Power Matters

IEEE802.3 4P Task Force

PSE PI and PD PI Pair to Pair Specifications

Rev 002

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Objectives

- Proposing PSE PI and PD PI minimum set of unbalance parameters for having:
  - Complete specification (mathematically complete)
    - Derived from E2E_C_P2PRUNB
  - Implementation independent (as much as possible)
    - Ensures interoperability
  - Worst case value
    - Single value to single parameter
  - Allow flexible design of PSEs and PDs
  - Simple to use by PSE/PD designer

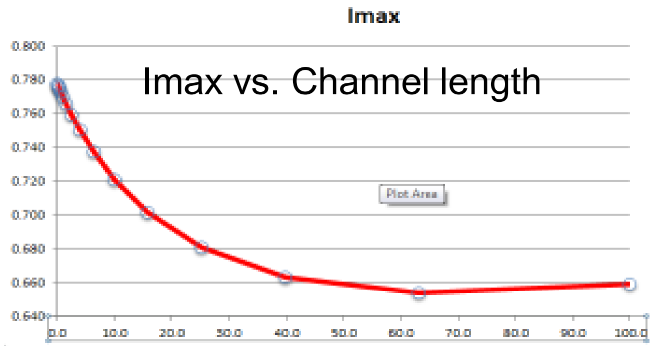
References

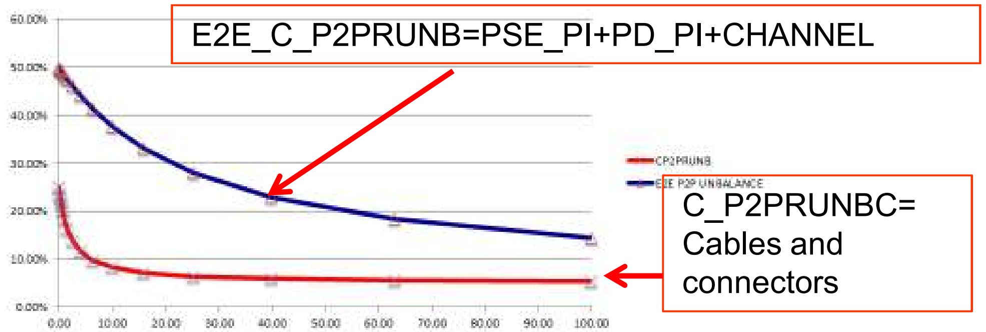
- Previous work:
- http://www.ieee802.org/3/bt/public/jul14/Generating%20the%20PSE%20and%20PD%20PI%20models%20and%20their%20unbalance%20requirements%20rev%20013b.pdf

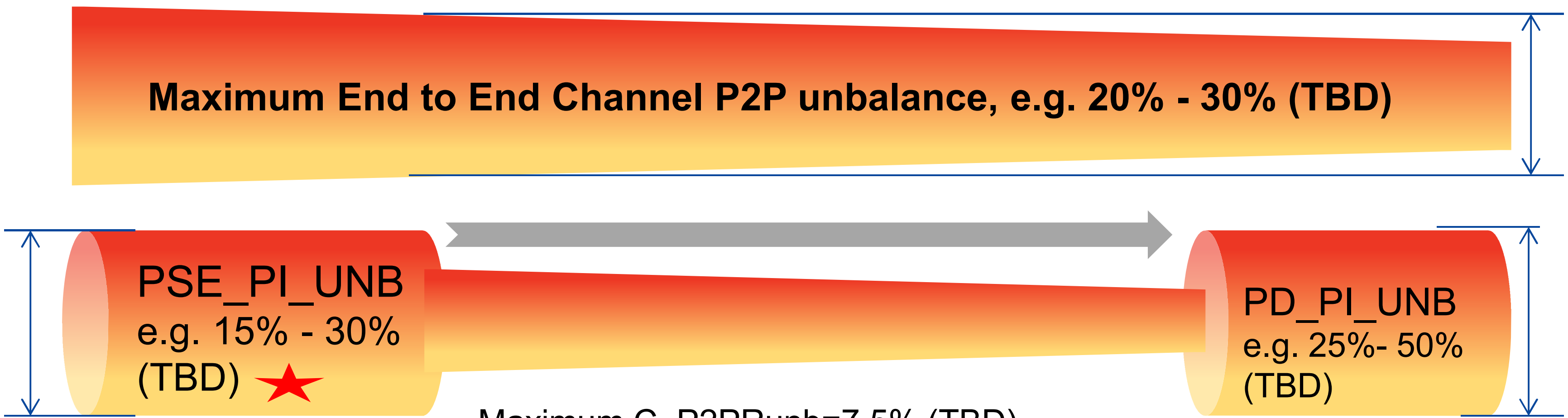
- Revision History:
- Rev 001:
  - Slide 9: The note at the title was updated to sync with slide 8 content.
  - Slide 17: Typo on last bullet.
- Rev 002:
- Slide 4: Adding title to the curve.
- Slide 14-17: updating numbers for sync with 0.72A max instead of 0.74A max.

