IEEE802.3bt 4-Pair Power over Ethernet Task Force

Prevention of Potential Damage – Use Case Analysis

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Objectives

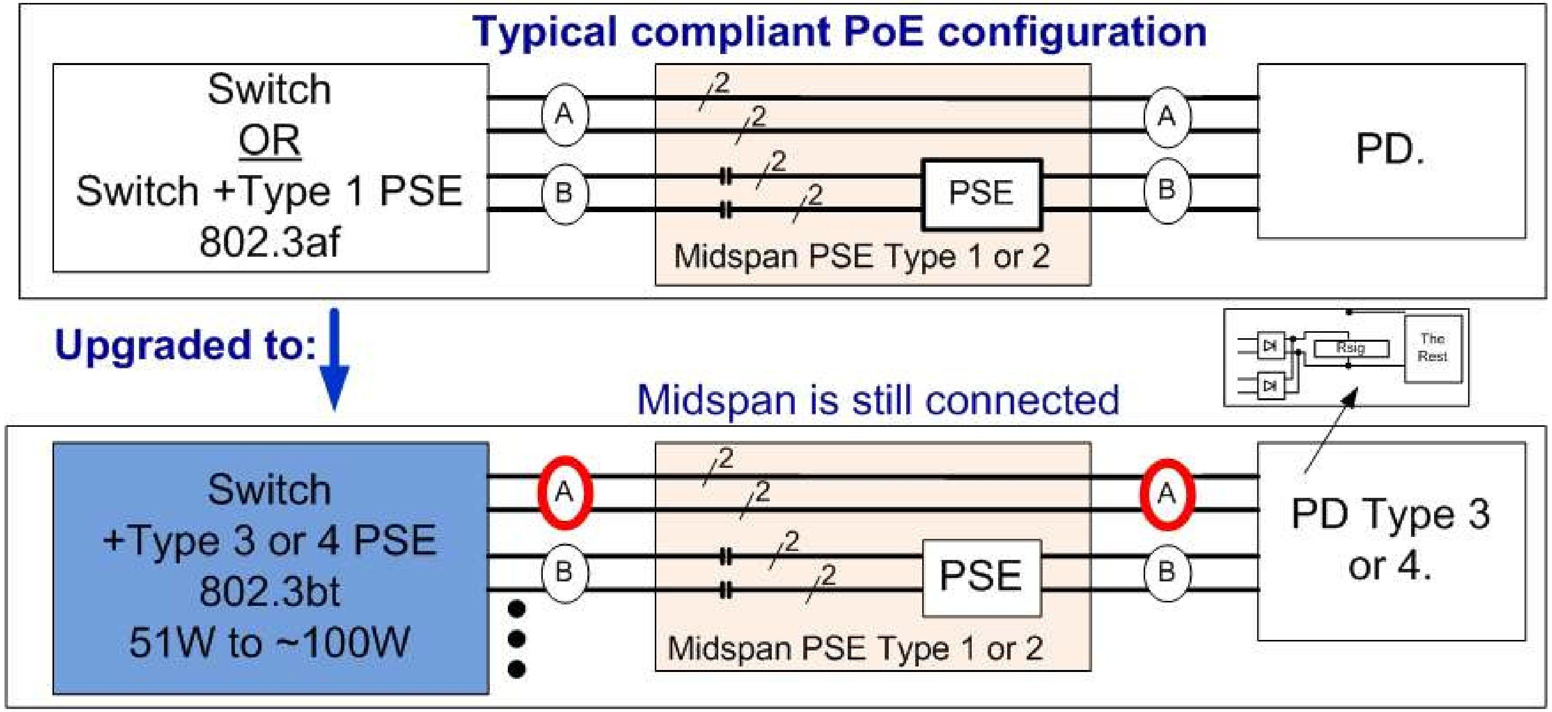
- To analyze some use cases that can end up with damage
- Focusing on cases were 4P total load current may flow through 2P
- To identify the means to prevent it

