IEEE802.3 4P Study Group

Analysis of usable PD input power in 4P system
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Objective

- To generate objective equivalent to the following:
  - The Project shall support a minimum of TBD watts at the PD PI
    - We need to specify the TBD.

Strategy Discussion - 1

- We already have Type 2 PD power of 25.5W
- A potential of at least twice the Type 2 PD exists (51W)
- The question is if at least 51W can be guaranteed without any working assumptions or limitations derived from *Pair to Pair Resistance Imbalance.*
- We can't imply or discuss implementations and we can't assume specific future implementations.
- However we can starting with worse case conditions assumption so it will help to meet current IEEE802.3 requirements for 2P systems in order to meet backwards compatibility and interoperability requirements.

Strategy Discussion - 2

#	Parameter	Value	Notes
Known Data			
1	Iport	600mA average/rms max.	Over 2P (Ref 2)
2	Temperature rise. (TIA information and IEEE802.3).	10°C temp rise for 2x(600mA/2P). When all pairs are energized	Over each 2P simultaneously. (Ref 2,3)
3	Type 1 and Type 2 magnetic components	Designed for Type 1/2 Iport with margins for Icut	Over each 2P
4	Over current limitations	Icut / ILIM	Over 2P (Ref 2)
5	PSE 4P output power	2x600mAx50V=60W	Over 4P
Need to be addressed			
6	*Pair to Pair Resistance Imbalance*	*Is not defined by TIA or IEEE. Lab results and hopefully some intelligent assumptions were used*	
7	*PD 4P input power*	*At least TBD Watts. See the following presentation discussion.*	*Over 4P*

Table 1 - List of known data

Strategy Discussion - 3

- Under **ideal conditions were t**he imbalance between Pairs (channel wise) is zero
  - The power at the PD is equally divided between ALT A and ALT B, i.e. 25.5W each, total 51W[1] all at PD input. No effects on Icut, Ilim, magnetics[2] etc.
- However what would be the answer for non-Ideal conditions i.e. P2P resistance imbalance> ?
  - What is the Pair to Pair (P2P) current imbalance that will not affect:
    - PD input power objective vs. P2P imbalance
    - Type 1 and Type 2 magnetic components performance (See note 2)
    - Cable temperature rise
    - Protection means if required such Overload conditions over 2P systems[3]

Notes:

1. 2x(0.6A*60V)-2x(12.5Ωx0.6A^2)=51W
2. In 4P operation we have two cases of current imbalance:
   a) The imbalance between two wires in a pair.
   b) The imbalance between ALT A and ALT B current that may affect (a) if e.g. Ib>Ia and Ib>600mA due to P2P imbalance.
3. could be argued if it is implementation dependent or not however the discussion is limited to (a) worst-case scenarios (b) to what we have now and not what we potentially could have which is not or may not guaranteed)

Introduction: Pair Imbalance - 1

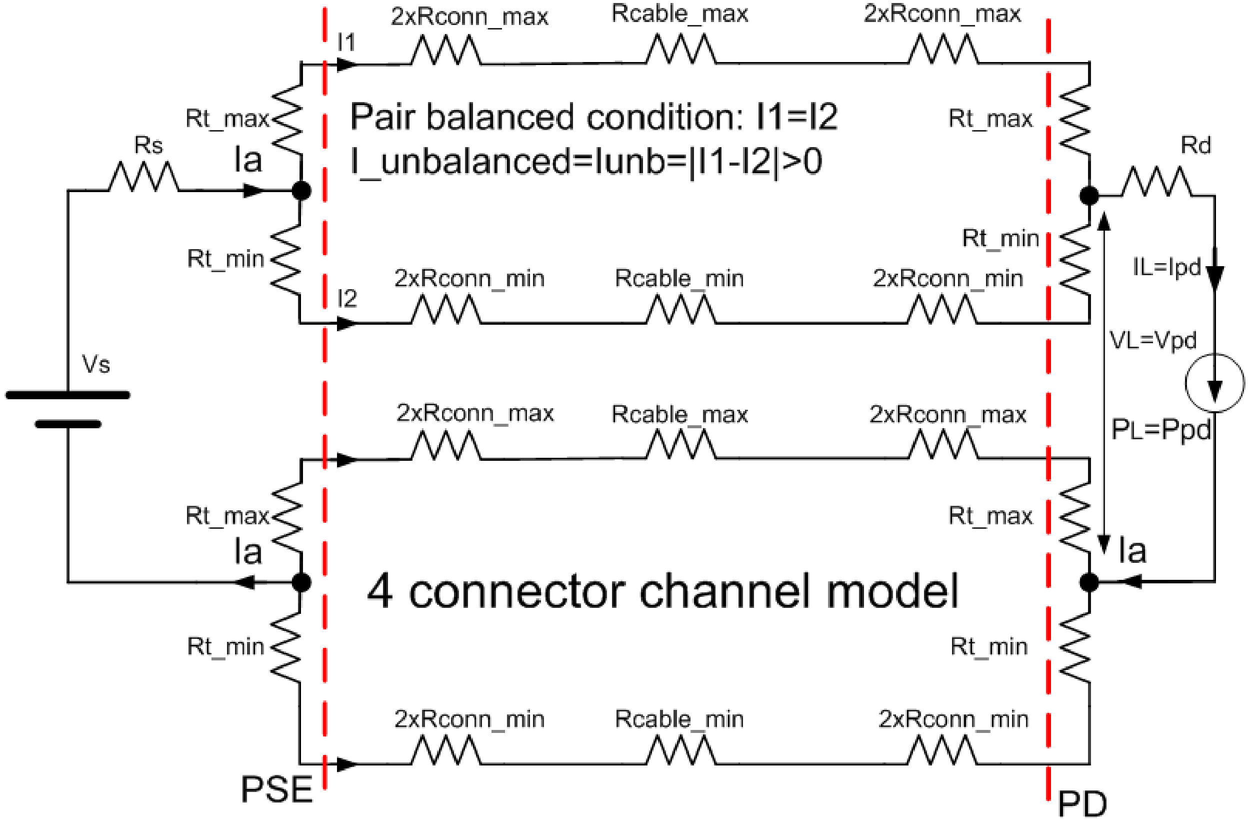
- In 4P operation we have two cases of current imbalance due to resistance imbalance:
  a) The resistance imbalance between two wires in a pair (Type 1 and 2 systems, IEEE802.3).Its requirements are defined in IEEE802.3-2012 as and ISO/IEC 11801. Pair imbalance affects channel data performance and magnetic components.
  b) The imbalance between ALT A current and ALT B current that may affect (a) which is not defined by the IEEE802.3 or cabling standard.
  c) With PD power > 51W we surely need to address again pair imbalance magnetics issue as well as other components.
- We will show how pair imbalanced is calculated.
- Why we review pair imbalance?
  - *We will use similar technique later to show how Pair to Pair imbalance is evaluated in a 4P system. P2P imbalance is currently not defined.*

