Updated comment #111 D2.2:

Subject: Equation 33A-4:

1. Should equation 33A-4 be mandatory or informative?

2. Do we need it in 33.3.8.10 or in Annex 33A-4 only?

End-to-end pair to pair resistance unbalance for any PSE+Channel+PD connection is described by the following equation:

(1) (U*Rpse_min - Rpse_max) +(U*Rch_min - Rch_max) +(U*Rpair_pd_min - Rpair_pd_max)=0

Where U=(1+E2EP2PRunb)/(1-E2EP2PRunb).

Worst case "U" corresponds to the min/max worst case effective resistance values of Rpse, Rch, Rpair_PD and maximum PClass_PD levels.

We can see that PSE PI output common mode effective resistance needs to meet the following to guarantee that the worst case unbalance is not exceeded for the worst case PD and Channel effective resistances:

(2) Rpse_max ≤ U*Rpse_min + (U*Rch_min - Rch_max) + (U*Rpair_pd_min - Rpair_pd_max)

This is actually identical to Equation 33-15 in the spec.

It is clear that PSE must meet this equation to guarantee Icon-2P_unb is met due to the following reasons:

a) PSE needs to support all PDs. PSE doesn't know which PD it is going to support and change its hardware design accordingly that is why PSE has to be designed for the worst case load which is defined by equation 33-15.

b) This is the only solution for the system equation (1) for a PSE regardless if PD equation 33A-4 is met or not.

c) And when PSE is connected to Rload_min and Rload_max (also derived from Equation 1) which represent channel + worst case PD, it need meet Icon-2P_unb in order to external test house to verify compliance with Equation 33-15.

So far, all is good; the above is covered by D2.2.

Question #1 is if the same concept should apply to the PD i.e. should we mandate to meet Equation 33A-4 or we can satisfied with measuring Icon-2P_unb and keep Equation 33-4 as a design guidelines in Annex 33A-5?

Discussion: (See next page)

We said already that both PSE and PD must comply with Equation 1 above:

(1) (U*Rpse_min - Rpse_max) +(U*Rch_min - Rch_max) +(U*Rpair_pd_min - Rpair_pd_max)=0

(2) The equation above is always true, however "U" is not constant. For example, it varies with channel length and is highly unbalanced for the minimum channel and further unbalance at lower load tan Pclass_PD. In the worst cases (of combinations of Vport_PSE, Pclass_PD, Channel resistance) the effective resistances do directly correspond to the worst case Icon-2P-unb. However, it is possible for Rpair_pd values to be worse than those in Equation 33A-4 and still meet Icon-2P-unb by simply lowering the max power below PClass_PD. "U" will be worse, but Icon-2P-unb can still be met.

As a result, PD PI input common mode effective resistance need to meet the following ***in order to operate at full PClass_PD*** levels only:
(3) Rpair_pd_max = U*Rpair_pd_min +(U*Rpse_min - Rpse_max) +(U*Rch_min - Rch_max)
This is actually identical to Equation 33A-4 in the spec in Annex 33A.5. However at power levels lower than Pclass_PD, PD may use larger ratios of Rpair_pd_maxand Rpair_pd_min that doesn't meet Equation 33A-4 but still meet Icon-2P_unb!

Now; we know for sure that if PD meets Equation 33A-4 than system equation is solved and PD meets unbalance requirements including Icon-2P_unb at any worst case parameter combinations. ***Doe's measuring Icon-2P_unb is sufficient?***

If Icon-2P-unb is met with the test circuit (which corresponds to the worst case channel and PSE ranges), then it has to be sufficient, because it will only improve with better PSE that meets Equation 33-15 and the channel values.

