IEEE802.3 4P Task Force

Channel Pair To Pair Resistance Imbalance

(End to End System Imbalance)

Ad Hoc

Norfolk VA

May 2014

Meeting #1: Rev_001 Monday February 17, 2014
Meeting #2: Rev_001b Monday February 24, 2014
Meeting #3: Rev 004, Thursday April 24, 2014
Meeting #4: Rev 005, Thursday May 1, 2014
Meeting #5: Rev 006, Thursday May 8, 2014
Meeting #5: Rev 008, Thursday May 8, 2014, Ad-hoc report for May 2014 meeting.
Meeting #6: Rev 009, Thursday May 15,2014 , Norfolk VA.
Meeting #7: Rev 010, Tuesday June 10, 2014 ,
Meeting #8: Rev 011, Tuesday June 24, 2014.

Yair Darshan
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Meeting # 8 Attendees (June 24, 2014)

- Please send email after the meeting to confirm your attendance.

Meeting # 7 Attendees (June 10, 2014)

Meeting # 7

Jeff Heath / LT
Brian Buckmeier / BEL
David Abramson / TI
Rimboim Pavlik / Microsemi
Yair Darshan / Microsemi
Ken Bennett / Sifos
Victor Renteria / BEL
Gaoling Zou / Maxim

If you attend meeting #7 on June 10, 2014, please verify your name is recorded.

Introduction

- The purpose of this ad-hoc is to recommend the Task-Force for what is needed to specify the channel pair to pair resistance unbalance while considering not only the formal channel components (Cable and Connector) but also the Power Interface (PI) components at both ends of the 4P PoE system.

- Patent Policy

-Please read the Patent Policy slides at http://www.ieee802.org/3/patent.html prior the meeting.

Proposed Agenda, Meeting #8, June 24, 2014.

- Introduction, Patent policy (1 minute)
- Worst Case Data Base (updates) (5 minutes)
- Reviewing Ken Bennett Presentation sent last meeting (10 minutes)
- Where we are and where we are going? (5 minutes)
- Reviewing Yair Darshan Presentation regarding

  Closing on a number for Channel P2PRUNB (20 minutes)
- PSE PI P2P model concept (5 minutes)
- PD PI P2P model concept (2 minutes)
- Summary and Action Items (10 minutes)

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	
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]	30mOhm min, 60mOhm max 45mOhm min, 60mOhm max	30mOhm min, 60mOhm max 30mOhm min, 45mOhm 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. TBD

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

- 1. Per standard. See annex E1.
- 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 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.
- 6. PSE PI and PD PI includes: connector, transformer, resistors. PD PI includes diode bridge.
- 8. Connector resistance was changed since the difference (60-30) miliOhm 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

Adhoc response, June 24, 2014. TBD

Annex G3: Deciding on Channel components data

Connector data combinations that don't make sense.				
#	Rmax miliΩ	Rdif miliΩ	Rmin miliΩ	Notes
1	201	-	-	200miliΩ max, standard
2	-	51	-	50miliΩ max, standard
3	60	10	50	Field results, 20miliΩ max
4	61	-	-	Field results, 60miliΩ max
5	-	30	-	Field results, 20miliΩ max
6	60	50	10	Meets the standard however doesn't make sense to have 71.4% P2PRUNB.
7	60	20	40	OK
8	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 200miliOhm max and Rdiff=50miliOhm 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. TBD

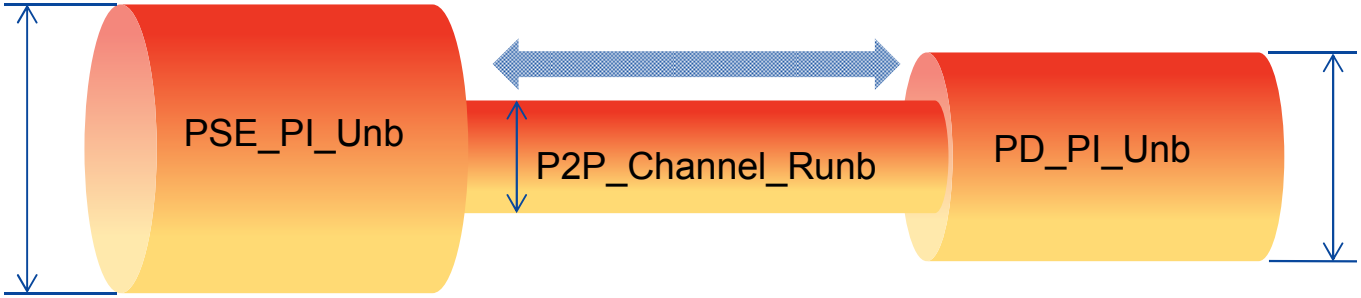
Where we are and were we are going -1

Ad-hoc response, June 24, 2014. TBD

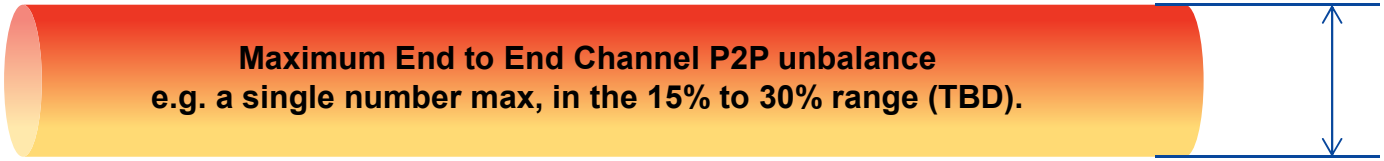
-Single maximum number max.
-Voltage and resistance unbalance.
-Test setup TBD. 25% -50% range (TBD)

-

-Single maximum number MAX.
-Voltage and resistance unbalance.
-Test setup TBD. 5% -20% range (TBD)



-Variable Channel Length
-Worst Case Runb
-7 to 9% (TBD) max. or 0.2Ω max which ever is greater.
-We may need minimum channel resistance definition.
function of # of connectors and cable length



- Channel capable of regulating/reducing of end to end unbalance as function of channel length.
- PD PI need to be better than PSE PI due to its higher effectiveness on end to end unbalance.
- PSE PI needs larger unbalance range to allow different implementations

Where we are and where we are going? -2

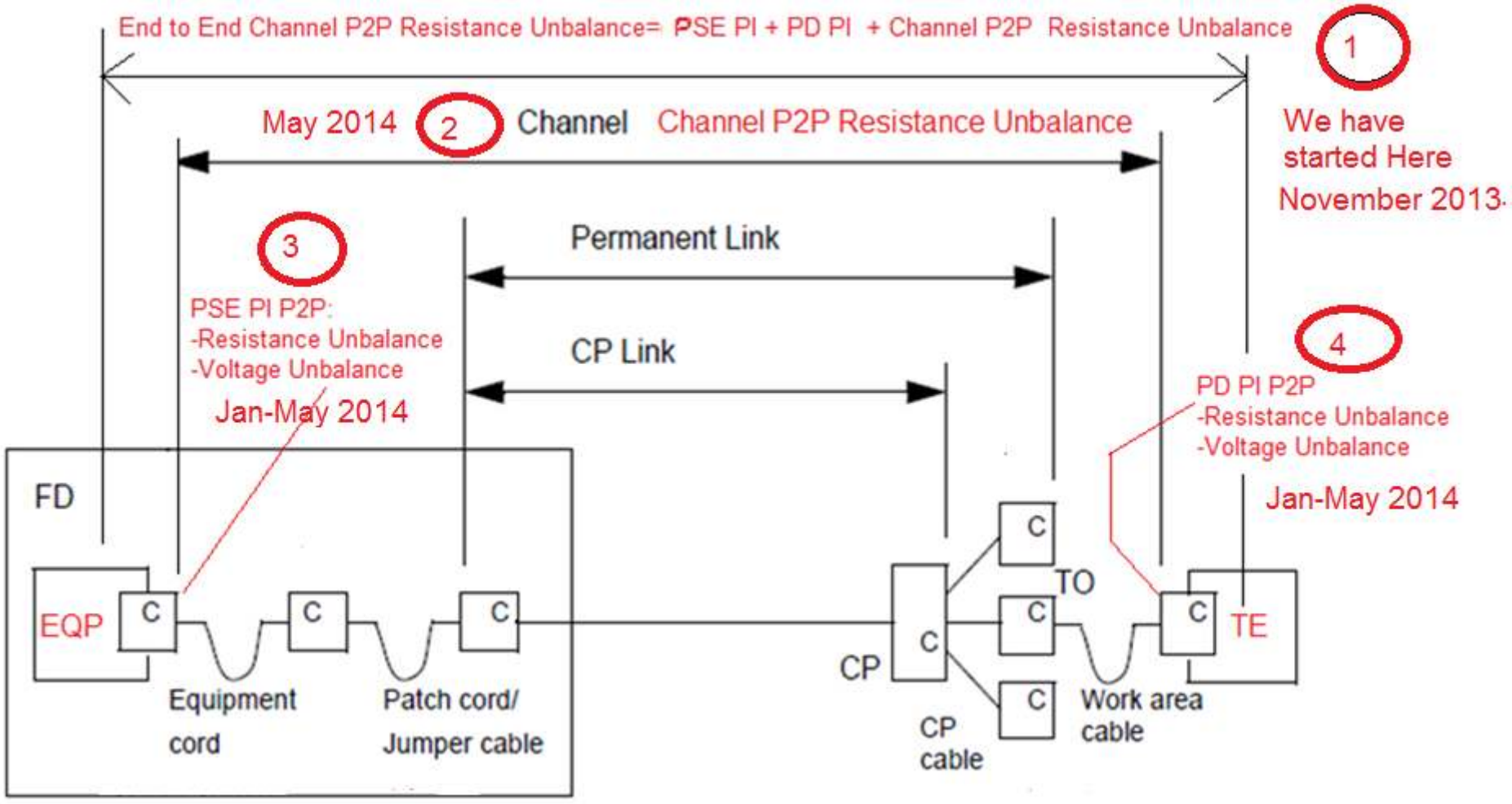


Figure 1. May 27, 2014

Ad-hoc response, June 24, 2014. TBD

Where we are and were we are going? -3

#	Parameter	Part of the spec.	Status
1	End to End Channel Pair to Pair Resistance Unbalance	No	-We have worst case numbers based on worst case data base. -Database is updated on the fly.
2	Channel Pair to Pair Resistance Unbalance	Yes	-Baseline text motion passed. -Numbers 0.2Ω, 6% max (TBD) -Working on 6% ➔ higher
3	PSE PI Pair to Pair Resistance Unbalance	Yes	-Consensus that P2P resistance unbalance need to be specified together with Voltage unbalance. -Models being discussed for testing, no complete work yet. -Numbers need to be derived from (1) and (2).
4	PD PI Pair to Pair Resistance Unbalance	Yes	

We agree that the above parameters will be calculated/defined at room temperature or close to it (see details next slide).
There is a consensus that the temperature will be 20°C. Ad-hoc to confirm on meeting #7

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

Where we are and were we are going? -4

- 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?
    - Adhoc response:
    - 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.

Where we are and were we are going? -5

- End to End Channel P2P RUNB.
  - Using Annex F model.
  - Ignoring Vdiff in PSE PI and PD PI for simplicity. Later their effects will be added.

$$E2E\_C\_P2PRUNB = \frac{\sum R\max - \sum R\min}{\sum R\max + \sum R\min} =$$

$$= \frac{R_{pse\_\max} + R_{pd\_\max} + R_{ch\_\max} - R_{pse\_\min} - R_{pd\_\min} - R_{ch\_\min}}{R_{pse\_\max} + R_{pd\_\max} + R_{ch\_\max} + R_{pse\_\min} + R_{pd\_\min} + R_{ch\_\min}} =$$

$$= \frac{(R_{pse\_\max} - R_{pse\_\min}) + (R_{pd\_\max} - R_{pd\_\min}) + (R_{ch\_\max} - R_{ch\_\min})}{\sum R\max + \sum R\min} =$$

Ad-hoc response, June 24, 2014. TBD

$$E2E\_C\_P2P\_RUNB = \frac{(R_{pse\_\max} - R_{pse\_\min})}{\sum R\max + \sum R\min} + \frac{(R_{pd\_\max} - R_{pd\_\min})}{\sum R\max + \sum R\min} + \frac{(R_{ch\_\max} - R_{ch\_\min})}{\sum R\max + \sum R\min}$$

Where we are and were we are going? -6

- How to specify PSE and PD PI (opt A: through simulation).
  - Step 1: Find End to End maximum Voltage and resistance unbalance max limit. (We already have worst case numbers based on worst case data base)
  - Step 2: Find/define convenient, practical PD max. unbalance parameters (voltage and resistance)
  - Step 3: Use calculated Channel maximum Runb at the working point of Step 1.
  - Step 4: Change PSE PI Vdiff_max, Rdiff_max, Rmin parameters to achieve maximum Runb until the limits of Step 1 is crossed.
- How to specify PSE and PD PI (opt B: The analytical way).

$$\frac{(R_{pse\_\max}-R_{pse\_\min})}{\sum R\max+\sum R\min}+\frac{(R_{pd\_\max}-R_{pd\_\min})}{\sum R\max+\sum R\min}+\frac{(R_{ch\_\max}-R_{ch\_\min})}{\sum R\max+\sum R\min}=$$

$$Kpse\cdot\frac{(R_{pse\_\max}-R_{pse\_\min})}{\sum R\max+\sum R\min}+Kpd\cdot\frac{(R_{pd\_\max}-R_{pd\_\min})}{\sum R\max+\sum R\min}+Kch\cdot\frac{(R_{ch\_\max}-R_{ch\_\min})}{\sum R\max+\sum R\min}$$

Ad-hoc response, June 24, 2014. TBD

- Find Kpse, Kpd and Kch that meets the limits of step 1.
- Kxx may be a Vandermonde matrix for perfect fitting or scalar for worst case points only.

IEEE802.3 4P Task Force

Channel Pair To Pair Resistance Unbalance

(only cables and connectors)

Analysis of ad-hoc proposed use cases

July 2014

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Objectives: Channel P2P RUNB: Closing on TBDs

- In May 2014 we vote for the following base line text (showing only the part with TBD).

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 analysis in the following slides is based on use case data proposed by the ad-hoc in previous meetings.

Channel Component Data used in this work

#	Component	Value	Reference
1	Patch Cord	0.14Ω/m	Adhoc, Standard.
2	Horizontal Cable	CAT6A AWG23	1. Adhoc 2. See Annex G1, G2, G3, E1 3. See Slide 20
3	Connector	Rmin=0.03Ω **Rdiff=0.02Ω** Rmax=0.06Ω	1. Rdiff (TBD) : Adhoc 2. Rmin, Rmax: Adhoc 3. See Annex G1, G2, G3, E1-E6 4. See Slide 21

Questions such:

1. Why not to use 0.098 Ω/m as per standard etc. are answered in annexes above. If more data are needed, please addressee this question at the reflector.
2. Why not using Rmax=0.2Ω and Rdiff=0.05Ω for connector. Answer: It is maximum values and we need minimum values for Rmax and Rmin and maximum practical values for Rdiff.
3. The conclusions that was resulted from the issues analyzed in this work, will not change dramatically for other practical data number sets.

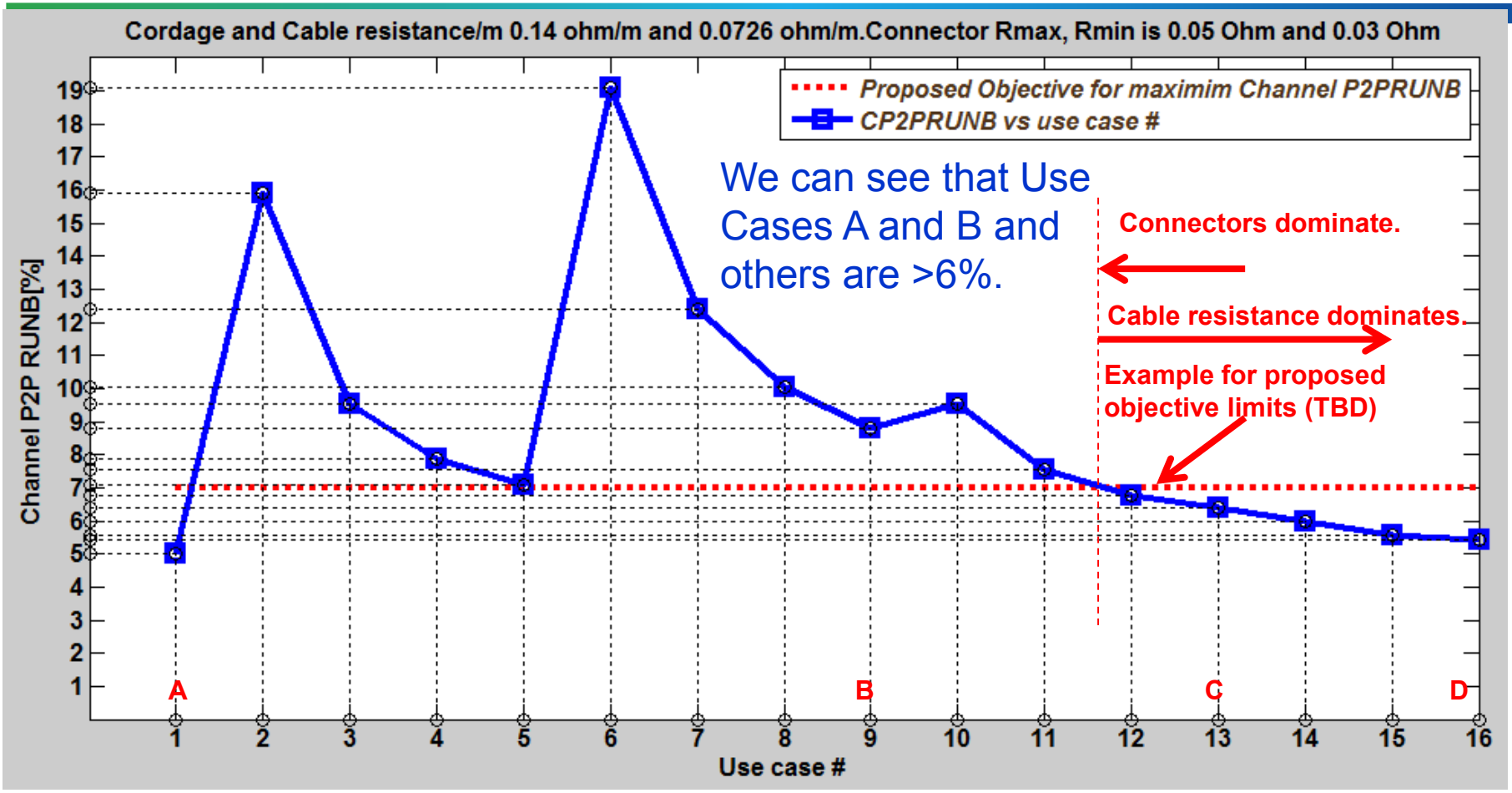
Use cases to be checked during analysis

- **From previous ad-hoc meetings decisions:** To check use cases A, B, C and D per the table below for Channel P2PRUNB specification derivation.
- Additional use cases were added (total 16) after running the simulations in order to find Channel P2PRUN hidden peaks.
- Table below is results summary. **See details next slides.**

