BER considerations for 200 Gb/s per lane AUIs

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802.3dj electrical ad hoc meeting

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Introduction

- Need to set a BER target or set of BER targets for 200 Gb/s per lane C2M and C2C AUIs.
- A higher AUI BER target provides tolerance for higher insertion loss, crosstalk, and reflections.
- Choice of AUI BER target has implication on definition of PMDs and physical layer implementations.

High-BER and Low-BER AUIs in MAC-to-MAC link

The following presentation illustrated the impact of AUI BER choice on a MAC-to-MAC link:

https://www.ieee802.org/3/dj/public/23_03/gustlin_3dj_01_2303.pdf

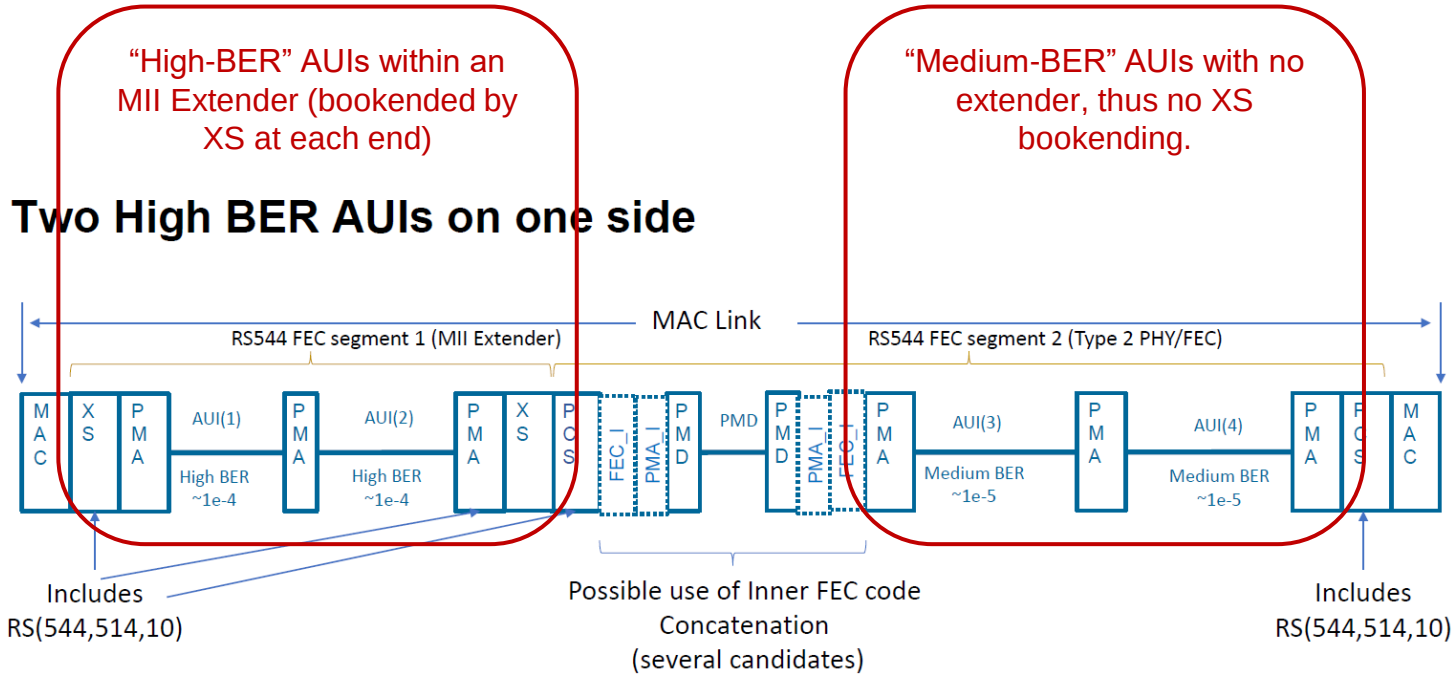
The slide to the right shows “high-BER” (~1E-4) and “medium-BER” (~1E-5) AUI types in a system.

The assumption in that presentation are:

#1 If there is one or more “high-BER” AUI in a Physical Layer implementation, then they must be within an extender, thus FEC segmentation.

#2 If there is one or two “medium-BER” AUIs in a Physical Layer implementation, then an extender is not required; thus no FEC segmentation.

However, an intermediate BER value, e.g., 5E-5, was not considered.



