IEEE802.3 4P Task Force

Generating the PSE and PD PI models and their unbalance requirements

July 2014

Rev 000 adhoc meeting # 2, March 2014
Rev 009 adhoc meeting # 7, June 2014
Rev 012b adhoc meeting # 8,9, July 2014
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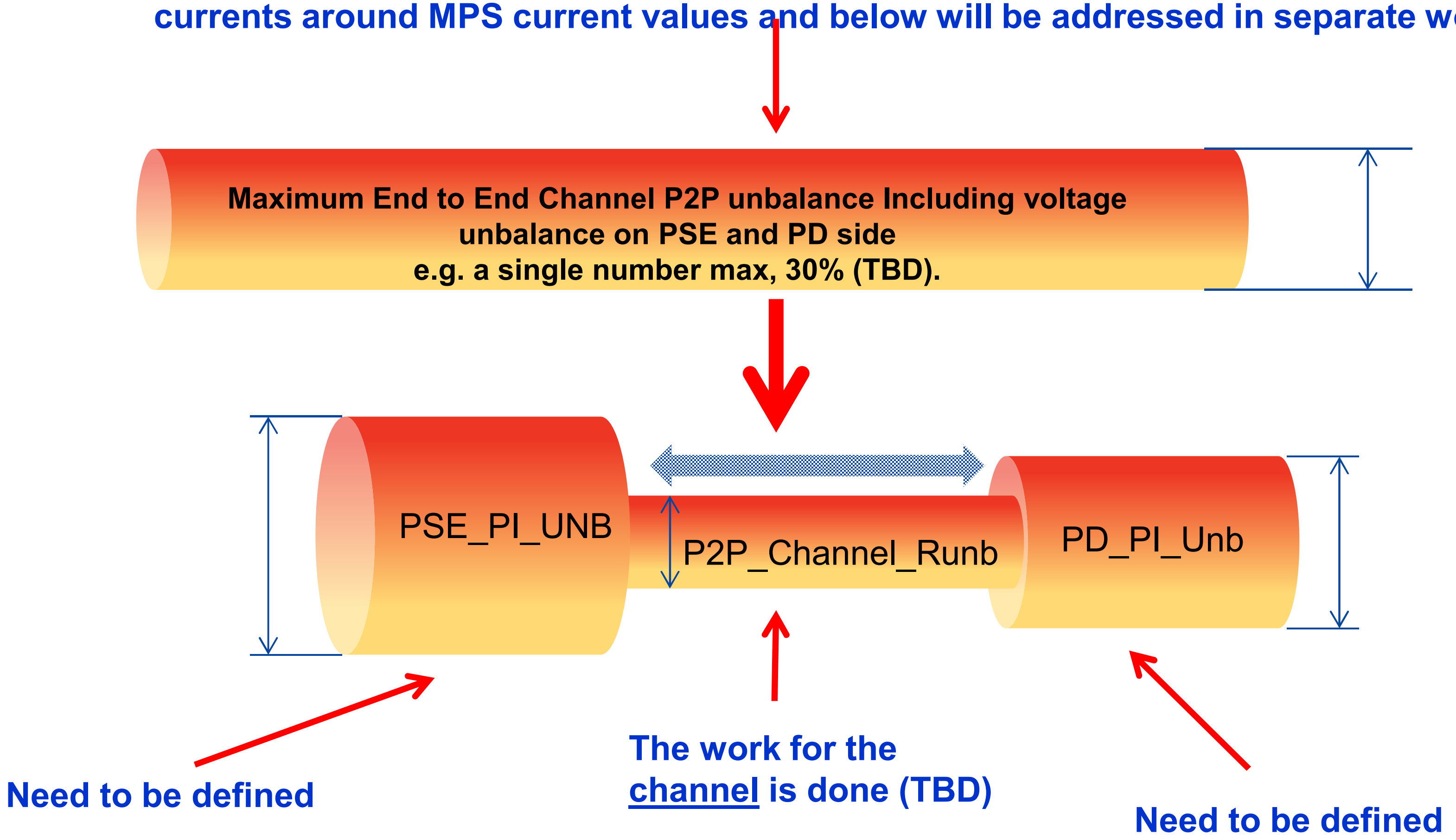
Objectives

- Generating PSE and PD PI models addressing the following:
  - Minimum set of parameters required for complete, interoperable and flexible solution.
  - Implementation independent as much as possible.
  - Based on End to End Channel Target performance i.e. maximum current over the minimum resistance pair represented by P2PRUNB numbers and additional parameters as required.
- Maximum pair current as function of
  - End to End (E2E) Channel P2P unbalance parameters:
    - E2E_C_P2PRUNB (function of Rmax, Rmin elements)
    - P2P voltage difference.
- End to End (E2E) Channel P2P unbalance parameters (*):
  - The channel P2PRUNB 7.5%(TBD) or 0.1Ω which ever is greater
  - Transformed PSE PI unbalanced parameters to meet (*)
  - Transformed PD PI unbalanced parameters (*)

Annex 1: Where we are and where we are going

<u>End to End Channel P2P Resistance Unbalance:</u> We understand the behavior, the effect of all channel parameters and for a given set of parameters we can define target unbalanced parameters for a given maximum pair current at ON_STATE. Low currents around MPS current values and below will be addressed in separate work.



The End to End Channel P2P maximum pair current

$$\mathrm{Im}ax = \frac{It}{2} + \frac{It \cdot E2E\_P2PRUNB}{2} = \frac{It \cdot (1 + E2E\_P2PRUNB)}{2}$$

$$\mathrm{Im}in = \frac{It}{2} - \frac{It \cdot E2E\_P2PRUNB}{2} = \frac{It \cdot (1 - E2E\_P2PRUNB)}{2}$$

$$\mathrm{Im}in + \mathrm{Im}ax = It = \frac{It}{2} + \frac{It \cdot E2E\_P2PRUNB}{2} + \frac{It}{2} - \frac{It \cdot E2E\_P2PRUNB}{2}$$

- It=Total PD current
- E2E_P2PRUNB=The end to end effective channel P2PRUNB
  - The **effective** value incudes P2P voltage difference effects for simplicity.
  - In final model P2P voltage difference will be separate parameter for the purpose of testing for compliance.

The End to End Channel P2P Resistance Unbalance

- Current Unbalance between any two pairs is determined by the following:

$$\frac{Idiff}{It} = \left(\frac{\sum R_{\max} - \sum R_{\min}}{\sum R_{\max} + \sum R_{\min}} \right) = E2ECP2P\_Runb = E2ECP2P\_Iunb$$

- The Rmax/min sum are the sum of all component s resistance from PSE PI to PD PI circutry i.e. Hence forming End to End Channel P2PRUNB.
- The E2ECP2PRUNB can be separated to PSE and PD PI and Channel.

- Important: PSE PI P2PRUNB=P2PCUNB is not equal to

- Show the differences between terms

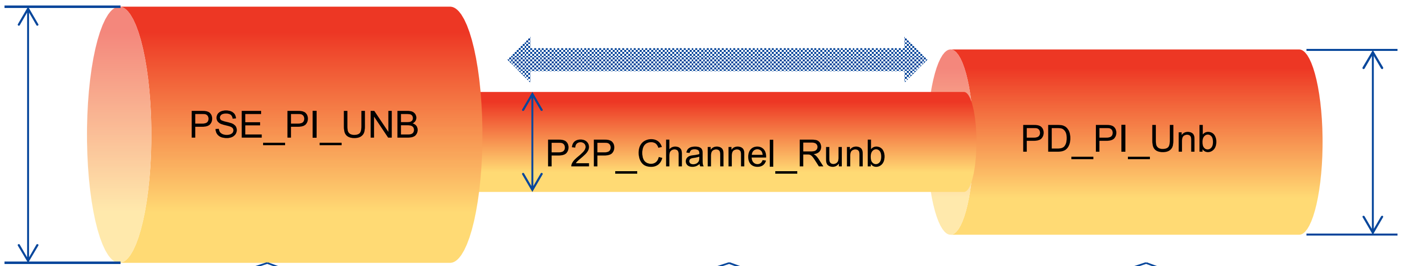
- See annex … meeting … for references.

The End to End Channel P2P Resistance Unbalance system parts

- The E2ECP2P_RUNB

$$E2ECP2P\_Runb = \left(\frac{\sum R_{\max} - \sum R_{\min}}{\sum R_{\max} + \sum R_{\min}} \right)$$

- Can be break into the 3 system parts



$$E2ECP2P\_Runb = \frac{\left(\sum R^{PSE}_{\max} - \sum R^{PSE}_{\min}\right) + \left(\sum R^{CH}_{\max} - \sum R^{CH}_{\min}\right) + \left(\sum R^{PD}_{\max} - \sum R^{PD}_{\min}\right)}{\sum R^{PSE}_{\max} + \sum R^{PSE}_{\min} + \sum R^{CH}_{\max} + \sum R^{CH}_{\min} + \sum R^{PD}_{\max} + \sum R^{PD}_{\min}}$$

Sum of end to end Rmax+Rmin Resistances

Transformation of The End to End Channel P2P Resistance Unbalance to PSE PI and PD PI unbalance parameters

- It is obvious from the previous mathematical expression that:

  (confirmed by simulations since Feb 2013 presentations:

  - http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf
  - http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf
  - http://grouper.ieee.org/groups/802/3/4PPOE/public/jul13/darshan_2_0713.pdf

- PSE_PI_P2PRUNB:

$$PSE\_PI\_P2P\_Runb = \frac{\left(\sum PSE\, R_{\max} - \sum PSE\, R_{\min}\right)}{\sum PSE\, R_{\max} + \sum PSE\, R_{\min}}$$

- In not equal PSE_PI_P2PRUNB effective effect in the total E2ECP2P_RUNB

$$PSE\_Effective\_CP2P\_Runb = \frac{\left(\sum PSE\, R_{\max} - \sum PSE\, R_{\min}\right)}{\sum PSE\, R_{\max} + \sum PSE\, R_{\min} + \sum CH\, R_{\max} + \sum CH\, R_{\min} + \sum PD\, R_{\max} + \sum PD\, R_{\min}}$$

Transformation of The End to End Channel P2P Resistance Unbalance to PSE PI and PD PI unbalance parameters to Extract PSE and PD PI models

- So how to define PSE PI unbalance parameters (and later PD PI) based on E2ECP2P_R_UNB/E2ECP2P_C_UNB?.

$$E2ECP2P\_Runb = \frac{\left(\sum R_{\max}^{PSE} - \sum R_{\min}^{PSE}\right) + \left(\sum R_{\max}^{CH} - \sum R_{\min}^{CH}\right) + \left(\sum R_{\max}^{PD} - \sum R_{\min}^{PD}\right)}{\sum R_{\max}^{PSE} + \sum R_{\min}^{PSE} + \sum R_{\max}^{CH} + \sum R_{\min}^{CH} + \sum R_{\max}^{PD} + \sum R_{\min}^{PD}} =$$

$$= Kpse \cdot \frac{\left(\sum R_{\max}^{PSE} - \sum R_{\min}^{PSE}\right)}{\sum R_{\max}^{PSE} + \sum R_{\min}^{PSE}} + Kch \cdot \frac{\left(\sum R_{\max}^{CH} - \sum R_{\min}^{CH}\right)}{\sum R_{\max}^{CH} + \sum R_{\min}^{CH}} + Kpd \cdot \frac{\left(\sum R_{\max}^{PD} - \sum R_{\min}^{PD}\right)}{\sum R_{\max}^{PD} + \sum R_{\min}^{PD}}$$

Find Kpse and Kpd that meets the limits of step the required E2E_C_P2P_RUNB.

a) Channel max P2PRUNB[%] and Channel Rdiff max or {Rmax, Rmin} value set per table in annex G1 component values and chennel length use cases.

b) Kpse and Kpd can be varied per the target requirements of PSE and PD PI for covering PD and PSE implementations.

c) Kpse and Kpd may be a **Vandermonde matrix** for perfect fitting or scalar (single equation) for worst case points only.

d) Kch=need to be set to 1 due to the fact that it is know per channel given physics. See Table in annex G1.