Use case	Connectors	Cordage[m]	Cable[m]	Max. Channel P2PRUN
A	0	≥0.15	0	5% (equal to Cable P2PRUNB)
	0	0	≥0.15	
2,6 6-12	1, 2 1,2,4	See curve next slide		9%/16% /19% (Other use cases, not in the list proposed by the ad-hoc however cannot be ignored since we cannot control field use cases, so we need to discuss it to know how to address it)
B	2	1	3	8.9%
C	4	8	15	6.47%
D	4	10	90	5.45%

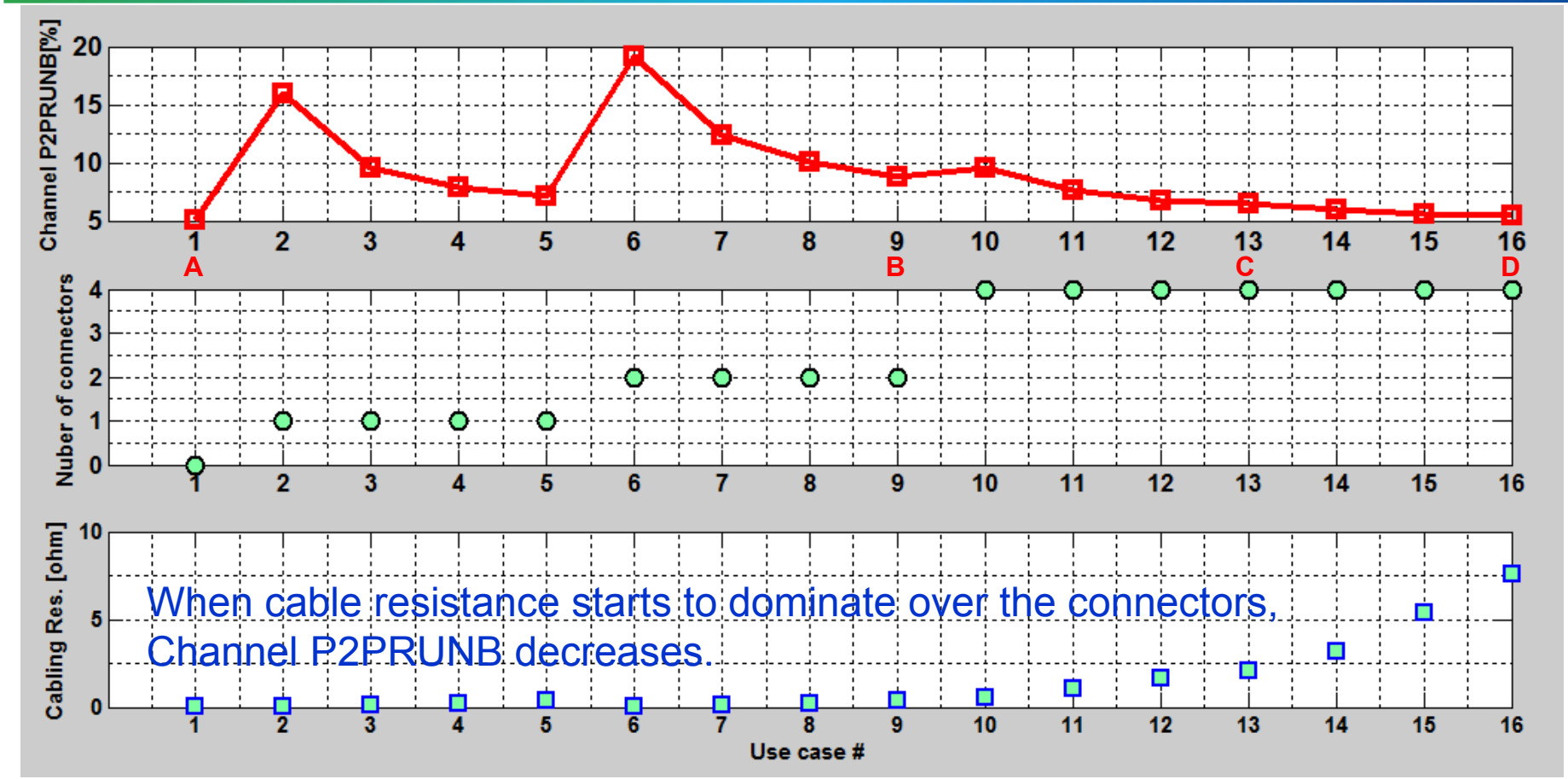
See curve next slide for more data

Use case analysis results and proposed objective -1.



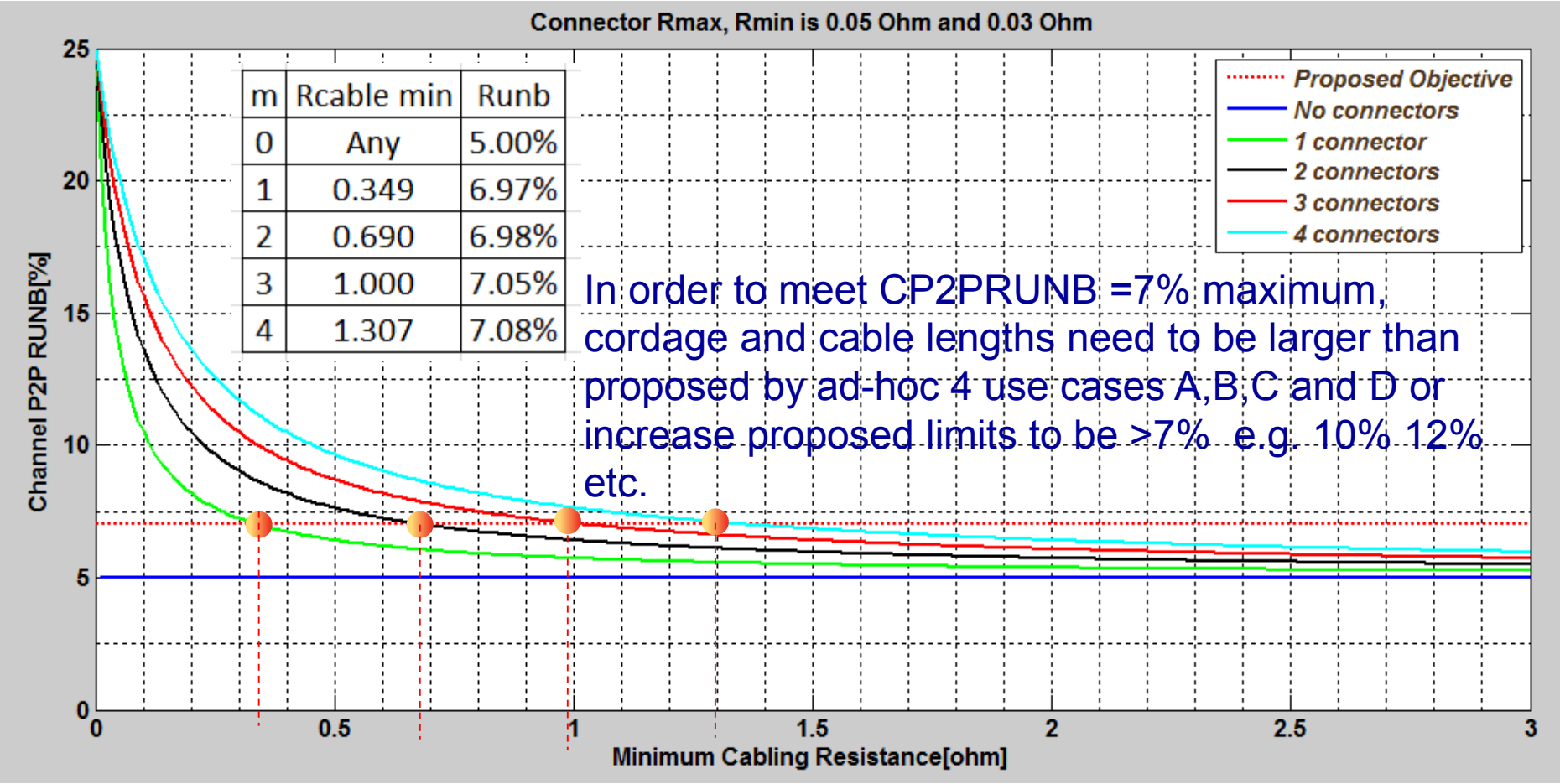
	A							B					C			D	
	[1,	2,	3,	4,	5,	6,	7,	8,	9,	10,	11,	12,	13,	14,	15,	16];	Use Case Number
m =	[0,	1,	1,	1,	1,	2,	2,	2,	2,	4,	4,	4,	4	4,	4,	4];	number of connectors
L1=	[0.15,	0.25,	0.5,	0.75,	1,	0.25,	0.5,	0.75,	1,	2,	4,	6,	8,	8,	9,	10];	Cordage[m]
L2=	[0,	0,	1,	2,	3,	0,	1,	2,	3,	4,	8,	12,	15,	30,	60,	90];	Cable[m]

Channel P2PRUNB vs. Use case parameters -2



	A								B				C			D	
	[1,	2,	3,	4,	5,	6,	7,	8,	9,	10,	11,	12,	13,	14,	15,	16];	Use Case Number
m =	[0,	1,	1,	1,	1,	2,	2,	2,	2,	4,	4,	4,	4	4,	4,	4];	number of connectors
L1=	[0.15,	0.25,	0.5,	0.75,	1,	0.25,	0.5,	0.75,	1,	2,	4,	6,	8,	8,	9,	10];	Cordage[m]
L2=	[0,	0,	1,	2,	3,	0,	1,	2,	3,	4,	8,	12,	15,	30,	60,	90];	Cable[m]

Channel P2PRUNB vs. Cable Minimum resistance and number of connectors. -1.



m	Rcable min	Runb
0	Any	5.00%
1	0.349	6.97%
2	0.690	6.98%
3	1.000	7.05%
4	1.307	7.08%

- Connector P2PRunb=(50-30)/(50+30)=0.25
- Cable P2PRUNB=5%.
- Channel P2PRUNB: See 5 curves with different connector numbers

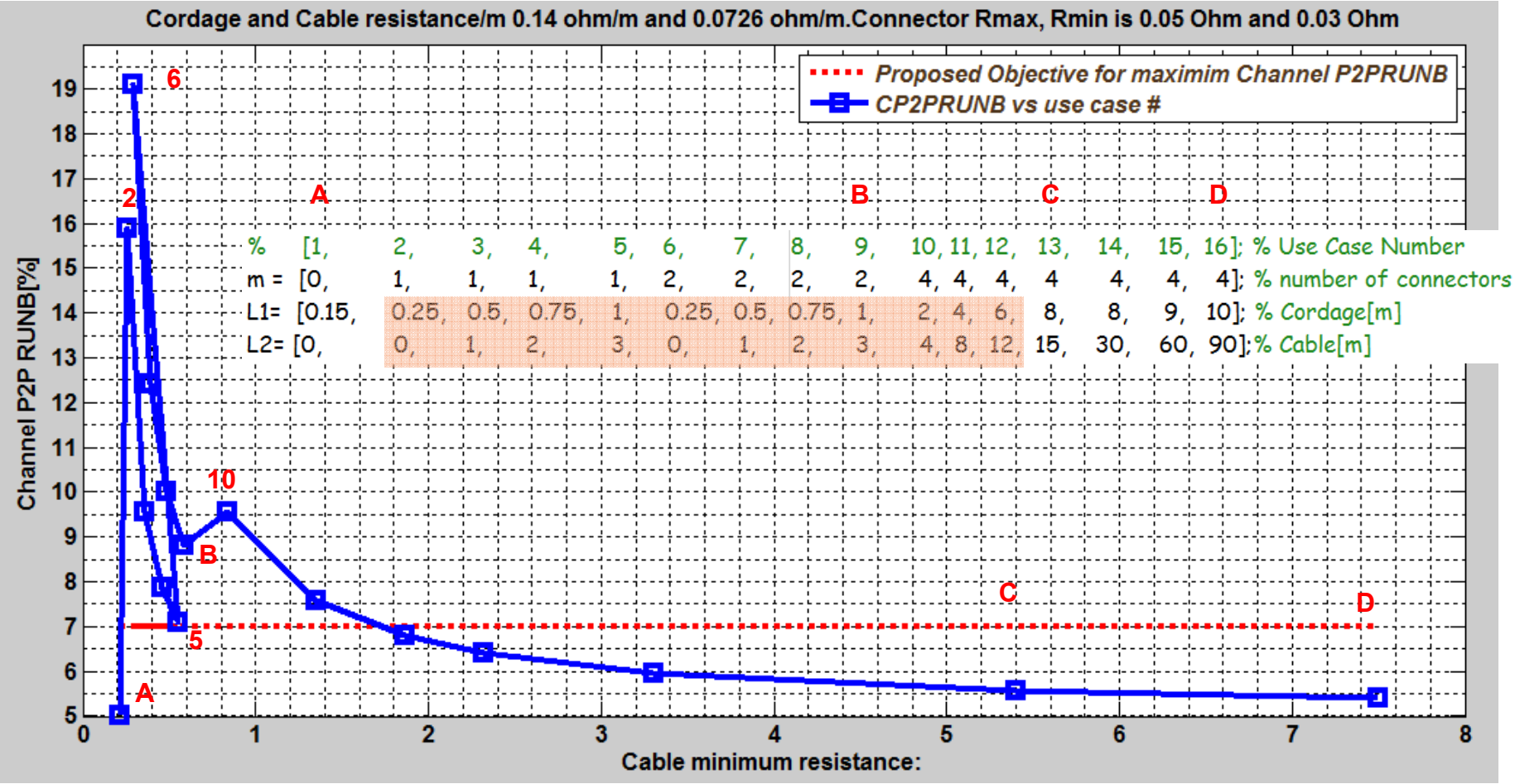
Channel P2PRUNB vs. Cable Minimum resistance and number of connectors. -2.

- If we set Channel P2PRUNB limit to 7%, it requires cordage and cable lengths larger that proposed in ad-hoc use cases.

- Otherwise we need to use much higher limits as high as 19% which is not good for the end to end P2PRUNB objectives.
- Other solutions are presented later.

Use case analysis results – Sanity Check -1.

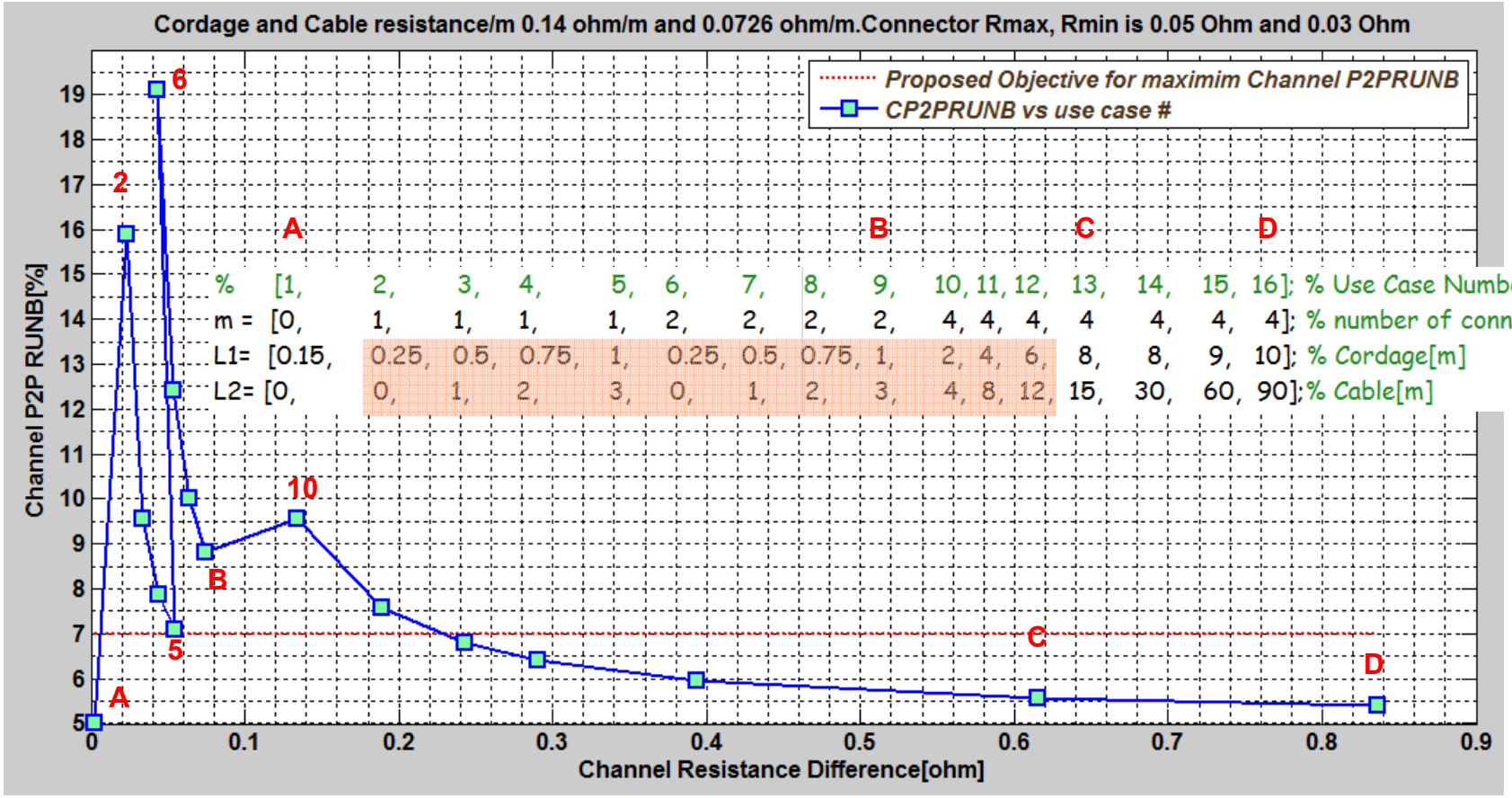
Filtering the main problem by Changing **X axis for Cabling Minimum resistance**



- All peaks now are concentrated in minimum cabling resistance region.
- Minimum total cabling resistance of ~1.75 Ω is required to reduce CP2PRUNB peaks below 7%.

Use case analysis results – Sanity Check -2.