Terms

- Mode A: Power/Data Channel A =Pairs 1,2,3,6 in the PD.
- Mode B: Power/Data Channel B=Pairs 4,5,7,8 in the PD.
- Alternative A: Power/Data Channel A = Pairs 1,2,3,6 in the PSE as defined by IEEE802.3-2012
- Alternative B: Power/Data Channel B = Pairs 4,5,7,8 in the PSE as defined by IEEE802.3-2012
- PSE: Power Sourcing Equipment, as defined in IEEE Standard 802.3
- PD: Powered Device, as defined in IEEE Standard 802.3
- Detection: Per IEEE802.3 clause 33.1 and 33.3.5:
  - A protocol allowing the detection of a device that requests power from a PSE.
  - In any operational state, the PSE required not apply operating power to the PI until the PSE has successfully detected a PD requesting power.
  - Moreover the PSE is required to turn on power only on the same pairs as those used for detection.
- Type "3" (Temporary type name):PDs with up to 49W and PSE to support it.
- Type "4" (Temporary type name):PDs with >49W and less than 100W and PSE to support it.
- Ipeak, I_{CUT}, I_{LIM}: Pair current levels thresholds for peak power support, overload and short
- 1 P_CHANNEL: The two Alternative A and Alternative B are tied together at the PSE to form single 4P power channel by using single power switch between PSE load to PSE power supply.
- 2 P_CHANNEL: Per the current IEEE802.3-2012 standard, Alternative A and Alternative B are connected to PSE power supply through power switch per ALT A and ALT B.

Use Case #1 – Midspan in the channel - 1

During system upgrade, **or**
user connection error at comm. room patch panels to high power port equipment or to load ports.

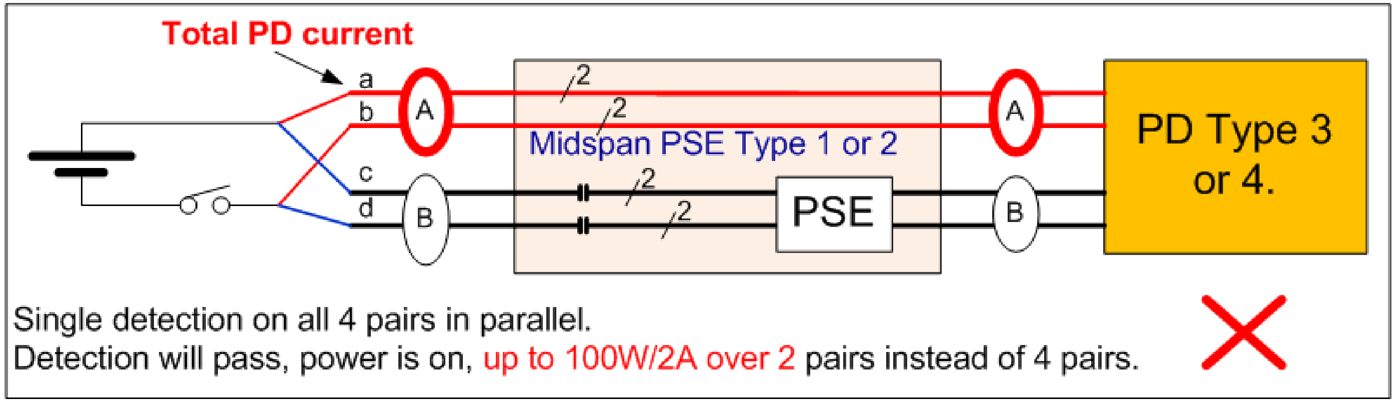


With 1 P_CHANNEL: If new 4P PSE performs single detection on all 4 pairs in parallel:

- PD asks for high power (51W or higher).
- End span wins the arbitration and provides power to PD.
- End span cannot see that it provides the 51W-100W power over 2P only

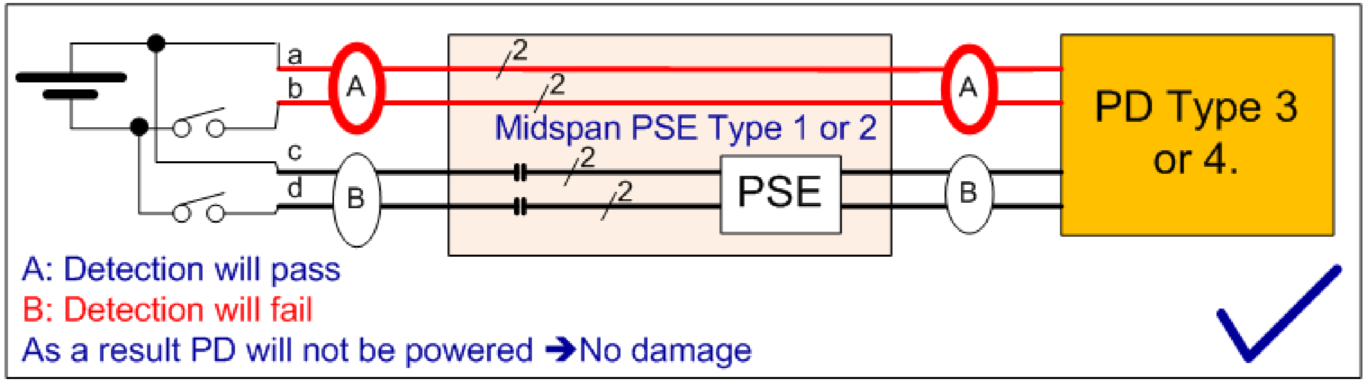
Use Case #1 – Midspan in the channel -2

- If single detection is used at the same time for all 4P in 1-Power Channel approach:
  - **PSE will turn on due to valid detection on ALT A. ALT B is open.**
- All power will be on the ALT-A pair resulting with damage to:
  - **Magnetics/ICMs, PCB traces? Connector pins?, compensation networks? PDs?**