Proposal for PSE PI ★ - Overview -1

- All parameters are specified between pairs of the same polarity







Maximum C_P2PRunb=7.5% (TBD)
or Rdiff=0.1Ω which ever is greater

- See Annex G5, G6 and G7 examples for systems with lower unbalance as well.

Example for Existing PSE PD PI P2PRUNB Source: Annex G1, PSE PI Vdiff=0.

- Reqv=The resistance equivalent caused by P2P voltage difference on the E2E_C_P2PRUNB
- Rd_eqv=The resistance equivalent caused by PD diode voltage difference and Diode dynamic resistance difference
- The following example is with PSE PI Vdiff=0.

	PSE PI POS								
	Traces	Rt	Rc			Reqv	Sum	Rdiff	P2PRUNB
Rmin [ohm]	0.01	0.12	0.03			0	0.16	0.031	8.83%
Rmax [ohm]	0.011	0.13	0.05			0	0.191		
	PSE PI NEG								
	Traces	Rt	Rc	Rsense	RDSon	Reqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03	0.098	0.05/0.099	0	0.308/0.357	0.083/0.034	11.87%/4.55%
Rmax	0.011	0.13	0.05	0.1	0.1/0.1	0	0.391/0.391		
	PD PI POS								
	Traces	Rt	Rc			Rd_eqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03			0.25	0.41	0.281	25.52%
Rmax	0.011	0.13	0.05			0.5	0.691		
	PD PI NEG								
	Traces	Rt	Rc	Rsense	RDSon	Rd_eqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03	0	0	0.25	0.41	0.281	25.52%
Rmax[ohm]	0.011	0.13	0.05	0	0	0.5	0.691		

Example for Existing PSE PD PI P2PRUNB Source: Annex G1, PSE PI Vdiff>0.

- Reqv=The resistance equivalent caused by P2P voltage difference on the E2E_C_P2PRUNB
- Rd_eqv=The resistance equivalent caused by PD diode voltage difference and Diode dynamic resistance difference
- The following example is with PSE PI Vdiff>0. P2PRUNB=(Rmax-Rmin)/(Rmax+Rmin)

	PSE PI POS								
	Traces	Rt	Rc			Reqv	Sum	Rdiff	P2PRUNB
Rmin [ohm]	0.01	0.12	0.03			0	0.16	0.131	29.05%
Rmax [ohm]	0.011	0.13	0.05			0.1	0.291		
	PSE PI NEG								
	Traces	Rt	Rc	Rsense	RDSon	Reqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03	0.098	0.05	0	0.308	0.183	22.90%
Rmax	0.011	0.13	0.05	0.1	0.1	0.1	0.491		
	PD PI POS								
	Traces	Rt	Rc			Rd_eqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03			0.25	0.41	0.281	25.52%
Rmax	0.011	0.13	0.05			0.5	0.691		
	PD PI NEG								
	Traces	Rt	Rc	Rsense	RDSon	Rd_eqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03	0	0	0.25	0.41	0.281	25.52%
Rmax[ohm]	0.011	0.13	0.05	0	0	0.5	0.691		

Example for Existing PSE PD PI P2PRUNB
Source: Annex G1, PSE PI Vdiff=0, PD Match diodes.

- Reqv=The resistance equivalent caused by P2P voltage difference on the E2E_C_P2PRUNB
- Rd_eqv=The resistance equivalent caused by PD diode voltage difference and Diode dynamic resistance difference
- The following example is with PSE PI Vdiff=0 and PD using matched diodes. With ideal diode bridge PDE PI P2PRUNB may be a bit higher due to lower resistance and process.

	PSE PI POS								
	Traces	Rt	Rc			Reqv	Sum	Rdiff	P2PRUNB
Rmin [ohm]	0.01	0.12	0.03			0	0.16	0.031	8.83%
Rmax [ohm]	0.011	0.13	0.05			0	0.191		
	PSE PI NEG								
	Traces	Rt	Rc	Rsense	RDSon	Reqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03	0.098	0.05/0.099	0	0.308/0.357	0.083/0.034	11.87%/4.55%
Rmax	0.011	0.13	0.05	0.1	0.1/0.1	0	0.391/0.391		
	PD PI POS								
	Traces	Rt	Rc			Rd_eqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03			0.225	0.385	0.056	6.78%
Rmax	0.011	0.13	0.05			0.25	0.441		
	PD PI NEG								
	Traces	Rt	Rc	Rsense	RDSon	Rd_eqv	Sum	Rdiff	P2PRUNB
Rmin[ohm]	0.01	0.12	0.03	0	0	0.225	0.385	0.056	6.78%
Rmax[ohm]	0.011	0.13	0.05	0	0	0.25	0.441		