- Type 2 PHY/FEC with no AUIs on left side and 2 AUIs on right side
- MII Extender with 2 high BER AUIs on left side
- Current assumption: High BER AUIs targeting ~1e-4 require XS
  - Isolates errors from the high BER AUI
  - One extender in this example (covering two high BER AUIs)
- Higher latency option (does not consider FEC inner code decision)

Straw poll

Straw polls #9 and #10 taken at the March 2023 Plenary meeting are shown to the right.

https://www.ieee802.org/3/dj/public/23_03/motions_3dfdj_2303.pdf

Straw poll #9 demonstrates strong desire for a AUI BER limit of 1E-5 and less so 5E-5.

Straw poll #10 demonstrates a split opinion on what to allow for the “high-BER” BER case:

- BER target to be 1E-5
- BER target to be 5E-5
- BER target to be 1E-4

Straw Poll #9

I believe 200G Medium BER C2M AUI specifications will require support for:

A. BER ≤ 1e-5 (per segment)
B. BER ≤ 5e-5 (per segment)
C. BER ≤ 1e-4 (per segment)
D. BER ≥ 1e-4 (per segment)
E. Need more information

(pick one)

Results (all): A: 49 , B: 30 , C: 0 , D: 0 , E: 25

Straw Poll #10

I believe 200G High BER C2M AUI specifications will require support for:

A. BER ≤ 1e-5 (per segment)
B. BER ≤ 5e-5 (per segment)
C. BER ≤ 1e-4 (per segment)
D. BER ≥ 1e-4 (per segment)
E. Need more information

(pick one)

Results (all): A: 16 , B: 47 , C: 17 , D: 1 , E:23

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PHY/FEC “types”

For review, the following presentation introduced 3 PHY types relating to the way the FEC is used with the AUIs.

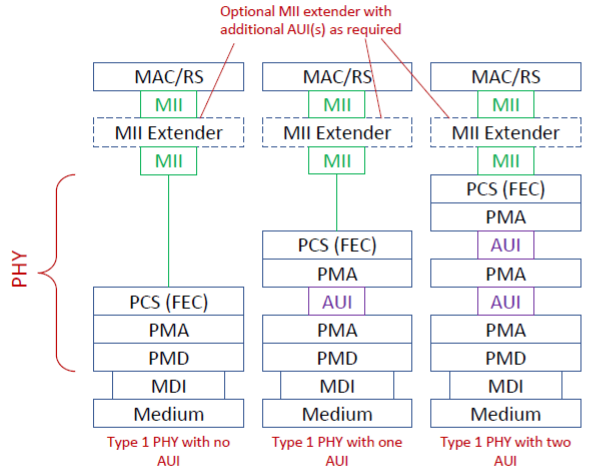
https://www.ieee802.org/3/dj/public/23_03/brown_3dj_01a_2303.pdf

A Type 1 PHY (top right) allows up to 2 AUI segments within the PHY (at each end) with BER less than 1E-5. The AUI BER target influences the choice of the PMD BER target.

A Type 2 PHY (bottom right), which includes concatenated inner FEC, allows up to 2 AUIs within the PHY (at each end) with BER less than ~5E-5 (see later slide) each. The AUI BER target influences the choice of the PMD BER target.

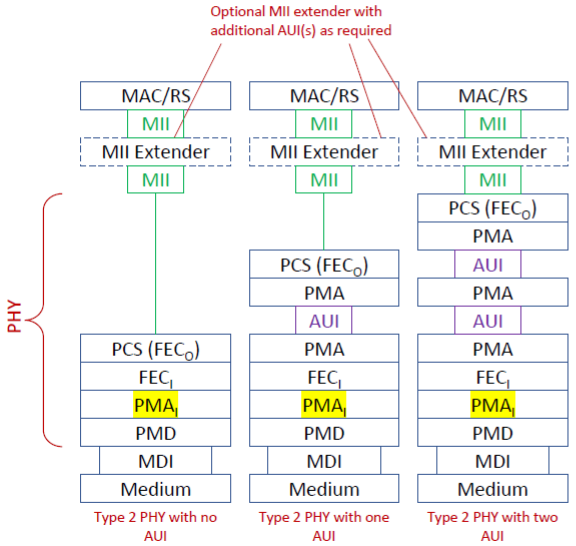
A Type 3 PHY allows no AUIs within the PHY. An extender is always required if an AUI is required. The AUI BER does not affect the PMD link.

