in the first case, the TP0d-TP0 IL should be taken from s-parameters.
- in the second case, the transmitter IL should be omitted from the calculation.
- in the third case, the device should comply with either Tx class A or Tx class B, and the IL of the corresponding package model should be used.

Implement the suggested remedy with the additional considerations above, with editorial license, and with consideration of the response to comment #371.

D1.1, 179.3.3.3, P. 306

e) For the calculation of test channel COM, the transmitter model is determined in one of the following ways.

— If the transmitter is a device with known S-parameters and transition time T_r, these parameters should be used instead of the transmitter package model in 93A.1.2. T_r should be provided as the value at the input of the device S-parameters network, as defined in 120G.3.1.4 but with no observation filter.

— If a calibrated instrument-grade transmitter is used, the TP0 to TP0a trace in Figure 93C–2 and Figure 93C–3 and TP0 to TP0a replica trace in Figure 93C–4 are omitted and the transmitter device package model $S^{(tp)}$ is omitted from Equation (93A–3). The filtered voltage transfer function $H^{(k)}(f)$ calculated in Equation (93A–24) uses the filter $H_t(f)$ defined by Equation (93A–46), where T_r is the measured transmitter transition time (see 120G.3.1.4).

— If the transmitter is composed of a device with unknown S-parameters or unknown transition time, then the transmitter device package model $S^{(tp)}$ in 93A.1.2 is used, and T_r is determined from measurement at TP0v and the TP0 to TP0v S-parameters. The transmitter transition time (see 120G.3.1.4) is measured at TP0v with transmit equalization turned off by setting coefficients to preset 1 values (see 179.9.4.1.3). T_r is set as the value in Equation (93A–46) that would result in the reference transition time $T_r^{(ref)}$, determined according to 163A.3.1.3 with f_b and A_v equal to values in Table 178–13, being equal to the measured transition time.

TX Jitter

Comments 174, 176

TX Jitter
Comment 174, 176

Cl **178** SC **178.9.2** P **301** L **47** # 174

Hidaka, Yasuo — Credo Semiconductor, Inc.

Comment Type **TR** *Comment Status* **D** *Tx jitter*

J3u03 for Tx package Class A is specified as 0.106 UI that is same as clause 163.9.2. Since the loss to the measurement point is higher than clause 163, we need to relax the jitter spec value to take account of larger measurement errors due to higher insertion loss or improve the jitter measurement methodology, for example by UPOJ in calvin_3dj_01b_2407.

SuggestedRemedy

Relax J3u03 for Tx package Class A to 0.138 UI and J3u03 for Tx package Class B to 0.140 UI, or extend and apply UPOJ method in calvin_3dj_01b_2407 to J3u03.

Proposed Response *Response Status* **W**

PROPOSED REJECT.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
The limit for J3u03 in this clause cannot be determined without the loss to TP0v which is not yet defined.
The UPOJ method is mentioned on slide 8 of https://www.ieee802.org/3/dj/public/24_07/calvin_3dj_01b_2407.pdf but isn't described in detail. A more complete proposal is required to implement it into a standard.

Cl **176D** SC **176D.3.3** P **678** L **12** # 176

Hidaka, Yasuo — Credo Semiconductor, Inc.

Comment Type **TR** *Comment Status* **D** *Tx jitter*

J4u03 for Tx package Class A is specified as 0.118 UI that is same as annex 120F.3.1. Since the loss to the measurement point is higher than annex 120F, we need to relax the jitter spec value to take account of larger measurement errors due to higher insertion loss or improve the jitter measurement methodology, for example by UPOJ in calvin_3dj_01b_2407.

SuggestedRemedy

Relax J4u03 for Tx package Class A to 0.153 UI and for Tx package Class B to 0.156 UI, or extend and apply UPOJ method in calvin_3dj_01b_2407 to J4u03.

Proposed Response *Response Status* **W**

PROPOSED REJECT.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
Resolve using the response to comment #174.

The comments propose to either

1) adjust J3u03 to account for higher package loss in .dj relative to .ck.
   - However, loss to TP0v is not defined.
2) Apply the UPOJ method from calvin_3dj_01b_2407.
   - More complete proposal is needed to implement in the standard.

Editors' recommendation: REJECT.

