IEEE802.3 4P Task Force

Channel Pair To Pair Resistance Imbalance

(End to End System Imbalance)

Ad Hoc

Meeting #1: Rev_001 Monday February 17, 2014
Meeting #2: Rev_001b Monday February 24, 2014
Meeting #3: Rev_001c

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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

Proposed Agenda

- Introduction
- Summary of previous work and conclusions
  - Cable pair to pair resistance unbalance (P2PRU)
  - Channel pair to pair resistance unbalance (C_P2PRU)
  - General Channel Model and its components
  - Simulation Results
  - Sensitivity Analysis
  - Conclusions
- What are the parameters that must be define?
  - Cable Pair to Pair Resistance Unbalance (P2PRU)
  - Channel Pair to Pair Resistance Unbalance (C_P2PRU)
- Analysis Methods and Data-Base
  - Analysis Method
  - Data Base
- 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 (PD_P2PRU)

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

- All attendees to send mail approving their attendance at the add-hoc today

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

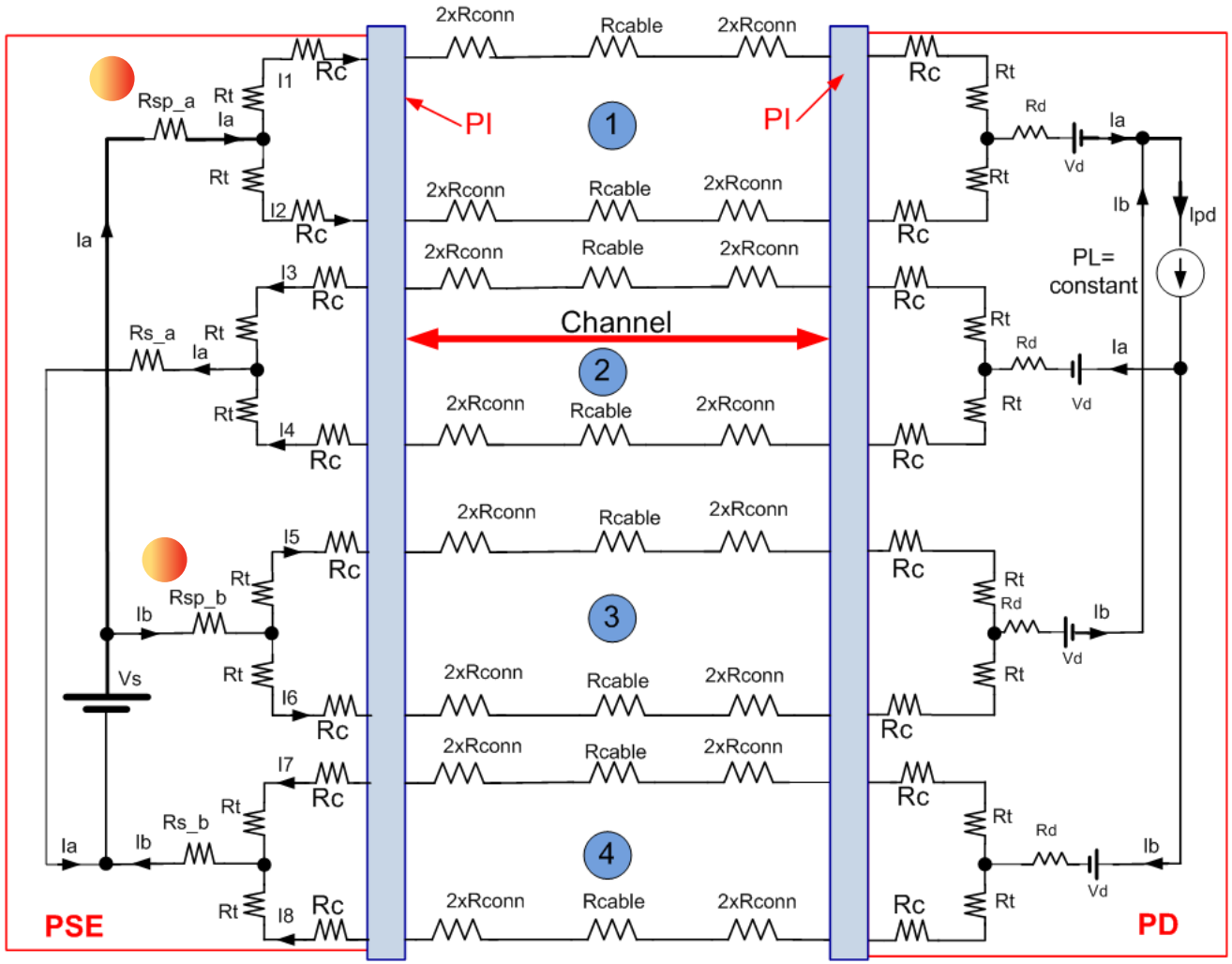
- After getting comments from the group and using same worst-case data base and model:
  - http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf
  - http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf

  - 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.

Updated Model to include equipment connector for accurate end to end worst case analysis.



Drawing 1

Notes for the general Model:

1. Adding resistors on positive path for general model per previous discussion (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% ➔air resistance max=~(117mΩ/m)/2 ➔air 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% ➔air resistance max=~(66mΩ/m)/2 ➔air 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	0.3V+0.4Ohm*Id min; 0.4V+0.5Ohm*id max	0.3V+0.4Ohm*Id min; 0.4V+0.5Ohm*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 (updates from last meeting)

- 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

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

Results with 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

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 [%]
1	385	659	275	26.30
10	415	636	221	21.04
100	500	626	126	11.19

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 [%]
1				
10				
100				

Summary of previous work and conclusions -7

- See details: http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf
- What we did was a sensitivity Analysis to identify the main contributors of lesser power delivery.
- 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%

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%

Summary of previous work and conclusions -8

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 -9

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 slide “results” and see:
  http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf

  - To set a worst case conditions for evaluating maximum current imbalance through transformers.

  Actually done: Ibias=Iunbalance/2=CP2PRU*Icable_max.

  - Consider analyzing P2P current imbalance higher category cables than CAT6A
  - To perform sensitivity analysis for P2P current and resistance imbalance.

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.

- 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.

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: This is implementation issue of PSE PD which needs to meet P2P channel resistance unbalance anyway.
    - Any comments on the model used
- Next Steps
  - Are we Ok with the results obtain and can live with it or we need to do a statistical analysis to lowering the numbers of worst-case analysis?

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.
- 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.
- 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 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.