Type 1 PHY/FEC



- A single FEC spans the PHY link (PCS to PCS) which may include up to four AUIs.
- FEC corrects errors that are contributed by the PMD link and the AUIs.
- PMD and Medium characteristics are defined with AUI errors in mind.
- BER trade off between the AUIs and the PMD link.
- More AUIs may be added above the PHY using the optional MII Extender without affecting PHY performance.
- The following PHYs are Type 1 PHY/FEC:
  all 200GBASE-R in 802.3, 802.3ck, 802.3db
  all 400GBASE-R in 802.3, 802.3ck, 802.3db
  all 800GBASE-R in 802.3df

Type 2 PHY/FEC



- An outer FEC (FEC$_O$) spans the PHY link (PCS to PCS) including up to four optional AUIs (like Type 1)
- An inner FEC (FEC$_I$) spans only the PMD link (PMD to PMD)
- The PMA below FEC$_I$ (PAM$_I$) is different from the PMAs above FECI.
- FEC$_I$ corrects “most” errors contributed by the PMD link
- FEC$_O$ corrects errors not corrected by FEC$_I$ and error contributed by the AUIs
- The combined effect of FEC$_I$ and FEC$_O$ results in the target frame loss ratio (FLR) for the PHY.
- FEC$_I$ and FEC$_O$ defined in conjunction with each other.
- PMD and Medium characteristics defined with AUI errors in mind.
- BER trade off between the AUIs and the PMD link.
- More AUIs may be added above the PHY using the MII Extender without affecting PHY performance.
- This PHY/FEC type is new for 802.3.

Type 1 PMD BER Specification Example

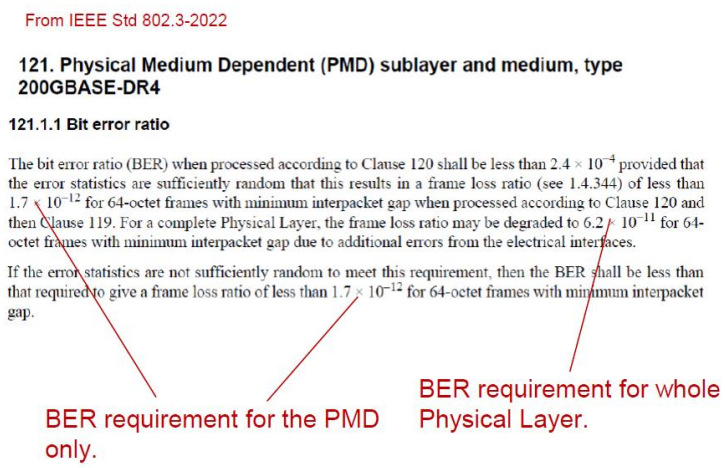
For review, the following presentation gave an example of how the AUI BER affects the allowable PMD FLR and BER.

https://www.ieee802.org/3/dj/public/23_03/brown_3dj_01a_2303.pdf

In this example...

- the PMD/FLR allows for two AUI segments in a PHY (at each end) with 1E-5 BER per AUI segment
- the FLR for the whole physical layer implementation is 6.2E-11
- the PMD FLR target is reduced to 1.7E-12 FLR for the PMD link to allow for the AUI BER

Type 1 BER Specification Example



- 200GBASE-DR4 is a typical Type 1 optical PHY
- For the PMD link:
  - BER limited to 2.4E-4 (if random errors)
  - FLR limited to 1.7E-12
- For the PHY link:
  - FLR is limited to 6.2E-11

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C2M AUI channel analysis

The following presentation explored the tradeoff between C2M channel insertion loss, DER target, and reference receiver characteristics.

https://www.ieee802.org/3/dj/public/23_03/li_3dj_01a_2303.pdf

Using a full CR-like reference receiver and DER of 1E-5 a die-to-die insertion loss of only 31.75 dB is achievable.

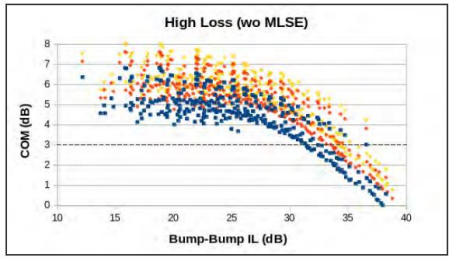
To achieve longer reach, higher DER target and/or more complex reference receiver (e.g., MLSE) is required.