Proposal for PSE PI Solution 1 - Derivation

- End to End Channel P2PRUN that sets Imax including P2P Vdiff in PSE and diode effect in PD is embedded in form of resistance in the following equation:

$$\mathrm{Im}\,ax = \frac{It\cdot(1+E2E\_P2PRUNB_{MAX})}{2} = \frac{It\cdot\left[1+\frac{\left(\sum PSE\,R_{\max}-\sum PSE\,R_{\min}\right)+\left(\sum PD\,R_{\max}-\sum PD\,R_{\min}\right)+\left(\sum CH\,R_{\max}-\sum CH\,R_{\min}\right)}{\left(\sum PSE\,R_{\max}+\sum PSE\,R_{\min}\right)+\left(\sum PD\,R_{\max}+\sum PD\,R_{\min}\right)+\left(\sum CH\,R_{\min}+\sum CH\,R_{\max}\right)}\right]}{2}$$

- The transformed (equivalent) PSE PI value (The real PSE PI contribution to Imax, PSE_PI_P2PRUNB_eqv).

$$PSE\_PI\_P2PRUNB_{MAX}\_eqv = \frac{\left(\sum PSE\,R_{\max}-\sum PSE\,R_{\min}\right)}{\left(\sum PSE\,R_{\max}+\sum PSE\,R_{\min}\right)+\left(\sum PD\,R_{\max}+\sum PD\,R_{\min}\right)+\left(\sum CH\,R_{\min}+\sum CH\,R_{\max}\right)}$$

- The physical PSE PI P2PRUNB

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

- We need to implement PSE PI to meet PSE_PI_P2PRUNB_eqv.

$$PSE\_PI\cdot f(k,\alpha,\beta) = PSE\_PI\_P2PRUNB_{MAX}\_eqv$$

- The physical PSE PI P2PRUNB is not equal to its contribution in the system equation above as a result we need to equalize both terms above.
- For examples how to do it please see:
- http://www.ieee802.org/3/bt/public/jul14/bennett_01_0714.pdf and updated versions at E2E_C_P2prunb adhoc site.
- http://www.ieee802.org/3/bt/public/jul14/Generating%20the%20PSE%20and%20PD%20PI%20models%20and%20their%20unbalance%20requirements%20rev%20013b.pdf

Summary -What are the minimum parameters set?

Note: All values and parameters are after transformation to fit E2CP2PRUNB behavior and limits

α, Rmax, Rmin are the effective behavior derived from system E2E_C_P2PRUNB

$$\alpha = \frac{\sum R\max - \sum R\min}{\sum R\max + \sum R\min} = \frac{\sum Rdiff}{\sum R\max + \sum R\min}$$

Option	PSE PI P2PRUNB_eqv= α	Rmax	Rmin	Rdiff	Notes
1	α	-	-	-	1. **Ratio.** 2. **implementation independent** 3. **Not completed**
2	(Rmax-Rmin)/ (Rmax+Rmin)	Rmax	Rmin	-	1. Complete solution.
3	α	Rmax	Rmax*(1-α)/(1+α)		1. Complete solution.
4	α	=Rmin*(1+α)/(1-α)	Rmin	-	1. Complete solution. 2. Rmin is exists anyway.
5	α	Rmin+Rdiff	0.5*Rdiff*(1-α)/α	Rdiff	1. Complete solution.
6	Can't be defined			Rdiff	1. Not complete 2. Implementation dependent 3. Interoperability issues

- Option 1: *Implementation independent but not fully mathematically complete. If Rmin is added, it is mathematically complete and will help limit pair current since Rmin exists anyway which makes it Option 4.*
- Options 2-5: Complete solutions
- Option 6: Impossible

Recommended option for PSE PI spec.

- Option 2 and option 4 are recommended as candidates. Vdiff can be addresses as separate parameter or embedded in Rmin, (Rmax).
  - Option 2: Rmax and Rmin
    - Rmax and Rmin sets PSE PI P2PRUNB.
    - No limits on Rmin. (Totally flexible design)
    - As long as Rmin is going low, Rmax will be more close to Rmin.
  - Option 4: PSE PI P2PRUNB and Rmin
    - Rmin is variable but has a minimum value. Rmin exist anyway in all PSEs and PDs (connectors, transformers traces etc.)
    - We should allow Rmin_min as low as 0.1Ω or lower value to enable future implementations.
    - Having normative Rmin_min in the specification help PD unbalance at short channel and allows PDs with higher unbalance currently and in the future with affecting Imax limits.
    - As long as Rmin is going low, Rmax will be more close to Rmin.

Both concepts are similar since their mathematical origin is the same and they will lead to same behavior. Option 4 allows reducing the burden on the PD by forcing minimum resistance at PSE PI and PD PI that are there anyway.