A_v, A_{ne}, A_{fe} and v_f

Comments 528, 160, 161, 534, 376, 573, 563, 162, 163, 410, 538

A_v, A_ne, A_fe vs. R_d
Comments 528, 160, 161, 534

Cl 178 SC 178.10.1 P311 L10 # 528

Li, Mike Intel

Comment Type TR Comment Status D A_v, A_fe, A_ne

Av, Afe, Ane TBDs

SuggestedRemedy

Replace them w
0.413, 0.413, 0.608 V (Av, Afe, Ane)
see lim_3dj_01a_2407.pdf, slide 4

Proposed Response Response Status W

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: TBD, P311 L10-12]
Resolve using the response to comment #376.

Cl 179 SC 179.11.7 P358 L10 # 534

Li, Mike Intel

Comment Type TR Comment Status D A_v, A_fe, A_ne

Av, Afe, Ane TBDs

SuggestedRemedy

Replace them w
0.413, 0.413, 0.608 V (Av, Afe, Ane)
see lim_3dj_01a_2407.pdf, slide 4

Proposed Response Response Status W

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: TBD, P358 L10-12]
Resolve using the response to comment #376.
[Editor's note: Changed subclause from 179.11.11 to 179.11.7]

Cl 178 SC 178.10.1 P311 L10 # 160

Dudek, Mike Marvell

Comment Type TR Comment Status D A_v, A_fe, A_ne

With the change of Rd from 50 Ohm to 46.25 Ohm in COM the effective output amplitude into a 50 Ohm load increased resulting in a requirement for approximately 4% larger steady state output amplitude from the transmitter than for 100G per lane if Av is the same as for 100GBASE-KR1.

SuggestedRemedy

Make Av and Afe equal to 400mV and Ane to 585mV.

Proposed Response Response Status W

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
Resolve using the response to comment #376.

Cl 179 SC 179.11.7 P356 L10 # 161

Dudek, Mike Marvell

Comment Type TR Comment Status D A_v, A_fe, A_ne

With the change of Rd from 50 Ohm to 46.25 Ohm in COM the effective output amplitude into a 50 Ohm load increased resulting in a requirement for approximately 4% larger steady state output amplitude from the transmitter than for 100G per lane if Av is the same as for 100GBASE-CR1.

SuggestedRemedy

Make Av and Afe equal to 400mV and Ane to 585mV.

Proposed Response Response Status W

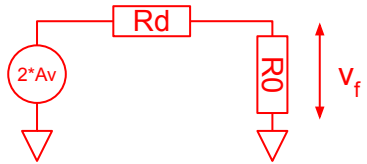
PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
Resolve using the response to comment #376.
[Editor: Page changed from 356 to 358]

Comments 528 and 534 propose using the values from 802.3ck for the COM parameters A_v, A_{fe}, and A_{ne}.

Comments 180 and 181, as well as 376 (next slide), propose modified values to account for the change in R_d from 50 Ω to 46.25 Ω.

These parameters are related to the minimum and maximum values of transmitter parameter v_f, divided by a factor calculated as $2*R_0/(R_0+R_d)=1.04$, giving:

- **$A_v = A_{fe} = 0.385$ V** (corresponding to min $v_f = 0.4$)
- **$A_{ne} = 0.578$ V** (corresponding to max $v_f = 0.6$)



The proposed relationship assumes that the value of $1.04*A_v$ is achieved at the measurement point TP0v/TP2 with the specified v_f measurement method (despite loss effects that might reduce the measured value). It is suggested to add an editor's note stating that this needs confirmation.

A_v, A_ne, A_fe vs. R_d, increased minimum Comment 376

Cl **178** *SC* **178.10.1** *P* **311** *L* **10** # **376**

Ran, Adee — Cisco Systems, Inc.

Comment Type **TR** *Comment Status* **D** *A_v, A_fe, A_ne*

The value of A_v and A_fe in Table 178-13 is TBD.

In previous PMD clauses it was assumed that a transmitter can have a minimum output voltage of A_v=0.413 V with a reference die impedance Rd=50 Ohm. This somewhat matches the specification of min V_f=0.387 V as measured on a 50 Ohm load (although since the reference was equal to the load, these should be the same; the difference is due to a historic definition of v_f).

However, in this project we changed the reference Rd to 45.25 Ohm, so to get 0.413 V on a 50 Ohm load the A_v should be increased by at least a factor of 2*50/(45.25+50)=1.05, resulting in 0.434 V.