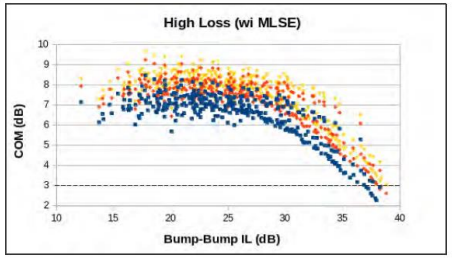
Achievable IL of High Loss C2M

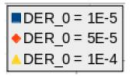
DER_0	Reference TX & RX	Achievable IL
1E-5	3ck CR/KR-like	31.75
1E-5	3ck CR/KR-like + MLSE	36.5
5E-5	3ck CR/KR-like	33.5
5E-5	3ck CR/KR-like + MLSE	38.13
1E-4	3ck CR/KR-like	34.37
1E-4	3ck CR/KR-like + MLSE	38.82

Evolution from 802.3ck CR

- Further relax DER_0 from 5E-5 to 1E-4 doesn't seem to help much
- MLSE can provide ~4.5 dB IL margin under 3dB COM
  - b_max (1) = 0.85





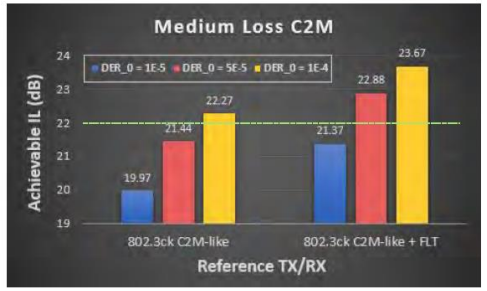


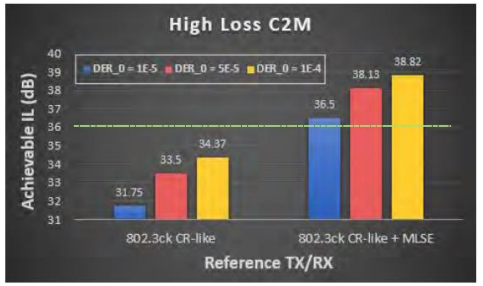
802.3dj C2M Candidates vs Achievable IL

- This presentation address C2M technical considerations from the perspective of achievable loss
  - Again, please be aware this is a conservative estimate of achievable IL due to the lack of channel compliance

AUI interaction with optical PMDs development

Ref TX & RX: SerDes/AUI DER_0	1E-5	5E-5	1E-4
802.3ck C2M-like	19.97	21.44	22.27
802.3ck C2M-like + FLT	21.37	22.88	23.67
802.3ck CR-like	31.75	33.5	34.37
802.3ck CR-like + MLSE	36.5	38.13	38.82





Impact of AUI BER on PMD

The following presentation provided impact of AUI BER on the BER limit for the Type 2 PMD.

https://www.ieee802.org/3/dj/public/23_03/he_3dj_01_2303.pdf

Per the slide on the right, the allowable PMD BER is dependent upon the AUI BER and the amount of interleaving in the in the inner FEC (FEC_I).

If we allow either 2 AUIs with BER 5E-5 each or 1 AUI with BER 1E-4 the PMD BER limit is:

- 3.5E-3 if 12 CW interleaving
- 2.4E-3 if 4 CW interleaving

Alternately, C2C and C2M could have different limits with sum of 1e-4, e.g., 2E-5 for C2C and 8E-5 for C2M.

PMD BER Threshold Considering AUI

- Up to 2 segments of AUI on each side, not including MII Extenders, shall be supported.
- The combined effect of FEC_I and FEC_O results in the target frame loss ratio (FLR) for the PHY.
  - AUI BER threshold will affect the PMD BER allowed.
  - BER threshold listed below are updated data based on he_3dj_01a_230206.pdf and he_3df_01_2211.pdf.

AUI BER (each segment)	PMD (w/ Convo. Int.)	PMD (w/o Convo. Int.)
1E-5	4.4E-3*	3.1E-3*
5E-5	3.5E-3*	2.4E-3*

*Assuming the error statistics are sufficiently random. If the error statistics are not sufficiently random, the BER allowed shall be lower.

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Next steps, thoughts

- Is it necessary to support 2 AUIs per PHY?
  - If we limit to one AUI per PHY then:
    - a single AUI with 2E-5 is compatible with Type 1 PHY
    - a single AUI with 1E-4 is compatible with Type 2
- If we need two AUIs sometimes, can we specify different BER targets for C2M and C2C?
  - C2M may be more difficult due to high reflections on front-panel connectors
  - For example, could specify C2M BER 8E-5 and C2C BER 2E-5

AUI BER Target Options

(A) C2M and C2C AUI BER 1E-5

- Up to 2 AUI per Type 1 or Type 2 PHY
- Minimum channel reach/tolerance per AUI

(B) C2M and C2C AUI BER 2E-5

- Up to 1 AUI per Type 1 or Type 2 PHY
- Improved channel reach/tolerance per AUI

(C) C2M and C2C AUI BER 5E-5

- Up to 2 AUI per Type 2 PHY
- Extender always required for Type 1 PHY
- More improved channel reach/tolerance per AUI