- See Ken Bennett presentation at the adhoc meeting #8 for example implementing a derivative of the above general concept for PSE PI transformation.

Transformation of The End to End Channel P2P Resistance Unbalance to PSE PI and PD PI unbalance parameters to Extract PSE and PD PI models

- As a result of the previous procedure we can see that PSE PI unbalanced behavior is defined by:

$$PSE\_PI\_P2P\_R\_UNB = Kpse \cdot \frac{\left(\sum \frac{PSE}{R_{\max}} - \sum \frac{PSE}{R_{\min}}\right)}{\sum \frac{PSE}{R_{\max}} + \sum \frac{PSE}{R_{\min}}}$$

- Kpse may be a matric or constant (pending type of curve fitting needed (continues or single worst case value etc. (TBD)).
- Kpse is a function depending on the channel and PD affecting parts as shown in previous slide.
- Example for general Kpse: $Kps = \left(\frac{\alpha + \beta}{\gamma + \delta}\right)$

What are the minimum parameters set?

- Assuming we did the previous procedure and we got NEW converted form of PSE_PI_RUNB that is equivalent to its real contribution in the system.
- We need to see what are the minimum parameters that we need to define?
- From previous transformed PSE_PI equation model:

$$PSE\_PI\_P2PRUNB = \frac{\sum {}^{PSE}R_{\max\_new} - \sum {}^{PSE}R_{\min\_new}}{\sum {}^{PSE}R_{\max\_new} + \sum {}^{PSE}R_{\min\_new}}$$

- PSE PI P2P voltage difference is required.
  - Until this point of the analysis, its effect was lumped in the element resistance values for simplicity.
  - Now it is separate again.

- **What else is required?**

What are the minimum parameters set?

$$PSE\_PI\_P2PRUNB\_new = \frac{\sum \frac{PSE}{R_{\max\_new}} - \sum \frac{PSE}{R_{\min\_new}}}{\sum \frac{PSE}{R_{\max\_new}} + \sum \frac{PSE}{R_{\min\_new}}}$$

- By definition the PSE unbalanced parameters are controlled by knowing either one of the parameters sets:
- 1. P2P_RUNB_new (see option 4 which is an improved version due to the effect of transformation)
- 2. Rmax and Rmin
- 3. P2P_RUNB and Rmax
- 4. P2P_RUNB and Rmin
- 5. P2P_RUNB and Rdiff

- All of the above can be considered as complete solutions.

What are the minimum parameters set?

$$PSE\_PI\_P2PRUNB\_new = \frac{\sum PSE\ R_{max\_new} - \sum PSE\ R_{min\_new}}{\sum PSE\ R_{max\_new} + \sum PSE\ R_{min\_new}}$$

- The following cannot be used:
- 6. Rdiff= $PSE\_Rdiff = \sum PSE\ R_{max\_new} - \sum PSE\ R_{min\_new}$
  - Can not be used alone.
  - Cannot solve two parameter equation with single parameter. Leads to interoperability issues.
  - **See annex L1-L8 for details**
- Examples:
- Rdiff=Rmax-Rmin=0.2=X:
  - P2PRUNB=(0.2-0)/(0.2+0)=100%
  - P2PRUNB=(0.23-0.03)/(0.23+0.03)=77%
  - P2PRUNB=(0.3-0.1)/(0.3+0.1)=50%
  - P2PRUNB=(1-0.8)/(1+0.8)=11%

Interoperability Issue:
Different UNBALANCE
For the same Rdiff resulting
With different Imax for the
Same channel and PD

Absolute values of Rmin or Rmax are extremely important.

What are the most implementation independent minimum parameters set?

- Options 1 -5 are mathematically complete solutions.

- What is best for implementation independent?
  - Option 1: P2PRUNB_new is a ratio, hence implementation independent. But may need Rmin for complete solution (TBD)
  - Option 2: Rmax, Rmin is highly implementation dependent.
  - Option 3: P2PRUNB_new, Rmax limits implementations when ballast means may be needed.
  - Option 4. P2P_RUNB and Rmin. Same as 1 but a bit less implementation independent
  - Option 5. P2P_RUNB and Rdiff. Highly implementation independent.

Summary -What are the minimum parameters set?

Option	PSE PI P2PRUNB	Rmax	Rmin	Rdiff	Notes
1	Yes	-	-	-	1. Ratio. Fully implementation independent . 2. Need two parameter to solve equation with two variables. Need more research to verify completeness with or without Rmin.
2	-	Yes	Yes	-	1. Complete solution. 2. Not flexible, Implementation dependent.
3	Yes	Yes			1. Complete solution. 2. Not flexible, Implementation dependent. Problem to limit Rmax
4	Yes	No	Yes	-	1. Complete solution. 2. Rmin is exists anyway. 3. Not fully Implementation in dependent but tolerable.
5	Yes	NO	NO	YES	1. Complete solution. 2. Implementation dependent.
6	NO	NO	NO	YES	1. Not complete 2. Implementation dependent 3. Interoperability issues

Summary

- It is recommended that the The PSE PI minimum model parameters required to define complete PSE PI unbalance behavior are:
  - PSE PI P2P Voltage difference =(TBD)
  - PSE PI P2PRUNB =(TBD)
  - To research the need for Rmin.
- It is recommended that the adhoc will focus on the above option first.
- The test setup and electrical model drawing will be addressed after the above are agreed.

References

1. Adhoc material: presentations and simulation results.

Q&A

Where we are and where we are going -1

Ad-hoc response, July 1, 2014. TBD

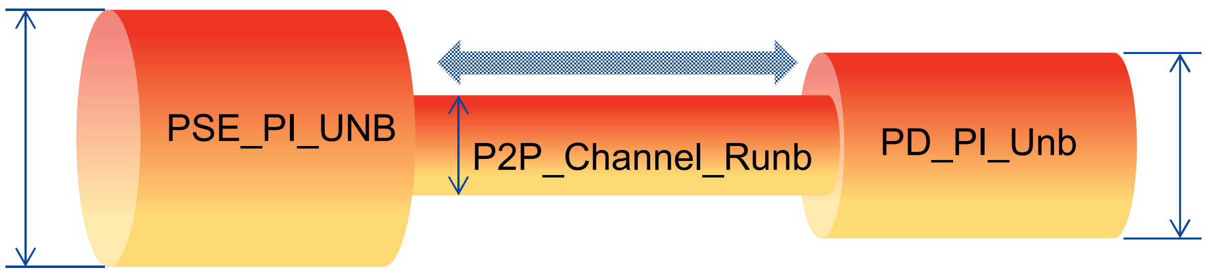
For PSE and PD PIs P2P UNB parameters.

-a single maximum number for each parameter.

-Parameters are: Voltage difference and resistance unbalance.

-For improved spec, we may need to defined additional parameter: Rmin (TBD under research).

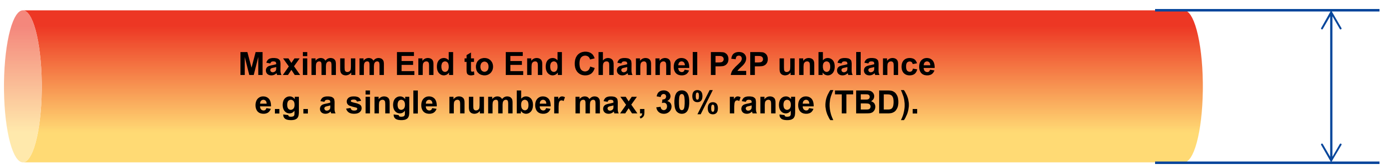
-Test setup TBD.



For Channel P2PRUNB:

-Variable Channel Length, number of connectors up to 4.

-A single maximum number representing maximum C_P2PRunb. (Target 7.5% (TBD) or 0.1Ω which ever is greater. See details in Annex K.