In addition, experience shows that devices typically have higher than the minimum output voltage allowed in by previous specifications. This improves the reach by providing larger signal to the link partner. Increasing the minimum output will improve COM for high loss channels targeted by KR and CR PMDs, and from design point of view it is preferable over assuming more capable receivers.

It is therefore suggested that A_v is increased from 0.434 V (which would create the same output voltage) to 0.525 V (which would create 500 mV on a 50 Ohm load).

Note that this change would directly affect the Tx output requirements for KR because the spec parameter is dv_f, where the reference is calculated with A_v. For CR, the minimum v_f needs to be set correspondingly (ideally 0.5 V but may be lower for high-loss hosts). Since host channels have not been adopted, a change in v_f is not proposed at this time.

This should be applied in KR and CR, but not in C2C and C2M, which target lower loss channels.

SuggestedRemedy

Change A_v and A_fe in Table 178-13 and Table 179-16 from TBD to 0.525 V.

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: This comment proposes an update to a technically complete area in the draft]

The comment suggests that A_v should be increased by a factor 1.05 due to the change in R_d, but that is incorrect. As noted by Comment #160 on the same topic, the correct factor is 2*50/(46.25+50)=80/77≈1.04, and A_v should actually be decreased by that factor. Assuming that v_f (measured on 50 Ohm load) is specified as 0.4 V (min) and 0.6 V (max), A_v and A_fe should be changed to 0.385 V, and A_ne should be changed to 0.578. This should be applied in Clauses 178 and 179 and Annexes 176D and 176E.

The values above assume that the value corresponding to A_v (with the 1.04 factor) is achieved in measurement of v_f. An editor's note should state that this needs confirmation.

Comment #376 suggests a correction based on the change in R_d. The suggested remedy incorrectly suggests multiplying by the correction factor 1.04 in the previous slide, instead of dividing by it. The proposed response shows the correct values.

In addition, this comment proposes that, **for the CR and KR PMDs only**, A_v and A_{fe} be increased to a value corresponding to v_f (min) = 0.5 V instead of 0.4 V, to enable operation with the higher loss channels assumed for these PMDs. With a division by the factor 1.04, this would result in $A_v = A_{fe} = 0.481$ V.

Note that v_f (min) is currently TBD in clause 179 for all 3 host designations. In clause 178 the specification is dvf (min), where the reference value is based on A_v.

Increasing A_v and A_{fe} as suggested is expected to improve COM, but no data has been provided. In addition, it is unclear if this increase can be supported by a wide range of PMD implementations.

A_v, A_ne, A_fe, reduced maximum
Comment 573, 563

Cl 176E SC 176E.5.2 P 704 L 8 # 573

Dawe, Piers Nvidia

Comment Type TR *Comment Status* D *A_v, A_fe, A_ne*

These voltages Av Afe Ane look like old style backplane-style values, which should be reduced even for CR and KR, and should be reduced further for C2M. They are TBD in 178 and 179, so it's hard to see why they are not TBD here also.

SuggestedRemedy

Reduce Av Afe Ane. Assuming this COM table passes and fails the right scenarios, reduce eta0 in proportion.

Proposed Response *Response Status* W

PROPOSED REJECT.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
The suggested remedy does not provide sufficient detail to implement.
The values in the table were adopted based on analysis made in numerous contributions and long consensus building, summarized in https://www.ieee802.org/3/dj/public/24_06/lusted_3dj_01a_2406.pdf, as a result of comment #72 against D1.0. The comment does not provide justification or indication of consensus to change these values.

Cl 179 SC 179.9.4 P 334 L 53 # 563

Dawe, Piers Nvidia

Comment Type TR *Comment Status* D *Tx diff PtP, vf*

Supply voltages and voltage swing trend downwards over the years. This 1200 mV max has not changed since 10GBASE-KR, a long time ago. In 3ck and D1.0, C2M had 750 mV, and other C2M had 900 mV. A high max is harmful when a receiver can ask someone else's transmitter to turn up to the max, causing the second party to suffer unnecessary NEXT in its receiver.

SuggestedRemedy

Reduce 1200 mV to e.g. 1000 mV, here, in the receiver Table 179-10 and in the text in 179.9.5.2. Reduce the steady-state voltage vf max from 0.6 V to 0.5 V. Make appropriate adjustments to Av Afe Ane and eta0 in COM tables.
Similarly for KR and C2C. See another comment for C2M.