Introduction: Pair Imbalance - 2

- Pair resistance imbalance: The resistance imbalance between the conduction path in a pair. Its requirements are defined in IEEE802.3-2012 as and ISO/IEC 11801:

$$R_{UNB}[\%] = 100\% \cdot \frac{\sum R\max - \sum R\min}{\sum R\max + \sum R\min}$$

$$I_{UNB} = Ia \cdot R_{UNB}$$



- Rs is the resistance from vs. to transformer center tap.
- Rd is the resistance between transformer center tap to the load.
- Ia is the port current
- Rmin=Rmax – Runb, per component.

Figure 1

Introduction: Pair Imbalance-3. *Worst-Case Analysis*

- Simplifying 2P model drawing

R1_max=max{2xRt+4*Rconn+Rc}

R1_min=min{2xRt+4*Rconn+Rc}

I1=Ia*(Rmin/(Rmax+Rmin))

I2=Ia*(Rmax/(Rmax+Rmin))

Iunb=|I1-I2|=Runb[%]*Ia

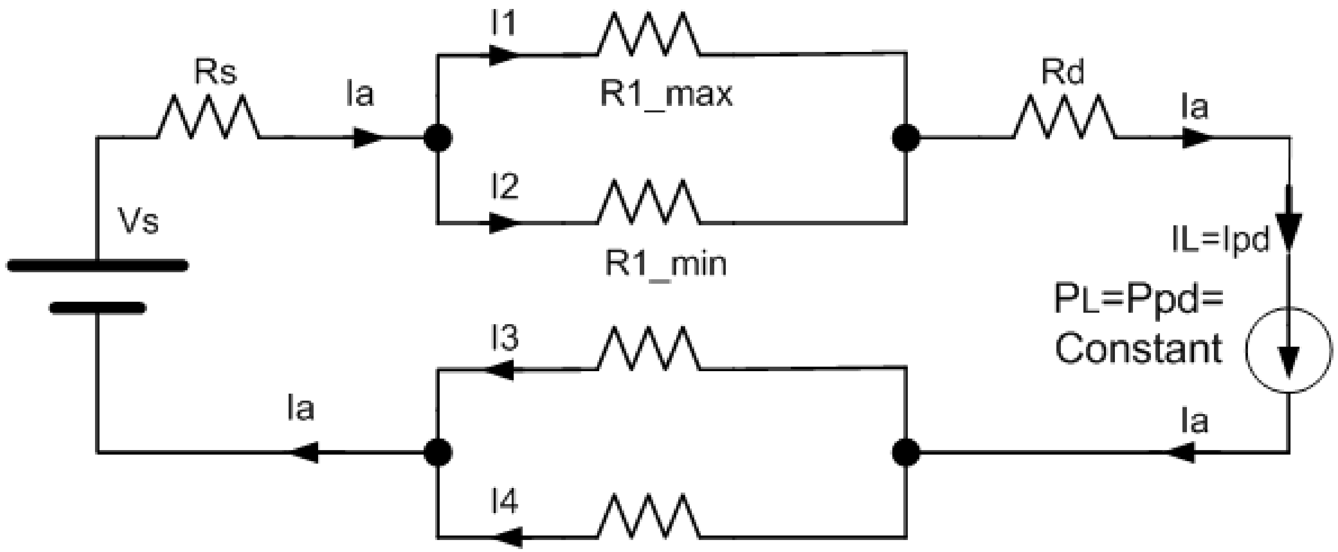


Figure 2

$$R_{UNB}[\%] = 100\% \cdot \frac{\sum R\max - \sum R\min}{\sum R\max + \sum R\min}$$

$$I_{UNB} = Ia \cdot R_{UNB}$$

Introduction: Pair Imbalance - 4

- Specifications and data used in the pair model[1].

#	Component	Rmax [Ω]	Runb[Ω]	Runb[%]	Rmin[Ω]
1	Wire	11.7[2] /100m		2	=Rmax[L]*(1-2%)/(1+2%)
2	Channel			3	3% is maximum value for any channel length ≤100m.
3	Connector	0.2[3]	0.05		Rmax- 0.05

Table 2

#	Component	Rmax [Ω]	Runb[Ω]	Runb[%]	Rmin[Ω]
1	Transformer winding	0.5[4]	0.03		Rmax – 0.03

Table 3

Notes

1.See reference 4: www.ieee802.org/3/at/public/2006/01/diminico_1_0106.pdf

2.Based on 25 Ω total loop resistance, 12.5 Ω per wire including 4 connectors resulting with 11.7 Ω /100m per wire (25 Ω- 8*0.2 Ω). 19Ω/100m loop resistance is specified per 61156-5 Cable - 3.2.1 Conductor resístanse. Analysis results are not significantly changed between the two max values at 100m.