1 P_CHANNEL

Over Temperature
➔ Damage
➔ Magnetic Overdesign
➔ Increased cost /size
See slides 15-18 for details



2 P_CHANNEL

-Following current IEEE802.3-2012 spec:
-Will not power ➔
-No damage to ICMs etc.

Detection is performed not simultaneously (staggered) on ALT A and on ALT B.

Use Case #1 summary

See slides 7 and 14-18 for details

- This is a clear case, that will easily happen in the field and does not require:
  - any broken wire or connection, any unusual condition
  - Even an IT specialist can experience it, or doing errors in equipment connections

#	Parameter	PSE Concept	
		1-Switch Approach	**2-Switch Approach**
1	Allows meeting Detection per IEEE802.3 clause 33.1 and 33.3.5	NO	YES
2	Prevent powering open pairs	NO	YES
3	Existing 802.3 Type 2: ICM temperature rise. -for 1 port out of 2x6 ICM -If all ports experience open load on 2Pair	May reach 150°C May reach 220°C	Normal Normal
4	Cost of ICMs compared to Type 2	Increased (30-50%)	Normal
5	Size of ICMs compared to Type 2	Increased	Normal
6	Over current protection for I_pair	2.3 x I_pair for all 4Pairs	1.2xI_pair over each 2Pairs
6.1	Overdesign Ratio compared to Type 2.	1.9	1

Use Case #2 – Wire/Pin Open/disconnected -1

4P Type 3/4 PSE connected to 4P Type 3/4 PDs.

- Type 2 PSE/PD magnetics can work with Type 3 (2x30W at PSE) systems.

  See slides 14 for details
- Rt=Transformer winding resistance
- R=The other channel components resistance.
- Total load current between channels is split between power channel (ignoring the P2P Channel RUNB for simplifying the discussion)