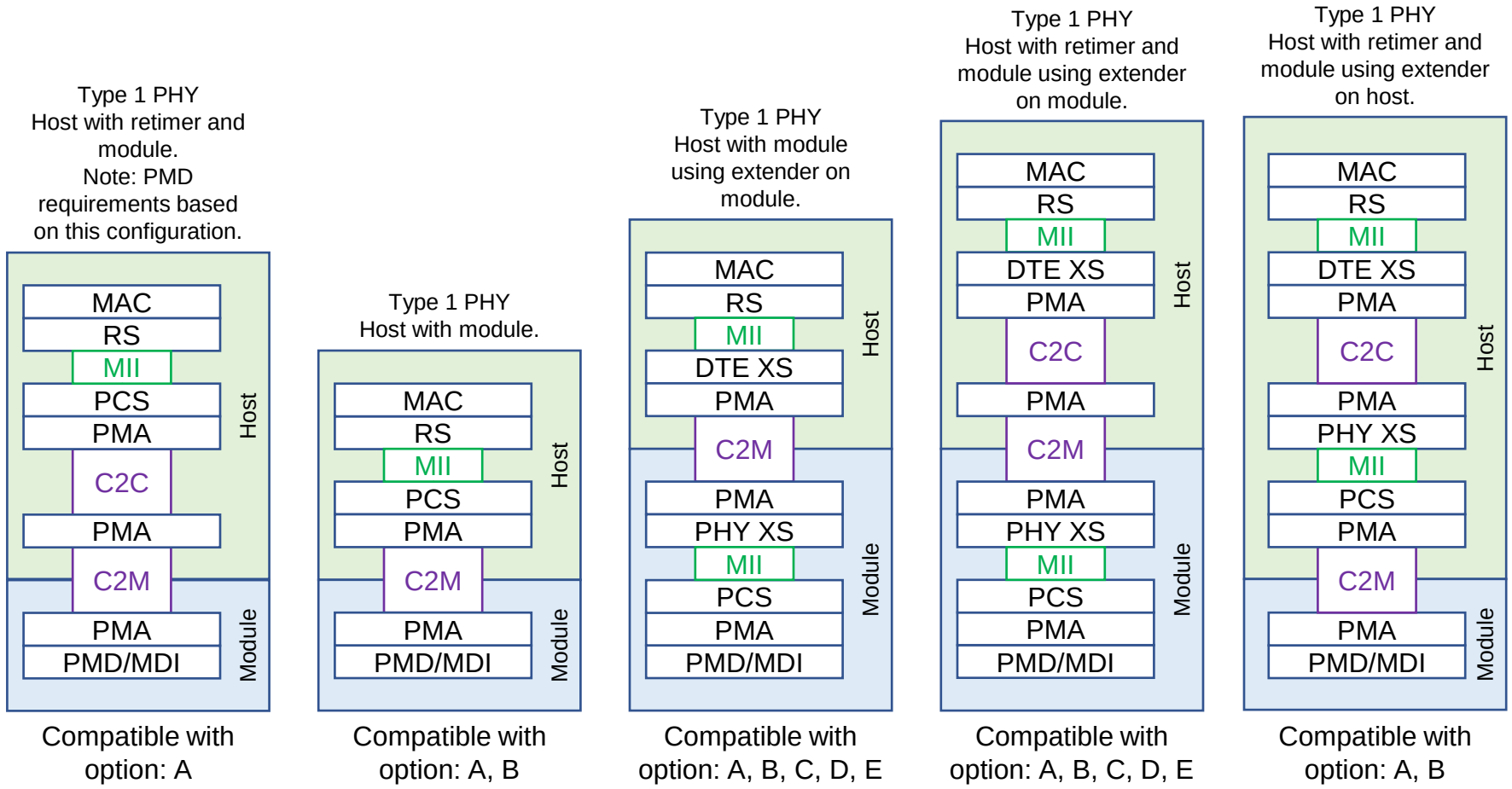
(D) C2M and C2C AUI BER 1E-4

- Up to 1 AUI per Type 2 PHY
- Extender always required for Type 1 PHY
- Most improved channel reach/tolerance per AUI

(E) C2M AUI BER 8E-5 and C2C AUI BER 2E-5

- Up to 1 C2C AUI per Type 1 PHY
- Up to 1 C2C AUI + 1 C2M AUI per Type 2 PHY
- Extender required for C2M AUI for Type 1 PHY
- Best compromise channel reach/tolerance