3.Connector maximum spec. value is given. In reality it is lower and channel imbalance is increased further at short cable.

3. Rmax for transformers is for Type 1 systems (vendor data, not spec.). may be lower in higher power devices than Type 1 systems.

Introduction: Pair Imbalance - 5

- Calculation Methods:
  - Worst-Case analysis (will be used in this presentation) for Pair and P2P analysis.
  - Statistical Analysis. (will be used in the task force for derive specifications)
- Worst case analysis to evaluate 1st iteration conclusions. It is good enough for crafting our objective wording.
- In the Task Force we will do statistical analysis (we need more data for it.) for crafting the specification. Statistical analysis will results with lower P2P imbalance at short cable as we saw in 802.3at project. See Ref 6.

Introduction: Pair Imbalance - 6

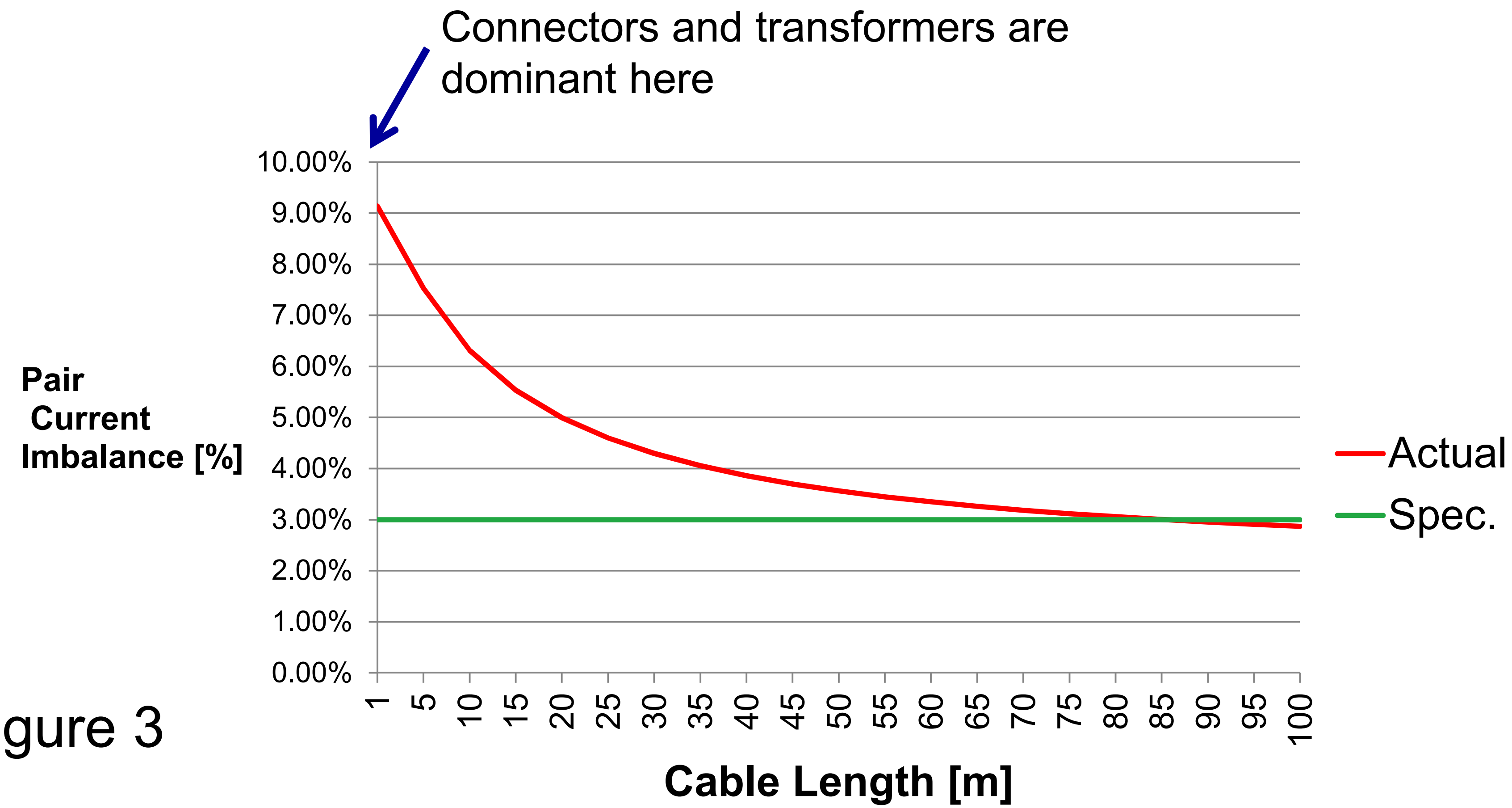


Figure 3

<u>How we resolved actual vs. specification?</u>
Using statistical calculations instead of worst-case analysis, actual transformers were designed for higher Iunb, reduction of inductance was tolerated by PHYs, typical Cable length was >>1m and Inductance specifications and droop concept was generate to allow improved design flexibility. So life was good. If not, (rare condition), the PD has handle it by using balancing technique as recommended in earlier versions of IEEE802.3 standard annexes.)

Pair to Pair (P2P) Imbalance - 1

- Pair to Pair (P2P) resistance imbalance: The resistance imbalance between wires in different pairs. P2P imbalance is not defined by the cabling standards nor by the IEEE standard[1].
- Why we need it? Resistance Imbalance between ALT A and ALT B results with $Ia=I+\Delta I$ and $Ib=I-\Delta I$. If Ib is limited to 600mA average max, then the total useable power at PSE output will be 50V*(0.6A+0.6A-ΔI) which results with lower than 51W at the PD input; ~(51W - ΔI*42.5V). (Iunb=2xΔI=Runb*1200mA.)
- The following actions has started for getting some P2P data.

a) Lab measurements of P2P resistance imbalance of cables from different vendors. preliminary results: We tested 6 vendors resulting with P2P max imbalance of <2%. In most cases it was <1%. This is not cable vendor data.)