In other words, we need to be sure (by mathematical proof) that PD that meets Icon-2P_unb by definition meets Equation 33A-4 (Rpair_PD_min and Rpair_PD_max) when connected to Rsource_min and Rsource_max which is also derived from Equation 1 above. We expect that if Icon-2P-unb is met for all worst case PSE+channel combinations, then the most important limit has been met. Otherwise, we need to move Equation 33A-4 to 33.3.8.10 that addresses PD pair to pair current unbalance.
Such mathematical proof is shown in Annex B. The mathematical proof shows:

A) It is sufficient for the PD to test Icon-2P_unb when it is loaded with its maximum requested Pclass_PD.
B) In case of (A), the burden will be on the PD designer to try many sets of Rpair_PD_min and Rpair_PD_max until one set will cause Icon-2P_unb to be met. ***Since Annex 33A-5 where equation 33A-4 is located is far away from the standard body, it is recommended to move Equation 33A-4 as informative design guidelines to the main standard body in clause 33.3.8.10.***

Proposed Remedy:

This is not part of the base line
The proposed remedy based on the following: 1. No change in Equation 33A-4 status. It is still informative. See Annex A and B for details. 2. Equation 33A-4 was moved to 33.3.8.10 in order to be accessible to the reader due to its importance. 3. Adding introduction part for 33.3.8.10

33.3.8.10 PD pair-to-pair current unbalance

Make the following changes:

This section describes unbalance requirements for Type 3 and Type 4 PDs that operate over 4-pair. The contribution of PD PI pair-to-pair effective resistance unbalance to the effective system end to end resistance unbalance, is determined by PD maximum (RPair_PD_max) and minimum (RPair_PD_min) common mode effective resistance in the powered pairs of same polarity. See Figure 33A-4.
Effective resistances of RPair_PD_min and RPair_PD_max include the effects of PD pair to pair voltage difference and the PD PI resistive elements. See definition and measurements in Annex 33A.5.

The PD PI pair-to-pair effective resistance unbalance determined by RPair_PD_max and RPair_PD_min ensures that along with any other parts of the system, i.e. channel (cables and connectors) and the PSE, the maximum pair current including unbalance does not exceed ICon-2P-unb as defined in Table 33–18 during normal operating conditions.

Under all operating states, single-signature PDs assigned to Class 5 or higher shall not exceed ICon-2P-unb for longer than TCUT-2P min as defined in Table 33–18 on any pair when PD PI pairs of the same polarity are connected to all possible common source voltages in the range of VPort_PSE-2P through two common mode resistances, Rsource_min and Rsource_max, where Rsource_max = 1.186 * Rsource_min, and Rsource_min are all possible resistances in the range of 0.168 Ω to 5.28 Ω as shown in Figure 33–37.

Under all operating states, dual-signature PDs shall not exceed ICon-2P as defined in Equation (33–8) for lon-ger than TCUT-2P min as defined in Table 33–18 on any pair when PD PI pairs of the same polarity are connected to all possible common source voltage in the range of VPort_PSE-2P through two common mode resistances, Rsource_min and Rsource_max, where Rsource_max = 1.186 * Rsource_min, and Rsource_min are all possible resistances in the range of 0.168 Ω to 5.28 Ω as shown in Figure 33–37.

Rsource_min and Rsource_max represent the Vin source common mode effective resistance that consists of the PSE PI components (RPSE_min and RPSE_max as specified in 33.2.8.5.1, VPort_PSE_diff as specified in Table 33–18, the channel resistance, and influence of RPair_PD_min and RPair_PD_max ~~specified in Annex 33A.5~~ as function of system end-to-end unbalance). Common mode effective resistance is the resistance of two conductors of the same pair and their other components, which form Rsource, connected in parallel including the effect of the total system pair to pair voltage difference. IA and IB are the pair currents of pairs with the same polarity.