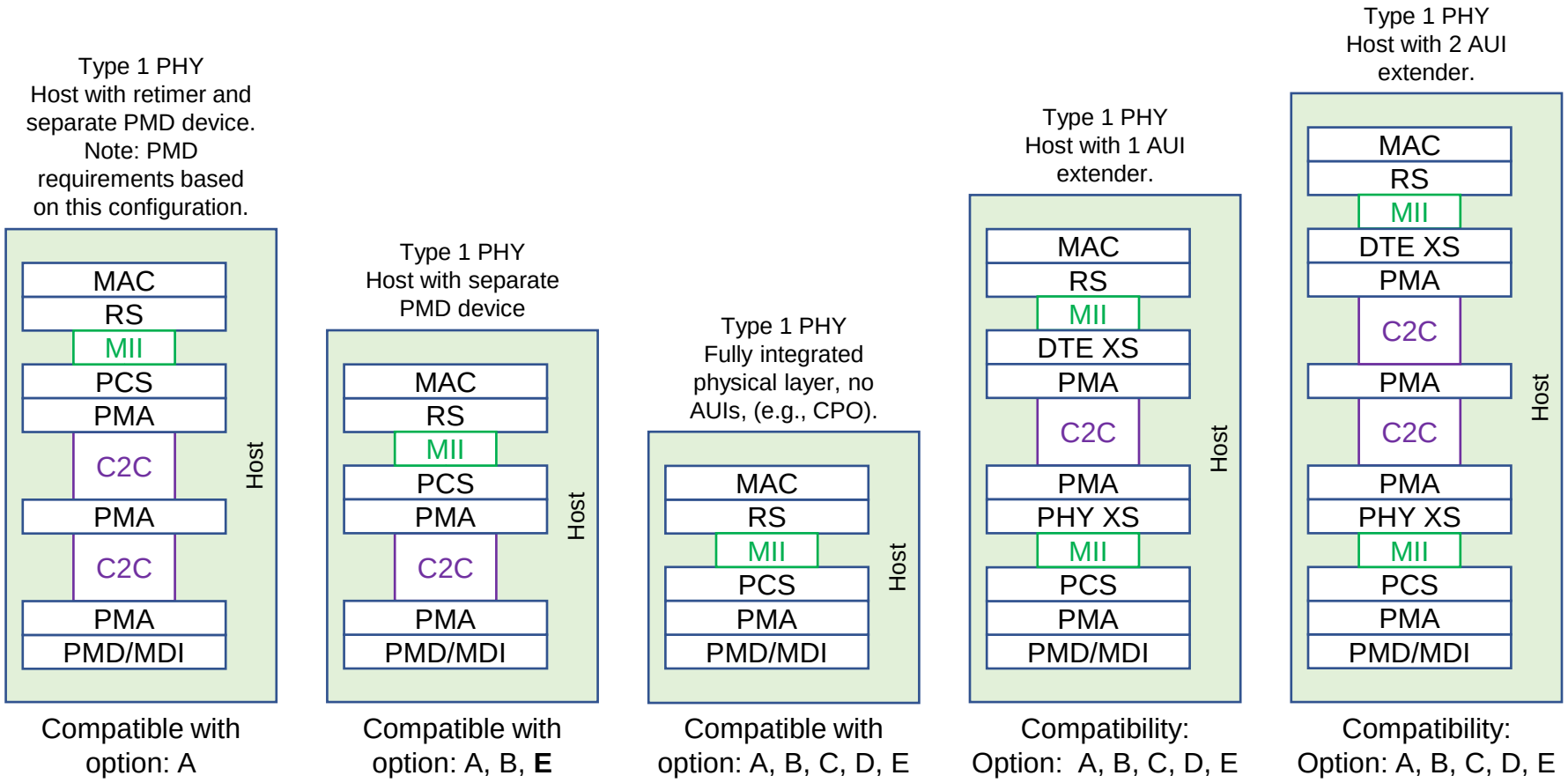
AUIs and Type 1 modular PHYs



Option	C2M BER	C2C BER
A	1E-5	1E-5
B	2E-5	2E-5
C	5E-5	5E-5
D	1E-4	1E-4
E	8E-5	2E-5

Type 1 PHY (e.g., 800GBASE-DR8)
Total AUI BER per PHY must be less than 2E-5.
Higher BER AUIs force use of an extender with PHY XS and PCS on the module.
Applies to any 100 Gb/s per lane PMD specified thus far.
Applies to any 200 Gb/s per lane Type 1 PMD that might be specified.