Proposed Specifications for PSE PI

#	Parameter	Additional Information
1	Imax continuous DC current for the pair with minimum common mode resistance	-0.72A (TBD) for Type 3 systems *(In a presence of PSEP PI P2PUNB>0)* -Total ALT A and ALT B current=1.2A max for type 3 systems
2	(Option 4) α=PSE_PI_P2PRUNB_EQV Value: TBD	EQV means after transformation to fit E2E_C/R_P2PRUNB limit. Value:TBD. Rmax will be calculated by Rmin_eqv*(1+α)/(1-α)
3	(Option 4 and 2) Rmin_eqv	• It is required for complete mathematical solution. • **(option 2) It is possible to use Rmax_eqv and Rmin_eqv per Ken's proposal which actually defines PSE_PI_P2PRUNB_EQV.**
4	Vdiff. **Value TBD.**	• include **all** PSE PI internal components (including of AC disconnect diode • Implementations of diodes (AC disconnect) is controlled by Imax value that sets E2ECP2PRUNB (highest priority compared to flexible design objective) • Vdiff may be redundant if embedded in Rmin and Rmax equivalent values by mean of 2nd transformation i.e. d_Vdiff/d_Idiff=d_Rdiff_max ➔ P2PRUNB_equv. See: slides 40-43 at http://www.ieee802.org/3/bt/public/unbaladhoc/Meeting_6_7_8__IEEE802_3bt_Channel_Pair_To_Pair_Resistance_Imbalance_ad_hoc_rev_011a.pdf

- No need to address nonlinearities since we use single worst case unbalance parameter.
- Solution will not prevent implementing low value of sense resistor or Mosfet RDSON.

Proposal for PD PI

- Similar way, to finalize PD PI spec.

  - PD_PI_P2PRUNB_eqv parameter (after transformation to fit E2E_C_P2PRUNB)
  - Rmin_eqv.

  - Or Rmax_eqv and Rmin_eqv

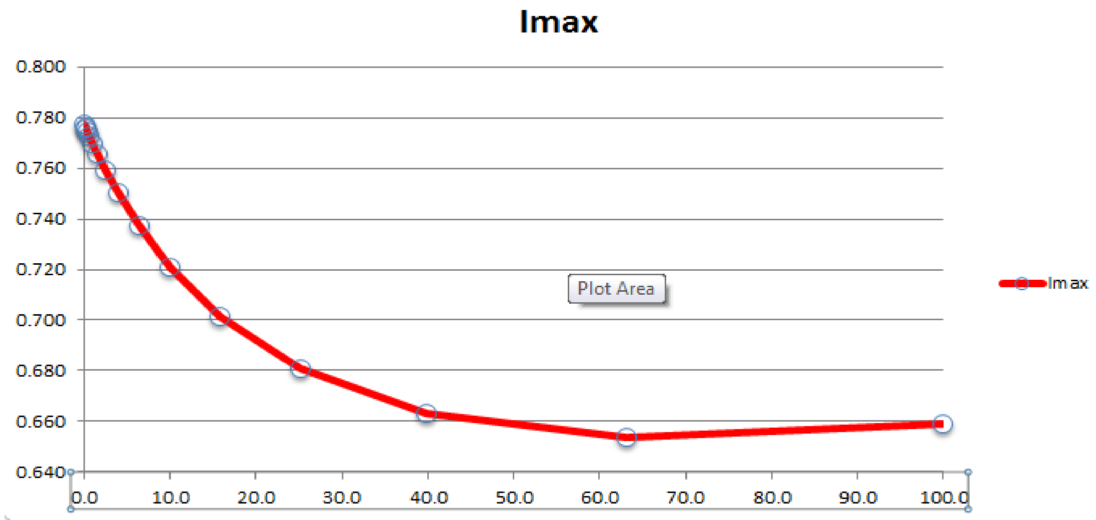
  - For all options to be discussed:
    - Vdiff or Idiff as separate parameters or
    - Finding equivalent transformation from Vdiff to Rdiff by Iunb_max.
      - Values TBD.

Details to be discussed next meeting

New topic

Top down derivation of Imax and E2E_C_P2PRUNB

- How we define system E2E_C_P2PRUNB requirements
- It starts with setting maximum pair current at all operating conditions
  - Short Channel
  - Long channel
  - Minimum worst case round loop resistance of all elements
  - 12.5Ω channel (where P2PRUNB will be minimum)
- We will look for It/2+(1+**max**{Runb_max*It_min, Runb_min*It_max})/2
  - It_min is the total PD current at short channel e.g. 51W/50V=1.02A
  - It_max is the total PD current at long channel <u>with maximum possible resistance</u>: 1.2A



Top down derivation of Imax and E2E_C_P2PRUNB Example 1.