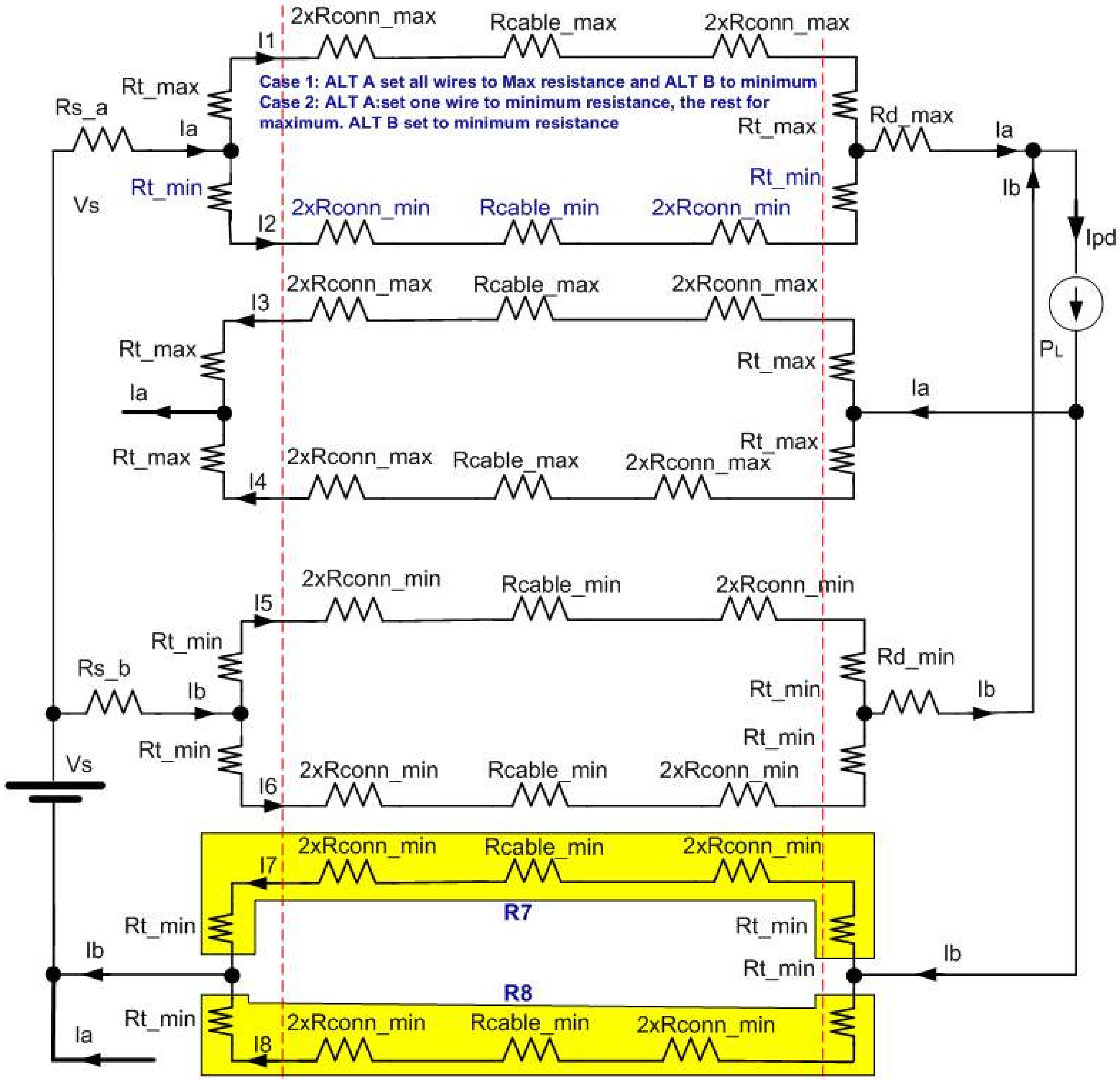
b) Worst case calculations of P2P resistance imbalance based on pair imbalanced data, due to the preliminary data that we have and need to be confirmed by other vendors that pair and P2P imbalance is within the same range.

c) Lab tests of current imbalance between pairs in a 4P system[2] for validation of the analysis.

Notes:

1. Cable vendor agree to test and supply P2P imbalanced data
2. Data analysis is in progress.

Pair to Pair (P2P) Imbalance - 2



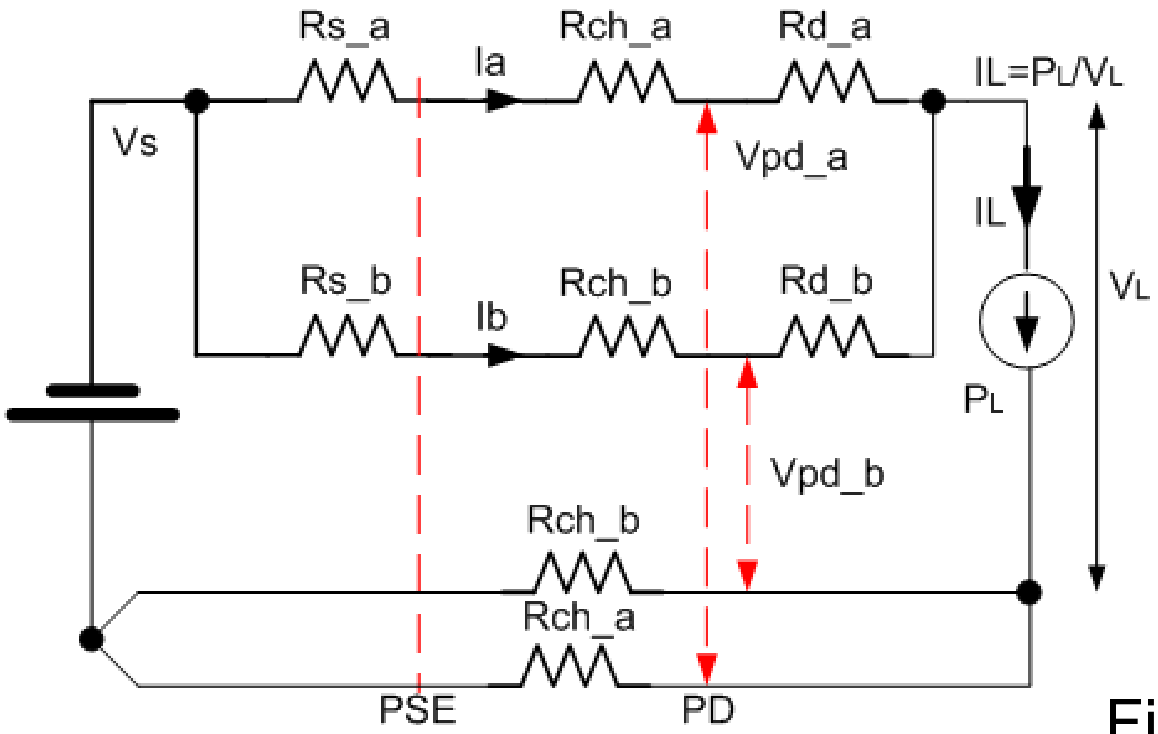
Rs: Resistance between voltage source to transformer center tap (e.g. Rs=Rsense+Rds_on).

Rd: Resistance between transformer center tap to the load RL.

Figure 4

Pair to Pair (P2P) Imbalance - 3

- Simplified general model with:
  - Single load[1]
  - Rc_x is the pair equivalent resistance e.g. R7||R8=R7*R8/(R7+R8) shown full 4P model



Rs: Resistance between voltage source to transformer center tap.
(e.g. Rs=Rsense+Rds_on).

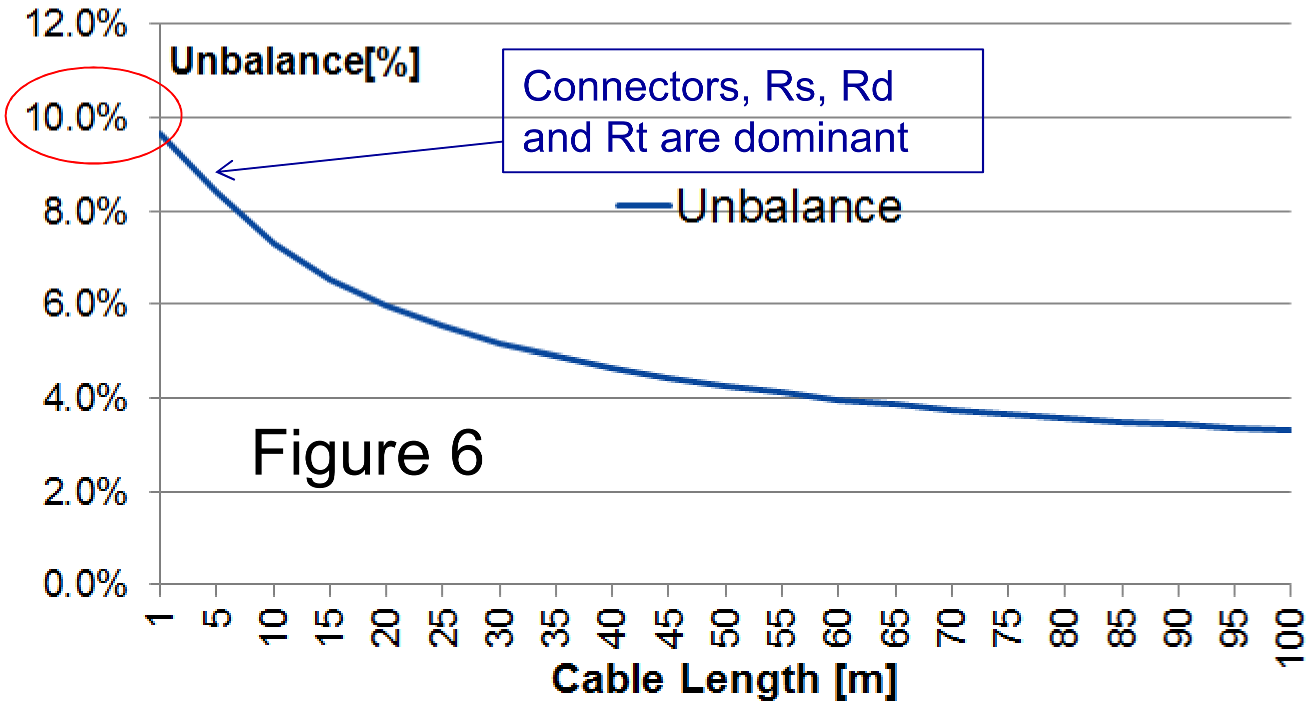
Rd: Resistance between transformer center tap to the load RL.

P_L: Is constant power sink as would be PD DC/DC.