Filtering the main problem by Changing **X axis for Channel Resistance Difference.**



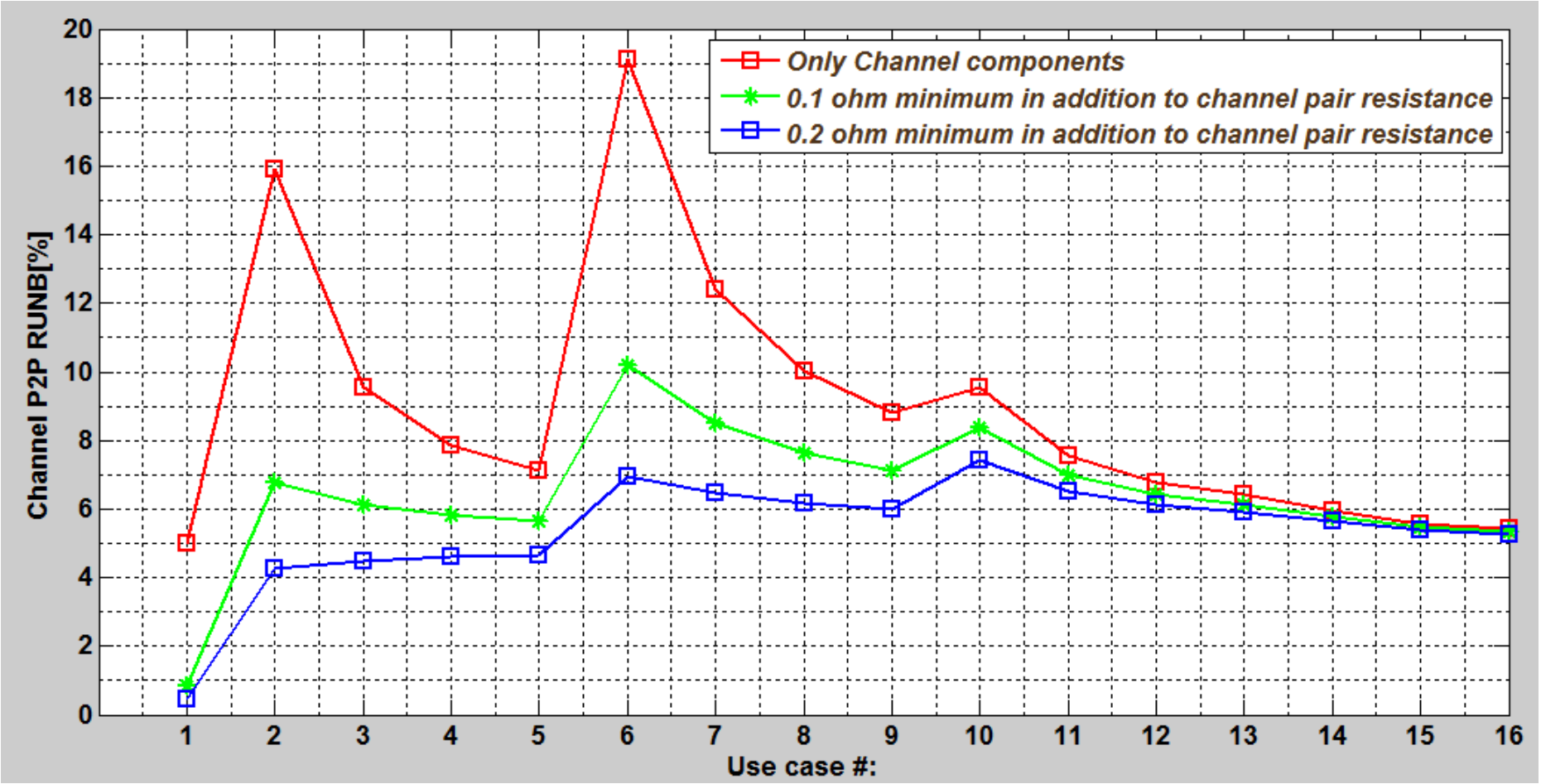
- Using different X axis that shows were the problems are concentrated.
- Checking the 4 use case from the table A,B,C and D.
- (My opinion) We can't control all use case combinations such 1 connector use case (e.g. Use case #2, etc.). We need to find ways to reduce 2, 6, B and 10 peaks.

Now we are not talking on the channel

- We will check the effect of adding external minimum resistance to the channel for only during Channel P2PRUNB compliance tests.

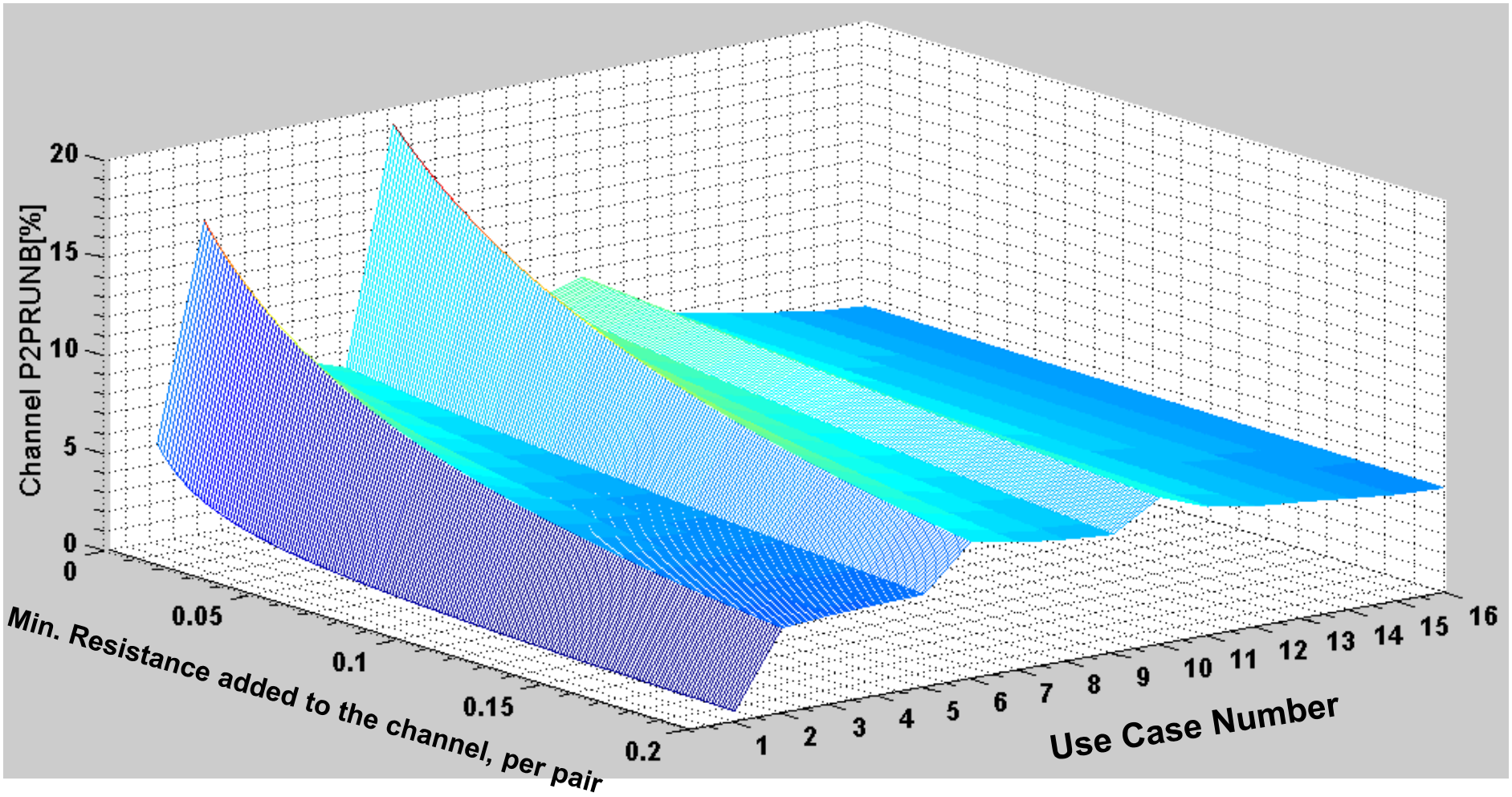
- It will give us a direction for possibilities how to specify Channel P2PRUNB with reasonable limits without worrying about P2PRUNB peaks that may not exist when the 4P channel is in the system i.e. connected to PSE and PD PIs.

Use case analysis results when adding external minimum resistance requirement per pair for filtering C_P2PRUNB peaks during: (a) During Channel Compliance test for C_P2PRUNB. (b) PSE and PD PI).



- The peaks are filtered when channel is tested with some minimum resistance that exists anyway in PSE and PD PIs. It is equivalent to testing the channel in some minimum system conditions and not just as a channel which is meaningless without minimum requirements from PSE and PD PIs.

The CP2PRUNB per use case, vs. external minimum pair resistance added to the channel.



- The additional resistance added, is for channel compliance test to "filter" use cases that may/will not happen in reality or we may recommend not to use etc.

Summary - 1

- In all use cases, 0.14Ω/m was used for cordage.
- All use cases was calculated with cable resistance per meter of:
  - (a) 0.0792Ω/m (CAT6A cable with AWG#23 wire).
  - (b) 0.098 Ω/m per standard.
  - (c) 0.117 Ω/m for maximum channel resistance of 12.5 Ω/100m with 4 connectors.
  - **For worst case analysis of P2PRUNB and maximum current we need to use only (a) and (c). (b) is not important for worst case analysis.**
  - **For the current work of Channel P2PRUN only (a) is important.**
- We got >9% P2PRUNB according the recommended use cases list. More over it can get to 19% if other use case combinations are tested which mean that we need more robust specification resulting with more requirements.
- It is proposed to aim for 7% (or a bit higher (TBD)) maximum so all margins will go to PSE and PD PI requirements. The question is how we do it after looking at the analysis results? (see next slide)

Summary - 2

- Proposed solutions to consider:
  - (1) Set higher spec limit e.g. 10% or 19% instead of 6% (TBD) as stated in the motion.
  - (2) Justify why the peaks can not be real per the proposed 4 use cases?
  - (3) To consider using use-case list base on total minimum cable resistance as function of the target maximum Channel P2PRUNB. (It may be part of the informative section?)
  - (4) To add minimum resistance to the channel tests to account for the minimum effect of PSE and PD PI on filtering CP2PRUNB peaks that will not be seen in actual work of the channel.
    - 0.1Ω or 0.2Ω (TBD) added to the channel per pair will do the work during channel compliance tests.
  - In addition to all proposals, it is worth to calculate Channel P2PRUB based on statistics, it may help to reduce peak numbers as well.

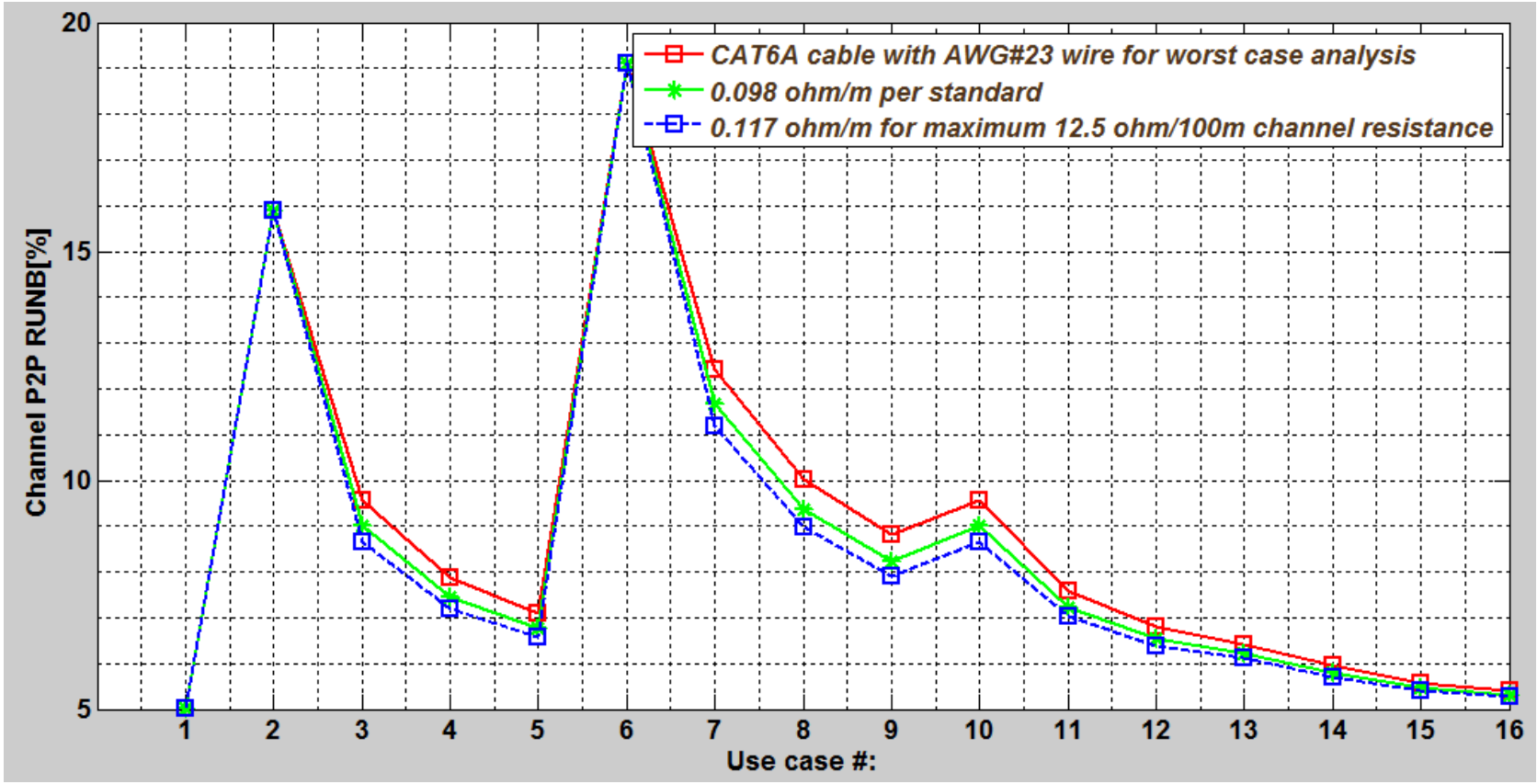
Questions for the group

- Why we need the 0.2Ω max definition?
- Response1(Wayne): Per connector standards resistance difference between pins is 0.05Ω max, 4 connectors ➔ 0.2Ω max.
- Response 2 (Yair): It make sense per slide 11: C_P2PRUNB vs. Channel P2P Resistance difference.
- Other inputs/response?

Q&A

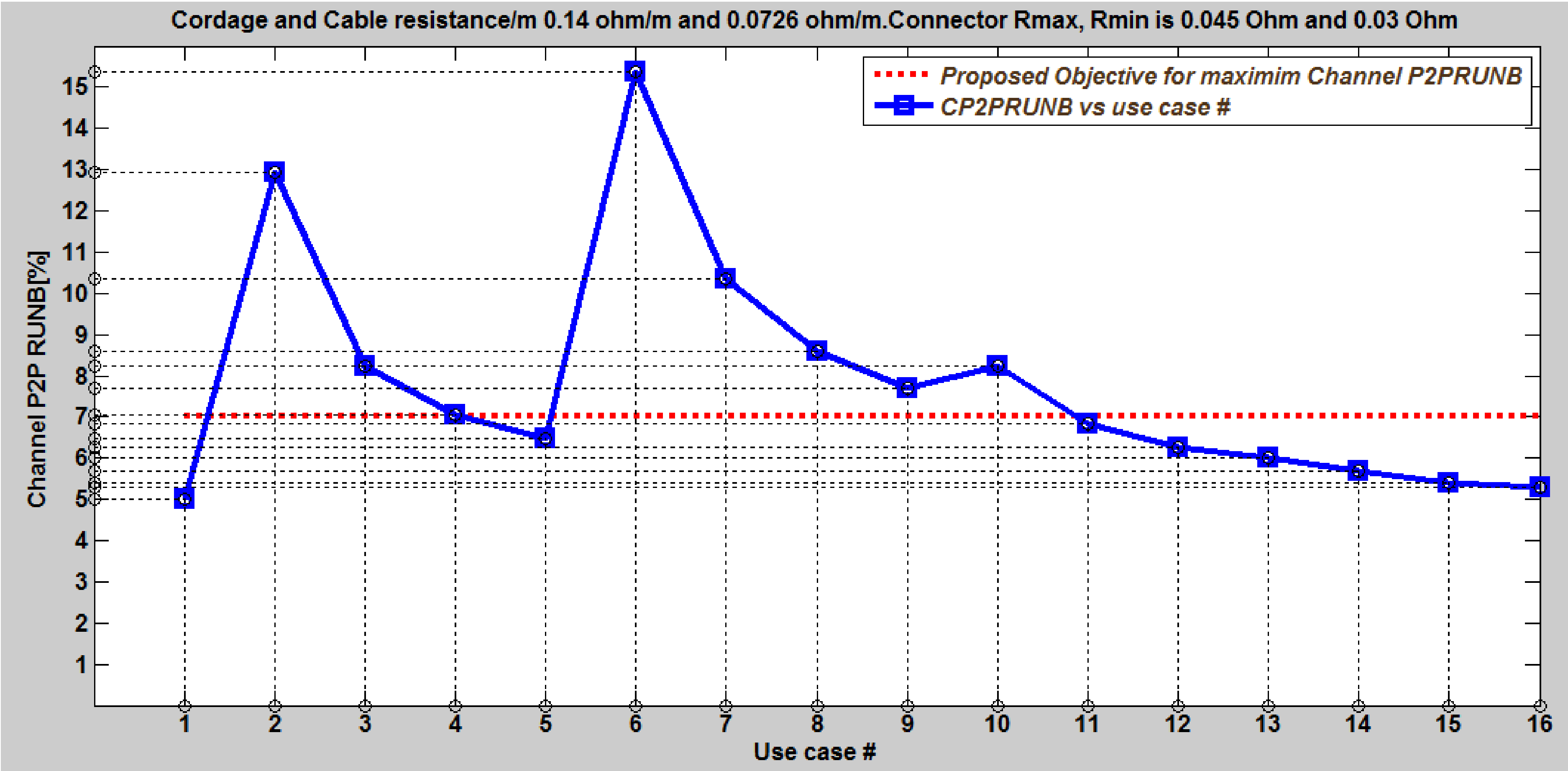
Backup slides

Channel P2PRUNB use cases vs. Cable resistance per meter.



- As can be seen, CAT 6A cable with AWG#23 need to be selected for worst case analysis.
  - When we analyze the end to end Channel P2PRUNB, the 0.117Ω/m will be used too for generating maximum channel current.
- Standard value 9.8Ω/100m is maximum value which is between the two other cables. As a result, it will not be used for the purpose of this work.

Use case analysis results with connector Rdiff=0.015Ω instead 0.02 Ω.



- Lower peaks received with using connector Rdiff=0.015Ω instead of 0.02 Ω compared to previous run.

	A								B				C	D	
%	[1,	2,	3,	4,	5,	6,	7,	8,	9,	10, 11, 12,	13,	14,	15,	16];	% Use Case Number
m =	[0,	1,	1,	1,	1,	2,	2,	2,	2,	4, 4, 4,	4	4,	4,	4];	% number of connectors
L1=	[0.15,	0.25,	0.5,	0.75,	1,	0.25,	0.5,	0.75,	1,	2, 4, 6,	8,	8,	9,	10];	% Cordage[m]
L2=	[0,	0,	1,	2,	3,	0,	1,	2,	3,	4, 8, 12,	15,	30,	60,	90];	% Cable[m]

Annex G3: Deciding on Channel components data

Connector data combinations that don't make sense.				
#	Rmax miliΩ	Rdif miliΩ	Rmin miliΩ	Notes
1	201	-	-	200 max, standard
2	-	51	-	50 max, standard
3	60	10	50	Field results, 20 max
4	61	-	-	Field results, 60 max
5	-	30	-	Field results, 20 max
6	60	50	10	Meets the standard however doesn't make sense to have 71.4% P2PRUNB.
7	60	20	40	OK
8	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 200miliOhm max and Rdiff=50miliOhm 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.