- Channel is capable of reducing the end to end unbalance as function of channel length.
  - PSE PI and PD PI need to be better than the channel maximum P2PRUNB.
    - PSE PI and PD PI needs larger unbalance range than channel P2PRUNB to allow different implementations

Where we are and where we are going -2

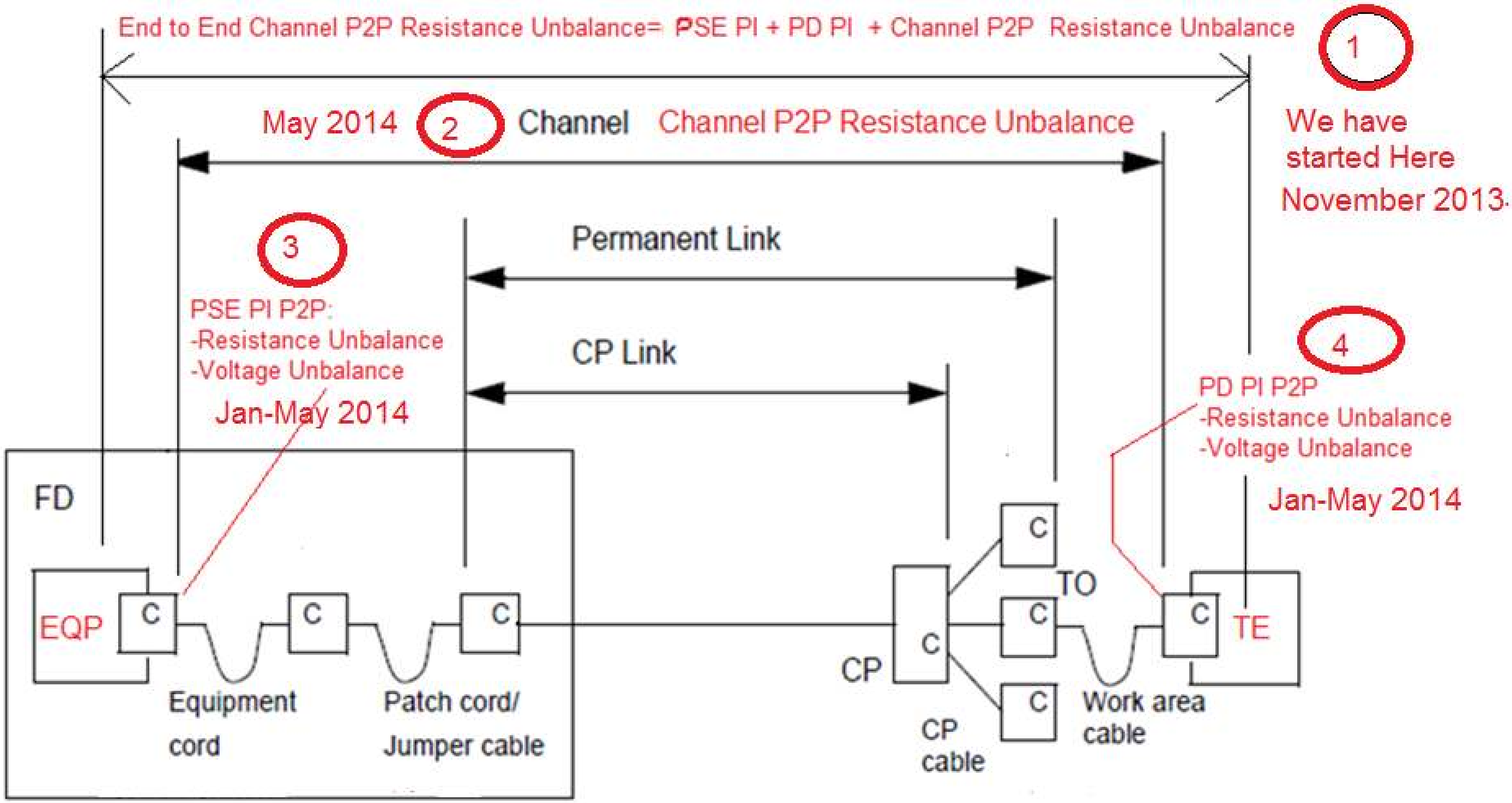


Figure 1. May 27, 2014

Ad-hoc response, June 24, 2014. No comments.

Source: Yair Darshan. Based on model used in IEEE802.3-2012.

Annex A

33.1.4.2 Type 1 and Type 2 channel requirement

Type 1 and Type 2 operation requires that the resistance unbalance shall be 3 % or less. Resistance unbalance is a measure of the difference between the two conductors of a twisted pair in the 100 Ω balanced cabling system. Resistance unbalance is defined as in Equation (33–1):

$$\left\{\frac{(R_{max}-R_{min})}{(R_{max}+R_{min})}\times 100\right\}_{\%} \qquad (33\text{–}1)$$

where

R_{max}	is the resistance of the channel conductor with the highest resistance
R_{min}	is the resistance of the channel conductor with the lowest resistance

- The way channel pair (the differences between two wires in a pair) resistance unbalance was defined.

Source: Yair Darshan per IEEE802.3-2012

Annex A1

- Inputs from Pete Johnson:
- 3% DC Unbalance comes from ISO / IEC.
- **TIA 568** has DC Unbalance specified as 5% using **ASTM D 4566** definition of DC Unbalance that is different from that used by ISO.
- The ASTM method is % Runb = 100 * (Max R – Min R) / Min R
-
- Yair Response (to be discussed by the group) next (3rd meeting):
  - Since cables vendor wants to meet "all standards" they meets the 2% cable. System and component vendors count on the 3% channel.
  - Our IEEE POE standard is counting on the 3% max.
  - The ASTM method that calculates % Runb = 100*(Max R – Min R) / Min R is familiar but has no practical physical meaning related to current unbalance that we can use e.g. for transformers. The equation that we are using is a derivation of the current unbalance definition and rationale.
  - As a result, I believe we should stay with current 3% pair resistance unbalance and our IEEE equation for Unbalance.
- Pete agrees to this response.
- Group agreed to Yair proposed response as well.

Annex A2 - ANSI/TIA-568-C.2

- Resistance unbalance of a channel

6.2.1 DC loop resistance

DC loop resistance for category 3, 5e, 6, and 6A channels shall not exceed 25 Ω. Refer to TIA TSB-184 for additional information on channel resistance related to guidance on delivering power.

6.2.2 DC resistance unbalance

DC resistance shall be measured for all channel conductors. DC resistance unbalance shall be calculated for each pair of the channel in accordance with equation (14) and shall not exceed the greater of 3% or 200 milliohms. DC resistance unbalance is not specified for category 3 channels.

$$Resistance\_Unbalance_{pair} = \left(\frac{|R_1 - R_2|}{R_1 + R_2} \right) \cdot 100\% \tag{14}$$

where:

R_1 is the DC resistance of conductor 1.

R_2 is the DC resistance of conductor 2.

Source: Yair Darshan per
ANSI/TIA-568-C.2

Annex A3 - ANSI/TIA-568-C.2

- Connecting Hardware requirements

6.8.1 DC resistance

DC resistance shall be measured in accordance with ASTM D4566 at 20 ℃ ± 3 ℃ for all connecting hardware cable pairs.

> NOTE – DC resistance is a separate measurement from contact resistance as specified in Annex A. Whereas DC resistance is measured to determine the connector's ability of transmit direct current and low frequency signals, contact resistance is measured to determine the reliability and stability of individual electrical connections.

Category 3 connecting hardware DC resistance between the input and the output connections of the connecting hardware (not including the cable stub, if any) used to terminate 100 Ω twisted-pair cabling shall not exceed 0.3 Ω.

Category 5e, 6, and 6A connecting hardware DC resistance between the input and the output connections of the connecting hardware (not including the cable stub, if any) used to terminate 100 Ω twisted-pair cabling shall not exceed 0.2 Ω.

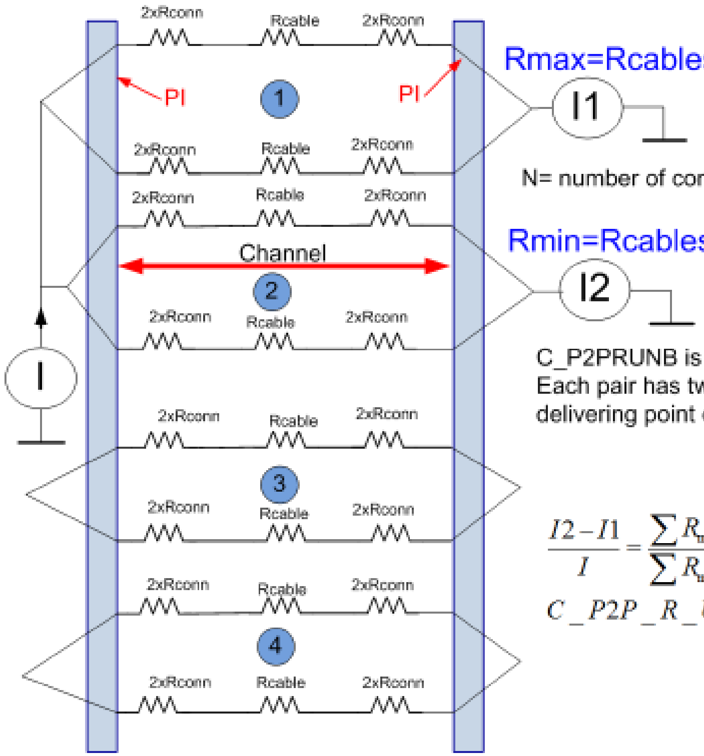
6.8.2 DC resistance unbalance

DC resistance unbalance shall be calculated as the maximum difference in DC resistance between any two conductors of a connector pair measured in accordance with IEC 60512, Test 2a.

Category 3 connecting hardware DC resistance unbalance should not exceed 50 mΩ. Category 5e, 6 and 6A connecting hardware DC resistance unbalance shall not exceed 50 mΩ.

Source: Yair Darshan per ANSI/TIA-568-C.2

Annex A4 – Channel P2P Resistance Unbalance



Rmax=Rcables_max+N*Rc_max

N= number of connectors, 0 to 4

Rmin=Rcables_min+N*Rc_min

C_P2PRUNB is defined between any two pairs
Each pair has two wires in parallel from power delivering point of view

$$\frac{I2-I1}{I}=\frac{\sum R_{max}-\sum R\min}{\sum R_{max}+\sum R\min}=$$

$$C\_P2P\_R\_UNB=C\_P2P\_Current\_UNB$$

$$Channel\_P2P\_Current\_DIFFERENCE=$$

$$=I1-I2=I\cdot\frac{\sum R_{max}}{\sum R_{max}+\sum R_{min}}-I\cdot\frac{\sum R_{min}}{\sum R_{max}+\sum R_{min}}=I\cdot\frac{\sum R_{max}-\sum R_{min}}{\sum R_{max}+\sum R_{min}}$$

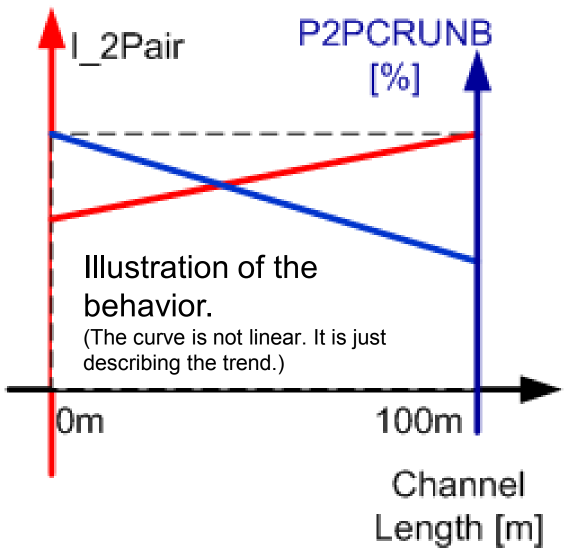
As a result, Channel P2P Resistance or Current Unbalance ratio is::

$$\frac{I2-I1}{I}=\frac{\sum R_{max}-\sum R\min}{\sum R_{max}+\sum R\min}=C\_P2P\_R\_UNB=C\_P2P\_Current\_UNB$$

Annex B: What is more important P2PRUNB or Current increase/pair due to at worst case conditions?