Figure 5

Notes:
1. split load is easier to analyze and has no issue in regard to P2P current imbalance as long as Iport_max as specified over 2P is met

Pair to Pair (P2P) Imbalance - 4



Results for Case 1 from Figure 4:

Rs_max	See note below
Rs_unb	**25%**
Rt_max	**0.5Ω**
Rt_unb	**0.03Ω**
Rconn	**0.2Ω**
Rconn_unb	**0.05Ω**
Rcable	***0.117Ω/m***
Rcable unb	**2%**
Rd_max	**0.3Ω**
Rd_unbl	**25%**

Table 4

- All ALT A wires set to Rmax. All ALT B wires set to Rmin.
- We can see that current imbalance between ALT A and ALT B is increased in short cable length were all channel components imbalance excluding cable has strong effect.
- Normally, if current sharing balance is required, it is best that PD will take care of it since only the PD knows its maximum working power since for PD input power below X level no special means are required.
- It will be advantageous in future 4P specification to define the resistance imbalance [%] of Rs_a and Rs_b, Rd_a and Rd_b.
- In this analysis Rs=R_sense+Rds_on. R_sense=0.2Ω, with 5% imbalance in both Tables 4 and 5. Rds_on is 0.2 Ω with variable Runb per table 4 and 5

Pair to Pair (P2P) Imbalance - 5

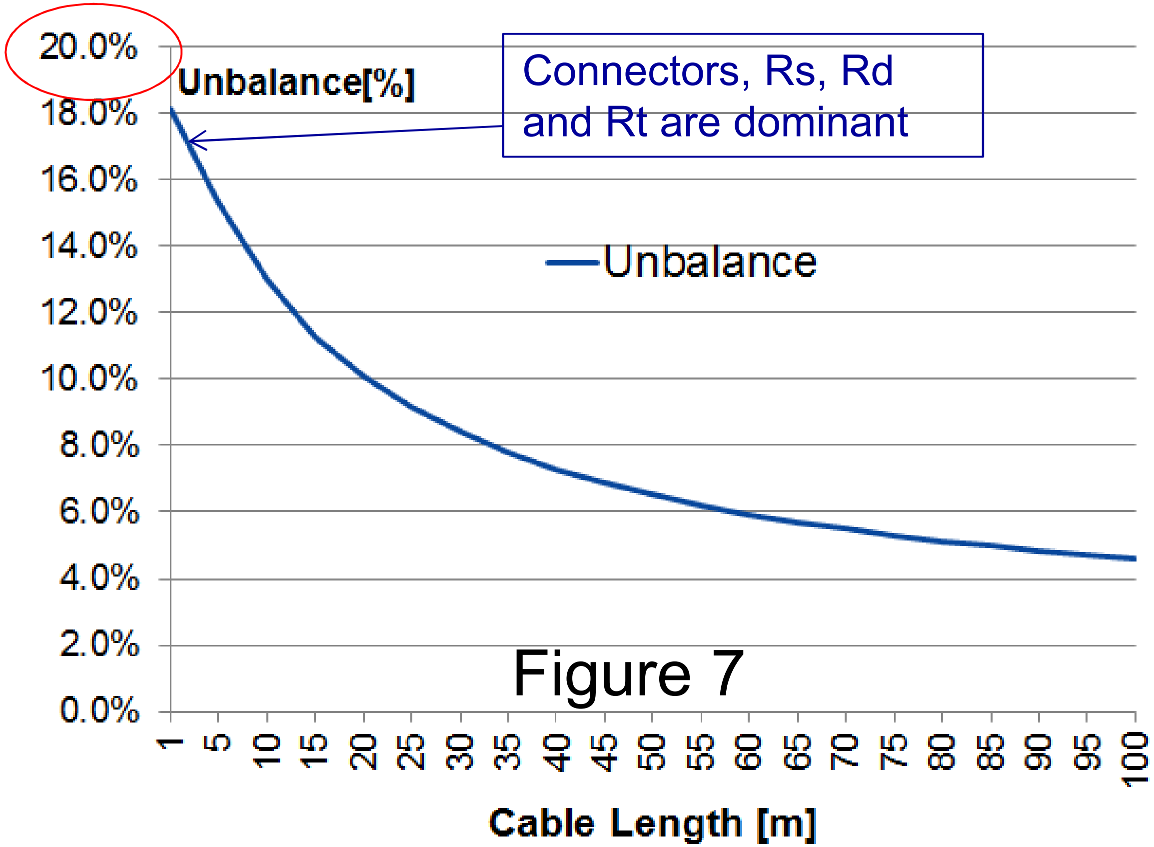


Figure 7

Rs_max	See note below[1]
Rs_unl	**50%**
Rt_max	0.5Ω
Rt_unb	0.03Ω
Rconn	0.2Ω
Rconn_unb	0.05Ω
Rcable	*0.117Ω/m*
Rcable unb	2%
Rd_max	0.3Ω
Rd_unb	**100%**

Table 5

- Increasing Runb for Rs and Rd for sensitivity analysis

1. In this analysis Rs=R_sense+Rds_on. R_sense=0.2Ω, with 5% imbalance in both Tables 4 and 5. Rds_on is 0.2 Ω with variable Runb per table 4 and 5
2. The imbalance[%] is dramatically increased if Rconn_max and Rs_max are reduced which cause Runb[%] of this component to be increased.

Simulations vs. Calculation. Vpse=50V

Simulations shows good match with calculations (done for Table 4 and 5 op. range).

Per Table	Cable Length [m]	Ia [mA]	Ib [mA]	Ia-Ib [mA]	Notes
4	1	463	566	-103	Ia and Ib<600mA → OK
	100	585	614	-29	Ib>600mA. Are we allow it?→ Task Force Ib<Icut=15%*0.6=90mA → Good. PD input guaranteed: 50.3W (50W)
5	1	438	589	-151.6	Ia and Ib<600mA → OK
	100	580	617	-37	Ib>600mA. Are we allow it?→ Task Force Ib<Icut=15%*0.6=90mA → Good. PD input guaranteed: 50.16W (50W)

In addition:100

In 1m cable, Vpd is increased, Iport is decreased. Example: Vpd=~49.6V, Ppd=51W →2 Iport=~1.029A.
In 100m cable Vpd is decreased, Iport is increased. Example: Vpd=42.5V, Ppd=51W→ 2Iport=1200mA.
The difference is (~-170mA total for 4P) from 100m to 1m.
Since we have higher R_unb in short cable, and lower Runb at long cable, The increase in Iport do to I_unbalance, is reduce by the reduction of Iport due to PD constant power model that reduces Iport when Vpd is going up.