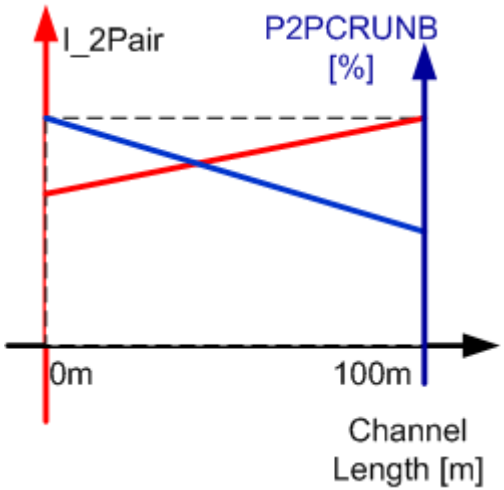
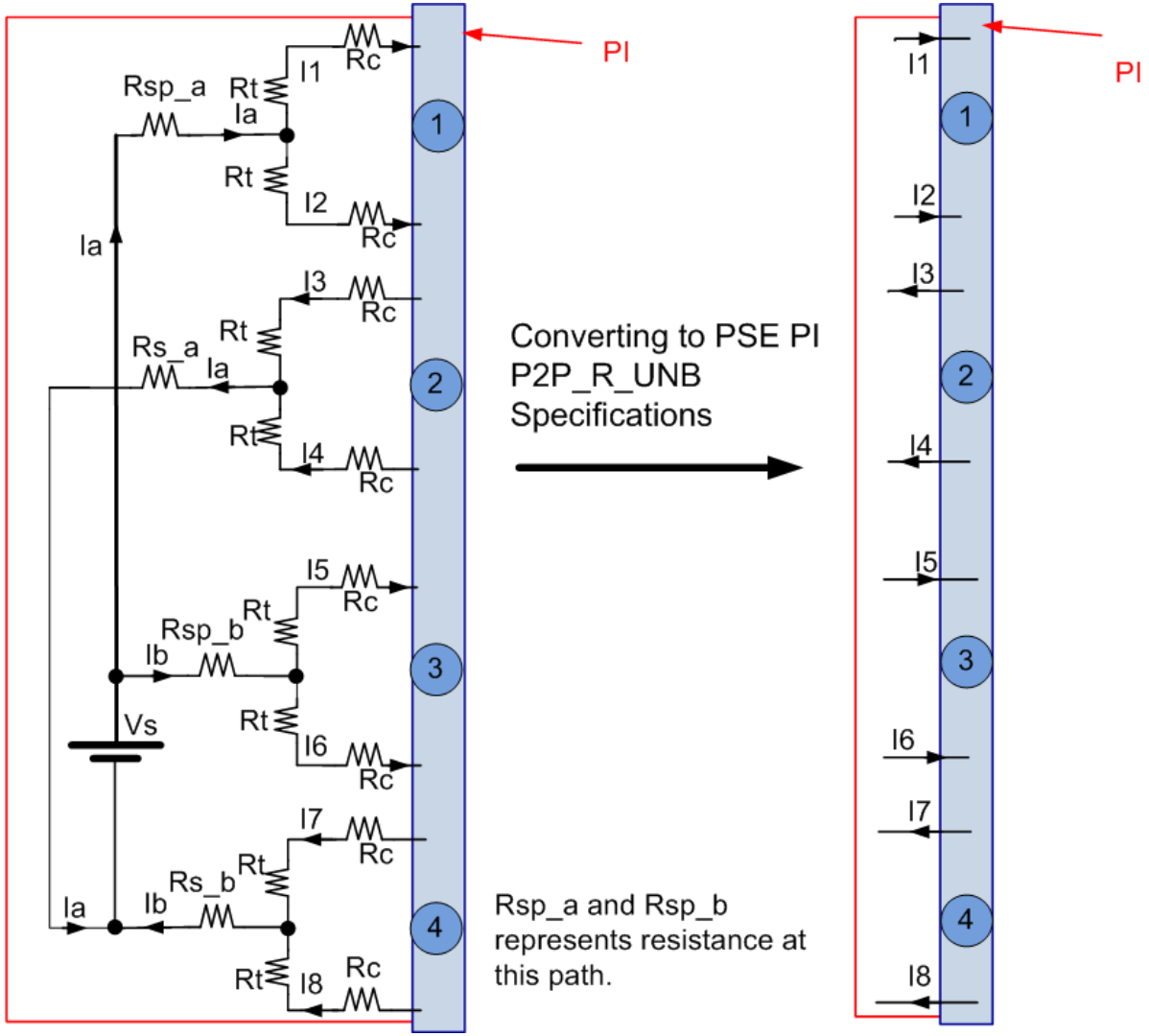


Illustration of the behavior.
(The curve is not linear. It is just describing the trend.)

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.

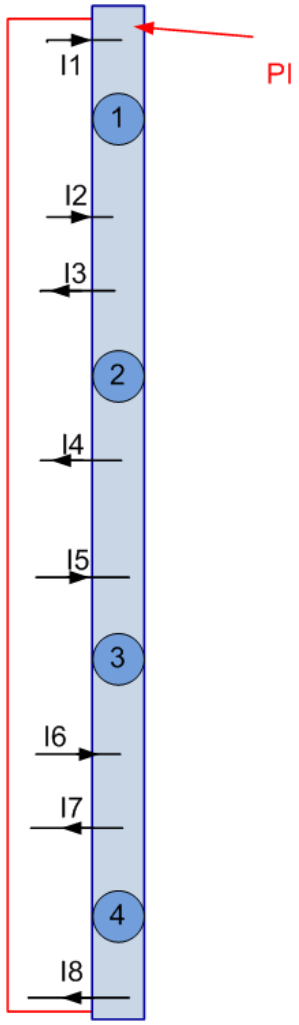
PSE_PI Pair to Pair Resistance Unbalance



- 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



Summary of 2nd meeting - 1

- 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 I 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 vendor 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.

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 physical meaning related to current unbalance. 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.

Annex B – Connectors terms.

- **Source Yakov Belopolsky / Stwconn.**
- 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 typoes 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