Comment #573 suggests a reduction of A_v, A_{fe}, and A_{ne} for C2M, and possibly also for KR and CR, without specific values. However, based on comment #563 (which is mentioned in simms_3dj_01_0924 along with 523, 524, and 570), it is assumed that a value of 0.5 V is suggested for v_f (max) in CR, KR, and C2C, without changing the minimum. (#570 suggests 0.45 for C2M)

Justification for changing the *maximum* and not the minimum seems to be based on COM results, but COM uses an extreme assumption of maximum swing for NEXT, and devices are not required to reach that maximum. It is likely that reducing the *minimum* would be more beneficial for transmitter implementations than reducing the maximum.

A possible set of values for this comment (as understood by the editors) is shown as option C below.

Interim summary: possible directions are

A. $A_v=A_{fe}=0.385$ V and $A_{ne}=0.578$ V, consistent with v_f range of 0.4 V to 0.6 V.
B. $A_v=A_{fe}=0.481$ V and $A_{ne}=0.578$ V, consistent with v_f range of 0.5 V to 0.6 V.
C. $A_v=A_{fe}=0.385$ V and $A_{ne}=0.481$ V, consistent with v_f range of 0.4 V to 0.5 V.

Editors' recommendations:

- In 178 and 179, use $A_v = A_{fe} = 0.385$ V and $A_{ne} = 0.578$ V (option A).
- In 176D and 176E, use the same values for A_v, A_{fe}, but for A_{ne} use the response to comment #162 (next slide).
- In 179 and 176E, set v_f min and max to values corresponding to A_v and A_{ne}, for all host designations.
- Add an editor's note on v_f as suggested on a previous slide.

A_v, A_ne, A_fe vs. R_d
Comments 162, 163, 410, 538

Cl 176D SC 176D.4.1 P686 L8 # 162

Dudek, Mike Marvell

Comment Type TR *Comment Status* D *A_v, A_fe, A_ne*

With the change of Rd from 50 Ohm to 46.25 Ohm in COM the effective output amplitude into a 50 Ohm load increased resulting in a requirement for approximately 4% larger steady state output amplitude from the transmitter than for 100G per lane.

SuggestedRemedy

Change the values of Av and Afe to 400mV and Ane to 585mV. If that is not done then the Test transmitter constraint on page 682 line 37 should be increased from 800mV to 830mV

Proposed Response *Response Status* W

PROPOSED REJECT.
[Editor's note: technically incomplete - mismatch of specifications and COM parameters]
The values for A_v, A_ne, A_fe were adopted based on https://www.ieee802.org/3/dj/public/24_06/lusted_3dj_01a_2406.pdf along with an editorial note stating that the values are to be confirmed and may change based upon further analysis.
For CRG discussion.

Cl 176E SC 176E.5.2 P704 L8 # 163

Dudek, Mike Marvell

Comment Type TR *Comment Status* D *A_v, A_fe, A_ne*

With the change of Rd from 50 Ohm to 46.25 Ohm in COM the effective output amplitude into a 50 Ohm load increased resulting in a requirement for approximately 4% larger steady state output amplitude from the transmitter than for 100G per lane.

SuggestedRemedy

Change the values of Av and Afe to 400mV and Ane to 585mV. If that is not done then the Transmitter steady-state Voltage Vf(min) in Table 176E-1 needs to be increased to 400mV and the steady state output voltage Vf (min) in Table 176E-2 increased to 415mV

Proposed Response *Response Status* W

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
Resolve using the response to comment #162.

Cl 176D SC 176D.4.1 P686 L9 # 538

Li, Mike Intel

Comment Type TR *Comment Status* D *A_v, A_fe, A_ne*

Ane of 0.45 is inconsistent with the TX Vdiff max

SuggestedRemedy

Change it to 0.6 to be consistent

Proposed Response *Response Status* W

PROPOSED REJECT.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
Resolve using the response to comment #162.

Cl 176D SC 176D.4.1 P686 L9 # 410

Ran, Adee Cisco Systems, Inc.