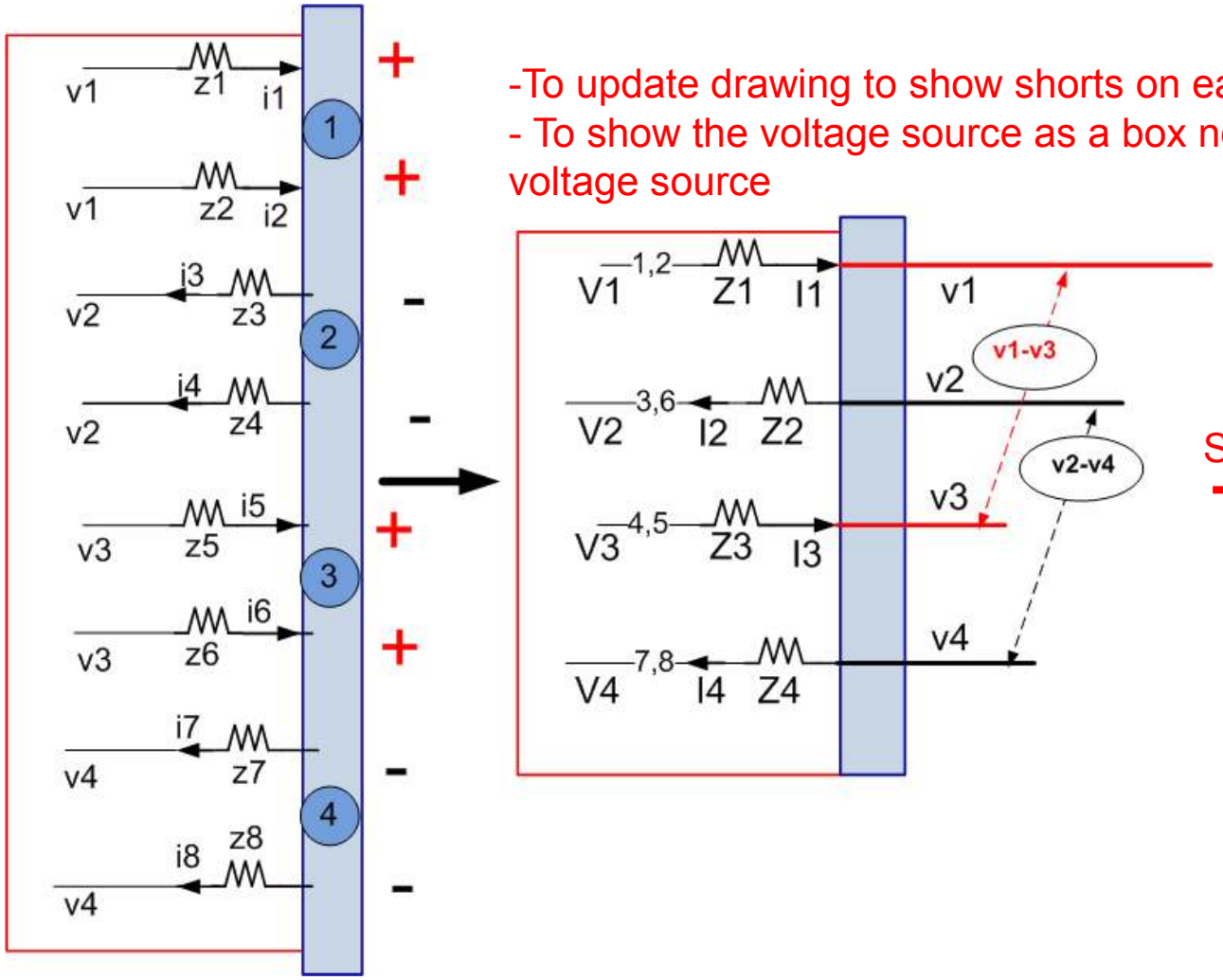
PSE PI Model

- **PSE PI affects the End to End Channel P2P resistance unbalance and as a result, the current unbalance.**
  - It is resulted from:
    - The PSE PI pair output resistance and
    - The PSE PI pair to pair output resistance unbalance and
    - The PSE PI pair to pair output open voltage difference.

- **The objectives are:**
  - How to specify the PI unbalance parameters?
  - How to test it

- **The difficulties to resolve:**
  - PSE PI unbalance parameter as stand alone parameter, has value to our research.
    - Different resistance, P2PRUNB and voltage unbalance will result with different results
    - Limiting resistance to minimum or maximum value doesn't make sense since it limits implementations e.g more dissipative ,less dissipative interfaces, where to locate control circuitry and how many pairs current to sense and control etc.
  - The value of this parameter became apparent when connected to a channel and to a PD with specified maximum resistance unbalance and current unbalanced. .

PSE PI model derivation–implementation independent approach -1



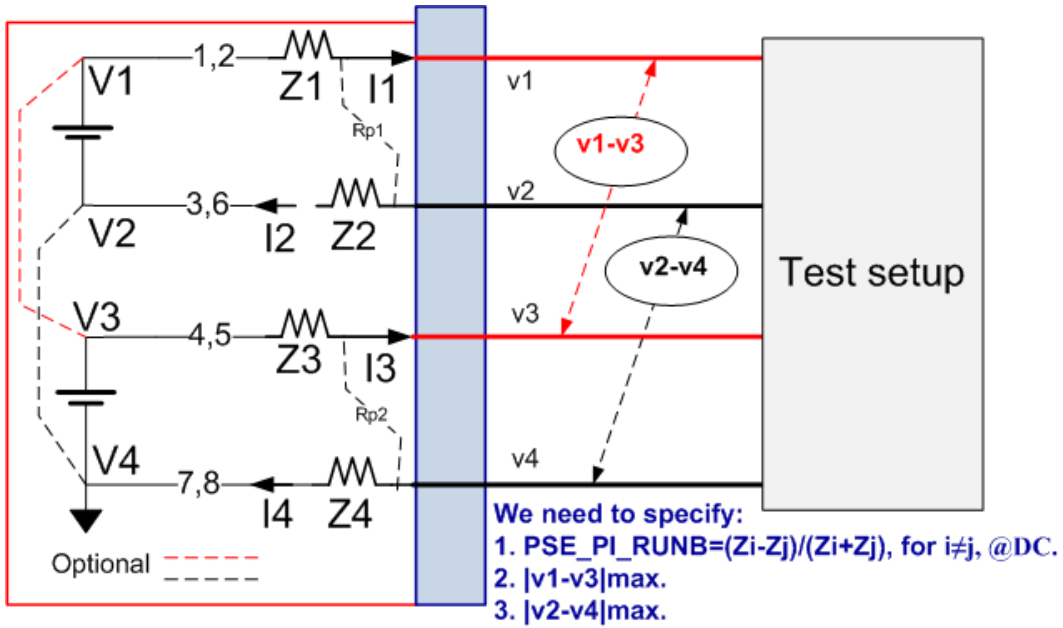
-To update drawing to show shorts on each pair output.
- To show the voltage source as a box not as a single or dual voltage source

Simplifying on next slide

Requirement Derivation – 1 (To update drawing per previous comments)

- By definition:
- I1=(V1-v1)/Z1 ➔ Z1=(V1-v1)/I1
- I2=(V2-v2)/Z2 ➔ Z2=(V2-v2)/I2
- I3=(V3-v3)/Z3 ➔ Z3=(V3-v3)/I3
- I4=(V4-v4)/Z4 ➔ Z4=(V4-v4)/I4

- By definition:
- P2P PSE PI Zunbalance=



In one typical application: V1=V3, V2=V4=0.
As a result, open load voltages: v1-v3➔ 0, v2-v4 ➔ 0

$$= \frac{Z_i - Z_j}{Z_i + Z_j} = \frac{\frac{V_i}{I_i} - \frac{V_j}{I_j}}{\frac{V_i}{I_i} + \frac{V_j}{I_j}} = TBD\max$$

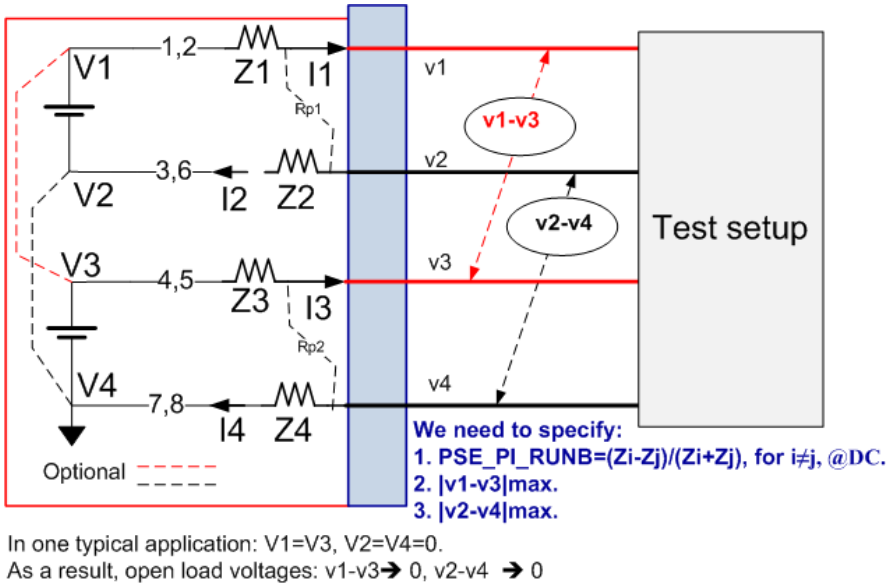
Between any two pairs i≠j .

Requirement Derivation – 2 (To update drawing per previous comments)

- P2P PSE PI Zunbalance=

$$= \frac{Z_i - Z_j}{Z_i + Z_j} = \frac{\frac{V_i - v}{I_i} - \frac{V_j - v}{I_j}}{\frac{V_i - v}{I_i} + \frac{V_j - v}{I_j}} = TBD \max$$

Between any two pairs i≠j.
Since we need Z in DC ➔ Z➔R



In one typical application: V1=V3, V2=V4=0.
As a result, open load voltages: v1-v3➔ 0, v2-v4 ➔ 0

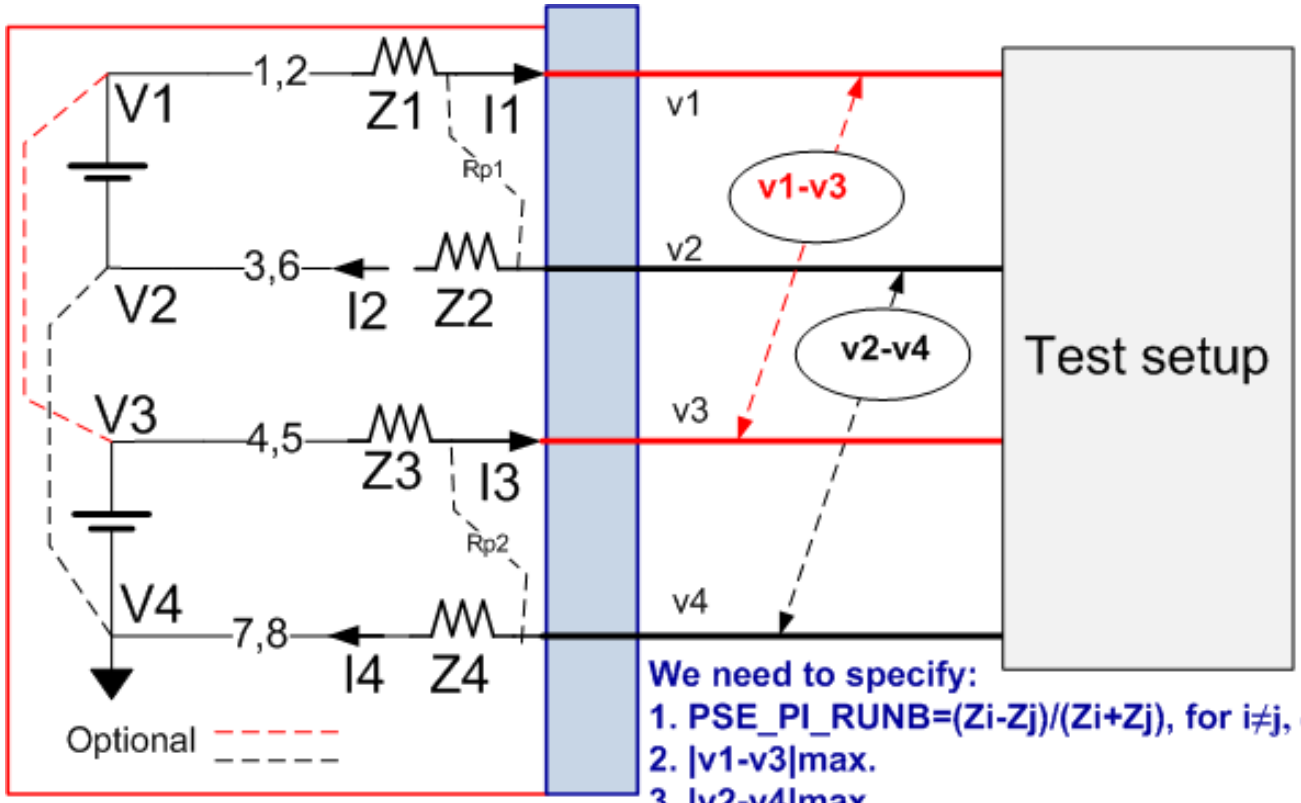
$$(1)\ \frac{Z_i - Z_j}{Z_i + Z_j} = \frac{R_i - R_j}{R_i + R_j} = P2PRUNB \max,$$

$$(2)\ \left|v_1 - v_3\right| < TBD$$

$$(3)\ \left|v_2 - v_4\right| < TBD$$

Ri is function of Vi/Ii which addresses non linear circuitry at worst case unbalance operating point defined by PSE vendor.

PSE PI P2P model concept -3 (update drawing)



In one typical application: V1=V3, V2=V4=0.
As a result, open load voltages: v1-v3➔ 0, v2-v4 ➔ 0

- In the test setup, it is possible to find P2PRUNB by measuring currents at PSE normal powering state. But this is test setup implementation issue and not part of the specification. The spec defines Voltage and Resistance to maintain implementation independent specifications.

PSE PI P2P model concept -4 (To Update)

- Part A:
- Specifying PSE P2P_R_UNB and PSE_P2P Voltage Difference
  - PSE P2P Voltage difference at no load condition.
    - Voltage difference between the two positive voltage rails
    - Voltage difference between the two negative voltage rails
  - P2P_R_UNB, will be single number, maximum number.

- Part B:
- Defining test model and test conditions.

- Ad hoc response: TBD

PSE PI P2P model concept -5 (To update how to test it)

- Proposed base line text:
- **33.1.4.xx Type 3 and Type 4 PSE PI Requirement for Pair to Pair unbalance**
- 4P pair operation requires the specification of resistance unbalance between each two pairs of the PSE PI, not greater than TBD milliOhms or TBD% which ever is greater. The resistance unbalance requirements between each two pairs of the PSE PI shall be met for a maximum voltage difference TBDmVdc between the two positive pairs and between the two negative pairs. The Resistance unbalance between the PSE PI pairs is a measure of the difference of resistance of the common mode pairs of conductors used for power delivery. See figure TBD for PSE PI model. PSE PI pair to pair resistance unbalance is defined by equation 33-1.XX:

- **Insert Equation here that ties Resistance and voltage unbalance together or other description TBD.**
- Equation TBD 33-1.xxx

Where:

Rpse_max is the sum of PSE PI pair elements with highest common mode resistance.

Rpse_min is the sum of PSE PI pair elements with lowest common mode resistance

Common mode resistance is the resistance of the elements over each PSE PI wires in the PI pair connected in parallel.

PD PI P2P model concept

- TBD
- Looking for volunteers to do it.

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.

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 % Runbal = 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 % Runbal = 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.

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

where:

R_1 is the DC resistance of conductor 1.

R_2 is the DC resistance of conductor 2.

Annex A2 - 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.

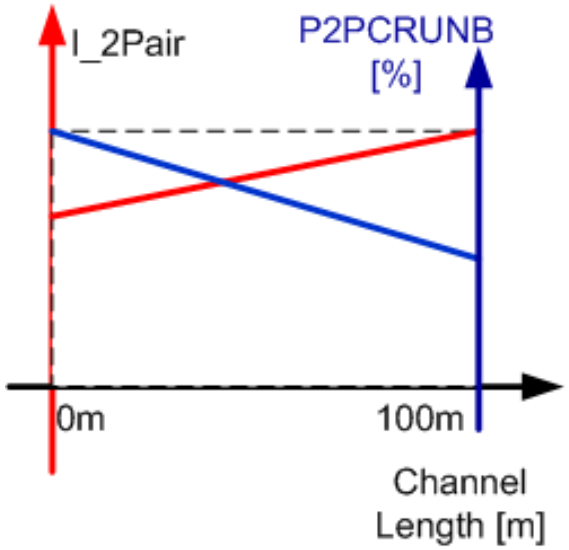
6.8.2 DC resistance unbalance

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.

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

- To discuss the advantages that PD constant Power Sink allows us.
- Background material for considering:
  - 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 is not an issue.**
  - 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.



Answer:
In order to answer the question we need to check both data sets 1 and 2 in the worst case data base.

Illustration of the behavior.
(The curve is not linear. It is just describing the trend.)

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

- 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 were 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.