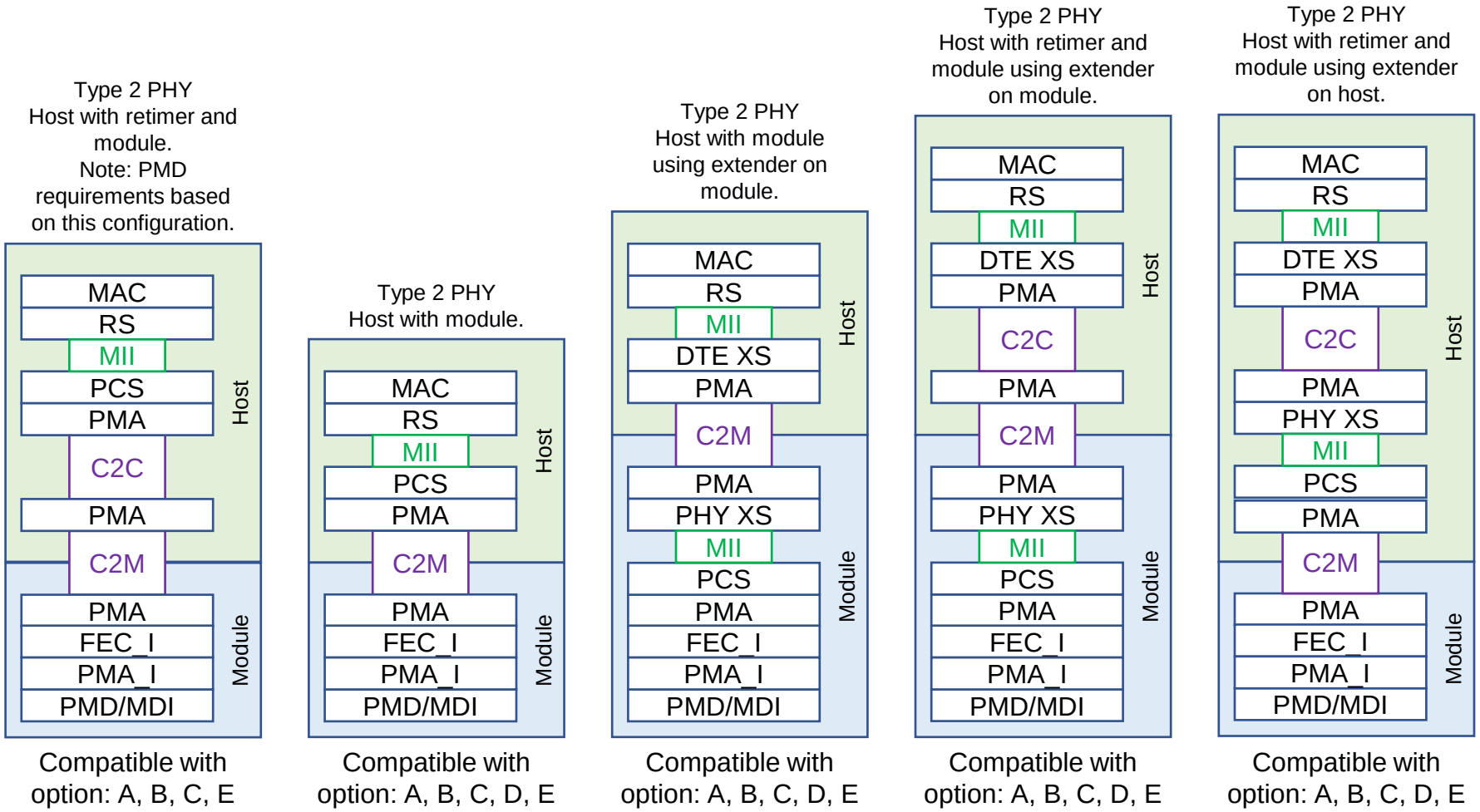
AUIs and Type 1 on-board PHYs



Option	C2M BER	C2C BER
A	1E-5	1E-5
B	2E-5	2E-5
C	5E-5	5E-5
D	1E-4	1E-4
E	8E-5	2E-5

Type 1 PHY (e.g., 800GBASE-CR8)
Total AUI BER per PHY must be less than 2E-5.
Higher BER AUIs force use of an extender with PHY XS and PCS near the PMD.
Applies to any 100 Gb/s per lane PMD specified thus far.
Applies to any 200 Gb/s per lane Type 1 PMD that might be specified.