Comment Type TR *Comment Status* D *A_v, A_fe, A_ne*

The value of A_ne in Table 176D-7 is 0.45.
The maximum allowed differential peak-to-peak voltage for a transmitter in Table 176D-1 is 1200 mV.
The local device's transmitter (which creates the NEXT) can have this maximum, so its A_ne should be at least 600 mV to match. In 802.3ck, the value 0.608 V was used, but since the maximum differential applies to any signal (not just PRBS13Q) there is no need to exceed 600 mV.
Alternatively the max diff ptp voltage in the Tx could be reduced to 900 mV, but it is likely that this would reduce reach in practical implementations, so it is not desired.

This also applies to A_ne in Table 176E-6 (currently 0.45 V) and in Table 178-13 and 179-16, (currently TBD).

SuggestedRemedy

Change A_ne to 0.6 V in Table 176D-7, Table 176E-6, Table 178-13, and Table 179-16.

Proposed Response *Response Status* W

PROPOSED REJECT.
[Editor's note: This comment proposes an update to a technically complete area in the draft]
Resolve using the response to comment #162.

Comments 162 and 163 propose changes to the values for A_v, A_{fe}, and A_{ne} in Annexes 176D and 176E to account for the reduced R_d.
The values for A_v and A_{fe} are expected to be resolved by the response to comment #376.

Comments #538 and #410 ask to set the value of A_{ne} to correspond to the maximum v_f, which is currently 0.6 V in 176E and 179. As shown on the previous slide, this would result in A_{ne} = 0.578 V.
The value of 0.45 V for A_{ne} in 176D and 176E of D1.1 was adopted by consensus, see lusted_3dj_01a_2406. Based on the previous slide, this value corresponds to maximum v_f of 0.433 V.

Thus:

A. If the value of A_{ne} for AUI-C2M and AUI-C2C is retained, then v_f (max) in Table 176E–1 should be reduced from 0.6 V to 0.468 V.
B. If v_f (max) is retained, then A_{ne} for AUI-C2M and AUI-C2C should be set to 0.578 V (option A in the previous slide).
C. Or, as middle ground, v_f (max) can be set to 0.5 and A_{ne} to 0.481 (option C in the previous slide).

Note that for AUI-C2C the parameter is dv_f, which is addressed by comment #139.

Editors' recommendation: Choose one of the options above; based on the choice, set A_{ne} in 176D and 176E and set maximum v_f in 176E.

C2M lLdd budget

Comments 422, 115, 418, 420

C2M ILdd budget and host model Comments 422, 115

Cl 176E SC 176E.5.2 P703 L41 # 422

Ran, Adee Cisco Systems, Inc.

Comment Type **TR** *Comment Status* **D** *C2M Host channel*

Host PCB channel is TBD.
In addition, there are two package models with different parameters; we need to choose the package model as part of the host model.

A set of possible C2M host models was presented in https://www.ieee802.org/3/dj/public/24_07/ran_3dj_01b_2407.pdf, slide 16, using PCB parameters on slide 8, which result in 1.7 dB/inch (same as those used in clause 162).

With a host channel IL of 27.3 dB, option 2, with 45-mm class B package trace and 217-mm PCB zp, represents a reasonable high-radix host design.

Note that the zp is not the actual PCB trace length but only TP0-TP1 (see slide 7).

SuggestedRemedy

Use the parameters on slide 8 with PCB zp=217, C0=C1=0, as the host PCB model for C2M in Table 176E-5.
Delete the "Class A package model" row and set "Transmission line 1 length" in the "Class B package model" row to 45 mm (one value).
Refer to this model in "Host channel parameters" in Table 176E-9 (interference tolerance) and in 176E.6.12.2.

Change TBDs in "Test channel insertion loss at 53.125 GHz" row to:
Low loss: min=9 dB, max:10 dB (a mated test fixture)
High loss: min=33.5 dB, max=34.5 dB (maximum TP0d-TP1a loss)

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.
[Editor's note: TBD, P703 L41]
Based on the comment it is assumed that the suggested remedy refers to option 2 on slide 16 in the referenced presentation, and specifically proposed the values Pkg zp=45, PCB zp=217, C0=C1=0. The resulting IL of the mathematical channel added in COM calculation at 53.125 GHz would be 24.62. The "total host channel channel" and "Tp0d-TP1a IL" are informative, and may need to be adjusted based on the responses to comments #566 and #520.

Note that comment #537 suggests a different PCB model for CR host.

Pending CRG discussion.