- Starting with high level system approach: (See simulation results in Annex G5)
- Objectives in this example: Reusing 802.3at practice (components e.g. magnetic design) resulting with the following table. (ILIM, ICUT curve allows sufficient flexibility so other numbers are possible):

Parameter [A]	Value	Additional Information
It at 1m	1.061	Sim results
It at 100m	1.170	Sim results
It	1.061	Select option between 1m and 100m
INOM=Icut_min=	0.531	Calculation
Icut_th	0.570	(Icut_min+Icutmax)/2
Icut _max=ILIM_min	0.610	
ILIM_th	0.656	(Ilim_min+Ilim_max)/2
ILIM=	0.702	
Imax<ILIM_th	0.656	Actual operating point for Imax
Actual possible Imax per current magnetics	0.720	To keep the same magjack etc. as in Type 2 and pre-802.3bt 4P applications
Imax=	0.720	Actual possible Imax
DI/2=	0.190	(Imax-Icut_th)/2
Imin=	0.341	Icut_th -DI/2
DI=	0.379	2xDI/2
E2E_C_P2PRUNB[%]	35.72%	DI/Icut)min =DI/It at 1m

- Worst case analysis at 1m with lowest round loop resistance

- The PSE maximum pair current: Imax=0.72A under the following conditions
  - 4P is used
  - Total 4P current=1.2A (Type 3)

Imax=0.72A force system end to end channel effective P2P resistance unbalance=*35.72%* max calculated between pairs with the same polarity.

Note: Total current need to be calculated with constant power sink and round loop conditions.

Proposed Imax=0.72A on minimum resistance pair

Top down derivation of Imax and E2E_C_P2PRUNB Example 2.

Parameter [A]	Value	Additional Information
It at 1m	1.061	Sim results
It at 100m	1.170	Sim results
It	1.170	Select option
INOM=Icut_min=	0.585	Calculation
Icut_th	0.629	(Icut_min+Icutmax)/2
Icut _max=ILIM_min	0.673	
ILIM_th	0.723	(Ilim_min+Ilim_max)/2
ILIM=	0.774	
Imax<ILIM_th	0.723	Actual operating point for Imax
Actual possible Imax per current magnetics	0.720	To keep the same magjack etc. as in Type 2 and pre-802.3bt 4P applications
Imax=	0.720	Actual possible Imax
DI/2=	0.135	(Imax-Icut_th)/2
Imin=	0.450	Icut_th -DI/2
DI=	0.270	2xDI/2
E2E_C_P2PRUNB[%]	23.08%	DI/Icut)min =DI/It at 1m

- Worst case analysis at 100m with lowest round loop resistance

Proposed E2E_CHANNEL_P2PRUNB

- Worst case analysis numbers for system End to End CP2PRUNB (to be used to allocate unbalance numbers at PSE and PD)
  - **36% (Imax=0.72A) (TBD)max at 1m**
  - 15% - 20% (TBD,) max at 100m/12.5Ω
    - 24% (TBD) Max at 100m for worst case database with <12.5 Ω round loop resistance

Summary

- Two options for PSE PI speciation parameters were shown:
  - Imax definition in a presence of P2PRunb>0, 4P system
  - Specifying PSE_PI_RUNB_eqv and Rmin_eqv OR
  - Specifying Rmax_eqv, Rmin_eqv
  - Both options are derived via transformation from E2E_C_P2PRUNB
    - PSE Vdiff and diode Voltage difference and Rd difference can be specified as separate parameters or embedded in the above parameters for simpler specification.

- A methodology were shown to set the Imax and as a result the system E2E_C_P2PRUNB.
  - Imax is proposed to 0.72A (TBD)
  - E2ECP2PRUNB <=36% at worst case analysis and worst case end to end channel combinations.