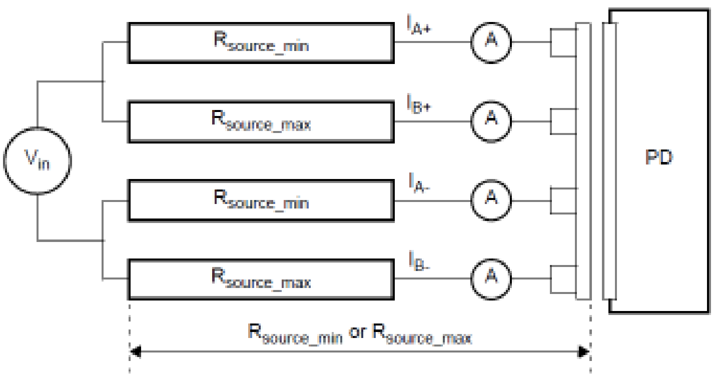

Figure 33–37—$I_{Con\text{-}2P}$ and $I_{Con\text{-}2P\text{-}unb}$ evaluation model

NOTE 1—Rsource includes resistance Rcon which is the connection resistance at the PD. The maximum recommended Rcon value is 0.02 Ω.

NOTE 2—The pairset current limits should also be met when Rsource_max and Rsource_min are swapped between pairs of the same polarity.

Design guidelines for RPair_PD_max and RPair_PD_min is described by Equation 33-XX1. RPair_PD_max and RPair_PD_min are specified and measured under maximum PClass_PD load conditions and $V_{Port\_PD\text{-}2P}$ operating range. RPair_ PD_min need to be greater than $\{(-\beta/\alpha)\}_{\Omega}$ according to Equation 33-XX1format of RPair_PD_max ≤ α x RPair_ PD_min +β in order to satisfy Equation 33-XX1.

-Update equation 33A-4 constants as follows (Updates are due to: Changing 71W to 71.3W, final updates of PD Vdiff to 60mV for Type 3 and Type 4, channel P2PRun changes made for D2.2)
-Update equation 33A-4 from “Rpair_pd_max=” to “Rpair_pd_max≤”

$$R_{Pair\_PD\_max} \le \left\{ \begin{array}{ll} 2.170 \times R_{Pair\_PD\_min} + 0.125 & for\ PD\ Type\ 3,\ Class\ 5 \\ 1.988 \times R_{Pair\_PD\_min} + 0.105 & for\ PD\ Type\ 3,\ Class\ 6 \\ 1.784 \times R_{Pair\_PD\_min} + 0.080 & for\ PD\ Type\ 4,\ Class\ 7 \\ 1.727 \times R_{Pair\_PD\_min} + 0.074 & for\ PD\ Type\ 4,\ Class\ 8 \end{array} \right\}_{\Omega} \quad (33\text{-}XX1)$$

where

RPair_PD_max is, given RPair_PD_min, the highest allowable common mode effective resistance in the powered pairs of the same polarity.
RPair_PD_min is the lower PSE common mode effective resistance in the powered pairs of the same polarity.

Common mode resistance is the effective resistance of the two wires and their elements in a pair of the same polarity connected in parallel.

33A.5 PD PI pair-to-pair current unbalance requirements

Delete Equation 33A-4 and the following text:

~~The following design guide lines may be implemented to ensure PD PI pair-to-pair current unbalance requirements are met:~~

$$R_{Pair\_PD\_max} = \left\{ \begin{array}{ll} 2.182 \times R_{Pair\_PD\_min} + 0.125 & for\ PD\ Type\ 3,\ Class\ 5 \\ 1.999 \times R_{Pair\_PD\_min} + 0.106 & for\ PD\ Type\ 3,\ Class\ 6 \\ 1.904 \times R_{Pair\_PD\_min} + 0.095 & for\ PD\ Type\ 4,\ Class\ 7 \\ 1.832 \times R_{Pair\_PD\_min} + 0.087 & for\ PD\ Type\ 4,\ Class\ 8 \end{array} \right\}_{\Omega} \quad (33A\text{-}4)$$

~~RPair_ PD_min need to be greater than { (-β/α)}$_{\Omega}$ according to Equation 33A-4 format of RPair_PD_max ≤ α x RPair_PD_min +β in order to satisfy Equation 33-A4.~~

If TDL#44 from D2.1 (or comments 90# and #112 in D2.2) will be accepted, delete the following text:

~~Smaller constants α and β in the equation RPair_PD_max = α × RPair_PD_min + β ensure that ICon-2P-unb is not exceeded for PD power consumption above the values in Table 33–26.~~

RPair_PD_max and RPair_ PD_min represent PD common mode input effective resistance of pairs of the same polarity. Common mode effective resistance is the resistance of two conductors of the same pair and their other components connected in parallel including the effect of PD pair-to-pair voltage difference of pairs with the same polarity (e.g. Vf1-Vf3). The common mode effective resistance Rn is the measured voltage Veff_pd_n, divided by the current through the path as described below and as shown in the example in Figure 33A–4, where *n* is the pair number.