Source: Yair Darshan

- To discuss the advantages that PD constant Power Sink allows us.
- Background material for considering (P2PRUNB in this slide refer to the end to end channel P2PRUNB):
  - Worst case End to End Channel Pair to Pair Channel Resistance Unbalance is at short cable (<100m).
  - At short cables PD voltage is higher that at 100m channel length and pair/port current is lower
  - Not only that the port current is lower, it is <600mA for Type 3 systems below TBD channel length.
    - **As a result, P2PCRUNB max may not an issue (pending the P2PCRUNB value).**
  - At 100m the P2PCRUNB is much smaller than at short channel
  - Resulting with less significant contribution to Ibias due to P2PCRUNB and as a result to OCL.
  - **This approach was validated in:** http://grouper.ieee.org/groups/802/3/4PPOE/public/jul13/darshan_2_0713.pdf and requires further investigation for completing this work.



The answer is: In order to answer the question we need to check both data sets 1 and 2 in the worst case data base. We need to check the following equation:

$$0.5\cdot(1+\alpha_{(L=100m)})\cdot I_{total\_100m} < or > 0.5\cdot(1+\alpha_{(L=0.15m)})\cdot I_{total\_0.15m}$$

$$\alpha_{(L=100m)} = End2End\_C\_P2PRUN\_at\_100m$$

$$\alpha_{(L=0.15m)} = End2End\_C\_P2PRUN\_at\_0.15m$$

Source:
1. See link above, from July 2013.
2. Adhoc meeting #2, February 24, 2014.

Annex C1: Why we care for P2P resistance unbalance parameters

Source: Yair Darshan

- In 4P system:
- If P2PRUNB>0 the PD current over each 2P will not be the same.
  - 51W PD with maximum total current of 1.2A, the current will split to 0.6A+0.18A=0.78A over the 2pairs with minimum resistance and 0.42A with the pair with maximum resistance.
- In general: The pair with the highest current will be: It*(1+P2PRUNB)/2
  - This will require to overdesign the magnetics for high P2PRUNB values.
  - Watching limits of connector pins, PCB traces and power components on the DC current path at PSE and PD and overdesign accordingly.
  - So there is interest to have components with lower P2PRUNB along the channel as possible by cost and manufacturability limitations to result with lower End to End Pair to Pair RUNB.

Annex C2: Why we care for P2P resistance unbalance parameters

- Other concerns was how it will affect on PD minimum available power for a 60W system (two times the 802.3at power). The decision was that for our current data base we can supply 49W for the PD (instead of 51W). See 802.3bt objective.
  - This was done by calculating what will be the power at the PD if we keep maximum 600mA at the pair in order not to cause issues to Type 2 component/ devices that can work with 4P
- Other concern was if P2PRUNB will increase power loss on the cable. We show that now it will not. Moreover we show that if P2PRUNB increased, the power loss is decreased.

$$Trise = 0.5 \cdot N \cdot It^2 \cdot R_{loop\_\max} \theta_N \cdot [1 - P2PCRUNB]$$

- See: http://www.ieee802.org/3/4PPOE/public/nov13/darshan_02_1113.pdf for more details.

Source: Yair Darshan

Annex D1: Calculations of CP2PRUNB with constant power sink model and the effect on transformer bias current.

Equation	Symbol	Units	Channel Length	
			1m	100m
End to End Pair to Pair Channel Resistance Unbalance: $$CP2PRUNB = \frac{\sum R\max - \sum R\min}{\sum R\max + \sum R\min}$$	CP2PRUB	-	0.26	0.112
	I	A	1.02	1.2
	I/2	A	0.51	0.6
I*CP2PRUNB	DI	A	0.2652	0.1344
I*CP2PRUNB/2	DI/2	A	0.1326	0.0672
I*(1+CP2PRUNB)/2	Imax=(I+di)/2	A	0.643	0.667
I*(1-CP2PRUNB)/2	Imin=(I-di)/2	A	0.377	0.533
Ibias=3%*Imax/2		A	0.0193	0.02
Sanity Check	I	A	1.02	1.2
Effect on Ibias of transformer: 3%*(Imax-0.6)/2	d(Ibias)	mA	0.639	1.008

Source: Yair Darshan

Annex D2: Affecting parameters on Transformer Ibias

- PSE Rsense and Rdson are out of the loop for pair unbalance
  - They affect only on P2P unbalance
    - Which affect Iport (increase or decrease) which affect Ibias by 3%*(Iport_max-Iport_nominal)
- How to reduce Ibias?
  - Adding Rballast on transformers reduces Ibias directly
  - Defining minimum cable length reduces P2PRUNB_max. The effect on Ibias is 3%*(Iport_max-Iport_nominal).
  - Adding in PD ballast resistors (cost effective in PD and not in PSE)
    - May not be needed for PD power below TBD.
  - Using matched diode bridges, significantly reduces P2PRUNB and as a result, the current unbalance

Source: Yair Darshan

Annex E1 – Connector and Cabling standard data

- Summary of resistivity and resistance unbalance (Source Wayne Larsen)
- specifications in TIA cabling standards
- Resistivity of cable and “cordage” from cabling standards
- – Cable DC resistance is 9.38 Ohms / 100 meters, ANSI/TIA-568-C.2, 6.4.1, page 58. Cat 5e, 6, and 6A are all the same.
- – Cordage DC resistance is 14 Ohms / 100 meters, ‘568-C.2, 6.6.1,page 74. Cat 5e, 6, and 6A are all the same.
- – Cable and cordage resistance unbalance with a pair is 2.5 % per IEC 61156-1, ‘568-C.2-1 6.4.2 page 58. All categories are the same.
- – Cable and cordage resistance unbalance between pairs is not specified, but has been studied and found to be less than 5 %.
- – Connectors are allowed 200 milliohms resistance and 50 milliohms resistance unbalance between any conductor. They actually have much less resistance.
- Yair Darshan notes:
- These values are maximum values, pre PoE standard.
- There are no specifications for minimum values as needed for P2P unbalance analysis. As a result, to cover both angles of P2PRUNB at short and long channel, maximum 12.5Ω channel was used for generating maximum pair current and channel with horizontal cable resistivity of 0.066 Ω/m was used to generate worst case P2PRUNB. Later this number was updated to 0.079 Ω/m to include twist rate effect.
- As for connectors: less than 0.06 Ω connector resistance was used. See worst case data base for details.

Annex E2 – Connectors terms.

- **Source Yakov Belopolsky / BEL**
- The term used in the connector industry is LLCR (Low Level Contact Resistance)- Bulk $\mathbf{R}_{\mathbf{LLCR\text{-}B}}$
- Low Level Contact Resistance (LLCR-Bulk) consists of four components
- Plug Conductor Resistance $\mathbf{R}_{\mathbf{CR}}$
- Plug Blade/Conductor Contact Resistance $\mathbf{R}_{\mathbf{PBCR}}$
- Plug Blade/Jack Wire Contact Resistance or TRUE LLCR $\mathbf{R}_{\mathbf{CRTRUE}}$
- Jack Wire Resistance $\mathbf{R}_{\mathbf{JWR}}$
- $\mathbf{R}_{\mathbf{LLCR\text{-}B}} = \mathbf{R}_{\mathbf{CR}} + \mathbf{R}_{\mathbf{PBCR}} + \mathbf{R}_{\mathbf{CRTRUE}} + \mathbf{R}_{\mathbf{JWR}}$
- However, it is easy to measure and subtract $(\mathbf{R}_{\mathbf{CR}} + \mathbf{R}_{\mathbf{PBCR}})$ from the Bulk so many connector vendors use the Contact resistance $(\mathbf{R}_{\mathbf{CRTRUE}} + \mathbf{R}_{\mathbf{JWR}})$
- **A typical differential between two types measurements is less than 20 milliohm**
- The reason is that the $(\mathbf{R}_{\mathbf{CRTRUE}} + \mathbf{R}_{\mathbf{JWR}})$ is affected by environmental exposure and defines the quality of the connector design separately from the plug blade termination quality

Annex E3: Connector data from vendors datasheet

Source: Yair Darshan

	Vendor	Resistance per datasheet
CAT6	A	30 milliohm max ,Jack only[1]
CAT6	B	35 milliohm max ,Jack only[1]
CAT6	C	30 milliohm max ,Jack only[1]

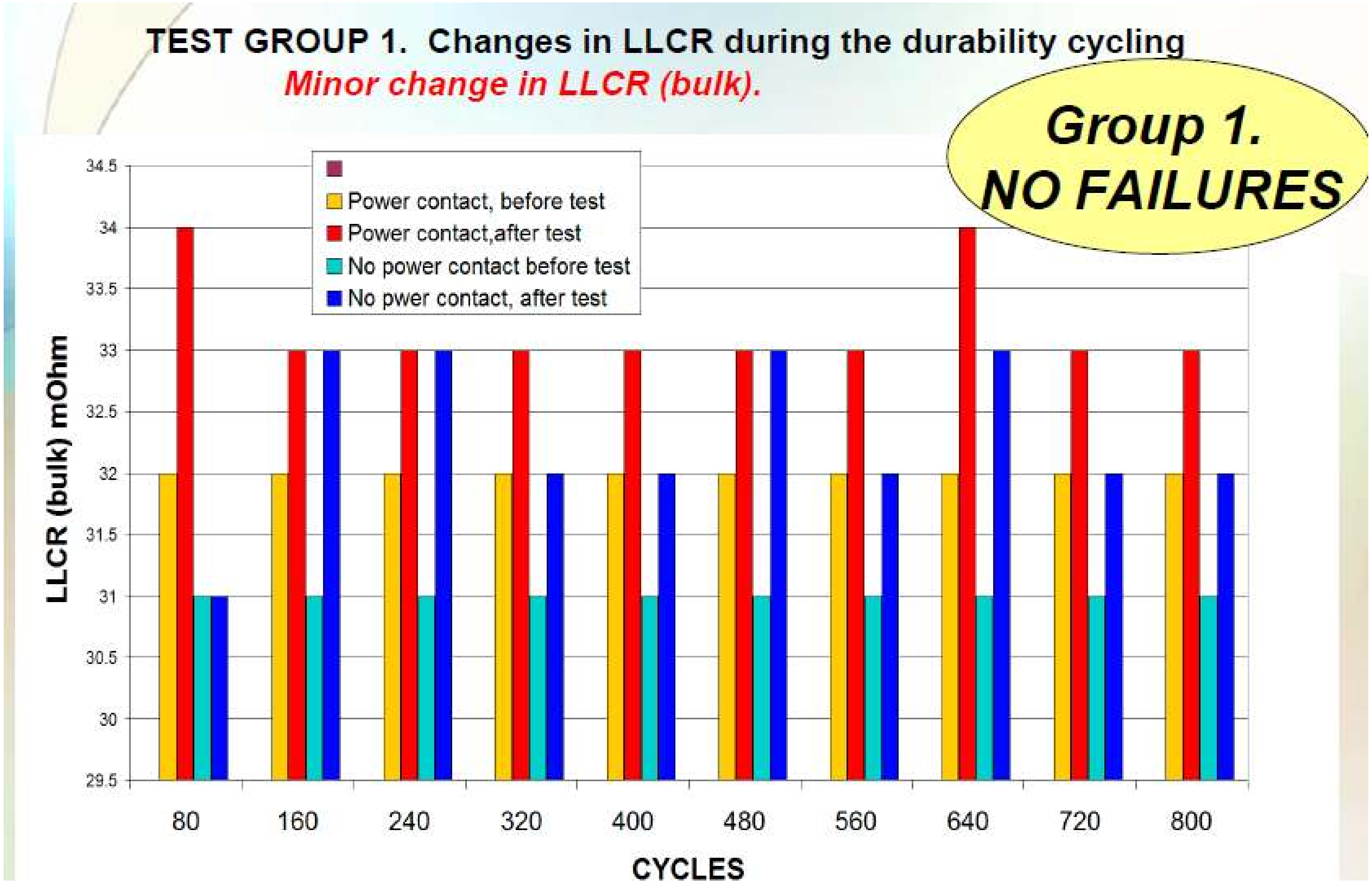
1. It is per datasheet so actual values are lower.