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

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 match diode bridges, significantly reduces P2PRUNB and as a result, the current unbalance

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 mOhms resistance and 50 mOhms resistance unbalance between any conductor. They actually have much less resistance.
- <u>Yair notes:</u>
- 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.
- 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 R_{LLCR-B}
- Low Level Contact Resistance (LLCR-Bulk) consists of four components
- Plug Conductor Resistance R_{CR}
- Plug Blade/Conductor Contact Resistance R_{PBCR}
- Plug Blade/Jack Wire Contact Resistance or TRUE LLCR R_{CRTRUE}
- Jack Wire Resistance R_{JWR}
- $R_{LLCR-B} = R_{CR} + R_{PBCR} + R_{CRTRUE} + R_{JWR}$
- However, it is easy to measure and subtract $(R_{CR} + R_{PBCR})$ from the Bulk so many connector vendors use the Contact resistance $(R_{CRTRUE} + R_{JWR})$
- **A typical differential between two types measurements is less than 20 milliohm**
- The reason is that the $(R_{CRTRUE} + R_{JWR})$ 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: Microsemi

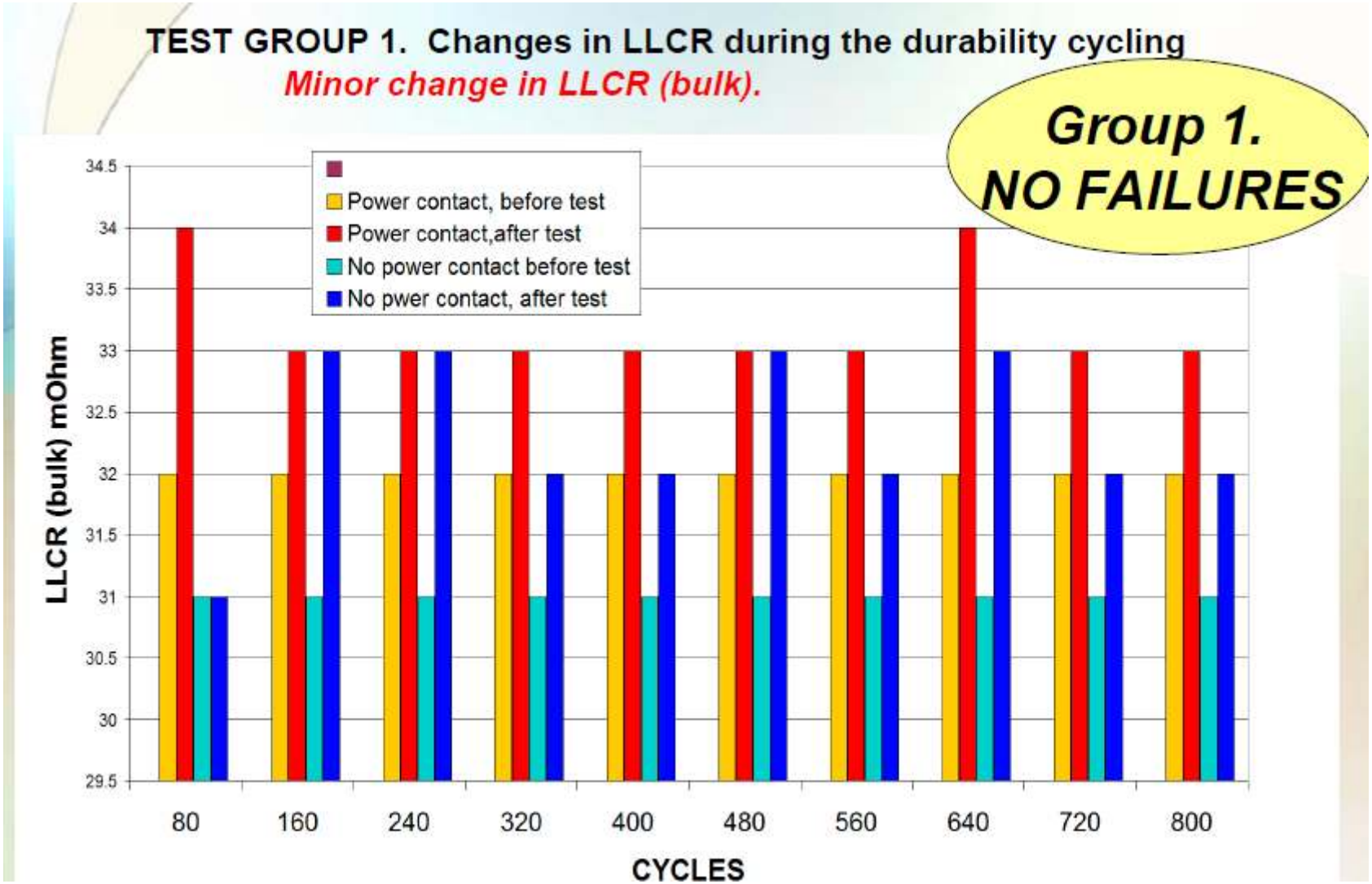
	Vendor	"Contact resistance" per datasheet
CAT6	CSAK	30 miliOhm max ,Jack only[1]
CAT6	CTK	35 miliOhm max ,Jack only[1]
CAT6	CSCE	30 miliOhm max ,Jack only[1]

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

Annex E4 - Connector data – Source BEL

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

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

Annex E6: Connectors test data

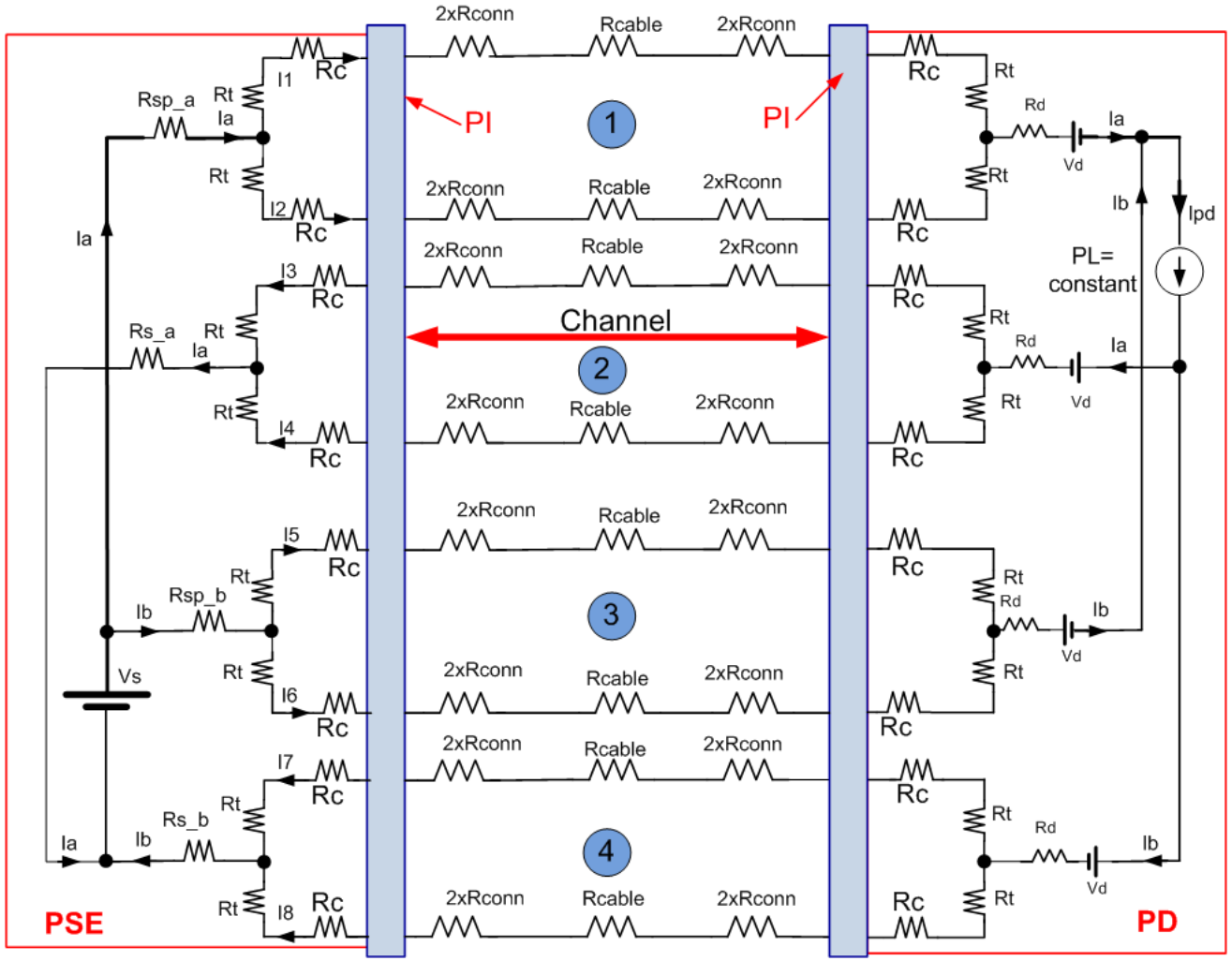
http://www.vtiinstruments.com/Catalog/Technotes/RJ-45_Excels_For_Stria_Gage_Connection.pdf

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

Annex F – End to End P2P Resistance Unbalance Model

General Channel Model and its components that we have used.

Adhoc: OK



Notes for the general Model:

1. Adding resistors on positive path for general model (Rsp_a and Rsp_b). It can be set to zero or >zero pending the case being investigated.
2. Adding equipment connectors per Wayne's comment. So total end to end channel connectors is 6 max.
3. The formal channel definition is marked in red arrow.
4. Our work addresses also the internal application resistance of known components that are used

Annex J1-Acronyms used in the ad-hoc activity

Adhoc: OK

- **(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.

Annex J2-Acronyms used in the ad-hoc activity

Adhoc: OK

- **(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.

Annex L: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.

Last meeting material

Meeting # 6 Attendees (Thursday May 15, 2014)

- Gaoling Zou / Maxim
- Christian BEIA / ST
- David Tremblay / HP
- Yair Darshan / Microsemi
- George Zimmerman/ CME Consulting, Affiliations: Commscope & Aquantia
- Peter Johnson / Sifos
- Rick Frosch / Phihong
- Yan Zhuang / Huawei
- Larsen, Wayne / Commscope
- Jeff Heath / LT
- Dave Dwelley / LT
- Fred Schindler / Seen Simply
- David Abramson / TI
- Rimboim Pavlik / Microsemi
- Victor Renteria / BEL
- Dave Dwelley / LT
- Heat Stuart / LT
- Sterling Vaden /
- Fred Dawson / duPont
- Shahar Feldman / Microsemi
- Wendt, Matthias / Philips
- Picard Jean / TI
- Lennart Yseboodt / Philips

Adhoc report May 15, 2014 Norfolk VA.

- 18 attendees
- Topics discussed:
  - How to handle PSE PI, PD PI Pair to Pair unbalance parameters and Channel P2RUNB as function of temperature?
    - Adhoc response:
    - Use PSE PI, PD PI pair to pair Unbalance parameters and Channel P2PRUNB that was calculated at 20°C (or pick a number at other temperature).
    - 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.
  - Two motions to specify Channel P2PRUNB and its base line text
    - Adhoc proposed the following two motions:
- Motion #1:
  - Move that 802.3bt specify the Channel Pair to Pair resistance unbalance for operating 4P systems

Motion #2. Motion to add the following text to clause 33 after 33.1.4.2.

- **33.1.4.3 Type 3 and Type 4 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 equation 33-1.1:
- $$\left\{\frac{\left(R_{ch\_\max}-R_{ch\_\min}\right)}{\left(R_{ch\_\max}+R_{ch\_\min}\right)}\times 100\right\}_{\%}$$ 33-1.1

Where:

Rch_max is the sum of channel pair elements with highest common mode resistance.

Rch_min is the sum of channel pair elements with lowest common mode resistance

Common mode resistance is the resistance of the two wires in a pair (including connectors), connected in parallel.

Open issues - 1

- Proposal for motion for specifying PSE PI Pair to Pair Output resistance unbalance and pair to pair output voltage unbalance during Power ON state for operating 4P systems.
  - Waiting for completion of test model.
  - Test model was presented see Annex E, inputs were received:
    - To consider changing voltage source load with current load

- What is the PD load current on Mode A and Mode B in which below that current, P2P requirements can be ignored.
  - Responses:

    (1) Below 25W no need for P2PRUNB requirements

    (2) We may care below 25W to optimize transformers for 4W loads

    (3) *Response (2) checked, negligible difference between Type 1 and 2, probably no incentive for special magnetics for below Type 1 power. See annex D shown in previous meeting.*

Open issues - 2

- Worst case Data Base
  - Comments:
    - Replace connector contact resistor with Connector resistance.
    - Yair to send Jeff connector test results.
    - To check results with connector resistance per standard with Rcmax=200miliOhm and 50miliOhms difference.
      - Response: No value. We are looking for worse case.
    - Connector resistance: 10miliom minimum – 60miliohm max.
      - Sterling to supply information for connector resistivity.
  - To check CAT6A cable resistance per the actual cable length
    - Cabling spec requires CAT6A resistance for 100m will be as defined for CAT5/e. In reality it will be lower for AWG23. To verify.
  - Diode bridges are worst case components compared to no diode or active diode bridge.
  - Clarify title of the two column use cases

Open issues - 3

- Test models for PD and baseline text:
  - Not started yet.

Adhoc meeting May 15, 2014, Norfolk VA

- Agenda
- Concept of how to address P2P unbalance as function of temperature (20 minutes)
- Discussing proposed motions from the adhoc (30 minutes)
- The PD power limits in which P2P requirements are not relevant.
- New Presentations? (10 minutes)

Adhoc report -1

- 5 adhoc meetings since March 2014 meeting
- 15 attendees in average each meeting
- See adhoc recommendations for:
  - How to handle temperature: See slide 19.
  - Discussion and straw poll slides 14-18.
- Agreement on which parameters need to be defined in the standard (PSE PI, PD PI and Channel P2P unbalance related parameters: Slide 8. Discussion slides 7-8.
- Agreement on terms and acronyms to be used in adhoc discussions: slides 7-8
- Motions drafts are ready for:
  - Channel P2P Resistance Unbalance are ready: Slides 10 and 11
  - PSE PI P2PRUNB and PSE P2P Voltage Difference: Slide 12
- Agreement on 4 channel length scenario to be calculate worst-case: Slide 24-25
  - Need to specify conditions for compliance based on cabling performance suggested by Wayne. Need farther discussion (9.38 ohms and 14 ohms data on slide 25)

Adhoc report -2

- Worst Case data base was updated (2,4,6 connectors, different channel lengths: Slide 27.
  - Simulation results: Slide 28-31.
  - Conclusions: Slide 32 to be discussed.

- Motions need to be closed soon
  - PD PI P2P unbalance requirements
  - In which temperature we will calculate spec P2P unbalance parameters? See slide 21

- Open issues
  - What is the PD power/current that below it, P2P requirements are not important?
    - Good discussions. Yair & Christian (and Ken?) will work on proposal.
- More relevant material and discussions on the rest of the slides

Meeting # 5 Attendees (Thursday May 8, 2014)

- Ronald Tellas / Panduit
- Gaoling Zou / Maxim
- Brian Buckmeier / BEL
- Christian BEIA / ST
- Steinke, Stephan / Molex
- Koussalya Balasubramanian / Cisco
- David Tremblay / HP
- Yair Darshan / Microsemi
- George Zimmerman/ CME Consulting,
  Affiliations: Commscope & Aquantia
- Ken Bennett / Sifos
- Rick Frosch / Phihong
- Yan Zhuang / Huawei

Meeting # 3 and # 4 Attendees (April 24, May 1, 2014)

Meeting # 3

- Yan Zhuang / Huawei
- Ronald Tellas / Panduit
- Larsen, Wayne / Commscope
- Jeff Heath / LT
- Brian Buckmeier / BEL
- Rick Frosch / Phihong
- Christian BEIA / ST
- Leonard Stencel / Bourns
- Fred Schindler / Seen Simply
- Koussalya Balasubramanian / Cisco
- David Tremblay / HP
- David Abramson / TI
- Rimboim Pavlik / Microsemi
- Yair Darshan / Microsemi
- Ken Bennett / Sifos
- Victor Renteria / BEL
- George Zimmerman/ CME Consulting, Affiliations: Commscope & Aquantia

Meeting # 4

- Steinke, Stephan / Molex
- Gaoling Zou / Maxim
- Jean Picard / TI
- Larsen, Wayne / Commscope
- Jeff Heath / LT
- Brian Buckmeier / BEL
- Christian BEIA / ST
- Koussalya Balasubramanian / Cisco
- David Abramson / TI
- Yair Darshan / Microsemi
- Ken Bennett / Sifos
- Wendt, Matthias / Philips

Proposed Agenda, Meeting #4, May 1, 2014.

- Introduction

- Planes for today, May 8, 2014
  - Introduction (1 minute)
  - Approving slide 6 and 7 updates (5 minutes)
  - Finalizing Motion 1 and/or 1.1. (10 minutes)
  - Approving slide 19 proposal (temperature issue) (10 minutes)
  - Christian Presentation – Data results from updated data base model (10m)
  - Discussion on other proposed motions. (10 minutes)

  - Discuss proposed baseline text (Moved to IEEE meeting next week)

Introduction

- The purpose of this ad-hoc is to recommend the Task-Force for what is needed to specify the channel pair to pair resistance unbalance while considering not only the formal channel components (Cable and Connector) but also the Power Interface (PI) components at both ends of the 4P PoE system.

- Patent Policy

-Please read the Patent Policy slides at http://www.ieee802.org/3/patent.html prior the meeting.

Acronyms used in the ad-hoc activity (1)

Adhoc: OK

- **(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 known 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.

Acronyms used in the ad-hoc activity (2)

Adhoc: OK

- **(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.

Proposal text for Motion (1) (From meeting #4). See next slides: Breaking to separate motions

- Move that 802.3bt specify the following parameters for operating 4P systems during Power ON state:

a) PSE PI Pair to Pair resistance unbalance and pair to pair voltage unbalance. (Adhoc-done)

(The model is the same, two voltage sources V1, V2 or single voltage source in the model is implementation issue. What we care is the voltage difference measured at the PI (max|V1-V2|). (Group response: ??)

b1) Specify test circuit/procedure for specifying PD PI Pair to Pair resistance unbalance (For this motion, a2 on separate motion after doing some work).

b2) PD PI Pair to Pair resistance unbalance and voltage unbalance.

(For next meeting to present PD test circuit for PD PI P2PRUNB)

c) Channel Pair to Pair resistance unbalance (Adhoc-done)

The above parameters will be analyzed and specified based on the End to End Channel Pair to Pair Resistance Unbalance model as proposed by the ad-hoc. See slide N, link..

A.I.: Jeff, Jean and interested parties for closing item b. Please prepare presentation with your comments and Suggested remedies to be discuss over the reflector and we help with our inputs.

Proposal text for Motion (1)

Adhoc: OK

- Motion to require that the 802.3bt Task force will specify the requirements for Channel Pair to Pair resistance unbalance for operating 4P systems.
- Meeting #5:Adhoc-done.

- (Better language suggested by George, send during the meeting)
- Move that 802.3bt specify the Channel Pair to Pair resistance unbalance for operating 4P systems
- Adhoc ok: 15/5/2014

Proposal text for Motion (1.1) (ad-hoc. Move Yair, 2nd :Christian)

Adhoc: OK 15/4/2014

Motion to add the following text to clause 33 after 33.1.4.2.

- **33.1.4.3 Type 3 and Type 4 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 equation 33-1.1:
- 33-1.1

$$\left\{ \frac{\left(R_{ch\_\max} - R_{ch\_\min}\right)}{\left(R_{ch\_\max} + R_{ch\_\min}\right)} \times 100 \right\}_{\%}$$

- Where
- Rch_max is the sum of channel pair elements with highest common mode resistance.
- Rch_min is the sum of channel pair elements with lowest common mode resistance
- Common mode resistance is the resistance of the two wires in a pair (including connectors), connected in parallel.

Proposal text for Motion (2)

- Move that 802.3bt specify PSE PI Pair to Pair Output resistance unbalance and pair to pair output voltage unbalance during Power ON state for operating 4P systems.

The above was item a in meeting #4.

Adhoc-done

(The model is the same, two voltage sources V1, V2 or single voltage source in the model is implementation issue. What we care is the voltage difference measured at the PI (max|V1-V2|). (Group response: ??)

The above parameters will be analyzed and specified based on the End to End Channel Pair to Pair Resistance Unbalance model as proposed by the ad-hoc. See slide N, link..

A.I.: Jeff, Jean and interested parties for closing item b. Please prepare presentation with your comments and Suggested remedies to be discuss over the reflector and we help with our inputs.

Proposal text for Motion (4)

Motion to add the following text to informative section.

Cable Requirement for Pair to Pair Resistance unbalance

4 pair operation, requires the additional specification of resistance unbalance between each two pairs of the cable. The cable pair to pair resistance unbalance was studied and found to be 5% or less. Resistance unbalance between the pairs is a measure of the difference of resistance of the common mode pairs of conductors used for power delivery. Cable pair to pair resistance unbalance is defined by equation 33-1.1:

$$\left\{ \frac{\left(R_{cm\_\max} - R_{cm\_\min} \right)}{\left({}_{cm\_\max} + R_{cm\_\min} \right)} \times 100 \right\}_{\%} \qquad \text{33-1.1}$$

where

*Rcm*_max is the pair with highest common mode resistance.

*Rcm*_min is the pair with lowest common mode resistance.

Common mode resistance is the resistance of the two wires in a pair, connected in parallel.

Issues to be discussed in #3/4 meeting 24/April/ May 1, 2014 (1)

- How to address temperature effect on P2PCRUNB?
  - We agree that we don't care of high temperature since it works for us (high temperature higher resistance lower P2PCRUNB)
  - So the question is narrowed to below room temperature (20-24°C)?.

  Yair response:

  1. All parameters in the standard are tested for compliance at room temperature.

  System and component vendors are responsible to design the parts/system to meet their spec over their spec of operating temperature range.