Cl 176E SC 176E.2 P695 L40 # 115

Ghiasi, Ali Ghiasi Quantum/Marvell

Comment Type **TR** *Comment Status* **D** *k diagram, C2M Host channel*

Figure TBDs

SuggestedRemedy

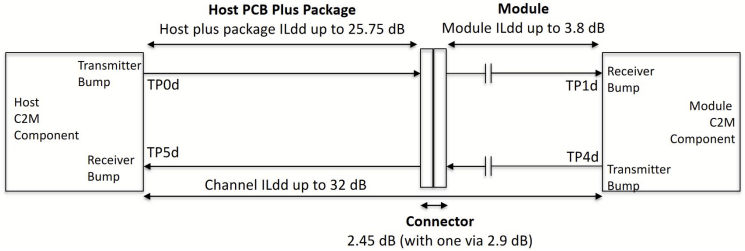
See Ghiasi_01 supporting presentation from July-24
Connector Ildd=2.45 dB
Module Ildd=3.8 dB
Host Ildd=23.75 dB

These two comments effectively suggest values for the host channel insertion loss.

- #422 suggests using host model option 2 on slide 16 of ran_3dj_01b_2407, which results in 34 dB from TP0d to TP1a.
- #115 suggests a budget of 2.45+3.8+23.75=30 dB die-to-die (from TP0d to TP1d).

There is an apparent difference of 4 dB, but note that the bookends (TP1a and TP1d) are not the same.

C2M ILdd budget and host model Comments 422, 115



Possible parameters for C2M (X=27.3 dB)

Using class B package with zp of either 30 or 45 mm, with/without C0

Option	pkg zp [mm]	C0 [fF]	PCB zp [mm]	C1 [fF]	COM channel IL [dB]	Total host channel IL [dB]	Tp0d-TP1a IL [dB]
1	30	0	258	0	24.58	27.28	33.98
2	45	0	217	0	24.62	27.32	34.02
3	30	29	249	0	24.62	27.32	34.02
4	45	29	205	0	24.61	27.31	34.01

Note that ghiasi_3dj_03_2409 slide 7 updates the proposal in #115 to 25.75+2.45+3.8=32 dB (TP0d-TP1d).

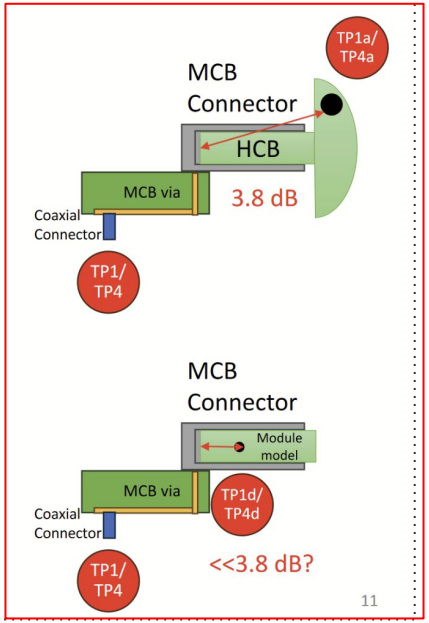
#422 suggests using host model option 2 on slide 16 of ran_3dj_01b_2407

C2M ILdd budget and host model Comments 422, 115

Recall an illustration of the two test points TP1d and TP1a in ran_3dj_elec_01a_240801 slide 11…

Creating C2M module specifications (cont)

- Even if we had a reference model for the module… deriving input/output specifications is more complicated than the host case
- We need reference models of the TP1-TP1d and TP4d-TP4 channels
  - These are shorter than TP1-TP1a and TP4a-TP4 in a mated test fixture
  - We can't start with measured MTF S-parameters and add some mathematical model, as in the host case…
- Contributions in this area are encouraged
  - Mathematical expressions
  - Explicit S-parameters
  - Combinations
  - Other ideas



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With an allocation of 3.8 dB to the HCB, The insertion loss between TP1d and TP1d is likely about 3 dB (it may be lower if the DSP in the module is packaged).

This means

- TP0d-TP1d is **~31** dB in #422 vs. **30 or 32** dB in #115
- TP0d-TP1a is **34** dB in #422 vs. **~33 or ~35** dB in #115
- The host model suggested by #422 is close to what is assumed in #115

There seems to be agreement between the two comments.