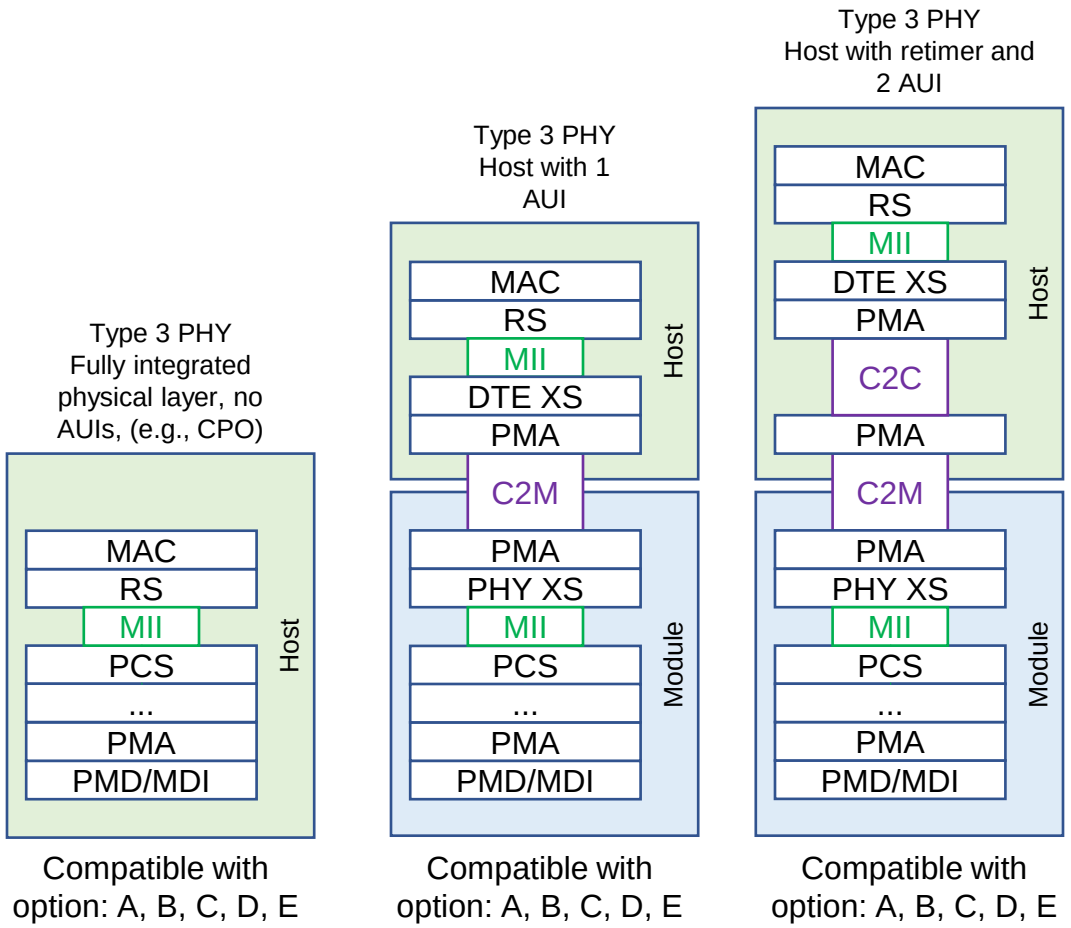
AUIs and Type 2 modular PHYs



Option	C2M BER	C2C BER
A	1E-5	1E-5
B	2E-5	2E-5
C	5E-5	5E-5
D	1E-4	1E-4
E	8E-5	2E-5

Type 2 PHY (e.g., 800GBASE-FR4)
Total AUI BER per PHY must be less than 1E-4.
Higher BER AUIs force use of an extender with PHY XS and PCS on the module.
Applies to new PHYs with 200 Gb/s per lane PMD and concatenated inner FEC.

AUIs and Type 3 PHYs



Type 3 PHY (e.g., 400GBASE-ZR, maybe 800GBASE-ER1)
XS always required regardless of AUI BER.

Option	C2M BER	C2C BER
A	1E-5	1E-5
B	2E-5	2E-5
C	5E-5	5E-5
D	1E-4	1E-4
E	8E-5	2E-5

Summary

- Choice of AUI BER has serious implications on the FLR and BER targets for a PMD.
- C2M channel analysis has shown that a conventional BER target of 1E-5 may not be practical for the reaches we want.
- BER higher than 1E-5 will not be compatible with Type 1 PHYs with 2 AUIs and thus MII Extender would be required for such PMD/AUIs.
- Type 2 PHYs can tolerate higher AUI BER: around 1E-4 total per PHY (e.g., 2 AUIs with 5E-5 or 1 AUI with 1E-4).
- Consider options B to E as alternatives to conventional AUI BER targets.

Thanks