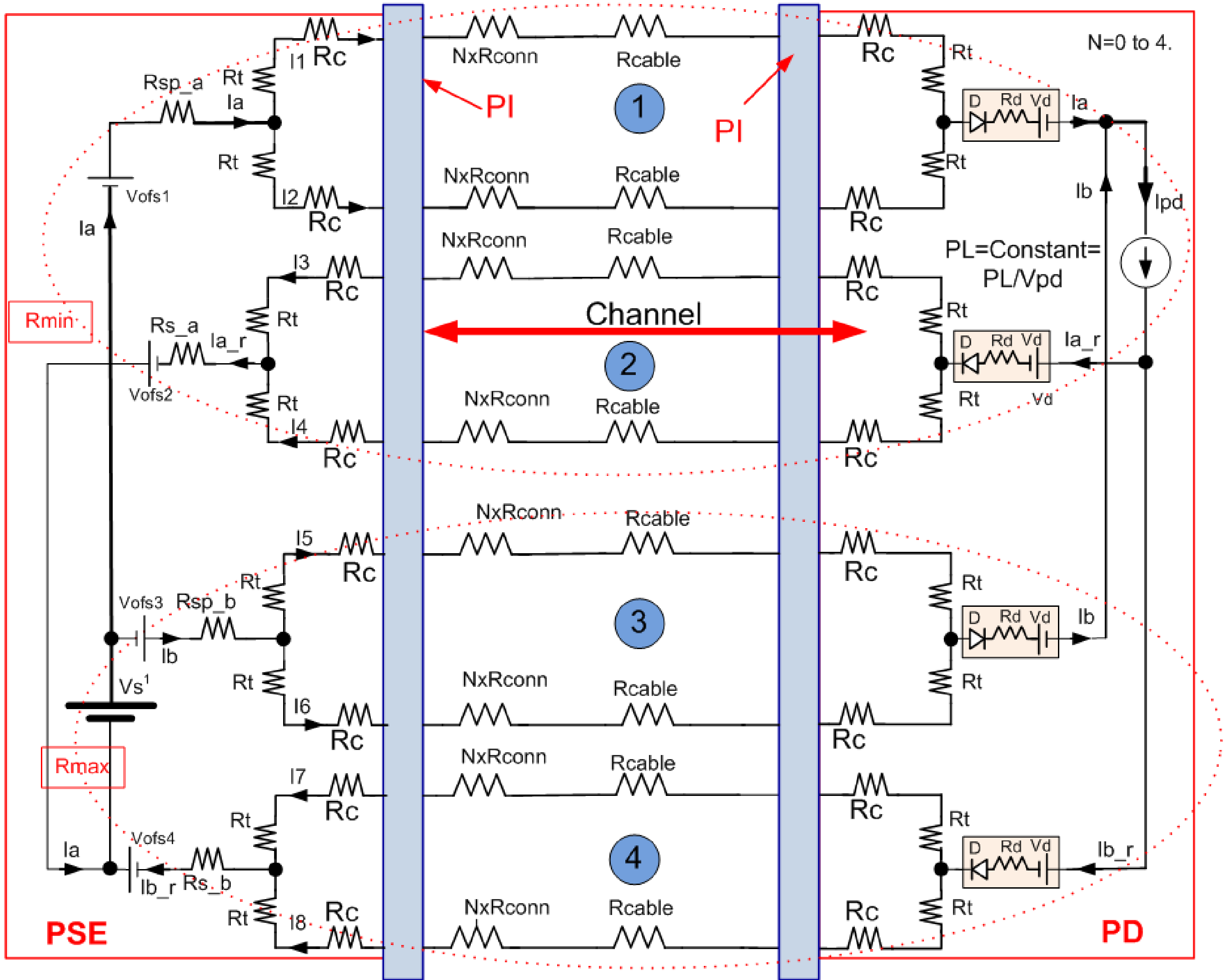
Reference Material

- http://www.ieee802.org/3/bt/public/unbaladhoc/Meeting_13_IEEE802_3bt_Channel_Pair_To_Pair_Resistance_Imbalance_ad_hoc_rev_017.pdf
- http://www.ieee802.org/3/bt/public/unbaladhoc/Channel%20Pair%20To%20Pair%20Resistance%20Unbalance%20Specification-What%20is%20the%20preferred%20concept.pdf
- http://www.ieee802.org/3/bt/public/unbaladhoc/Analzing_Channel_Pair_To_Pair_Resistance_Unbalance_use_cases_rev_6.1.pdf
- http://www.ieee802.org/3/bt/public/unbaladhoc/PI%20Balance%20Specifications%20rev%202.pdf

Backup slides

Annex F – Model updates to be review by adhoc.

Adhoc OK: August 26, 2014



1. A single Vs was not meant to imply specific implementations and is drawn as single voltage source for simplification of the drawing. The important parameter is the pair to pair voltage difference.

- Notes for the general Model:

1. Total end to end channel connectors is 6 max.
2. The formal channel definition is marked in red arrow and is with up to 4 connectors.
3. Our work addresses also the internal application resistance of known components that are used
4. In simulations, pairs 1 and 2 components were set to minimum and pairs 3 and 4 were set to maximum values. See simulation results on previous meetings
5. Vofs1/2/3 and 4 was added. Per adhoc consensus for Vdiff. To update the group. July 3, 2014.
6. "Real" Diode was added to the model for investigating behavior at low currents. July 3, 2014.
7. The maximum number of connectors are 4. Number of connectors can varies between 0 to 4 as function of channel use cases A,B,C and D per annex G1

Source: Yair Darshan and Christian Beia

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

See notes to the table in next slide

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

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

Source: Yair Darshan, Christian Beia, Wayne Larsen

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

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

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

Source: Yair Darshan and Christian Beia

Annex G5: Examples for Spice simulations for model shown in Annex F per data shown in Annex G1 with slight diode unbalance

Parameter	L=1m		L=100m	
	I (mA)	P2PRUNB	I (mA)	P2PRUNB
Ia+ (I(R41))	743.32	40.03%	649.94	11.12%
Ib+ (I(R42))	318.33	REF	519.88	REF
Ia- (I(R20))	671.34	26.4%	633.87	8.37
Ib- (I(R19))	390.3	REF	535.95	REF
Ia total	1061.65		1169.82	
Ib total	1061.65		1169.82	
Idiff_pos_max	425		130	
Idiff_neg_max	281		65	