Source: Yair Darshan

Annex E4 - Connector data – Source BEL

http://www.ieee802.org/3/at/public/2006/07/belopolsky_1_0706.pdf slide 22.

30milliohm connector resistance shown by BEL



Annex E5: Connectors test data

- Source: Microsemi
- Each number in the table is the average resistance of all pins from end to end (Plug and Jack) for each connector.

Connector #	Vendor A	Vendor B	Vendor C	Vendor D	
	CAT6	CAT6	CAT6A	CAT6A	
1	45	43	39	42	45
2	43	43	40	49	46
3	48	42	40	40	39
4	48	46	42	39	44
5	43	45	39	38	47
6	46	39	43	50	44
7	45	42	39	38	43
8	49	46	42	41	44
9	46	45	39	44	45
10	42	45		51	44
11	43	46		44	43
12	43	43		50	39
13		46		54	40
14		42		39	47
15		46		55	42
16		46		51	48

	Vendor A	Vendor B	Vendor C	Vendor D
Average	45.08	44.06	40.33	44.53
Max	49	46	43	55
min	42	39	39	38
Rdiff	7	7	4	17

Average connector resistance	43.50
Max	55
Min	38
Rdiff	17

- **All connector resistance: 55**milliΩ max.
  - **Vendors approve 60milliΩ** max.
  - There are high quality connector that get to **30**milliΩ.
  - The average resistance of these samples: **43.5milliΩ**
- **Additional Information (not shown from the tables attached):**
- Within a connector, **pair to pair resistance difference**≤20milliΩ was confirmed.
- Most results were below 15milliΩ, therefore this number chosen to be at the worst case data base table.
- Simulations will be done for 15 and 20 milliohms as well.

Source: Yair Darshan

Annex E6: Connectors test data

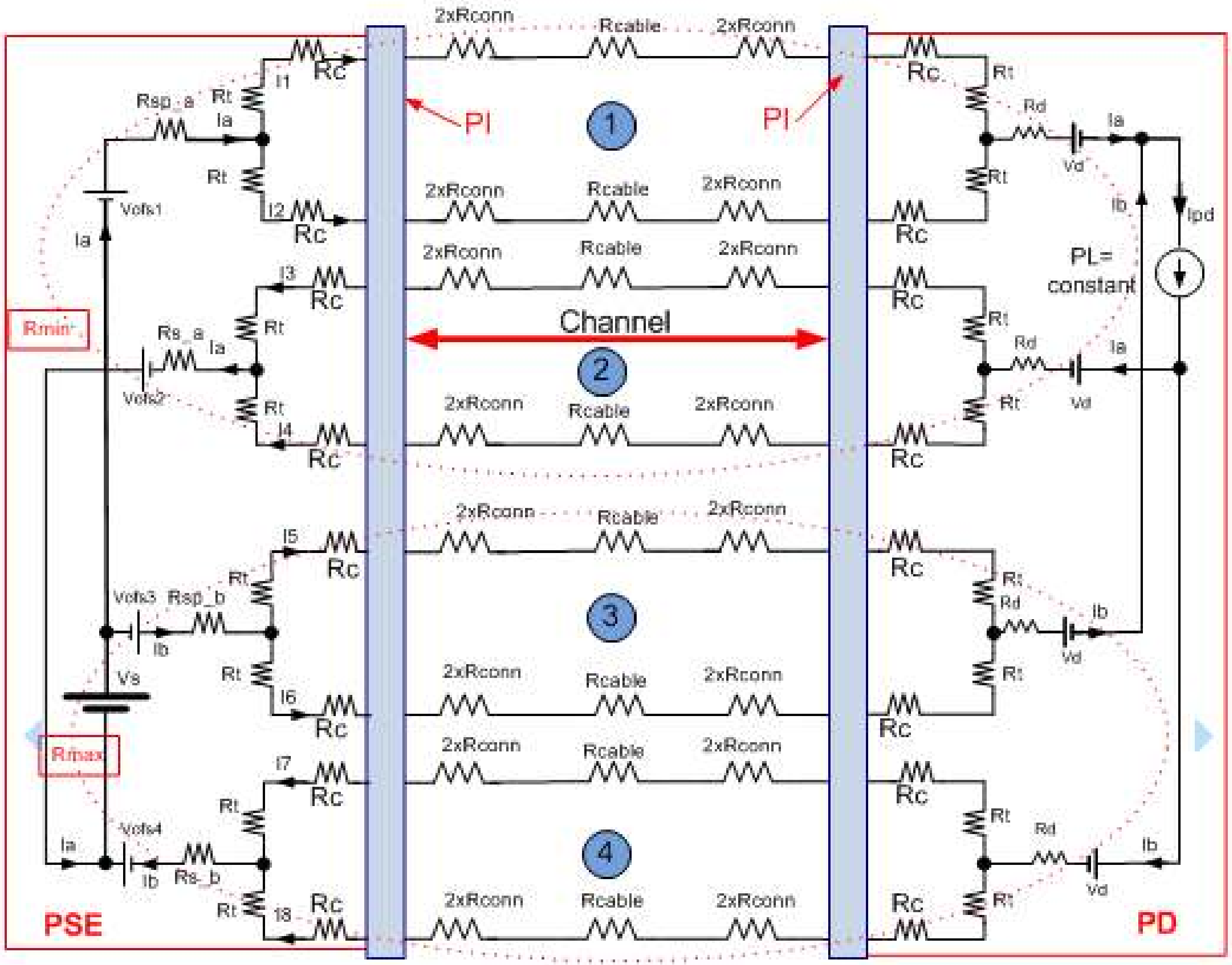
http://www.vtiinstruments.com/Catalog/Technotes/RJ-45_Excels_For_Stria_Gage_Connection.pdf

- See above link page 12.
- 45milliohm connector resistance of 40 connector samples.
- See page 13 at the above link for connector resistance over temperature

Source: Yair Darshan.
Based on the above link.

Annex F – End to End P2P Resistance Unbalance Model

General Channel Model and its components that we have used.



Notes for the general Model:

1. Total end to end channel connectors is 6 max.
2. The formal channel definition is marked in red arrow and is with up to 4 connectors.
3. Our work addresses also the internal application resistance of known components that are used
4. In simulations, pairs 1 and 2 components were set to minimum and pairs 3 and 4 were set to maximum values. See simulation results on previous meetings
5. Vofs1/2/3 and 4 was added. To update the group. July 3, 2014.

Source: Yair Darshan and Christian Beia

Annex G1:Worst Case Data Base (updates) -1

See notes to the table in next slide

#	Parameter	Data set 1	Data set 2
1	Cordage resistivity[1]	0.14Ω/m	
		0.09262Ω/m for AWG#24 for worst case analysis	
2	Horizontal cable resistivity option 1[2]	11.7Ω/100m=(12.5Ω - 4*0.2Ω) / 100m which is the maximum resistance resulting with maximum Iport.	7.92Ω/100m (CAT6A, AWG23) This is to give us maximum P2PRunb
3	option 2[3]	0.098Ω/m.	
4	Unbalance parameters	• Cable Pair resistance unbalance: 2%. Channel pair resistance unbalance: 3% • Cable P2P Resistance Unbalance: 5%. Channel P2P Resistance Unbalance: 0.2Ω/6% max TBD.	
5	Channel use cases to check. See figure 1 for what is a channel.	A. 6 inch (0.15 m) of cordage, no connectors. B. 4 m channel with 1 m of cordage, 3 m of cable, 2 connectors C. 23 m channel with 8 m of cordage, 15 m of cable, 4 connectors D. 100m channel with 10 m of cordage, 90 m of cable, 4 connectors	
6	End to End Channel[6]	The Channel per figure 1 + the PSE and PD PIs.	
7	Transformer winding resistance	120mOhm min, 130mOhm max	
8	Connector resistance[8]	40mOhm min, 60mOhm max	30mOhm min, 50mOhm max
9	Diode bridge[9]	Discreet Diodes: 0.39V+0.25Ω*Id min; 0.53V+0.25Ω*id max. (TBD)	
10	PSE output resistance [10]	0.25+0.1 Ohm min, 0.25+0.2 Ohm max	0.1+0.05 Ohm min, 0.1+0.1 Ohm max

Ad-hoc response, June 24, 2014. Adhoc accept this table

Source: Yair Darshan, Christian Beia, Wayne Larsen

Annex G2: Worst case data base- Notes. -2

1	Per standard. It is maximum value for solid and stranded wire. The maximum value is close to AWG#26 wire resistance/meter including twist rate effects. **See annex E1.** Due to the fact that patch cords may use AWG#24 cables with stranded (for mechanical flexibility) or solid wire (for improved performance), we will use the AWG#24A for worst case analysis as well. Cordage with AWG#24 wire has 0.0842Ω/m for solid wire and with 10% twist rate it will be 0.09262 Ω/m.
2	We need both data sets (data set 1 and data set 2) to find where is the worst condition for maximum current unbalance. **See Annex B curve and data** showing that at short channel we get maximum P2PRUNB but it may has less concern to us since the current is lower. We need to do all use cases calculation to see where is the maximum current over the pair; at short channel or long channel. The CAT6A cable with AWG#23 has 0.066 Ω/m. Including 12% increase on cable length due to twist rate, the effective cable resistance per meter will be 1.12*6.6 Ω/100m= 0.0792 Ω/m.
3	Standard definition per Annex E1. We will check how results will be differ when AWG#23 is used for worst case results (lower resistance than standard definition for horizontal cable which is a maximum value.
4	
5	
6	PSE PI and PD PI includes: connector, transformer, resistors. PD PI includes diode bridge.
7	
8	Connector resistance was changed since the difference (60-30) milliohm is not representing Rdiff, it is representing maximum and minimum results of connector resistance of different connectors. To correct it, we change the numbers according to inputs from connector vendors and measured data. See Annex E1-E6 for confirmation.
9	Vf and Rd are worst case numbers of discrete diode which there is no control on Vf and Rd. It needs more investigation to verify that we are not over specify. (Christian is checking it). Normally match components (e.g. matched two diode bridges) are used for 4P operation. Any how ,PD PI spec. will eventually set the requirement.
10	PSE output resistance e.g. Rs_a/b=Rsense+Rdson in addition to winding resistance. See model I Annex F for reference.