  1. We can study and supply the guidelines/equations in informative annex to help decide what to do in temperatures below room temperature but it can't be part of the standard. (not high priority)

  Please see what IEEE802.3-2012 says about this topic:

33.7.7 Temperature and humidity

The PD and PSE powered cabling link segment is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling. Specific requirements and values for these parameters are beyond the scope of this standard.

Recommendation: To focus on results at room temperature for the baseline.

Anything else could be:

a) left for the informative section of the standard

b) per 33.7.7

Issues to be discussed in #3/4 meeting 24/April/ May 1, 2014 (2)

Please see what IEEE802.3-2012 says about this topic:

33.7.7 Temperature and humidity

The PD and PSE powered cabling link segment is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling. Specific requirements and values for these parameters are beyond the scope of this standard.

Yair's Recommendation: To focus on results at room temperature for the baseline.

Anything else could be:

a) left for the informative section of the standard

b) per 33.7.7

--- DISCUSSION ----------

(1) Yair: Define at 25degC and the rest put in the informative section

(2) Jeff/Wayne: Mandatory section we need to define at 25degC and (–TBD)

(3) Jeff: To define one number which is the worst case and will include low temperature (similar to a worst case of insertion loss at high temp.)

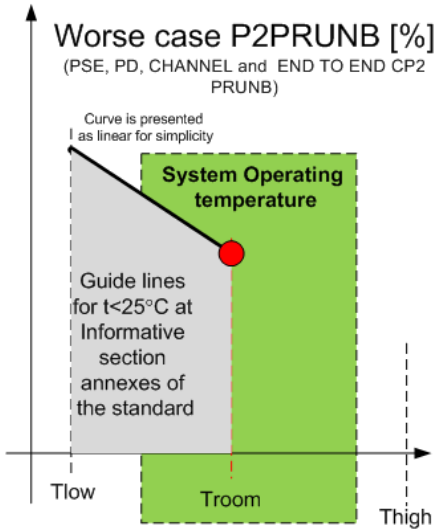
Yair: (May 1, 2014) During reflector discussion we saw that insertion loss is define at 20degC and at higher temperature derating is allowed by using shorter cable which means that insertion loss is not specified for worst case operating temperature (ANSI/TIA 568-C.2 Annex G Clause 6.4.7.

-Christian: Testing cost issues in (2)

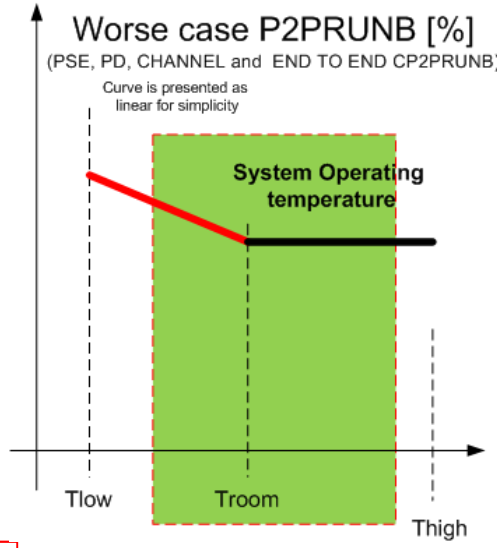
–Ad hoc agree to vote by mail and result will be our recommendation to task force to move forward.

Straw poll material was sent. See details next slides.

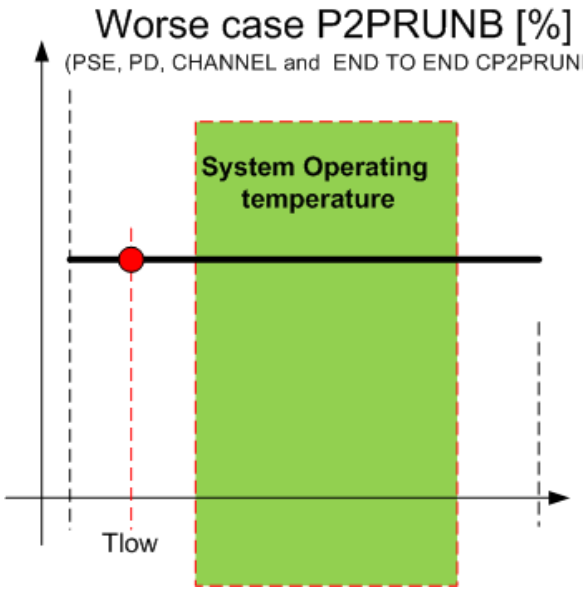
Options for CP2PRUNB vs Operating temperature



- Option1
- Defining single point at e.g. Troom=20°C and:
- (a) add information for T<Troom at the informative section **and/or**
- **(b)** follow Clause 33.7.7
- No Over Design since system vendor responsible to design their system to meet requirements.
- It may increase interoperability concerns???. This concern is valid in all options whenever there is no single worst case number that covers Tlow of 100% of use cases.
  - The remedy for it is specify the requirement and it is up to box designer to meet it over its operating temperature range.



- Option 2
- Defining curve from Tlow to Troom
- Tlow need to cover most of applications known to us.
- Prevents over design. (Allow system vendor to design for its operating temperature range)
- Tlow need to be investigated
- See interoperability concerns discussion in option 1



- Option 3
- Defining single point at Tlow which will be single worst case point.
- Tlow need to cover most of the applications min. temperature.
- This option may be overdesign for equipment with T>Tlow. (To investigate)
- Equipment that need to work at T<Tlow shall follow Clause 33.7.7
- See interoperability concerns discussion in option 1

Straw Poll Results

Adhoc: OK

- Select one option only.
- If possible, add rational for your selection, any concerns etc., new suggestions in the notes column.

	Options			Notes
Name	1	2	3	
Yair Darshan / Microsemi	x			Without having the informative part and using clause 33.7.7 instead (Option 1b or name it option 4)
Fred Schindler / Seen Simply			x	
Ken Bennett / Sifos	x			
Yseboodt, Lennart / Philips	x			
Jeff Heat / LT				Accept suggested proposal for option 4 (see mail) which is option 1b (to ask for email confirmation).
Wendt, Matthias / Philips	x			
Dave Dwelley / LT	x			
Rimboim Pavlik / MSCC	x			
Christian Beia / ST	x			Without having the informative part and using clause 33.7.7 instead (Option 1b or name it option 4)
Belopolsky Yakov / BEL	x			
Gaoling Zou / Maxim	x			

Note: **Option 4** language from reflector email exchange (short summary): "use the P2PRUNB for PSE, PD and Channel number that was calculated (total sum=26.2%(TBD)) at room temperature (or pick number at other temperature), set it as THE number to meet without saying at what temperature it is, and 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. This option is covered by 1b.

Issues to be discussed in #3/4 meeting 24/April/ May 1, 2014 (3)

- Results of the straw poll
- 9 for option 1 (7 for 1a or 1b, 2 for 1b)
- 1 for option 3
- 1 for 1b ?? (waiting for confirmation)

- Additional information:
- Base on reflector discussion it is summarized to:
- Use the P2PRUNB for PSE, PD and Channel number that was calculating (total sum=26.2%) at room temperature (or pick number at other temperature), set it as THE number to meet without saying at what temperature it is, and 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.
- This summary is covered by options 1b and 3.

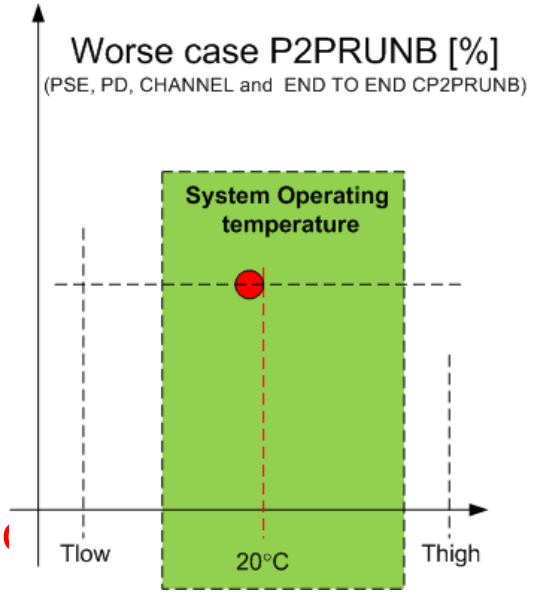
  (Option 1 says room temperature or other temperature
- Option 3 says lower temperature than room temperature)

Ad-hoc proposal for the Task force

Adhoc: OK

- To follow the following proposed concept:
- Use PSE PI, PD PI and Channel UNB parameters that was calculated 20°C (or pick a number at other temperature).
- 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.
- Add accepts this proposal. May 15, 2014, Norfolk VA.

- Note: Channel P2PUNB is not affected by temperature is fixed



- Ad-hoc response: Agree.
- Next question will be, OK, what is that temperature p

Next question will be, OK, what is that temperature point?

- Questions
  - Is it correct to assume that for Environment A all system parts (Switch, PSE , PD cablings etc.) are at near room temperature?
  - If bad ventilation it will be going up?
  - Is there situations that for Environment A temperature will be near zero degC? Or stay around 20°C and above?

- Proposals
  - A) T= 20°C
  - B) T= 0°C
  - C) The Typical minimum temperature at enterprise environment, Environment A or equivalent
  - Ad-hoc response:
  - Yair: It looks that the answer is not important. If we specify a number. The PSE vendor and PD vendor will have to meet it for the entire system op temperature.

Issues to be discussed in #3 meeting April 24, 2014

- We need to define the PD load current on Mode A and Mode B in which below that current, P2P requirements can be ignored.
  - Example: if Mode A requires 350mA and Mode B require 113mA than P2P discussion is not relevant to this case.
- We agree that wee need to investigate it and address it.
  - Dave Dwelley made a comment about this issue which I didn't record.
  - Dave please send us your comment about this topic to be recorded and addressed.
  - No response. Removing this item from the agenda.
- **Proposals:**

(1) For PD total power below 25.5 Watts (that ensures pair current <600mA/pair), for any pair, meeting Channel Pair to Pair Resistance Unbalance is not required.

Yair: I agree with it. It helps for low cost PDs.

Adhoc response:

(2) For PD total power below TBD Watts that ensures pair current <600mA/pair, for any pair, meeting Channel Pair to Pair Resistance Unbalance is not required.

- (To discuss this face to face at May meeting.)
- What is the TBD number ? Next question.

What is the PD power/current where P2P requirements for a given P2P limit numbers are not changing system/components performance as it was not important for Type 2 systems?

- To be discuss during face to face meeting at Norfolk VA.
- Analytical results showing:
  - It_max=1.2A - P2PCRUNB*It. (The decision break point of Type 3 systems)
  - If It>Itmax, CP2PRUNB requirements shall be met for Type 3 and up systems.
  - If It<Itmax for Type 3 system, CP2PRUNB requirements are not required to be met.
- It_max s total PD current over all 4 pairs that is the P2PRUNB requirements are not affecting 4P operation similar to that it is not affecting 2P operation.

- Example: It_max=1.2A-0.262*1.2A=0.885A.
- 4P PD with a power level that requires maximum 0.885A total on all 4 pairs, doesn't need to be concern by P2P requirements. To work with adhoc if this is true statement.

Issues to be discussed in #3 meeting April 24, 2014

- (1) What is the minimum resistance in the channel that above it, we don't care? In other words, what is the minimum resistance in the PD that makes the diodes, connectors, transformers less important in the total channel P2PRUNB?
- (2) Do we need to specify minimum length?.

  Yair Response: we will know the answer based on (1) and running simulations/calculations per Wayne proposal for 4 channel length options.
- What will be minimum Ω/m for patch cords?
- Yair: I suggest to use the 9.38Ω/100m (93.8mΩ/m as max value and 5% less as the minimum value since patch cords normally need to be flexible than the horizontal cable so their wire diameter is smaller that horizontal cables such as CAT6A.
- Yair: I remember that Wayne said that the 0.15m channel length option is with 14 Ω/100m.

  -Wayne to confirm.

  -Wayne: What is your opinion to the above proposal?
- **Wayne response: See next slide.**

Issues to be discussed in #3 meeting April 24, 2014

- **Wayne response:** Thinking about possible use cases, it seems to me it is possible, someone may provide PSE equipment in a rack and PD equipment in the rack unit below it in the same rack. If we agree this is a possible use case, it could be connected by a patch cord 0.15 m long. Patch cords have a de-rated DC resistance requirement of 14Ω/100m, as Yair states. In finding the absolute minimum, someone could also use un-de-rated patch cord material.
- In any case, for this use case, I think the DC resistance, and the DC resistance unbalance, of the cabling system, is low enough that the equipment MDI, and other elements of the equipment circuit, will dominate.
- Yair response: Yes, in very short channel the equipment MDI, and other elements of the equipment circuit, will dominate i.e. it will be almost similar to the PSE PI and PD PI P2PRUNB that we agree that we need to define anyway. I will simulate results with 0.15m cable with 0.14 Ω/m when simulation only PSE and PD PIs.
- Group OK. 0.15m minimum. Follow Wayne proposal for 4 different channel length for calculation/analysis.

Adhoc: OK

Issues to be discussed in #3 meeting April 24, 2014

- See inputs from Pete Johnson and Yair Darshan response regarding the method of calculating Runb at Annex A1. (If you disagree send email and we will discuss in next meeting. Other wise we agree to this response)
- Adhoc agrees (no responses, removed from the agenda).
- ----
- In IEEE802.3 March 2014 meeting , Jeff Heat had a comment for the PD model. Jeff to send the details of it to the ad-hoc if you want us to discuss it. (Jeff to send data and Dave response to next meeting).
- No response. Removing this item from the agenda.

- See new data for P2PCRUN with out limiting the current to 600mA /pair with 6 connectors (See Christian presentation)

- See previous data presented again on Annex C on issues reminding us why we are working on P2P issues and what was the concerns that we had to addressed.

Updated Worst Case Data Base

Adhoc: OK

Table 1	CAT5E Cable resistivity	CAT6/A Cable resistivity
Cable resistivity	117mOhm/m	66mOhm/m
Transformer winding resistance	120mOhm min, 130mOhm max	120mOhm min, 130mOhm max
2-connector Contact resistance	15mOhm min, 30mOhm max	15mOhm min, 30mOhm max
4-connector Contact resistance	30mOhm min, 60mOhm max	30mOhm min, 60mOhm max
6-connector Contact resistance*	45mOhm min, 90mOhm max	45mOhm min, 90mOhm max
Diode bridge	0.39V+0.25Ohm*Id min; 0.53V+0.25Ohm*id max	0.39V+0.25Ohm*Id min; 0.53V+0.25Ohm*id max
PSE output resistance (e.g. Rs_a/b=Rsense+Rdson)	0.25+0.1 Ohm min 0.25+0.2 Ohm max	0.1+0.05 Ohm min 0.1+0.1 Ohm max

- Source: Christian presentation on May, 8 2014 adhoc meeting.
- Diode model was changed
- **Replace connector contact resistor with Connector resistance. May 15, 2014**
- To supply Yair tests for connector tests
- To check what will be with 50miliom max difference. So it could be 10miliom minimum – 60miliohm max.
- Sterling to supply information for connector resistivity.
- To check CAT6A cable resistance per the actual cable length
- Change titels of the two columns

CAT6/A, 2-connector model

Length [m]	PD power [W]	Pair with min current [mA]	Pair with max current [mA]	Idiff [mA]	P2PCRunb [%]
0.15	51	713.09	333.59	379.51	**36.26%**
1	51	703.75	343.54	360.21	**34.39%**
10	51	647.97	405.83	242.14	**22.98%**
100	51	612.77	516.87	95.89	**8.49%**
0.15	75	975.35	571.98	403.37	**26.07%**
1	75	966.43	582.25	384.18	**24.81%**
10	75	915.09	648.09	267.00	**17.08%**
100	75	937.66	810.77	126.89	**7.26%**

- Source: Christian presentation on May, 8 2014 adhoc meeting.

CAT6/A, 6-connector model

Length [m]	PD power [W]	Pair with min current [mA]	Pair with max current [mA]	Idiff [mA]	P2PCRunb [%]
0.15	51	711.42	337.09	374.33	**35.70%**
1	51	703.83	345.29	358.54	**34.17%**
10	51	654.98	400.77	254.21	**24.08%**
100	51	617.65	514.68	102.96	**9.09%**
0.15	75	987.44	564.02	423.42	**27.29%**
1	75	979.68	573.15	406.53	**26.18%**
10	75	931.34	636.24	295.10	**18.83%**
100	75	947.13	808.59	138.54	**7.89%**

- Source: Christian presentation on May, 8 2014 adhoc meeting.

CAT5E, 2-connector model

Length [m]	PD power [W]	Pair with min current [mA]	Pair with max current [mA]	Idiff [mA]	P2PCRunb [%]
0.15	51	713.08	336.22	376.86	**35.91%**
1	51	697.53	352.86	344.67	**32.81%**
10	51	628.90	433.31	195.58	**18.41%**
100	51	653.74	568.96	84.78	**6.93%**
0.15	75	977.02	576.14	400.88	**25.81%**
1	75	962.23	593.34	368.89	**23.71%**
10	75	901.66	680.49	221.17	**13.98%**
100	75	1087.30	961.05	126.25	**6.16%**

- Source: Christian presentation on May, 8 2014 adhoc meeting.

CAT5E, 6-connector model

Length [m]	PD power [W]	Pair with min current [mA]	Pair with max current [mA]	Idiff [mA]	P2PCRunb [%]
0.15	51	711.75	339.41	372.33	**35.42%**
1	51	698.99	353.28	345.72	**32.85%**
10	51	636.67	427.56	209.10	**19.65%**
100	51	658.14	568.37	89.77	**7.32%**
0.15	75	989.47	567.90	421.57	**27.07%**
1	75	976.47	583.37	393.10	**25.20%**
10	75	917.08	669.74	247.35	**15.59%**
100	75	1099.57	964.24	135.33	**6.56%**

- Source: Christian presentation on May, 8 2014 adhoc meeting.

Conclusions

- Worst case condition for P2PCRunb is:
  - Single 0.15m CAT6A cable between PSE and PD (2-connector model)
- The max P2PCRunb is 36.26%, i.e. 380mA over 1.05A
- Increasing the number of connector has a ballasting effect, decreasing P2PCRunb.
  - 4-connector results are in the middle between 2 and 4 connector models
- ----------
- With CAT6/A cabling it is possible to deliver 75W to the PD without exceeding 1A per pair (for any cable length and # of connectors)
- A 100m CAT5E cable in a 6-connectors environment would require up to 1.1A to deliver 75W to the PD
- Yair comment: This part is not final conclusions since it is worst case analysis. We need to check if with statistical analysis were lower P2P numbers are obtained, we can work with CAT5e as well and getting 75W at the load. There is benefit to use CAT5e as well for Type 4.

Comparison between 4 connectors and 6 connectors Model. -6

Simulation Results

- Results for Table 1 right column data number set (minimum resistivity cable Type).
- Pairs were not limited to 0.6A
- Numbers were taken from the pairs with highest and lowest values.
- The model used is per Drawing #1

Simulation Results of worst-case analysis **with 4 connectors**				
Length[m]	Pair with minimum current [mA]	Pair with maximum current [mA]	Idiff=Max-Min [mA]	P2PCRunb [%]
0.15m				
1	385	659	275	26.30
10	415	636	221	21.04
100	500	626	126	11.19

Table 2

Simulation Results of worst-case analysis **with 6 connectors** **TBD**				
Length[m]	Pair with minimum current [mA]	Pair with maximum current [mA]	Idiff=Max-Min [mA]	P2PCRunb [%]
0.15m				
1				
10				
100				

Table 3

Summary of open/closed issues -1

P=priority. P=1:Required for generating baseline draft numbers. P=2: May be part of informative section. P=3: Nice to know.