PARAMETERS:
P2PRunb = 0.05 0.05 for Pait to Pair Run
Pair_Runb = 0.02 0.02 for Pair Runb
Ppd = 51
ILIM = 2
Lcable = 100
Resistivity = {0.1*Cordage_Resistivity+0.9*Cable_Resistivity}
Cordage_Resistivity = 0.0926
Cable_Resistivity = 0.0792
Rcable_max = {Lcable*Resistivity}

Spice model Revision 005. Note: Ppd is constant power sink parameter model. The actual PD input power (including Diode bridge is 53.339W at 100m per cable data below.

alfa = {(1-Pair_Runb)/(1+Pair_Runb)}
beta = {(1-P2PRunb)/(1+P2PRunb)}
beta_special = 0.925

Rt_max = 0.13 Rt_min = 0.12
Rsense_max = 0.25 Rsense_min = {Rsense_max*0.98}
Rdson_max = 0.1 Rdson_min = 0.05
Rconn_max = 0.05 Rconn_min = 0.03
Vd_max = 0.1 Vd_min = 0
Rd_max = 0.1 Rd_min = 0.0001

-Simulation results were validated with other simulation tools and was sync with lab results. (May 2013, July 2013, August 2014).
-Components value taken from Data base Annex G1 with some changes on diode data (tighter unbalance)

Source: Yair Darshan

See earlier work at:
http://www.ieee802.org/3/4PPOE/public/jul13/beia_1_0713.pdf
http://www.ieee802.org/3/4PPOE/public/jul13/darshan_2_0713.pdf
http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf
http://www.ieee802.org/3/4PPOE/public/nov13/darshan_02_1113.pdf
http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf

Real diodes in simulations. Vd and Rd is used to generate unbalance.

Annex G6: Examples for Spice simulations for model shown in Annex F per data shown in Annex G1 with PD identical diodes/ Ideal Diode Bridge(*)

Parameter	L=1m		L=100m	
	I (mA)	P2PRUNB	I (mA)	P2PRUNB
Ia+ (I(R41))	562.2 / 564.6	5.9% / 10.6%	630 / 602	7.73% / 8.12%
Ib+ (I(R42))	499.6 / 456.2	REF	540 / 512	REF
Ia- (I(R20))	567.2 / 557.7	6.8%/9.3%	617 / 588	5.4% / 5.6%
Ib- (I(R19))	494.7 / 463	REF	554 / 526	REF
Ia total	1061.82 / 1020.8		1170 /1114	
Ib total	1061.82 / 1020.8		1170/1114	
Idiff_pos_max	62.6		90.4 / 90	
Idiff_neg_max	72.45		62.3 / 62	

PARAMETERS:
P2PRunb = 0.05 — 0.05 for Pait to Pair Run
Pair_Runb = 0.02 — 0.02 for Pair Runb
Ppd = 51 — Spice model Revision 005. Note: Ppd is constant power sink parameter model. The actual PD input power (including Diode bridge is 51W+diode power loss.
ILIM = 2
Lcable = 100
Resistivity = {0.1*Cordage_Resistivity+0.9*Cable_Resistivity}
Cordage_Resistivity = 0.0926
Cable_Resistivity = 0.0792
Rcable_max = {Lcable*Resistivity}

alfa = {(1-Pair_Runb)/(1+Pair_Runb)}
beta = {(1-P2PRunb)/(1+P2PRunb)}
beta_special = 0.925

Rt_max = 0.13 Rt_min = 0.12
Rsense_max = 0.25 Rsense_min = {Rsense_max*0.98}
Rdson_max = 0.1 Rdson_min = 0.05
Rconn_max = 0.05 Rconn_min = 0.03
Vd_max = 0.01 Vd_min = 0.01
Rd_max = 0.1 Rd_min = 0.1

Simulation results were validated with other simulation tools and were sync with lab results. (August 2014). Components value taken from Data base Annex G1 with some changes on diode data (tighter unbalance)