This is not part of the baseline
We can simplify text and drawing by deleting R1, R2, R3 and R4 from the text and Figure 33A-4 since we have we have Rpair_PD_min/max definitions already in the drawing and the text.

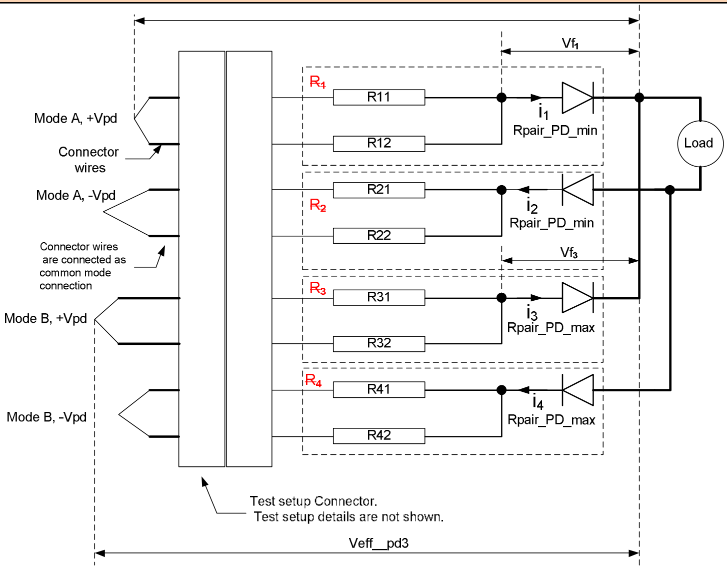

Figure 33A–4—PD resistance unbalance elements overview

Positive pairs:

RPair_ PD_min =Veff_pd1 / i1
RPair_PD_max =Veff_pd3 / i3

Negative pairs:

RPair_ PD_min =Veff_pd2 / i2
RPair_PD_max =Veff_pd4 / i4

End Of proposed baseline

Annex A: Derivation of E2EP2PRunb system equations

System End to End Pair to Pair Resistance Unbalance (PSE, Channel and PD):

(1) $$E2EP2PRunb = \frac{(Rpse_{max} - Rpse_{min}) + (Rch_{max} - Rch_{min}) + (R_{pairPD\max} - R_{pairPD\max})}{(Rpse_{max} + Rpse_{min}) + (Rch_{max} + Rch_{min}) + (R_{pairPD\max} + R_{pairPD\max})}$$

Presenting (1) is a shorter form:

(2) $$E2EP2PRunb = \frac{\left(\sum R_{max} - \sum R_{min}\right)}{\left(\sum R_{max} + \sum R_{min}\right)}$$

Opening and solving (2) in terms of Rmax/Rmin ratio and E2EP2PRunb:

$$\left(\sum R_{max} - \sum R_{min}\right) = E2EP2PRunb \cdot \left(\sum R_{max} + \sum R_{min}\right)$$
$$\sum R_{max} - \sum R_{min} = E2EP2PRunb \cdot \sum R_{max} + E2EP2PRunb \cdot \sum R_{min}$$
$$\sum R_{max} - E2EP2PRunb \cdot \sum R_{max} = E2EP2PRunb \cdot \sum R_{min} + \sum R_{min}$$
$$(1 - E2EP2PRunb) \cdot \sum R_{max} = (1 + E2EP2PRunb) \cdot \sum R_{min}$$

(3) $$\frac{\sum R_{max}}{\sum R_{min}} = \frac{(1 + E2EP2PRunb)}{(1 - E2EP2PRunb)} = U$$