#	Subject	Reference/Conclusions	Status	P
1	Model for simulations/calculations	Figure 1	Ad-hoc OK.	1
2	Worst case data base	Table 1	Ad-hoc OK.	1
3	Cable Channel P2PRUNB 5% max	Meeting #1	Ad-hoc OK.	1
4	Worst case End to End Channel P2P resistance/current unbalance results with 4 connectors	Table 2	Ad-hoc OK.	1
5	What is the equation to calculate Resistance unbalance and Current unbalance?	Physic's, Meeting #1 and 2. Annex a, A1 Iunb=Runb*Total load current.	Ad-hoc OK	1
6	sensitivity Analysis to identify the main contributors of lesser power delivery.	Table 4 and 5	Ad-hoc OK	3
7	Do we need to specify minimum length?	Meeting #2. See Wayne proposal for 4 channel length options	Ad-hoc OK	1
8	To define PSE PI P2PRUNB	Meeting #1 and 2	Ad-hoc OK	1
9	To define PD PI P2PRUNB	Meeting #1 and 2	Ad-hoc OK	1
10	To set equation for evaluation maximum current unbalance through transformers	Ibias=Iunbalance/2=CP2PRU*Icable_max	Ad-hoc OK	2
11	To considering 100BaseT Ethernet devices or switches that do not implement transformers on the spare pairs so the range should be 0 Ohm to 130mOhm. •In the switch and PD, vendors will have to add equivalent resistor to compensate the PSE PI unbalance	Group response: This is implementation issue of PSE PD which needs to meet P2P channel resistance unbalance anyway.	Ad-hoc OK.	2

Summary of open/closed issues -2

P=priority. P=1:Required for generating baseline draft numbers. P=2: May be part of informative section. P=3: Nice to know.

#	Subject	Reference/Conclusions	Status	P
12	How the constant power model at the PD helps us in regard to Channel P2PRUNB and specifically its effect on transformers?	Drawing 2. See the whole slide for details.	Ad-hoc OK.	1
13	sensitivity Analysis to identify the main contributors of resistance unbalance	Need to be done.	On going	1
14	Worst case End to End Channel P2P resistance/current unbalance results with 6 connectors	Table 3	On going	1
15	Statistical analysis results based on worst case data base in Table 1. Do we need to do it or we can live with worst case analysis?		On going	1
16	Channel P2PRUNB vs. operating temperature	Meeting #2 and #3. >room temperature: We don't care. Room temperature important for the standard. <Room temperature: Informative but not part of the standard	????	1
17	How connector contact aging will affect the results i.e. if min/max contact resistance difference will be increased	Meeting #1	???	1
18	Consider analyzing P2P current imbalance higher category cables than CAT6A.	Meeting #1 Response was: what will be the end of it? When to stop?	???	1

Summary of open/closed issues -3

P=priority. P=1:Required for generating baseline draft numbers. P=2: May be part of informative section. P=3: Nice to know.

#	Subject	Reference/Conclusions	Status	P
19	What is the load current that below it we don't care about Channel, PD PI and PSE PI P2PRUNB	Meeting #2 and 3	???	1
20	What is the minimum resistance in the channel that above it, we don't care about END TO END CHANNEL P2PRUNB?	Meeting #2		2
21	What is the wire resistance per meter for patch cords?	Meeting #2 and 3. Proposed 0.14Ω/m	????	1
22	To generate worst case analysis curve of maximum pair current vs cable length for Type 3 PD (51W max.)	Drawing 2. See the whole slide for details.	On going.	1
23	To investigate worst case results the 4 options proposed by Wayne	Summary of 2nd meeting.	On going.	2

- Previous Meeting Material

Meeting # 1 Attendees (Monday Feb 17,2014)

- Yan Zhuang / Huawei
- Abramson David / TI
- Kousalya Balasubramanian/ Cisco
- Leonard Stencel / Bourns
- Larsen Wayne / Commscope
- Woudenberg Rob / Philips
- Picard Jean / TI
- Steinke Stephan / Molex
- George Zimmerman / CME Consulting / Commscope
- Sesha Panguluri/Broadcom
- Ken Bennett/ Sifos

- Gaoling Zou / Maxim
- Dave Dwelley / LT
- Lennart Yseboodt / Philips
- Wendt, Matthias / Philips
- Christian Beia / ST
- David Law / Hp

Meeting # 2 Attendees (Monday Feb 24,2014)

- Yan Zhuang / Huawei
- Kousalya Balasubramanian/ Cisco
- Leonard Stencel / Bourns
- Larsen Wayne / Commscope
- Ken Bennett/ Sifos
- Dave Dwelley / LT
- Jeff Heath / LT
- Christian Beia / ST
- Steinke Stephan / Molex
- George Zimmerman / CME
- Victor Renteria/BEL
- Abramson David / TI
- Gaoling Zou / Maxim
- Tremblay David/ HP
- Lennart Yseboodt / Philips
- Rob Woudenberg / Philips

Summary of previous work and conclusions -1

Cable pair to pair resistance unbalance (P2PRU)

- In order to specify the ***pair to pair channel resistance imbalance*** we had to know the channel ***components pair to pair*** resistance unbalance such as:
  - Cable (not defined by cabling vendors),
  - Connectors, (Specified but not represents worst case numbers)
  - Transformers, (Vendors data is available. Not part of the formal channel)
  - PSE output resistance (Vendors data is available. Not part of the formal channel)
  - PD input resistance (Vendor data is available, Not part of the formal channel)
- We have good and sufficient data for all the components except the cable.
- We developed a method that predicted the cable Pair to Pair resistance imbalance from the other cable parameters such Propagation delay, Skew, wire diameter, wire insulation material and other.
- The predictions showed that P2P Cable Resistance Unbalance <5%
- Lab Tests confirmed that it was <5%
- Long list of experts (including cable experts) agree with the conclusions.
- All details can be found in: http://www.ieee802.org/3/4PPOE/public/nov13/darshan_01_1113.pdf

Summary of previous work and conclusions -2

Channel pair to pair resistance unbalance (C_P2PRU)

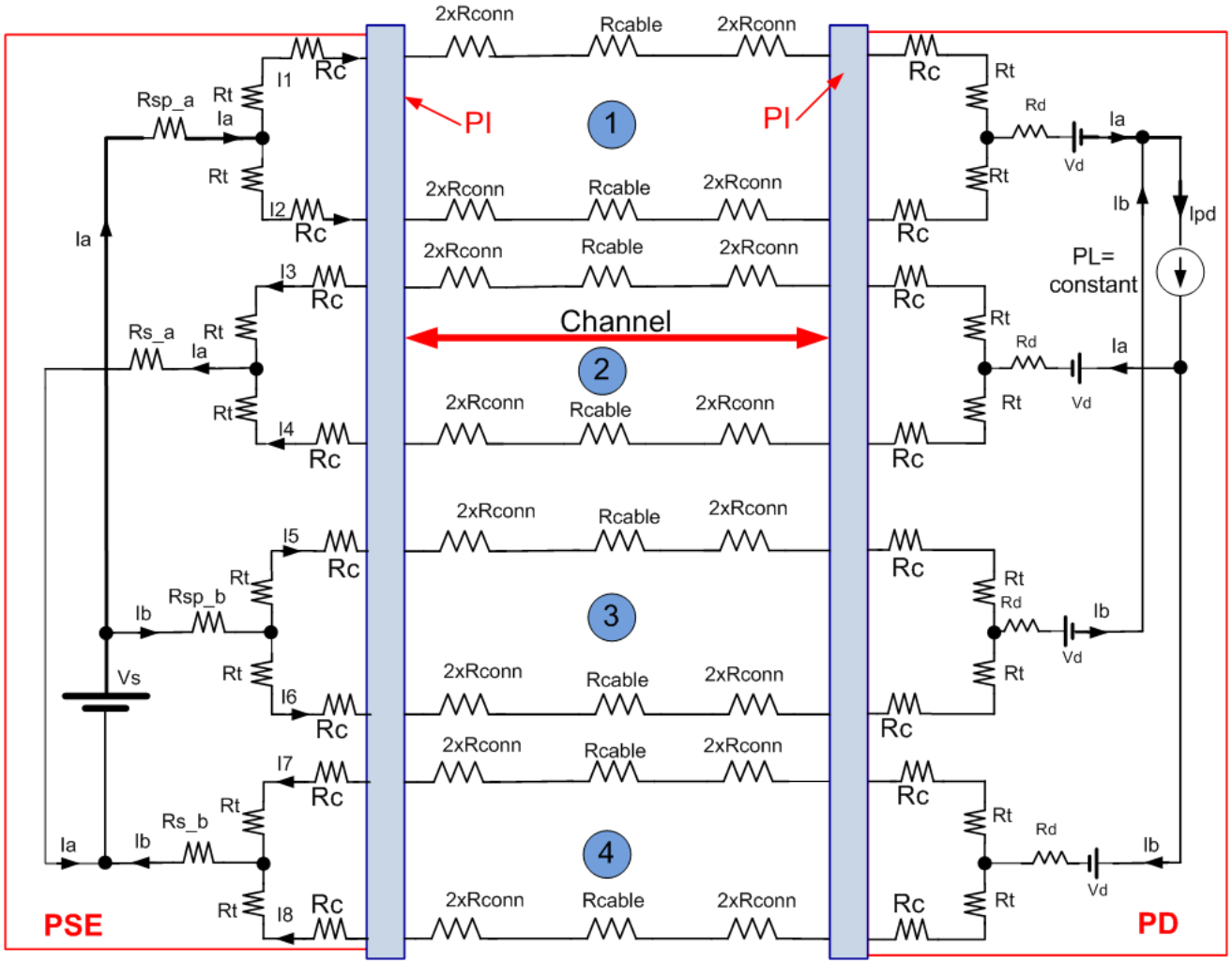
- Initial Work to determine channel pair to pair resistance unbalance:
  - http://grouper.ieee.org/groups/802/3/4PPOE/public/jul13/beia_1_0713.pdf
  - http://grouper.ieee.org/groups/802/3/4PPOE/public/jul13/darshan_2_0713.pdf

- After getting comments from the group and using same worst-case data base and model:
  - http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf
  - http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf

  - General Channel Model and its components that we have used: See next slide.

Summary of previous work and conclusions -3

General Channel Model and its components that we have used.



Drawing 1

Notes for the general Model:

1. Adding resistors on positive path for general model (Rsp_a and Rsp_b). It can be set to zero or >zero pending the case being investigated.
2. Adding equipment connectors per Wayne's comment. So total end to end channel connectors is 6 max.
3. The formal channel definition is marked in red arrow.
4. Our work addresses also the internal application resistance of known components that are used

Summary of previous work and conclusions -4

Data set that we use as worst case numbers

From: http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf

Table 1	**Data set 1 (Max Cable resistivity)**	**Data set 2 (Min Cable resistivity)**
Cable resistivity	117mOhm/m* (maximum value) (CAT5e) Pair resistance unbalance: 2% ➔ Minimum wire resistance=0.98*117mΩ/m Pair to pair resistance unbalance: 5% ➔ Pair resistance max=~(117mΩ/m)/2 ➔ Pair resistance min=~(0.95*117mΩ/m)2	66mOhm/m* (CAT6A) Pair resistance unbalance: 2% ➔ Minimum wire resistance=0.98*66mΩ/m Pair to pair resistance unbalance: 5% ➔ Pair resistance max=~(66mΩ/m)/2 ➔ Pair resistance min=~(0.95*66mΩ/m)2
Transformer winding resistance	120mOhm min, 130mOhm max	120mOhm min, 130mOhm max
Contact resistance	30mOhm min, ** 60mOhm max	30mOhm min, ** 60mOhm max
Diode bridge	0.39V+0.25Ohm*Id min; 0.53V+0.25Ohm*id max	0.39V+0.25Ohm*Id min; 0.53V+0.25Ohm*id max
PSE output resistance (e.g. Rs_a/b= Rsense+Rdson)	0.25+0.1 Ohm min 0.25+0.2 Ohm max	0.1+0.05 Ohm min 0.1+0.1 Ohm max

- Two scenarios have been identified: max wire resistivity Data set 1 (CAT5E cables) and min wire resistivity Data set 2 (CAT6/A cables)
- *Cable pair to pair resistance max unbalance is set to 5%. See darshan_1_1113.pdf. Cable resistance within pair unbalance is max 2%.
- **Connector contact aging will be addressed in other work.
- All parameters are at room temperature and further study is required to address temperature variations

Summary of previous work and conclusions -5

Simulation Results

- Results for Table 1 right column data number set (minimum resistivity cable Type).
- Pairs were not limited to 0.6A
- Numbers were taken from the pairs with highest and lowest values.
- The model that was simulated is with 4 connectors only as in the link below.
  - http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf

Simulation Results of worst-case analysis				
Length[m]	Pair with minimum current [mA]	Pair with maximum current [mA]	Idiff=Max-Min [mA]	P2PCRunb [%]
1	385	659	275	26.30
10	415	636	221	21.04
100	500	626	126	11.19

Table 2

$$P2PCRUNB = \frac{\mathrm{Im}ax - \mathrm{Im}in}{\mathrm{Im}ax + \mathrm{Im}in}$$

Summary of previous work and conclusions -6

- See details: http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf
- What we did was a We need to do the work for sensitivity analysis for channel pair to pair resistance unbalance regardless of power delivery constrains.

Max res scenario	Component UNB[±]	Effect on power delivery [-]		
Cable lenght		1m	10m	100m
Rt	4%	0.17%	0.10%	0.01%
Rconn	33.30%	1.02%	0.58%	0.08%
r_cable	5%	0.20%	1.13%	**1.68%**
Rdiode	11.10%	3.43%	1.96%	0.32%
Vdiode	14.30%	**5.72%**	**3.27%**	0.53%

Table 4

Min res scenario	Component UNB[±]	Effect on power delivery [-]		
Cable lenght		1m	10m	100m
Rt	4%	0.18%	0.12%	0.03%
Rconn	33.30%	1.06%	0.73%	0.16%
r_cable	5%	0.12%	0.81%	**1.79%**
Rdiode	11.10%	3.56%	2.48%	0.57%
Vdiode	14.30%	**5.94%**	**4.14%**	0.96%

Table 5

Summary of previous work and conclusions -7

Conclusions

- See details: http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf

- Main conclusions relevant for channel pair to pair resistance unbalance (short summary)
- P2P current imbalance increases when cable length decreases.
- P2P current imbalance increases when cable resistivity decreases i.e. CAT6A will have higher current imbalance compared to CAT5e.
- Unbalance within a pair (the famous 2% pair and 3% channel) has negligible effect on P2P unbalance.
- We need to define the requirements for P2PRunb for the PD, Channel and PSE in order to meet our objectives.

Summary of previous work and conclusions -8
Conclusions

- To analyzed the following scenarios:
  - How connector contact aging will affect the results i.e. if min/max contact resistance difference will be increased.
  - The current unbalance results as function of operating temperature range
  - To analyze the results when there is no hard limit of 600mA on the negative pair. Done: See Table 2 and see: http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf
  - Consider analyzing P2P current imbalance higher category cables than CAT6A
    - Response at the meeting was: what will be the end of it? When to stop?
  - To perform sensitivity analysis for P2P resistance (current) imbalance.
  - To set a worst case conditions for evaluating maximum current imbalance through transformers.

Done: Ibias=Iunbalance/2=CP2PRU*Icable_max.

What are the parameters that must be define?

- As done in IEEE802.3-2012 *(See Annex A)* when we define the pair (wire to wire in the same pair) in the cable pair(s) and in the channel, we need to do it for the Pair to Pair Resistance Unbalance in the cable and in the channel.

- Cable Pair to Pair Resistance Unbalance (P2PRU)
  - Based on the work done at http://www.ieee802.org/3/4PPOE/public/nov13/darshan_01_1113.pdf , it is proposed to specify it to 5% until formal number will be received from TIA/EIA. (group OK with recommendation)

- Channel Pair to Pair Resistance Unbalance (C_P2PRU)
  - We need to decide if we can work with the worst case numbers?

  Or we need to add the probability factors to lower them.
    - To add probability factors and move on (request from magnetic vendors for lowest number).

Analysis Methods and Data-Base

- Analysis Method
  - Worst-Case Analysis
    - We did a worst-case analysis for the channel pair to pair resistance unbalance on a proposed worst-case data
    - Any comments on the worst-case data base?
      - To considering 100BaseT Ethernet devices or switches that do not implement transformers on the spare pairs so the range should be 0 Ohm to 130mOhm.
        - In the switch and PD vendor will have to add equivalent resistor to compensate the PSE PI unbalance. To discuss this approach.
      - Group response: This is implementation issue of PSE PD which needs to meet P2P channel resistance unbalance anyway.
    - Any comments on the model used (Group response: No.)
- Next Steps

Do we need to specify PSE and PD PI P2P Resistance Unbalance or leave it to be implementation specific as long as C_P2PRU is met?

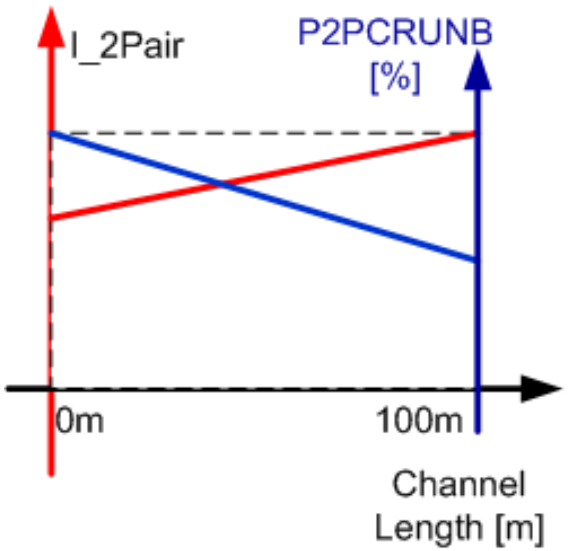
- Do we need to specify the following additional parameters or leave it to be implementation specific as long as C_P2PRU is met?
  - PSE PI Pair to Pair Resistance Unbalance (PSE_P2PRU)
  - PD PI Pair to Pair Resistance Unbalance (PSE_P2PRU)
  - In the current standard the pair resistance unbalance was defined to 2% and the channel (cable and connector only) to 3% (See Annex A).
  - It was the responsibility of the equipment vendor to make sure that his design will meet all system requirement based on the above specification.
  - In 802.3at extensive work was done and shows that the actual pair channel resistance unbalance is higher than 3% (due to other components in the system) and yet system vendors and components ensure operation under this conditions.
  - Now we are addressing the P2P channel Resistance Unbalance and we have the same question: Do we need to specify the following additional parameters or leave it to be implementation specific as long as C_P2PRU is met?
    - If we do want to define PSE_P2PRU and PD_P2PRU.
    - Should we define only PD_P2PRU since it is not always required for the PD (it is PD power dependent and if defined at PSE it will be required for every port

Discussions and conclusions

- To ask magnetic component vendors if they can handle the worst-case analysis numbers or we should do statistical analysis as well.
  - If they can, we use the results to define the end to end channel P2P resistance unbalance.
- To define 3 new parameters
  - (1) To define the channel (PI to PI) Resistance unbalance (cables and connectors) with the contributions of PSE and PD PI P2P Resistance Unbalance.
- From (1) to separately define
  - PSE PI P2PRUNB and PD P2PRUNB
  - To define the channel (PI to PI) Resistance unbalance (cables and connectors).
  - As a result component and system vendors could use it for designing their components.
- We accept that P2P Cable Resistance Unbalance is 5% until formal number will be received by TIA/EIA etc.
- Yair to work with transformer vendors to get the data we need.
- To look for the best cable (lower resistance per meter) expected in the next 10+years and use it in our worst case data base numbers.
- To verify that LDO is covered by PD constant power sink. Done. It is covered.
- To consider 100BaseT Ethernet devices or switches that do not implement transformers on the spare pairs so the range should be 0 Ohm to 130mOhm.
  - In the switch and PD vendor will have to add equivalent resistor to compensate the PSE PI unbalance. To discuss this approach.
- No other comments on previous work done nor on model or database used.
- Group to send comments on model and data base and we will update it if found.