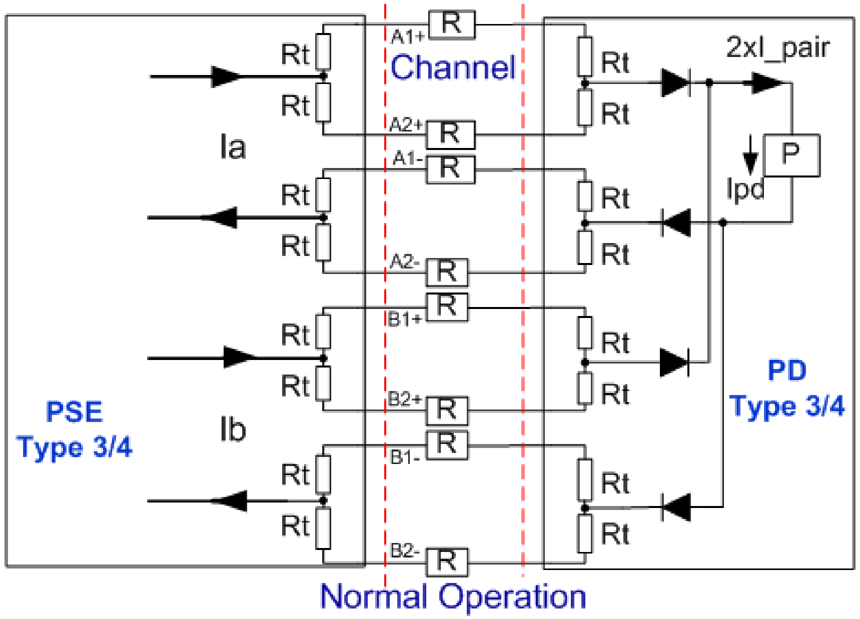


Figure 5

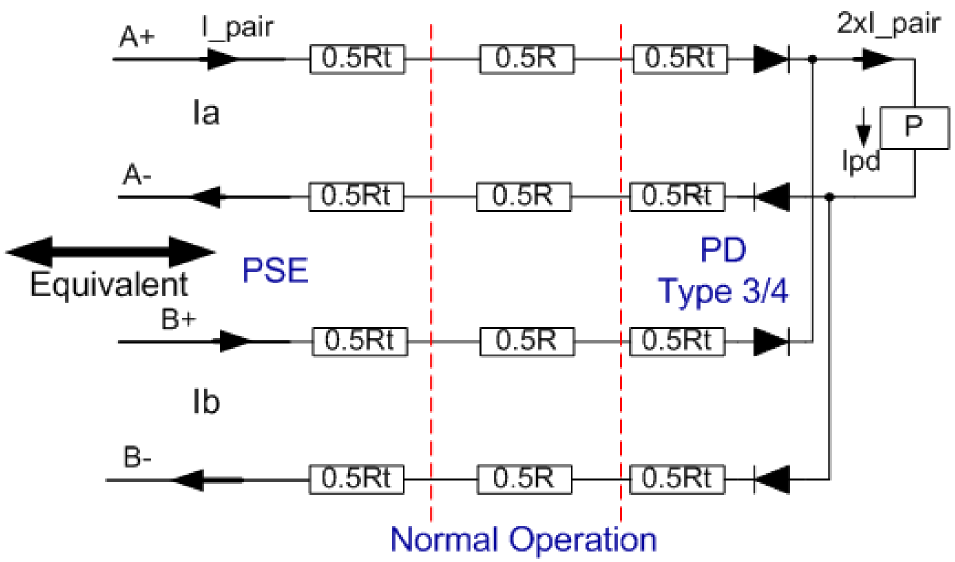


Figure 6

Typical 4P system

Use Case #2 – Wire/Pin Open/disconnected -2

4P Type 3/4 PSE connected to 4P Type 3/4 PDs.

(*) Rt is not shown in the drawings
(**) Example of w.c. 2xI_pair for 2 wires disconnected.

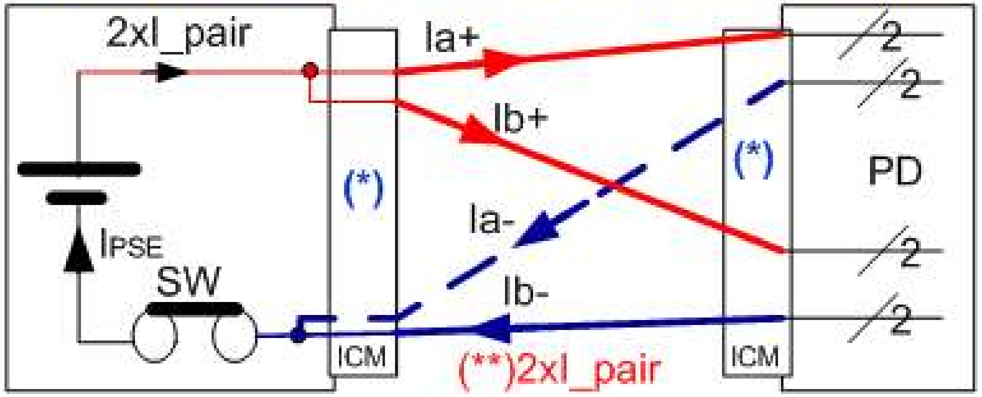


Figure 7

- Measured current=Ipse=Ipd
- Power switch threshold: >2.3xI_pair
- No protection for existing Type 2 magnetic components that can be used for Type 3.
- Very low fault coverage. (<15%).
  - *Can't detect current diff. between pairs*
- Magnetic components must be overdesigned for **>2.3xI_pair** current min. **See Annex B for details.**
- Cost and Size impact

(***) I_pair if sensing current on positive path. 2xIpair if not.

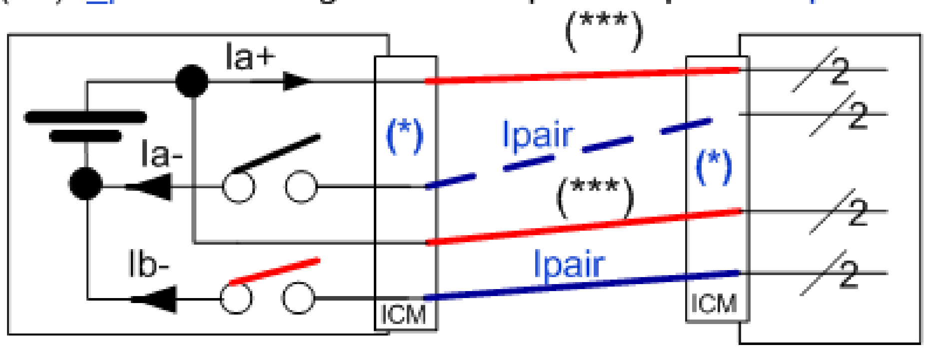


Figure 8

NO NEED magnetic component overdesign.