As a result from (3):

(4) $$\frac{\sum R_{max}}{\sum R_{min}} = u$$

And we get the general system unbalance equation:

(5) $$u \cdot \sum R_{min} - \sum R_{max} = 0$$

The general system unbalance equation (5) can be expended back by expressing all its components:

(6) U*Rpse_min + U*Rch_min + U*Rpair_pd_min - Rpse_max - Rch_max - Rpair_pd_max=0

Deriving from (7) the PSE PI equation:

From (6) we can solve for Rpse_max:

(7) Rpse_max =U*Rpse_min +U*Rch_min + U*Rpair_pd_min - Rch_max - Rpair_pd_max

(8) Rpse_max =U*Rpse_min +β1 (This is the form of Equation 33-15 in D2.2)

β1 = U*Rch_min + U*Rpair_pd_min - Rch_max - Rpair_pd_max

Additional information:

1. Equation 8 can be presented as function of Rload_min and Rload_max during testing for compliance which makes it clear why PSE cannot be tested only for Icon-2P_unb by only connected it to Rload_min and Rload_max.
2. PSE must be designed for the worst case unbalance since it needs to support all PDs (PDs on the other hand need to be designed only for their required Pclass_PD or lower power).

From (7) Rpse_max =U*Rpse_min +U*(Rch_min + Rpair_pd_min) – (Rch_max + Rpair_pd_max)

By definition:

Rload_max =Rch_max+Rpair_PD_max

Rload_min =Rch_min+Rpair_PD_min

(9) Rpse_max =U*Rpse_min + U* Rload_min – Rload_max

Deriving from (6) the PD PI equation:

(6) U*Rpse_min + U*Rch_min + U*Rpair_pd_min - Rpse_max - Rch_max - Rpair_pd_max=0

From (6) we can solve for Rpair_PD_max:

(10) Rpair_pd_max= U*Rpair_pd_min + U*Rpse_min + U*Rch_min - Rpse_max - Rch_max

(11) Rpair_pd_max= U*Rpair_pd_min + β2 **(This is the form of Equation 33A-4 in D2.2)**

β2= U*Rpse_min + U*Rch_min - Rpse_max - Rch_max

Additional information:

1. Equation 10 can be presented as function of Rsource_min and Rsource_max during testing for compliance.
2. PD must be designed for the worst case unbalance per its required Pclass_PD or lower power.
3. At this point, it is not clear if it is sufficient for the PD to meet Icon-2P_unb and is equivalent to meet Equation 10.
4. It is clear that if the PD meets Equation 10, then it will meet Icon_2P_unb by definition since Equation 10 is a complete solution of system equation (6).
5. See Annex B for derivation of mathematical proof that for a PD it is sufficient to meet Icon_2P_unb.

(10) Rpair_pd_max= U*Rpair_pd_min + U*Rpse_min + U*Rch_min - Rpse_max - Rch_max

By definition:

Rsource_max =Rpse_max + Rch_max

Rsource_min =Rpse_min + Rch_min

(12) Rpair_pd_max= U*Rpair_pd_min + U* Rsource_min – Rsource_max

Deriving Rload_min and Rload_max when PSE is tested for compliance

From (6): U*Rpse_min + U*Rch_min + U*Rpair_pd_min - Rpse_max - Rch_max - Rpair_pd_max=0

Finding Rload_max and Rload_min as function of the other system parameters:

By definition the PSE is loaded by:

Rload_max =Rch_max+Rpair_PD_max

Rload_min =Rch_min+Rpair_PD_min

As a result from (6):

(7) Rload_max = Rch_max+ Rpair_pd_max= U*Rch_min + U*Rpair_pd_min U*Rpse_min - Rpse_max -

(8) Rload_max = U*Rload_min + (U*Rpse_min - Rpse_max)

The values of Rload_max and Rload_min (Table 33-B1 in D2.2) are measured by simulation and are identical to the computed Rload_min and Rload_max in equation 8.