The net result is that ALT A and ALT-B are now <600mA despite the high %unbalance at short cable.

Results Analysis - 1

- Iport is decreasing when Cable length is decreases while current unbalance is Increased. It helps us to reduce the increase in Iport over 2P that crosses Iport max (600mA) on the lower resistance ALT_X.

- The lines in the curve are trends. They are actually not linear. Next work on the subject need to show accurate cancelation per meter. Only the start and end points are sufficiently accurate.

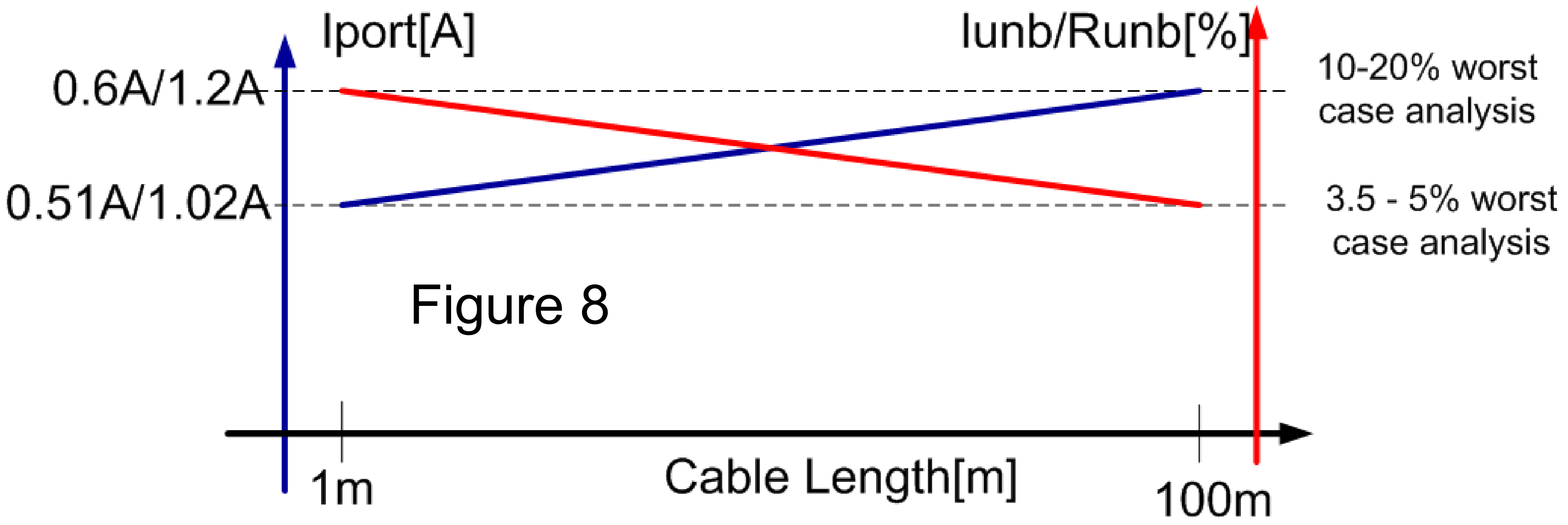


Figure 8

Results Analysis - 2

- The analysis was done for worst-case i.e. all components set to max or min resistance.
- In reality each component value has its own value distribution so %unbalance numbers at short cable are expected to be lower.
- Moreover Rs and Rd and Rt % unbalance values which are external components to the channel can be controlled (e.g. by specifying imbalance requirements e.g. "each PSE output resistance shall not exceed TBD% imbalance" to reduce channel sensitivity to their resistance imbalance. Therefore under controlled specification, Figure 6 lower imbalance results can be achieved.

Results Analysis - 3

- How P2P unbalance in 4P may affect Icut function of a 2P channel

- We saw that for Figure 6 data (10% maximum unbalance at 1m), Iport<Icut for 100m and 1m. ➔OK

- For higher %unbalance than 10% worst-case analysis method, we need to revisit this subject since the margin from Iport_max to Icut is significantly reduced and it is required to be addressed in the specifications[1]

Notes:

1. This is not implementation issue, it is worst-case analysis that try to cover most main possibilities

Results Analysis - 4

- Question: How I_unb affect cable temperature rise?
- Answer: The effect is negligible.
- Analytical Calculations will be presented in other presentation
- Power loss in unbalanced case is a bit lower than in balanced. Need to be verified in the analytical calculations.