- Inherent fault coverage of ~50% to 70% of wire disconnections/user faults.
- Can support 100% fault coverage with additional sense resistor(s) on one of the positive paths or both (e.g. Ia+).
- No need for magnetic component overdesign
- Same Type 2 PSE/PD components for Type 3 PDs can be used .
- For Type 4 PDs – ICM size is still related to only ½ of the total current

Use Case #1 & #2-Conclusions and PSE concept comparison

See slides 14-18 for details

#	Parameter	# of open wires	PSE Concept	
			1-Switch Approach	2-Switch Approach
1	Fault coverage	-	<15%	70% - ~100%****
2	Power dissipation increase ratio* (1 wire)	1	1.92	1
		2**	5.28	1
3	Size increase ratio	1	1.38	1
		2**	2.3	1
4	Existing 802.3 Type 2: ICM temperature***	0	120°C	120°C
	-for 1 port out of 2x6 ICM.	1	150°C	Protection is activated. Power is OFF
	-for 1 port out of 2x6 ICM.	2**	May reach 155°C	
	-If all ports see open two wires in a pair.	2**	May reach 220°C	
5	Cost Increase of ICMs compared to Type 2	1 / 2**	30-50%	
6	Over current protection for I_pair (min.)	-	2.3 x I_pair for all 4Pairs	1.2xI_pair over each 2Pairs
6.1	Overdesign Ratio compared to Type 2.	-	1.9	1

- * Compared to Type 2
- ** wires on the same pair
- *** Inside BOX temperature 70°C. Trise= ICM temperature - 70°C. Pout=60W.
- **** 70% inherent by measuring Ia-, Ib-. ~90% by measuring Ia+ and/or Ib+. 100% with current measurement and data.

Summary

- 1-Power Channel , all power channels are shorted in parallel at PSE side
  - It not allows preventing damage per the few examples described.
    - prevents using IEEE802.3-2012 current standard detection specifications over each two pair for not powering open pairs or invalid loads (e.g. use case #1).
  - It requires overdesign/cost/size increase to keep reliability under fault
    - Magnetic Components/ICM
    - Other system components/PCB etc. to endure >2xPair current
  - Pair/wires current may exceeds its spec limit under fault (e.g. use case #1/#2).
- 2-Power Channel (allows detection and power on/off capability over each 2P)
  - No overdesign is needed for Type 3 and 4 PoE systems.
  - Same reliability as Type 2 (802.3AT) systems at lower cost.
  - This project will increase PoE power capability by ≥2X factor and cost <2X. Resulting with reduction system $/W as W is increased as expected.
  - Type 3 systems will benefit the Cost, Size, and market quantities of Type 2.
  - Proven concept, used by many system vendors for long time.
- It is recommended to focus on 2-power channel approach as our base line

Q&A

Thank You

More information is available on next slides.

Current implementation of magnetic component

- Type 1 / 2 magnetic components are design to work at 350mA / 600 mA DC respectively .
- The OCL of the magnetic component need to be met at DC bias current of at least 13.25[1] mA for Type 1 and 18.23mA[1] for Type 2 not including temperature, production and other considerations.
- The DC bias is function of the channel pair resistance *unbalance* specified to be 3%.
  - In reality the pair channel resistance imbalance is higher than 3%. See details at reference 1 and 2.
- In 4 pair operation, channel pair to pair resistance unbalance (P2PCRUNB) is accounted for too[3] .as Worst-case P2PCRUNB was calculated to ≤26.3% at short cable[2,3].
  - At reality P2PCRUNB is much lower than 26.3% due to the statistics that works for us.
  - Fortunately at short cable, PD input voltage is higher ➔ <600mA /pair in Type 3 systems.
  - Even if P2PCRUNB=26.3% and Type 3 total current is 2x600mA=1.2A ➔ Ibias[1]=21mA
- As a result, the above Type 2 magnetic <u>component size </u>and performance that is used in the market today at high volumes, can potentially be used for Type 3 as well. As a result, the Type 2 magnetic component will be used as reference for cost and size ratio calculations.

1. See annex A for details. Type 1 magnetic vendors are often design Ibias to 10.5mA and yet system is working due to probably excellent PHYs.
2. As opposed to worst-case analysis, it will be shown in future work as done in reference 2 for pair channel resistance unbalance, that much lower than 26.3% channel pair to pair resistance unbalance is expected.
3. See reference 1, 3 and references 4 for derivation of worst-case analysis numbers and worst-case data base.