Deriving Rsource_min and Rsource_max when PD is tested for compliance

From (6): U*Rpse_min + U*Rch_min + U*Rpair_pd_min - Rpse_max - Rch_max - Rpair_pd_max=0

Finding Rsource_max and Rsource_min as function of the other system parameters:

By definition the PD is connected to the following source resistance:

Rsource_max = Rpse_max + Rch_max

Rsource_min = Rpse_min + Rch_min

As a result from (6):

(9) Rsource_max = Rpse_max + Rch_max =U*Rpse_min +U*Rch_min +(U*Rpair_pd_min - Rpair_pd_max)

(10) Rsource_max = U*Rsource_min +(U*Rpair_pd_min - Rpair_pd_max)

The values of Rsource_max and Rsource_min (Clause 33.3.8.10) are measured by simulation and are identical to the computed Rsource_min and Rsource_max in Equation 9.

Annex B – Does it is sufficient for a PD to meet Icon-2P_unb instead of meeting Rpair_PD_min and Rpair_PD_max equations?

From System End to End Pair to Pair Resistance Unbalance (PSE, Channel and PD) equation in Annex A:

(1) $$E2EP2PRunb = \frac{(Rpse_{max} - Rpse_{min}) + (Rch_{max} - Rch_{min}) + (R_{pairPD\max} - R_{pairPD\max})}{(Rpse_{max} + Rpse_{min}) + (Rch_{max} + Rch_{min}) + (R_{pairPD\max} + R_{pairPD\max})}$$

The pair with the maximum current is Imax=Icon-2P_unb and the pair with minimum current is Imin.
The total current of two pairs of the same polarity is It=Imax+Imin.
The current difference between Imax and Imin is Idiff=Imax-Imin=E2EP2PRunb*It.
Imax=0.5*It+0.5*Idiff
Imin=0.5*It-0.5*Idiff
As a result:

(2) Icon-2P_unb=0.5*It+0.5*It*E2EP2PRunb=0.5*It*(1+E2EP2PRunb)

Combining (1) and (2):

Icon-2P_unb=0.5*It*(1+E2EP2PRunb)=

(3) $$Icon - 2P\_unb = 0.5 \cdot \mathrm{It} \cdot \left(1 + \frac{(Rpse_{max} - Rpse_{min}) + (Rch_{max} - Rch_{min}) + (R_{pairPD\max} - R_{pairPD\max})}{(Rpse_{max} + Rpse_{min}) + (Rch_{max} + Rch_{min}) + (R_{pairPD\max} + R_{pairPD\max})}\right)$$

Due to the fact that:

(1) Icon-2P_unb is known (measured)

And

(2) Rpse_min and Rpse_max are defined by Equation 33-15 in the spec or in equation (8) in Annex A and are known.

And

(3) Rch_min and Rch_max are known (defined together with Rpse_min and Rpse_max known as Rsource_min and Rsource_max) and are known.

We can find by **trial and error** the values of Rpair_PD_min and Rpair_PD_max that solve Equation (3).
As a result, Equation (3) can be solved completely by either measuring Icon-2P_unb or by compliance to equation 33A-4 that defined Rpair_PD_min and Rpair_PD_max.

The only problem with the approach of measuring Icon-2P_unb is that the PD designer will need to guess what should be Rpair_PD_min and Rpair_PD_max in order to guaranteed meeting Icon-2P-unb while designing directly with Equation 33A-4 is cleaner and faster.

Recommendations:

C) For the PD section, it is sufficient to measure Icon-2P_unb which is equivalent to meet Rpair_PD_min and Rpair_PD_max.

D) Designing a PD without using Equation 33A-4 will be time consuming job due to the fact that the designer will have to test many Rpair_PD_min and Rpair_PD_max values combination until he will identify which pair of values guarantee meeting Icon-2P_unb.

E) Since Annex 33A-5 where equation 33A-4 is located is far away from the standard body, it is recommended to move Equation 33A-4 as informative design guidelines to the main standard body in clause 33.3.8.10.