C2M ILdd budget and host model
Comments 418, 420

Cl **176E** *SC* **176E.5** *P* **701** *L* **30** # 418

Ran, Adee
Cisco Systems, Inc.

Comment Type **T** *Comment Status* **D** *C2M Host channel*

The standard does not recommend a channel - and the full channel is not owned by a single designer, so no such recommendation can be made.

The content of this subclause would be better described as "Expected channel properties".

SuggestedRemedy

Change the heading of 176E.5 to "Expected channel properties".

Add the following paragraph after the existing paragraph:
"The following subclauses describe the expected properties of the channels between the two C2M components, from TP0a to TP1d and from TP5d to TP5d, as depicted in Figure 176E-2. These test points are typically not accessible in an implemented system."

Proposed Response *Response Status* **W**

PROPOSED ACCEPT IN PRINCIPLE.

[Editor's note: This comment proposes an update to a technically complete area in the draft]

Implement the suggested remedy with editorial license and with consideration of the resolution of comments #148, #196, and #420.

Note that the TP0d-TP1d insertion loss is not normative and is not even a recommendation, as this path is divided between the host and the module.
Comment #418 suggests rephrasing the text in 176E.5 to clarify that.

Comment #420 suggests using a table for the ILdd values of subsections of the path, instead of having numbers in the figure. The related contribution ran_3dj_03_2409 discusses this comment and proposes the table format.

Editors' recommendation:

- Adopt 34 dB as the reference max ILdd between TP0d and TP1a.
- Adopt the COM channel model parameters of "option 2" on slide 16 of ran_3dj_01b_2407 . Use these parameters for the host PCB model for C2M in Table 176E-5. Delete the "Class A package model" row and set "Transmission line 1 length" in the "Class B package model" row to 45 mm (one value).
- In Table 176E-9, change TBDs in "Test channel insertion loss at 53.125 GHz" row (module test) to: Low loss: min=9 dB, max:10 dB (a mated test fixture), High loss: min=33.5 dB, max=34.5 dB (reference TP0d-TP1a loss +/- 0.5 dB)
- Use the table format suggested in slide in ran_3dj_03_2409 instead of having ILdd values in the figure. Fill in the following values:
  - For module ILdd: 3.8 dB, for host channel including connector: 28.2 dB (as in slide 7 of ghiasi_3dj_03_2409).
  - For module + connector + MCB use 2.8+2.45+3.5=8.75 dB (as in slide 7 of ghiasi_3dj_03_2409 and Figure 179A–3)
  - For MCB use 3.5 dB (based on Figure 179A–3)
  - For HCB use 3.8 dB (based on Figure 179A–3).

C2M ILdd budget and host model
Comments 422, 115, 418, 420

Table 176E–5—Host device, package, and PCB model parameters

Class A package model			
Transmission line parameter γ_0	γ_0	5×10^{-4}	1/mm
Transmission line parameter a_1	a_1	8.9×10^{-4}	$ns^{1/2}/mm$
Transmission line parameter a_2	a_2	2×10^{-4}	ns/mm
Transmission line parameter τ	τ	6.141×10^{-3}	ns/mm
Transmission line 1 length, Test 1	$z_p^{(1)}$	33	mm
Transmission line 1 length, Test 2	$z_p^{(1)}$	12	mm
Transmission line 1 characteristic impedance	$Z_c^{(1)}$	87.5	Ω
Transmission line 2 length	$z_p^{(2)}$	1.8	mm
Transmission line 2 characteristic impedance	$Z_c^{(2)}$	92.5	Ω

Class B package model			
Transmission line parameter γ_0	γ_0	5×10^{-4}	1/mm
Transmission line parameter a_1	a_1	6.5×10^{-4}	$ns^{1/2}/mm$
Transmission line parameter a_2	a_2	2.93×10^{-4}	ns/mm
Transmission line parameter τ	τ	6.141×10^{-3}	ns/mm
Transmission line 1 length, Test 1, Tx / Rx	$z_p^{(1)}$		mm
Transmission line 1 length, Test 2, Tx / Rx	$z_p^{(1)}$	45	mm

Host PCB model, Host designation Host-Low	TBD	

option 2 on slide 16 of [ran_3dj_01b_2407]

Table 176E–9—Interference tolerance test parameters

Parameter	Host test	Module test 1 (low loss)		Module test 2 (high loss)		Units
		Min	Max	Min	Max	
Test channel insertion loss at 53.125 GHz	N/A	9	10	33.5	34.5	dB
Host channel parameters	Table 176E-5	N/A		N/A		