Adhoc response, June 24, 2014. Adhoc accept this table

Source: Yair Darshan and Christian Beia

Annex G3: Deciding on Channel components data

#	Rmax milliΩ	Rdif milliΩ	Rmin milliΩ	Notes
Connector data combinations that don't make sense.				
1	201	-	-	200milliΩ max, standard
2	-	51	-	50milliΩ max, standard
3	60	50	10	Meets the standard however doesn't make sense to have 71.4% P2PRUNB.
4	61	-	-	Field results, 60milliΩ max
5	-	30	-	Field results, 20milliΩ max
Connector data combinations that make sense.				
6	60	20	40	OK
7	50	20	30	OK for worst case.

- Connector vendors: connector resistance rage of different connectors for worst case lowest numbers: 0.03Ω to 0.06 Ω. (Standard is 200milliohm max and Rdiff=50milliohm max which is not helping us).
- With in a connector (pin to pin or pair to pair), the difference between Rmax and Rmin (=Rdiff) is 0.02Ωmax, Typically it is not more than 0.015Ω. (instead 0.03Ω).
- As a result, for worst case calculation we will use for connectors:
  - Connector Rmax=0.05Ω, Connector Rdiff=0.02Ω max.
- Cordage: 0.14 Ω/m per standard. Cable: 0.0792Ω/m for CAT6A AWG#23 cable for worst case analysis.

Adhoc response, June 24, 2014. Adhoc accept this table

Source: Yair Darshan

Annex G4: Minimum resistance existing in PSE and PD Pis, Example based on Annex G1 database.

- Calculating existing minimum resistance in PSE and PD PI.

All numbers calculated for a pair = two wires in parallel.

PSE PI minimum resistance range

	Max	Min	
Connectors	0.015	0.015	0.03 ohm per connector divided by 2
Diodes	0.25	0	If AC disconnect then higher e.g. 0.25 ohm
Transformers	0.06	0	For 1000BT and up, otherwise 0. transformer winding from center tap to outer leg=0.12ohm/2
EMI Filters	0.1	0.1	
PCB traces	0.01	0.01	
Total	0.435	0.125	

PD PI minimum resistance range

	Max	Min	
Connectors	0.015	0.015	0.03 ohm per connector divided by 2
Diodes	0.25	0.05	If active diodes are used (Mosfets) the resistance is lower (*)
Transformers	0.06	0	For 1000BT and up, otherwise 0. transformer winding from center tap to outer leg=0.12ohm/2
EMI Filters	0.1	0.1	
PCB traces	0.01	0.01	
Total	0.435	0.175	

Total minimimum PSE and PD resistance per pair 0.125 + 0.175 = 0.3

Source: Yair Darshan

Annex J1-Acronyms used in the ad-hoc activity

- **(1) Pair resistance unbalance :** Is the resistance unbalance between two wires in the same pair as specified by IEEE802.3 and other standards. This is 2% for cable and 3% maximum for the channel. Channel is a 4 connector model (cables and connector only).
- **(2) Pair to Pair resistance unbalance**: is the resistance unbalance between two wires of the same pair connected in parallel to another two wires of other pair connected in parallel. It is 5% for a cable.

(The resistance of the two wires of the pair is know also as the common mode resistance of the pair)

- **(3) End to End channel pair to pair resistance unbalance** it is the 26.2% (TBD) worst case calculation on a worst case data base that we have generated. The 26.2% (TBD) was calculated at 20degC. The channel is including components at PSE PI and PD PI that affects the whole end to end channel.
- **(4) PSE PI Pair to Pair resistance unbalance** is the P2P DC Common Mode PSE Output Resistance Unbalance measured at the PSE PI and include PI interface circuitry such RDSON, Current sense resistor, equipment connector, magnetic winding resistance. This is included in the " end to end channel resistance unbalance" and need to be extracted from it to be separate definition for PSE PI P2PRUNB.
- (4.1) PSI PI Pair to Pair voltage difference is the P2P DC Common Mode PSE Output Voltage Difference measured at the PSE PI under TBD conditions.

Source: Yair Darshan

Annex J2-Acronyms used in the ad-hoc activity

- **(5) PD PI Pair to Pair resistance unbalance** is the P2P DC Common Mode PD input Resistance Unbalance measured at the PD PI and include PI interface circuitry such Diode bridge voltage offset and dynamic resistance, equipment connector, magnetic winding resistance. This is included in the "end to end channel resistance unbalance" and need to be extracted from it to be separate definition for PD PI P2PRUNB.
- **(5.1) PD PI Pair to Pair voltage difference** is the P2P DC Common Mode PD input Voltage Difference measured at the PD PI under TBD conditions.
- **(6) Channel Pair to Pair resistance unbalance** is the P2P resistance unbalance of the cables and 4 connector model. This need to be excreted from the " end to end channel resistance unbalance" and specified separately.
- So (PSE PI +Channel + PD PI)p2prunb all together is 26.2% (TBD).
- Items 4,5 and 6 will be specified in the standard, (item 2 is covered by item 6).
- Meeting #4: Adhoc response: ok. Meeting #5: To discuss changes in RED. Done.

Source: Yair Darshan

Annex K:Same-Pair Current Unbalance vs. DC bias on Transformers

- Source: Dinh, Thuyen, Pulse.

- Current unbalance on cable pair: $\Delta I = I_1 - I_2$
- This ΔI is the net current difference between the 2 half windings of the cable side of the transformer, it only flows in one of the 2 half windings
- Since transformers are tested with bias current injected through both windings, as specified in clause 25 (sub-clause 9.1.7 of ANSI X3:263:199X), a DC bias of ($\Delta I/2$) injected into both windings will produce the same DC flux as that produced by ΔI flowing through one half winding.
- Transformers are, therefore, tested with ($\Delta I/2$) DC bias current to simulate current unbalance of ΔI.

Annex L1: What are the options for complete specification for unbalance PSE PI and PD PI models parameters

Source: Yair Darshan. June 25, 2014

- Current unbalance is a function of Voltage unbalance and resistance unbalance between pairs.
  - These are the only parameters that affect the current unbalance and as a result the maximum pair current due to the unbalance situation.
- For simplicity let's assume Voltage unbalance is zero. We will address the effect of Voltage difference later.
- By definition, the current unbalance between any two pairs is:

$$Idiff = |I_1 - I_2| = It \cdot \frac{\sum R_{\max}}{\sum R_{\max} + \sum R_{\min}} - It \cdot \frac{\sum R_{\min}}{\sum R_{\max} + \sum R_{\min}} = It \cdot \left(\frac{\sum R_{\max} - \sum R_{\min}}{\sum R_{\max} + \sum R_{\min}} \right)$$

$$\frac{Idiff}{It} = \left(\frac{\sum R_{\max} - \sum R_{\min}}{\sum R_{\max} + \sum R_{\min}} \right) = Runb = Iunb$$

Drawing

- Since we are discussing P2P unbalance the Runb and Iunb is between Pair to Pair and the sum of R1 and the sum of R2 represents two wires in parallel including all components connected to each wire.
- The above equations are the same for PSE PI, Channel and PD PI unbalance. The difference is the content of R1 and R2 e.g. for channel it is just cables and connectors. For PSE and PD PIs it contains additional other components such MOSFETs, Diodes, Transformers etc.

Annex L2: What are the options for complete specification for unbalance PSE PI and PD PI models parameters

- The maximum pair current is function of the total End to End Channel Resistance and Voltage Unbalance.
- The PSE PI and PD PI are affecting Imax at short and long channels.
- By definition for maximum pair current Imax as function of P2PRUNB and P2P Voltage Difference of the system from end to end:

$$\mathrm{Im}ax = \frac{It}{2} + \frac{It \cdot E2E\_P2PRUNB}{2} = \frac{It \cdot (1 + E2E\_P2PRUNB)}{2}$$

$$\mathrm{Im}ax = \frac{It \cdot (1 + E2E\_P2PRUNB)}{2} = \frac{It \cdot \left[1 + \left(\frac{\left(\sum R_{\max}^{PSE} - \sum R_{\min}^{PSE}\right) + \left(\sum R_{\max}^{PD} - \sum R_{\min}^{PD}\right) + \left(\sum R_{\max}^{CH} - \sum R_{\min}^{CH}\right)}{\sum R_{\max}^{PSE} + \sum R_{\max}^{PD} + \sum R_{\max}^{CH} + \sum R_{\min}^{PSE} + \sum R_{\min}^{PD} + \sum R_{\min}^{CH}} \right) \right]}{2}$$

$$\mathrm{Im}ax = \frac{It \cdot (1 + E2E\_P2PRUNB)}{2} = \frac{It \cdot \left[1 + \left(\frac{\sum R_{diff}^{PSE} + \sum R_{diff}^{PD} + \sum R_{diff}^{CH}}{\sum R_{\max}^{PSE} + \sum R_{\max}^{PD} + \sum R_{\max}^{CH} + \sum R_{\min}^{PSE} + \sum R_{\min}^{PD} + \sum R_{\min}^{CH}} \right) \right]}{2}$$

- **The PSE PI P2PRUNB can be defined in similar way by similarity.**
- Note: PSE PI P2PRUNB is not equal to E2E_CPWPRUNB nor to PD PI P2PRUN. It requires additional mathematical procedure to find this parameters so it will be equal to the E2E_CP2PRUNB target.