For next meeting -1

- To discuss the advantages that PD constant Power Sink allows us.
- Background material for considering:
  - 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 is not an issue.
  - 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.



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

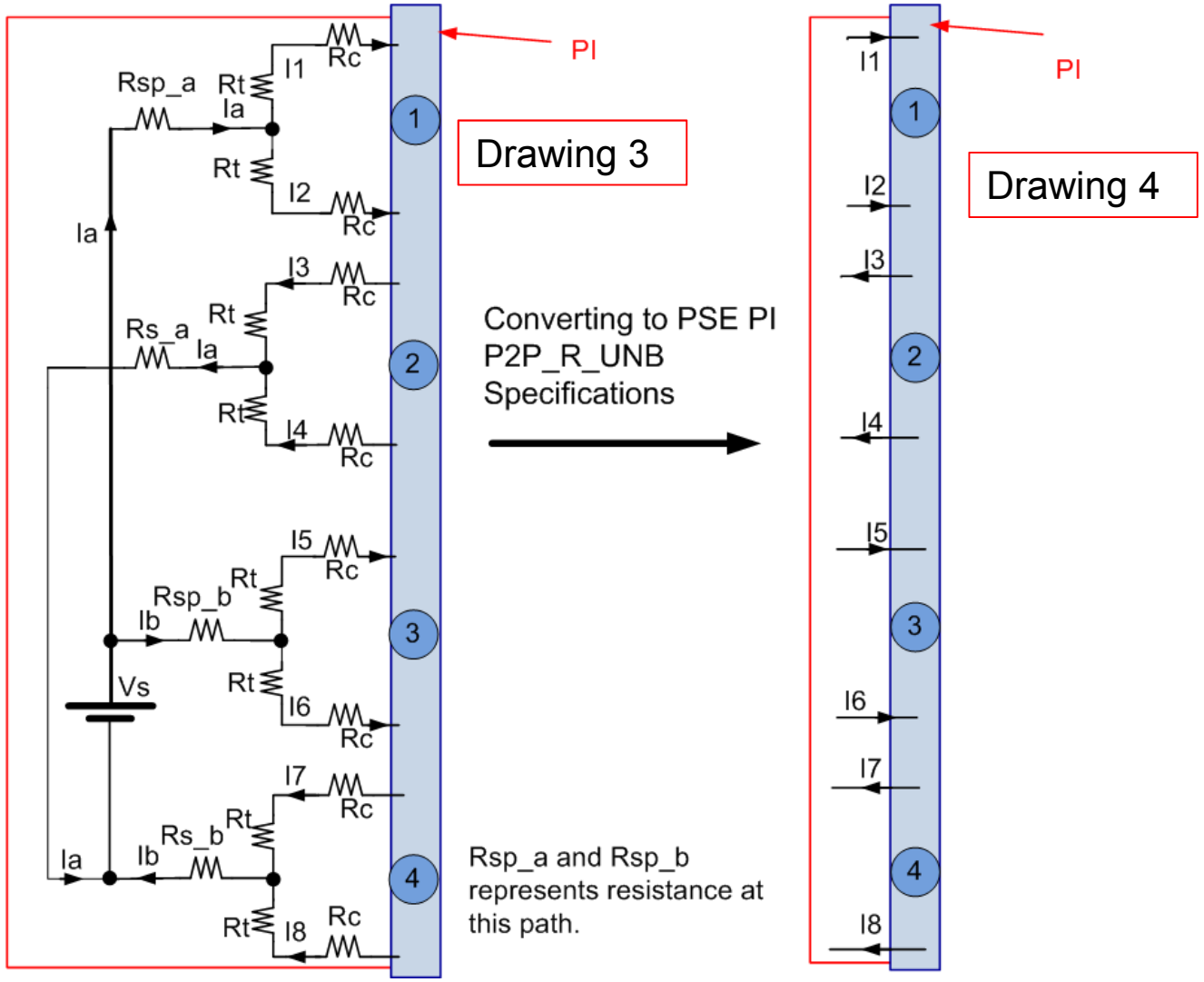
Illustration of the behavior.
(The curve is not linear. It is just describing the trend.)

Drawing 2

For next meeting -2

- We need to define the PD load current on Mode A and Mode B in which below that current, P2P requirements can be ignored.
  - Example: if Mode A requires 350mA and Mode B require 113mA than P2P discussion is not relevant to this case.

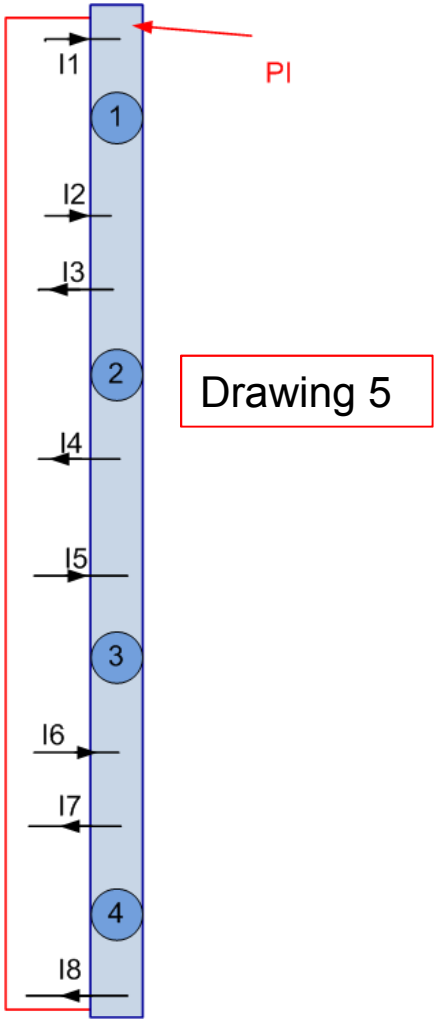
PSE_PI Pair to Pair Resistance Unbalance



- To specify test setup as well

PD_PI Pair to Pair Resistance Unbalance

- Same concept for PD PI P2P_R_UNB definitions
- To specify test setup
- We may need to define P2P voltage offset difference in addition to P2P resistance unbalance



Drawing 5

Summary of 2nd meeting - 1

- (Text marked blue was added after the meeting and is not part of the meeting summary. It will be discussed on our 3rd meeting to be approved.)
- Wayne Larsen present data regarding:
  - Summary of resistivity and resistance unbalance specifications in TIA cabling standards
  - **Suggested topologies to study**
    - 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 cable, 4 connectors
    - D. 100 m channel with 10 m of cordage, 90 m of cable, 4 connectors
  - Calculated channel resistance and unbalance (not including PSE and PD components) for the above topologies and the calculation details in separate Excel file done for maximum TIA numbers.
- Yair notes for the calculation results
  - The results reflects maximum cable (9.38Ω/100m) and connectors (300mΩ) resistance specified by TIA. *We are looking for lower cable resistance and connectors to reflect real life and also worst case in terms of P2PCRUB.*
  - *Christian and Yair proposed to use cable with* 66mOhm/m and connectors with 30mOhm min, 60mOhm max per the data in slide 9.
  - Proposed channel length options to investigate looks reasonable.

Summary of 2nd meeting - 2

- We review the updated model and we agree to use it as our base line for simulating different operation scenarios.
- Until other worst case numbers regarding cables and other components in the channel from end to end, we will use the numbers in the table slide 9, minimum resistivity cable model column.
- We adopt the 5% cable P2PRUNB until formal number will be received from TIA/EIA etc.
- We add two additional connectors to the model to investigate the effect of it on the end to end P2PCRUNB.

  (formal channel is 4 connectors maximum)
- To consider 100BaseT Ethernet devices or switches that do not implement transformers on the spare pairs so the range should be 0 Ohm to 130mOhm.
  - Yair note: In the Switch/Midspan and PD vendors will have to add equivalent resistor to compensate the PSE PI unbalance.
  - Group: This is implementation issue of PSE PD which needs to meet P2P channel resistance unbalance anyway. We will craft the optimum wording when the time comes.

Summary of 2nd meeting - 3

- The following questions and issues were raised
- (1) What is the minimum resistance in the channel that above it, we don't care? In other words, what is the minimum resistance in the PD that makes the diodes, connectors, transformers less important in the total channel P2PRUNB?
- (2) Do we need to specify minimum length?.

  Yair: we will know the answer based on (1) and running simulations/calculations per Wayne proposal for 4 channel length options.
- What will be minimum Ω/m for patch cords?
- Yair: I suggest to use the 9.38Ω/100m (93.8mΩ/m as max value and 5% less as the minimum value since patch cords normally need to be flexible than the horizontal cable so their wire diameter is smaller that horizontal cables such as CAT6A.
- Yair: I remember that Wayne said that the 0.15m channel length option is with 14 Ω/100m.

  -Wayne to confirm.

  -Wayne: What is your opinion to the above proposal?

Summary of 2nd meeting - 4

- We need to define the PD load current on Mode A and Mode B in which below that current, P2P requirements can be ignored.
  - Example: if Mode A requires 350mA and Mode B require 113mA than P2P discussion is not relevant to this case.
- We agree that wee need to investigate it and address it.
- **Dave Dwelley made a comment about this issue which I didn't record.**
- **Dave please send us your comment about this topic to be recorded and addressed.**

- We need to conduct sensitivity analysis for P2PCRUNB with constant power sink and without limitations on current per pair. What we had is for determining the PD minimum available power.

Summary of 2nd meeting - 5

- How to address temperature effect on P2PCRUNB?
  - We agree that we don't care of high temperature since it works for us (high temperature higher resistance lower P2PCRUNB)
  - So the question is narrowed to below room temperature (20-24°C)?.

Yair:

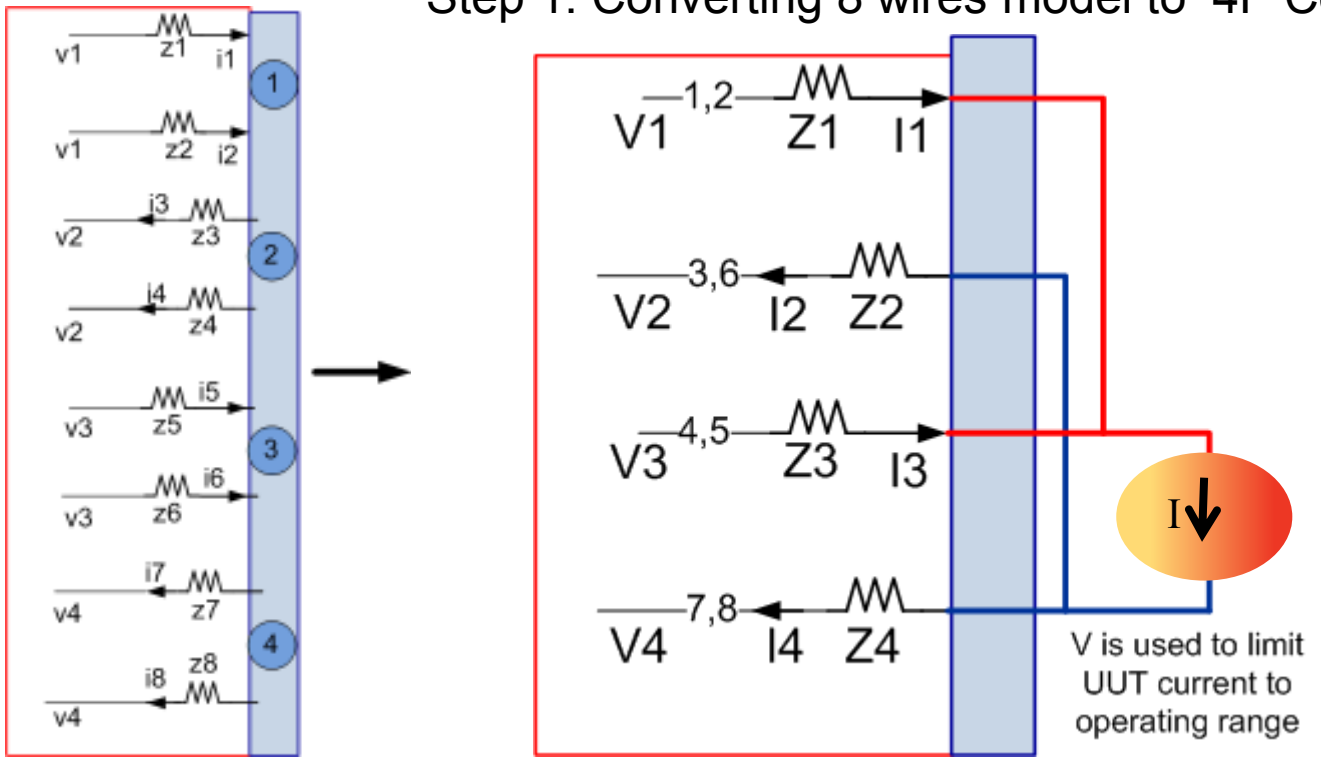
1. All parameters in the standard are tested for compliance at room temperature. (to confirm)
2. System and component vendors are responsible to design the parts/system to meet their spec over their spec operating temperature range.
3. We can study and supply the guidelines/equations in informative annex to help decide what to do in temperatures below room temperature but it can't be part of the standard.
4. Please see what IEEE802.3-2012 says about this topic:

33.7.7 Temperature and humidity

The PD and PSE powered cabling link segment is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling. Specific requirements and values for these parameters are beyond the scope of this standard.

Proposal for PSE PI P2PRUNB model

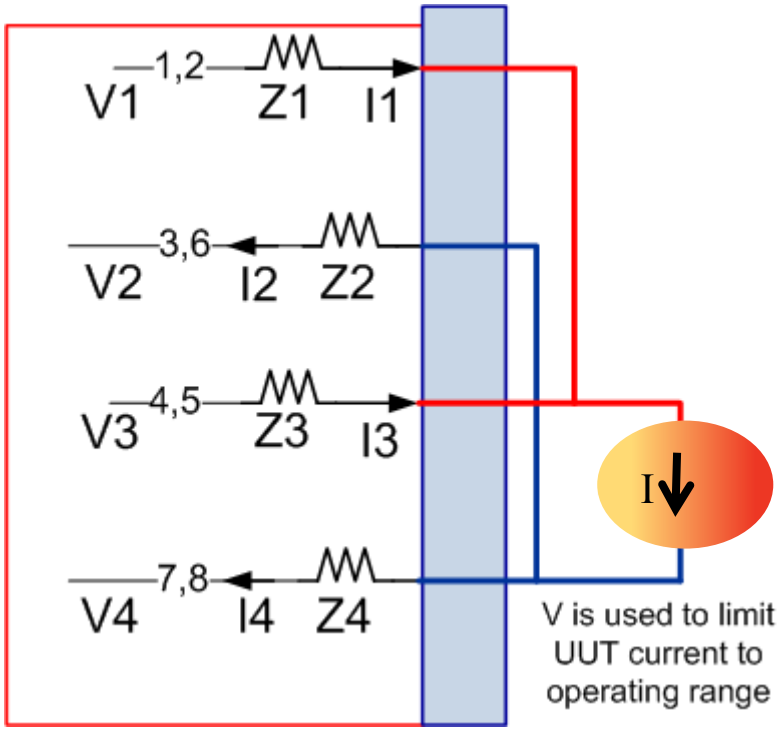
Step 1: Converting 8 wires model to 4P Common Mode Model



- Model is implementation independent
- Zi is the CM impedance of the implementation per pair. i=1to 4.
  - **We are interested in the DC value of that Impedance**.
- Vi is the voltage measured to the common point.
- Ii is PSE Icable current operating range per PSE type at ON_STATE.
- We want to specify P2P PSE PI Resistance Unbalance in terms of Vi and Ii.

Requirement Derivation - 1

- By definition:
- I1=(V1-V)/Z1 ➔ Z1=(V1-V)/I1
- I2=(V2-V)/Z2 ➔ Z2=(V2-V)/I2
- I3=(V3-V)/Z3 ➔ Z3=(V3-V)/I3
- I4=(V4-V)/Z4 ➔ Z4=(V4-V)/I4



- By definition:
- P2P PSE PI Zunbalance=

$$= \frac{Z_i - Z_j}{Z_i + Z_j} = \frac{\frac{V_i}{I_i} - \frac{V_j}{I_j}}{\frac{V_i}{I_i} + \frac{V_j}{I_j}} = TBD\max$$

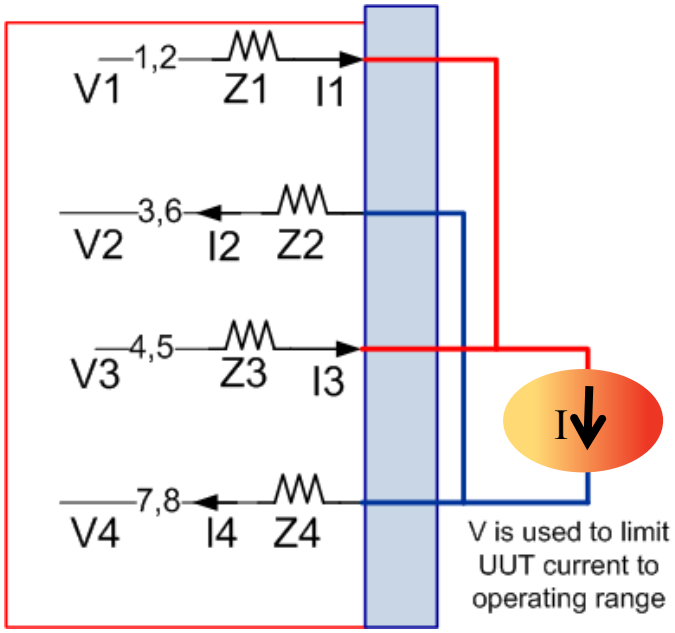
Between any two pairs i≠j .

Requirement Derivation - 2

- P2P PSE PI Zunbalance=

$$= \frac{Z_i - Z_j}{Z_i + Z_j} = \frac{\frac{V_i - V}{I_i} - \frac{V_j - V}{I_j}}{\frac{V_i - V}{I_i} + \frac{V_j - V}{I_j}} = TBD \max$$

Between any two pairs i≠j.
Since we need Z in DC ➔ Z➔R



$$(1)\ \frac{Z_i - Z_j}{Z_i + Z_j} = \frac{R_i - R_j}{R_i + R_j} = P2PRUNB \max,$$

$$(2)\ \left|v_1 - v_3\right| < TBD$$

$$(3)\ \left|v_2 - v_4\right| < TBD$$

Ri is function of Vi/Ii which addresses non linear circuitry at worst case unbalance operating point defined by PSE vendor.

Comments?