Use Case # 1 and #2
Implication on transformers/ICM -1

If 4P power e.g. 60W is flowing only over 2P **due to “Midspan on the way” (refer to figure 4) or disconnected pins/wire**

- Need to overdesign the magnetic components to support full PD power over one 2pair. Otherwise wire insulation could burn, creating a short → damaged equipment. As a result:
  - For 60W PD 1.2A flow over 2pair should be supported.
  - For 100W PD 2A flow over 2pair needs to be supported – Per the bullet below, not recommended
- In an ICM If the current rating in any pair is exceeded, the wire will generally open (disconnected) after overheating like a fuse.
- To mitigate it, larger power handling magnetic components are required and this would increase the ICM cost and would not be a practical approach to a cost sensitive design but could be done.
- If we can detect such cases than overdesign and increased cost /size can be significantly reduced.
- Currently it is not practical to accept all 100W over 1-power pair (Just RJ channels 1&2 or 3&6). This design is physically possible, but the cost adder would be over 50% which is not feasible for the market.
  - Size would also be an issue.
- At this time for the 100W solution it is recommend the power CMC’s be put outside the ICM due to heat related issues.

Use Case # 1 and Use Case # 2
Implications on transformer/ICM during fault -2

Source: Magnetic Component Vendors for a 12 port system using 2x6 ICM modules.

- If we cannot detect invalid signature of open pairs (case #1) and not power this pair(s) OR Open pairs/wires by detecting Over Current per power channel due to any reason
  We will have the following table results.
- Damage to ICMs that are designed to carry ½ of the total system power (plus unbalance). Temperature rise: ~150degC (even when just one port experiences this problem in a 2x6 ICM .
- To resolve it, overdesign the magnetics for 802.3bt Type 3 and 4 system is required which will results with 30-50% cost increase. (In addition to size impact).

System	Open RJ45 pin #	All current flow through pin #	Temperature Rise [C°]	System operating temperature inside[C°]	T_mag
30W	Normal connection	Alt-A = 0.6A all 12 ports	26	70	106
	3 (example)	6	50	70	120
60W	Normal connection	Alt-A & Alt-B = 0.6A	50	70	120
	3 (example)	6	~80	70	150
60W	1.2A on 2P with existing 802.3at ICMs in 4P systems	Only one pair carrying 1.2A, other 11 ports 0.6A on alt-A & alt-B	~85	70	155
	1.2A on 2P with existing 802.3at ICMs in 4P systems	In all ports, all current is going through 2P.	Estimated >150	70	>220

What-If analysis–wire disconnection on Type 3 systems magnetics

#	Wires/Pins Disconnected	P2PCRUNB[1]	Power Loss Ratio	Size Ratio to keep same Trise	No damage is required	System need to work
1	No Faults[2]	≤26.3%[3]	1	1	YES	YES
2	1. (Use Case#2)	>66%[4]	≥1.92[5]	≥~1.38[7]	YES	NO
3	2. (on same pair). (Use Case # 1 and 2)	➔100%[4,6]	≥5.282[5]	~2.3[7,8]	YES	NO

1. P2PCRU =Pair to Pair Channel Resistance Unbalance

2. No Faults =All wires connected. Currents are distributed evenly between pairs assuming P2PCRU=0 for simplicity.

3. P2PCRUNB is expected to be lower after statistical analysis and in addition, load current will be lower at short cable.

4. It doesn't include the inherent P2PCRU i.e. it will be higher than 66%.

5. See details in Annex C.

6. (Rmax-Rmin)/(Rmax+Rmin) for Rmax➔∞, =1 ➔ 100%. **See details in Annex C.**

7. Core size: Core size increase can be evaluated by Core Area product known as AP=Ac*Aw. Ac set the core size to meet signal parameters requirements and inductance and Aw sets the core window are that affected by number of winding and current. If the current is increase by a factor of α: the power loss is increased by α^2. To maintain the same power dissipation, the wire diameter need to be increased by α which requires increasing core window area Aw, by at least α. α=1.386 (~38% increase) for single wire disconnected and 2.298 for two wires of the same pair disconnected.

8. Area product is kind of discreet function i.e. a rang of operating currents can be use with same size. For Power levels approaching 100W/2A, significant size increase is a sure thing.