Source: Yair Darshan

Annex L3: What are the options for complete specification for unbalance PSE PI and PD PI models parameters

- We can see that Imax is function of Rmax and Rmin and Rdiff=Rmax-Rmin

$$\mathrm{Im}\,ax = \frac{It\cdot(1+E2E\_P2PRUNB)}{2} = \frac{It\cdot\left[1+\left(\frac{\sum R_{diff}^{PSE}+\sum R_{diff}^{PD}+\sum R_{diff}^{CH}}{\sum R_{\max}^{PSE}+\sum R_{\max}^{PD}+\sum R_{\max}^{CH}+\sum R_{\min}^{PSE}+\sum R_{\min}^{PD}+\sum R_{\min}^{CH}}\right)\right]}{2}$$

- From the above, PSE PI P2PRUNB upper limit can be extracted and it will have the same effect on Imax with the same exact concept.

$$PSE\_PI\_P2PRUNB = \frac{\sum R_{diff}^{PSE}}{\sum R_{\max}^{PSE}+\sum R_{\max}^{PD}+\sum R_{\max}^{CH}+\sum R_{\min}^{PSE}+\sum R_{\min}^{PD}+\sum R_{\min}^{CH}}$$

$$PSE\_PI\_P2PRUNB = \frac{(k+\alpha)\cdot\sum R_{diff}^{PSE}}{\sum R_{\max}^{PSE}+\sum R_{\min}^{PSE}+\beta} = \frac{\sum R_{diff\_new}^{PSE}}{\sum R_{\max\_new}^{PSE}+\sum R_{\min\_new}^{PSE}}$$

- The terms k, a and b are used to transform the true PSE PI P2PRUNB to PSE PI P2PRUNB as stand alone function.
- Now we can see what are the necessary unbalanced properties that are needed to uniquely specify the PSE PI?

Source: Yair Darshan

Annex L4: What are the options for complete specification for unbalance PSE PI and PD PI models parameters

$$PSE\_PI\_P2PRUNB = \frac{\sum_{R_{diff}\_new}^{PSE}}{\sum_{R_{\max\_new}}^{PSE} + \sum_{R_{\min}\_new}^{PSE}} = \frac{\sum_{R_{\max\_new}}^{PSE} - \sum_{R_{\min}\_new}^{PSE}}{\sum_{R_{\max\_new}}^{PSE} + \sum_{R_{\min}\_new}^{PSE}}$$

$$\mathrm{Im}\,ax = 0.5 \cdot It \cdot \left(1 + \frac{\sum_{R_{diff}\_new}^{PSE}}{\sum_{R_{\max\_new}}^{PSE} + \sum_{R_{\min}\_new}^{PSE}} \right)$$

- Conclusions: In order to limit Imax_pair you must have in addition to voltage difference and maximum load current It, two additional parameters.
- Firs and fast observation: Imax is equation with 3 parameters. Total current, It is given. We need two variable to solve equation with two parameters
- So specifying only Rdiff and Vdiff for PSE PI or PD PI will not work. It leads to interoperability issues. (one parameter is loose..)

Source: Yair Darshan

Annex L5: What are the options for complete specification for unbalance PSE PI and PD PI models parameters

- Imax is direct function of PSE PI RUNB and Channel and PD parts.
- The transformed PSE_PI_P2PRUNB_new control Imax.

$$\mathrm{Im}\,ax = 0.5 \cdot It \cdot \left(1 + PSE\_PI\_P2PRUNB\_new\right) = 0.5 \cdot It \cdot \left(1 + \frac{\sum R_{diff\_new}^{PSE}}{\sum R_{\max\_new}^{PSE} + \sum R_{\min\_new}^{PSE}}\right)$$

- If we specify PSE PI by only Rdiff and Vdiff we will have the following interoperability issues:

- Examples:
- Rdiff=Rmax-Rmin=0.2=X:
  - P2PRUNB=(0.2-0)/(0.2+0)=100%
  - P2PRUNB=(0.23-0.03)/(0.23+0.03)=77%
  - P2PRUNB=(0.3-0.1)/(0.3+0.1)=50%
  - P2PRUNB=(1-0.8)/(1+0.8)=11%

Interoperability Issue:
Different UNBALANCE
For the same Rdiff resulting
With different Imax for the
Same channel and PD

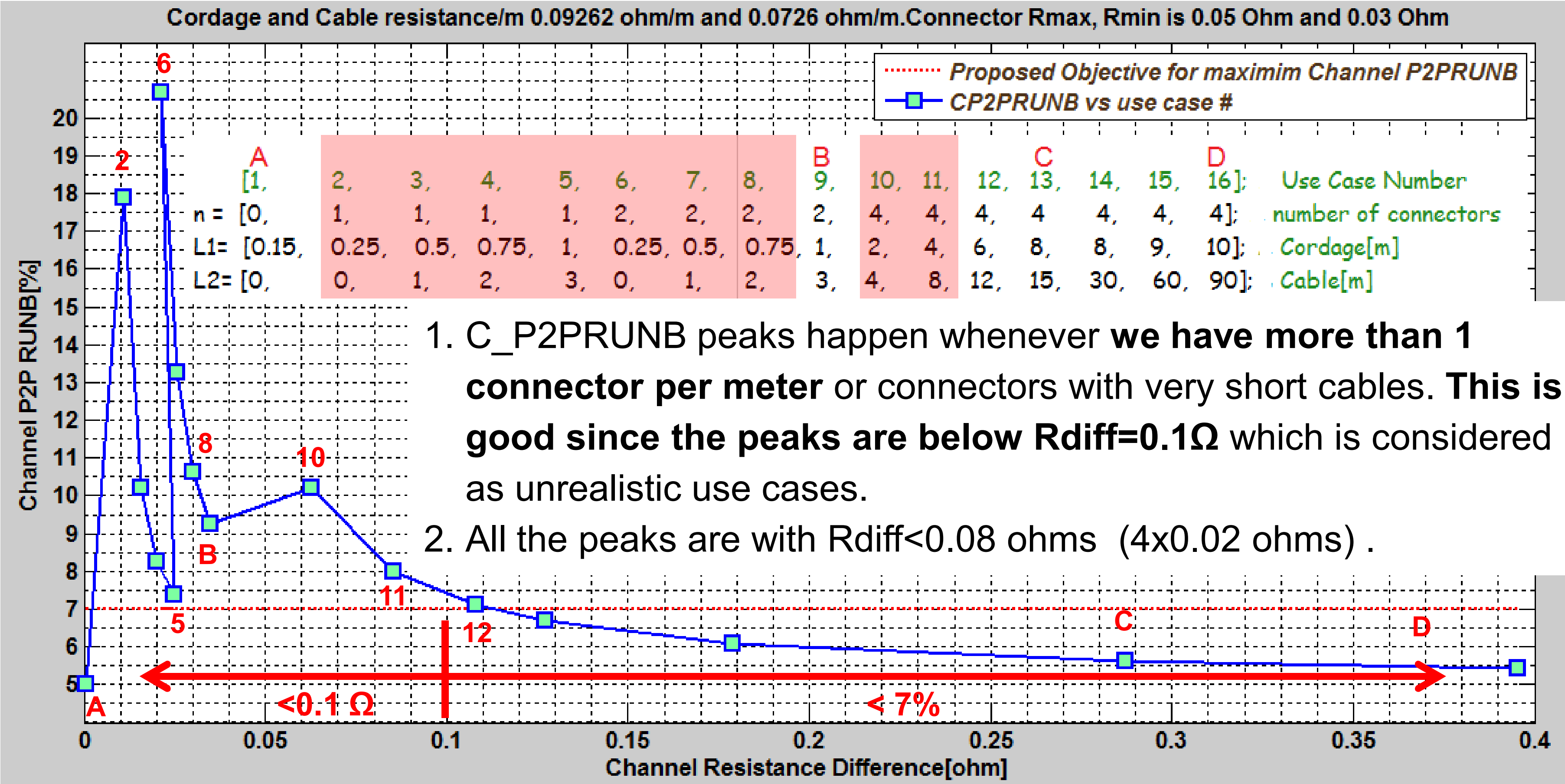
Source: Yair Darshan

Annex L6: What are the options for complete specification for unbalance PSE PI and PD PI models parameters

Source: Yair Darshan

Option	PSE PI P2PRUNB	Rmax	Rmin	Rdiff	Notes
1	Yes	-	-	-	1. Ratio. Fully implementation independent . 2. Need two parameter to solve equation with two variables. Need more research to verify completeness.
2	-	Yes	Yes	-	1. Complete solution. 2. Not flexible, Implementation dependent.
3	Yes	Yes			1. Complete solution. 2. Not flexible, Implementation dependent. Problem to limit Rmax
4	Yes	No	Yes	-	1. Complete solution. 2. Rmin is exists any way. 3. Not fully Implementation in dependent but tolerable.
5	Yes	NO	NO	YES	1. Complete solution. 2. Implementation dependent.
6	NO	NO	NO	YES	1. Not complete 2. Implementation dependent 3. Interoperability issues

Annex L7: Why Channel Rdiff=Delta R is not sufficient to define channel unbalance.



- The mathematical basics are the same as explained for PSE and PD PIs. See Annex L1-L6 for details. In the channel it is further more obvious per next slide.

Source: Yair Darshan

Annex L8: Why Channel Rdiff=Delta R is not sufficient to define channel unbalance.

- If we will specify Channel P2P RUNB by its Rmax-Rmin=Rdiff=0.1Ω (or any number) property only we will end with the following undesired results:
- (a) At long channel (high resistance) the unbalance is converging to lowest possible value. It is bounded by the P2PRUNB[%] property which is much lower than the connectors unbalance property.
- (b) At short channel when resistance is low, the P2PRUNB property is bounded by the connectors Rmax, Rmin which results with 25% unbalance for Rmax=0.05Ω, Rmin=0.03Ω ➔ Rdiff=0.02 Ω ➔ (50-30)/(50+30)=25%
- So it is obvious that best and optimized performance will be achieved with two properties needed for the channel: P2PRUNB and Rdiff.