C2M ILdd budget and host model
Comments 422, 115, 418, 420

Table 176E–5—Reference ILdd values for the C2M channel

Path	Reference ILdd	Units
Host channel, t Including package and connector	28.2	dB
~~Host connector~~		dB
Module channel, between paddle card edge and TP1d/TP4d	3.8	dB
Host and HCB, between TP0d/TP5d and TP1a/TP4a	34	dB
Module and MCB, between TP1d/TP4d and TP1/TP4	8.75	dB
HCB, between paddle card edge and TP1a/TP4a	3.5	dB
MCB, between the connector pads and TP1/TP4	3.8	dB

C2C channel

Comment 33

C2C Channel Comment 33

Cl **176D** *SC* **176D.1** *P* **674** *L* **17** # 33

Heck, Howard — Intel Corporation

Comment Type **T** *Comment Status* **D** *C2C channel*

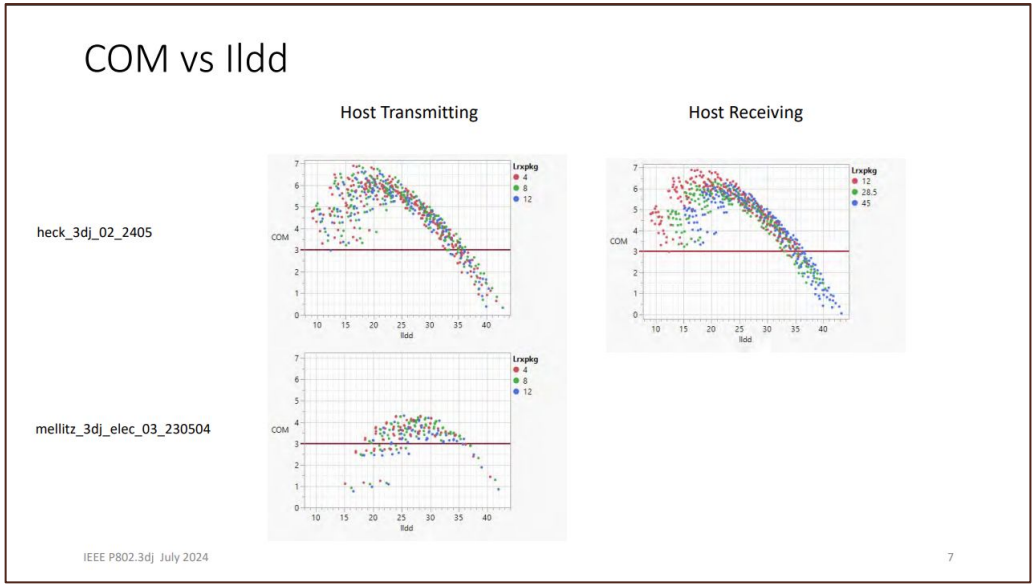
D1.1 contains a TBD for the approximate interconnect length. The contribution in https://www.ieee802.org/3/dj/public/24_07/heck_3dj_01a_2407.pdf indicates that an interconnect length of approximately 30 cm will pass COM

SuggestedRemedy

Replace "TBD" with "30 cm"

Proposed Response *Response Status* **W**

PROPOSED REJECT.
[Editor's note: TBD, P674 L17]
The contribution referenced in the comment does not mention interconnect length, so it does not justify the suggested remedy.
Nevertheless, it would be good to adopt a value instead of the TBD, if there is consensus.
For CRG discussion.



The comments proposes to replace a the TBD for approximate interconnect length. The referenced contribution, heck_3dj_01a_2407, contains COM results as a function of die-die insertion loss, but not PCB length.
The commenter indicated that the ILdd values that meet 3 dB COM correspond to up to 11.5-12 inches of PCB from the channels contributed in Heck_3dj_02_2405 and mellitz_3dj_elec_03_230504. However, this information was not included in the presentation.

Since the interconnect length is stated as approximate value in the overview section, this information may be sufficient to replace a TBD with a value, provided as a limit. The alternative is to delete the sentence.

Editors' recommendation: change "with electrical interconnect of approximately TBD cm in length" to "with electrical interconnect of up to approximately 30 cm in length".

heck_3dj_01a_2407.pdf