Annex A – Transformer Ibias calculations

- Per IEEE802.3-2012 Table 33-11 item 20, the I_unbalance is defined as:
- 3%*Icable for Type 1 systems
- 3%*Ipeak for Type 2 systems. Ipeak is defined by Equation 33-4.
- It was recommended that Type 1 will meet type 2 requirements.
  - **For Type 1:**
    - Iunbalance=3%*350mA=10.5mA.
    - Ibias=10.5/2=5.25mA not including the 8mA BLW which will result with total I bias=13.25mA.
    - Magnetic component vendors actually design for lower I_bias i.e. just 10.5mA due too probably the fact that current PHYs can easily handle lower OCL than 350uH.
  - **For Type 2**
    - Idc=600mA, Ipeak=680mA max for Peak=1.11*25.5W
    - 3%*680mA=20.47mA.
    - PoE contribution to Ibias=Iunb/2=10.23mA
    - In addition 8mA BLW need to be added so total is I_bias=18.23mA.
  - **For Type 3**
    - Ibias=0.008A+(2x680mA*0.262/2+680mA)*0.03/2=21mA for the worst-case analysis. While Type 2 magnetics need to meet OCL at 18.4mA.
- The above assumes channel unbalance of 3% per IEEE definitions HOWEVER we know that the real channel unbalance is >3% which will results with higher numbers than 18.23mA for Type 2, and higher for Type 3 and 4 that will include even worth channel pair unbalance and also P2P RUNB effect.
- <u>The general case is:</u>
- Ibias=data_avg_current+PoE_bias_current. For 100BaseT: data_avg_current=8mA dc bias caused by data.
- PoE bias current=+3%*I_pair_max/2. (3% is per spec. In reality it is higher.)
- Ipair_max=(P2PCRUNB*2*I/2+I)+ design margin.
  - I=0.6A for Type 2 systems. P2PCRUNB=0 for 2P system.
- Ibias=8mA+3%*(P2PCRUNB*2*I/2+I)+ design margin.

Annex B – Current limit threshold calculation

- IEEE802.3-2012 table 33-11 item 9 requires to limit the pair current to 1.14*I_pair/cable. See also in addition:
  - IEEE802.3-2012 Figure 33-11
  - IEEE802.3-2012 Clause 33.2.7.4 Eq. 33-4 for Ipeak
  - IEEE802.3-2012 Requirements for Icut and Ilim
- current limit threshold calculation for 4P PSEs:
- <u>Single power channel/switch approach</u>
  - I_limit_min≥2x1.14*Ipair=2.28*Ipair minimum (+ Design margin) ➔ rounding up to 2.3
  - Ilimit_min>2.3*Ipair + design margin to address all IEEE requirements above.
  - Ipair=0.6A for Type 3 systems and 1A max for Type 4 systems.
  - It impose magnetic component overdesign by factor of 2.3 minimum.
- <u>Two power channel/ switch approach</u>
- I_limit_min ≥ (1.14+0.5*P2PCRUNB(max current)*Ipair. Worst case P2PCRUNB at long cable for max current is 11.19% max ➔ <12% (and may be lower at statistical analysis).
- I_limit_min ≥ (1.14+0.5*0.12)*Ipair =~1.2*Ipair.

Parameter	2 power channel	1 power channel
Current limit threshold minimum	1.2*I_pair.	2.3*Ipair
Overdesign factor	1	2.3/1.2=1.916➔**1.9**

Annex C – Wire Disconnection, Ploss calculation

Rwire=	12.5
Vpse=	50
Ppd=	51

Input Data

A1+	Rwire 1	0	Rpos=	4.167	Rchannel=	7.291667	Vpd=	40.90990258
A2+	Rwire 2	1					Ipd=	1.24664
B1+	Rwire 3	1						
B2+	Rwire 4	1						
A1-	Rwire 5	1	Rneg=	3.125				
A2-	Rwire 6	1						
B1-	Rwire 7	1						
B2-	Rwire 8	1						

Wire Map: set wire to 0 for disconnect. See figure 5 for model and wire names.

1 wire disconnected		
Rch=7.291		
Ipd=	Symb	1.247
Normal curret	Ref	0.600
I(A1+) disconnected Current through A2+	min	0.416
Current through (B1+, B2+)	Max	0.831
Max/Ref ratio		1.386
(Max/Ref)^2 ratio		1.920