Source: Yair Darshan

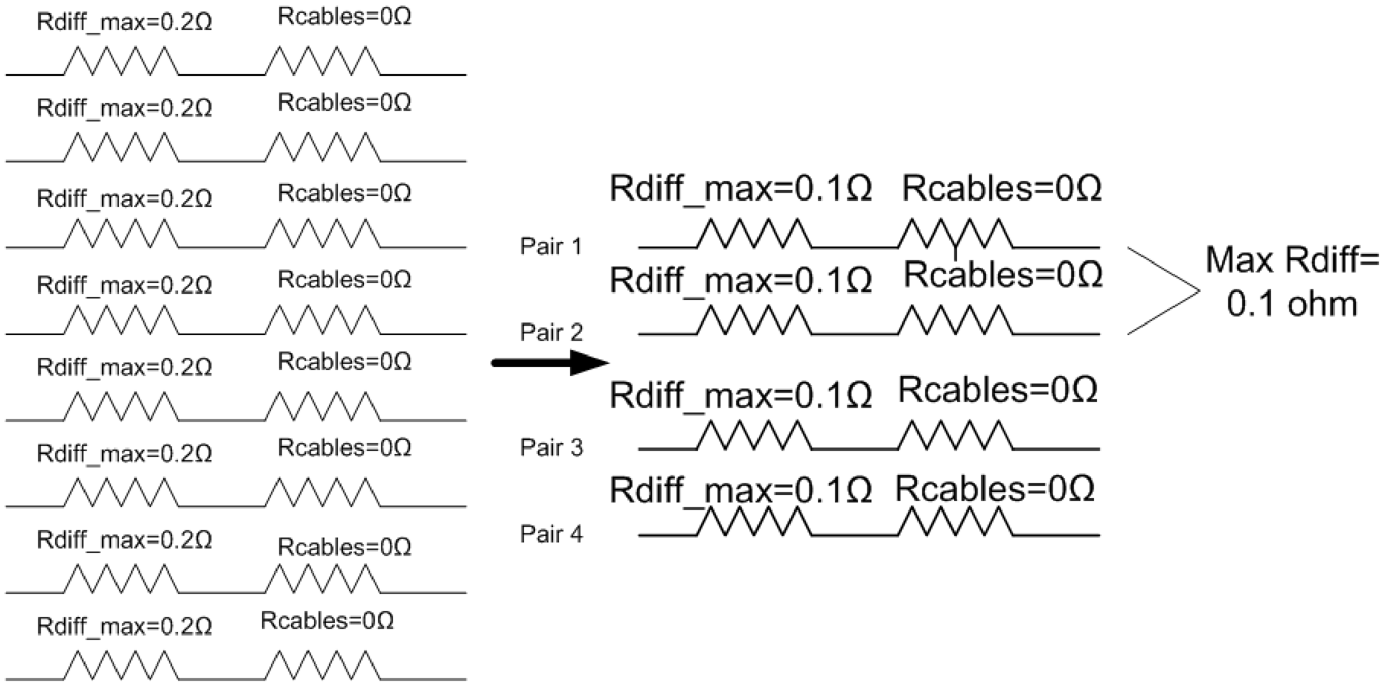
Annex M: How we address P2PRUNB vs Temperature

- Adhoc has recommended the following approach (meetings 5,6,7)
  - How to handle PSE PI, PD PI Pair to Pair unbalance parameters and Channel P2RUNB as function of temperature?
    - <u>Adhoc response:</u>
    - Use PSE PI, PD PI pair to pair Unbalance parameters and Channel P2PRUNB that was calculated at 20°.
    - Set it as the number to meet without saying at what temperature it is.
    - Vendors will have to assure that they meet it at their operating temperature range spec.
    - How they will do it, we don’t care. The rest is per 33.7.7.

Ad-hoc response, June 10, 2014. Ad hoc agrees to set temperature of P2PUNB numbers at 20degC.

Annex P: The value of channel maximum Rdiff

- On May 2014 we vote for the following base line text highlighting the TBD areas.
  33.1.4.3 Channel Requirement for Pair to Pair Resistance unbalance
  4P pair operation requires the specification of resistance unbalance between each two pairs of the channel, not greater than 200 milliohms or 6%(TBD) which ever is greater. Resistance unbalance between the channel pairs is a measure of the difference of resistance of the common mode pairs of conductors used for power delivery. Channel pair to pair resistance unbalance is defined by …..”
- The 200milliohm above should be 0.1Ω. Why?. Connector max Rdiff= 0.05Ω. 4 connectors is 4*0.05Ω=0.2Ω on each Wire. As a result, a pair is two connectors in parallel ➔ 0.1Ω
  - Connector maximum resistance is 0.2Ω and is not related to the discussion here which is pair to pair resistance difference.



Source: Yair Darshan.
Confirmed by Wayne Larsen

Annex P1: Channel P2PRUNB at Rdiff point

- Channel only Equation:

$$C\_P2PRUNB = \left(\frac{\sum R_{\max} - \sum R_{\min}}{\sum R_{\max} + \sum R_{\min}} \right) =$$

$$= \left(\frac{0.5 \cdot \left(L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc \right)_{\max} - 0.5 \cdot \left(L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc \right)_{\min}}{0.5 \cdot \left(L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc \right)_{\max} + 0.5 \cdot \left(L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc \right)_{\min}} \right)$$

  - The factor 0.5 was left intentionally.
- When L1+L2 approaching to zero:

$$C\_P2PRUNB = \left(\frac{0.5 \cdot \left(N \cdot Rc_{\max} - N \cdot Rc_{\min} \right)}{0.5 \cdot \left(N \cdot Rc_{\max} + N \cdot Rc_{\min} \right)} \right) =$$

$$= \left(\frac{0.5 \cdot N \cdot Rdiff}{0.5 \cdot \left(N \cdot Rc_{\max} + N \cdot Rc_{\min} \right)} \right) = 25\% \max$$

For Rc_min=0.03Ω and Rc_diff=0.02 Ω
Rdiff_max for channel: 0.1Ω

Source : Yair Darshan

Annex P2: Channel P2PRUNB at Rdiff point

$$C\_P2PRUNB = \left(\frac{0.5 \cdot N \cdot Rc_{\max} - 0.5 \cdot N \cdot Rc_{\min}}{0.5 \cdot \left(N \cdot Rc_{\max} + N \cdot Rc_{\min} \right)} \right) = \left(\frac{0.5 \cdot C\_Rdiff\_\max}{0.5 \cdot \left(N \cdot Rc_{\max} + N \cdot Rc_{\min} \right)} \right)$$

- Looking at the above equation:
- For C_P2PRUNB, as a parameter that specify the channel behavior, the number of connectors became irrelevant:

$$C\_P2PRUNB = \frac{\left(Rc_{\max} - Rc_{\min} \right)}{\left(Rc_{\max} + Rc_{\min} \right)}$$

Ratio ➔ Implementation independent

- However for Rdiff it is relevant:

$$C\_P2PRUNB = \left(\frac{0.5 \cdot C\_Rdiff\_\max}{0.5 \cdot \left(N \cdot Rc_{\max} + N \cdot Rc_{\min} \right)} \right)$$

$$C\_Rdiff = 0.5 \cdot N \cdot \left(Rc_{\max} - Rc_{\min} \right) =$$

$$= 0.5 \cdot N \cdot Conn\_Rdiff\_\max$$

ABS number ➔ Implementation dependent

Source : Yair Darshan

Annex P3: Channel P2PRUNB at Rdiff point

Complete Channel specification:

- (Complete specification is like defining the behavior of equation for its entire operating range and as close as possible to implementation independent)
- For $C\_Rdiff > 0.5 \cdot N \cdot Conn\_Rdiff\_\max = 0.1\Omega$

$$C\_P2PRUNB = \left(\frac{(L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc)_{\max} - (L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc)_{\min}}{(L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc)_{\max} + (L1 \cdot \rho_1 + L2 \cdot \rho_2 + N \cdot Rc)_{\min}} \right) = 7.5\% \max$$

- For $C\_Rdiff \leq 0.5 \cdot N \cdot Conn\_Rdiff\_\max = 0.1\Omega$

$$C\_Rdiff\_\max = 0.5 \cdot N \cdot Conn\_Rdiff\_\max = 0.1\Omega$$

$$C\_P2PRUNB\_\max = \frac{(Rc_{\max} - Rc_{\min})}{(Rc_{\max} + Rc_{\min})} = 25\%$$

Which ever is greater

Numbers are based on worst case data base numbers

Source : Yair Darshan

Annex Q: Channel Rmin vs. Channel P2PRUNB and number of connectors

Source : Yair Darshan.

Verified by analytical solution and simulations

$$Channel\_P2PRUNB = \alpha$$

$$Cable\_P2PRUNB = \beta$$

$$Rcable\_\min = R_{\min}$$

$$Rcable\_\max = R_{\max} = R_{\min} \cdot \frac{(1+\beta)}{(1-\beta)} = R_{\min} \cdot \delta$$

$$\alpha = \frac{(R_{\max} + N \cdot Rc_{\max}) - (R_{\min} + N \cdot Rc_{\min})}{R_{\max} + N \cdot Rc_{\max} + R_{\min} + N \cdot Rc_{\min}} =$$

$$\alpha = \frac{N \cdot (Rc_{\max} - Rc_{\min}) + R_{\min} \cdot (\delta - 1)}{N \cdot (Rc_{\max} + Rc_{\min}) + R_{\min} \cdot (\delta + 1)} =$$

$$\alpha \cdot (N \cdot (Rc_{\max} + Rc_{\min}) + R_{\min} \cdot (\delta + 1)) = N \cdot (Rc_{\max} - Rc_{\min}) + R_{\min} \cdot (\delta - 1)$$

$$\alpha \cdot N \cdot (Rc_{\max} + Rc_{\min}) + \alpha \cdot R_{\min} \cdot (\delta + 1) = N \cdot (Rc_{\max} - Rc_{\min}) + R_{\min} \cdot (\delta - 1)$$

$$\alpha \cdot R_{\min} \cdot (\delta + 1) - R_{\min} \cdot (\delta - 1) = N \cdot (Rc_{\max} - Rc_{\min}) - \alpha \cdot N \cdot (Rc_{\max} + Rc_{\min})$$

$$R_{\min} \cdot (\alpha \cdot (\delta + 1) - (\delta - 1)) = N \cdot (Rc_{\max} - Rc_{\min}) - \alpha \cdot N \cdot (Rc_{\max} + Rc_{\min})$$

$$R_{\min} = \frac{N \cdot (Rc_{\max} - Rc_{\min}) - \alpha \cdot N \cdot (Rc_{\max} + Rc_{\min})}{\alpha \cdot (\delta + 1) - (\delta - 1)}$$

- Rmin is given as round loop value.
- Rc_max=0.05 ,Rc_min=0.03, β=Cable_P2PRUNB=5%
- Channel_P2PRUNB=α=7% as an example.

$$R_{\min} = \frac{N \cdot (Rc_{\max} - Rc_{\min}) - \alpha \cdot N \cdot (Rc_{\max} + Rc_{\min})}{\alpha \cdot (\delta + 1) - (\delta - 1)}$$

n	Rcable min [ohm]	Channel Runb
0	Any	5.00%
1	0.342	7.00%
2	0.684	7.00%
3	1.026	7.00%
4	1.368	7.00%
Pair resistance is half the value		