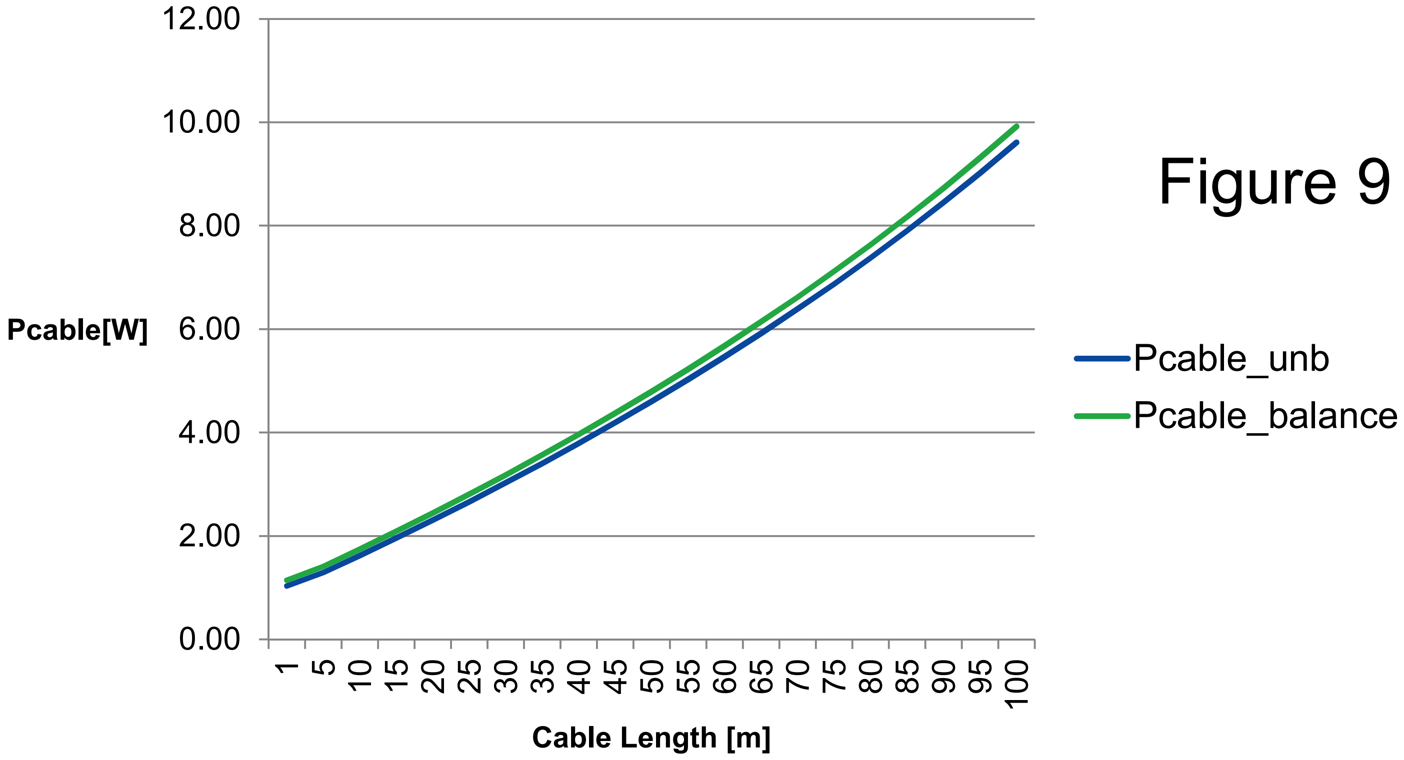


Figure 9

Summary-1

#	Parameter	Value	Notes
1	Worst-case P2P Current Imbalance calculation	<10%	-With typical controlled Table 4 components for short cable. -Gets to ~18% or 25-30% with lower connector resistance and much higher with uncontrolled components per table 5 example. -For 100m, the Imbalance is ~3.5 and 4.5% under Table 4 and 5 conditions respectively.
2	Effect of I unbalance on Magnetic components	Attention is required at 100m were Iport>Iport_max by ~29mA (3% unbalance for 1.2A is 29mA that can be distributed between the two channels. If equally distributed Channel A will be 585mA and Channel B will be 614mA which will affect Channel B Magnetic component (if pair unbalance exists within a single pair-i.e. case 2) by Pair_Runbl*14.5mA=0.435mA, Not significant effect but need to be addressed at higher power or higher allowance for P2P imbalance.	
3	Temperature Rise due to P2P imbalance	Negligible	

Summary-2

#	Parameter	Value	Notes
4	Current Imbalance effect on 2P overload.	The system works for us. At long cable the imbalance is small so I_imbalance<(Icut/Iport_max) ➔OK. For short cable, Imbalance is maximum however port current is lower which add margin for Icut.	
5	Results with Statistical Analysis	Statistical Analysis will supply lower imbalance results at short cable and in general. It will not change the conclusions of this work regarding the PD minimum power objective.	
5	Can we state the objective regarding PD min power for 4P PD?	Yes, with adding text that the means to ensure interoperability and compatibility while defining the minimum power to the PD, the Task Force should define the P2P imbalance in its text.	

Conclusions

- P2P imbalance need to be specified at the Task Force for all channel components including PSE output and PD input resistance.
- The PD constant power model works for us. It helps at short cable when P2P imbalance is higher but Iport is lower hence help to be still under 600mA per 2P pending P2P imbalance limits
- It is proposed to use the following text or equivalent for our objective:
- Option 1:

  The Task Force will define the P2P current imbalance in a 4P system while supporting a minimum of 51W power at the PD input.

Thank You

References

Ref	Sources
1	11801 © ISO/IEC:2002(E)
2	From IEEE 802.3at, page 40: Under worst-case conditions, Type 2 operation requires a 10 °C reduction in the maximum ambient operating temperature of the cable when all cable pairs are energized at ICable (see Table 33–1), or a 5 °C reduction in the maximum ambient operating temperature of the cable when half of the cable pairs are energized at ICable.
3	TIA information: TIA current capacity would be 600mA based upon 10degree temp rise or 735ma based upon 15degree temp rise. That is for all pairs energized over CAT5e, for 100 cables in a bundle
4	www.ieee802.org/3/at/public/2006/01/diminico_1_0106.pdf
5	Based on 19Ω/100m loop resistance as defined by 61156-5 Cable - 3.2.1 Conductor resístanse
6	IEEE802.3at Transformer and Channel ad-hoc: http://www.ieee802.org/3/at/public/2008/03/schindler_2_0308.pdf