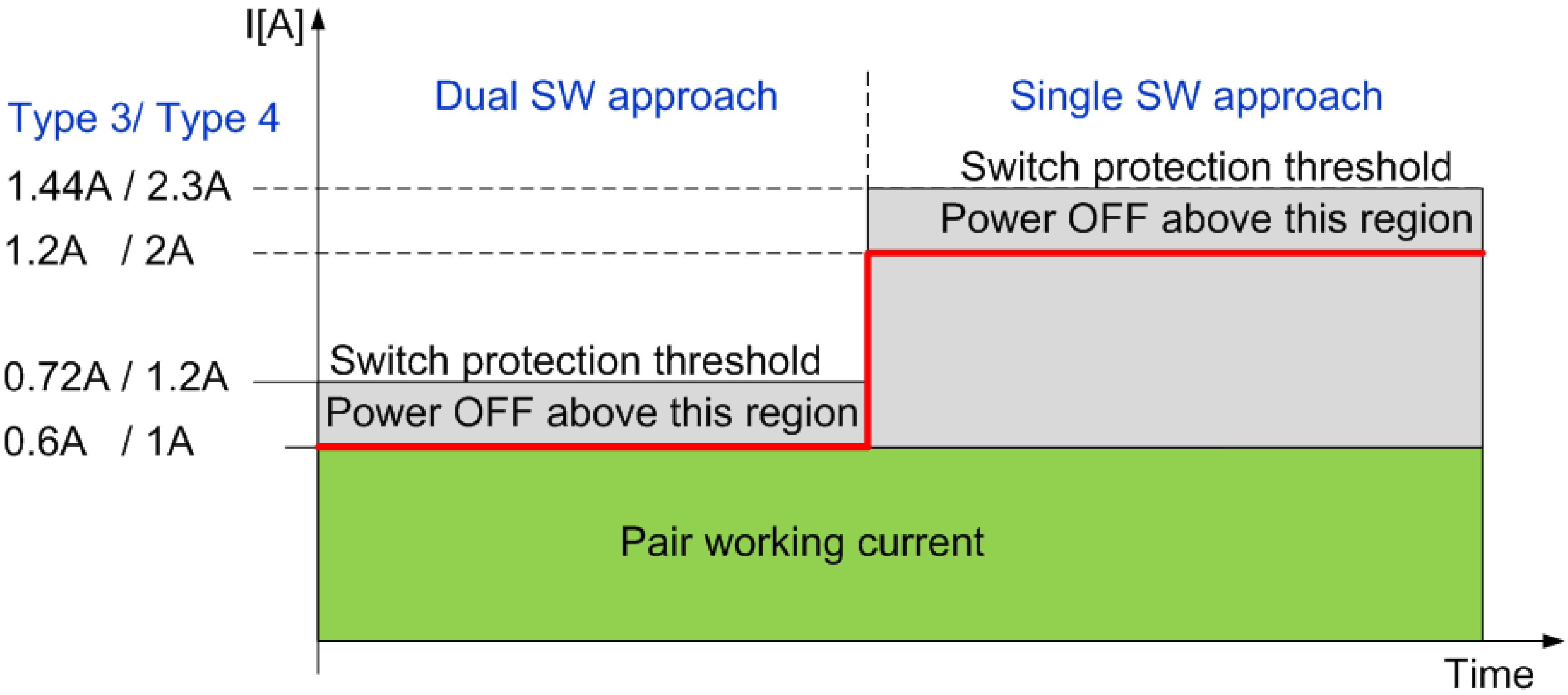
2 wire disconnected		
Rch=9.375		
Ipd=	Symb	1.374
Normal curret	Ref	0.600
(A1+, A2+) disconnected	min	
Current through (B1+, B2+)	Max	1.379
Max/Ref ratio		2.298
(Max/Ref)^2 ratio		5.282

- Rch is the total equivalent of 4P loop resistance.
- Ipd for type 3 system is 2x0.6A=1.2A for reference ignoring P2PCRUNB effects for simplicity.
- Power loss increase ratio

-1 WIRE DISCONNECTED: Due to constant power sink, Ipd will increase from 1.2A to 1.247A and will be 0.831A over wires B1+, B2+ while wire A1+ is disconnected. Current will increase by a factor of α=0.831A/0.6A=1.386 and power loss will increase by 1.386^2=1.92.

-2 WIRE DISCONNECTED ON THE SAME PAIR: Power loss will increase by a factor of (I/(0.5*I))^2=4 since now all the current is flowing through 2P. However due to the constant power sink effect current will increase to 1.379A so the the current will increase by a factor of α=1.379/0.6=2.298 and the power loss will increased by a factor of 2.298^2=5.282.

Continuous current before hitting protection threshold for Type 3 and 4 systems



- In single SW approach: protection threshold is >>normal pair current
  - All components from end to end need to be verified to stand 2.3xPair current
- In dual SW approach: Same 802.3at thresholds. No issues.

References

- 1. pair resistance unbalance and Pair to pair resistance unbalance: http://grouper.ieee.org/groups/802/3/4PPOE/public/jul13/darshan_2_0713.pdf
- 2. IEEE802.3at Transformer and Channel ad-hoc: http://www.ieee802.org/3/at/public/2008/03/schindler_2_0308.pdf
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