Source: Yair Darshan

See earlier work at:
http://www.ieee802.org/3/4PPOE/public/jul13/beia_1_0713.pdf
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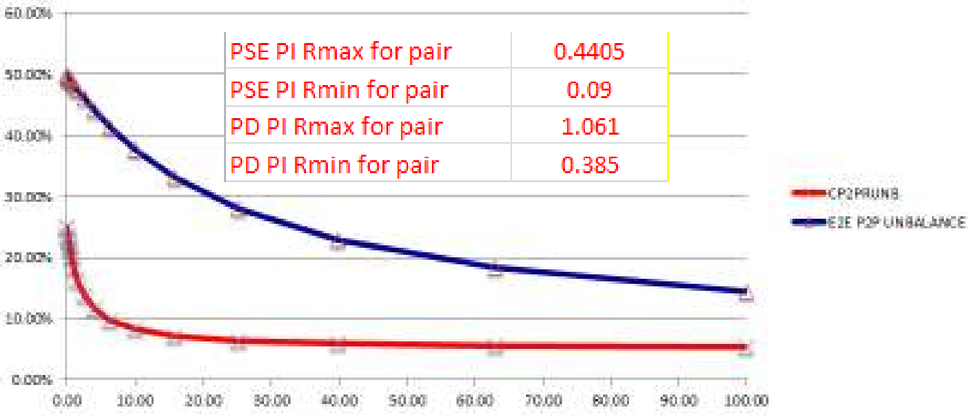
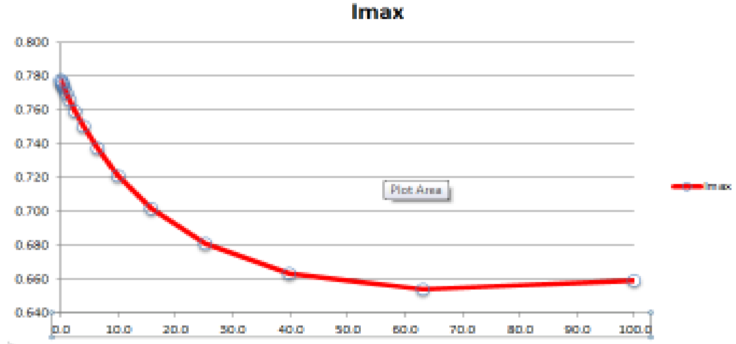
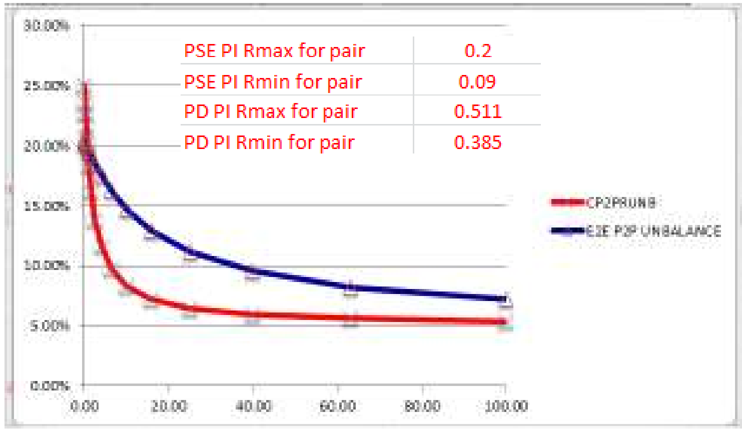
http://www.ieee802.org/3/4PPOE/public/nov13/beia_01_1113.pdf
http://www.ieee802.org/3/4PPOE/public/nov13/darshan_02_1113.pdf
http://www.ieee802.org/3/4PPOE/public/nov13/darshan_03_1113.pdf

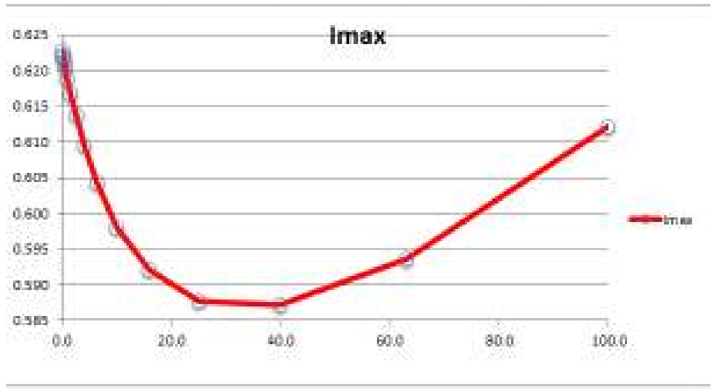
(*) For ideal diode bridge: Diode model was shorted by 0.01 ohm. Vd_max/min=0.01V, Rd_max/min=0.1

Annex G7: Comparison System End to End Channel P2PRUNB and Channel only P2PRUNB per Annex F model with two examples of PSE and PD Rmax, Rmin values that represents PSE and PD PI P2PRUNB. Data taken from Annex G1.









- Left side plots:
- PSE and PD with high unbalance
- System P2PRUNB way above Channel P2PRUNB
- System: ~50% at short channel, 15% at 100m
- Channel: 25% max short channel (Rdiff<0.1Ω), %5.5% at 100m

- Right side plots:
- PSE and PD with moderate unbalance
- System P2PRUNB regulates channel at short channels.
- System: ~20% at short channel 7.5% at 100m
- Channel: 25% max short channel (Rdiff<0.1Ω), %5.5% at 100m

Source: Yair Darshan. Tools: Excel. Confirmation tool: MATLAB

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

Source: Yair Darshan. June 25, 2014

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

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

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

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

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

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

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

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

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

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

Source: Yair Darshan

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

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

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

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

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

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

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

Source: Yair Darshan

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

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

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

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

Source: Yair Darshan

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

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

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

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

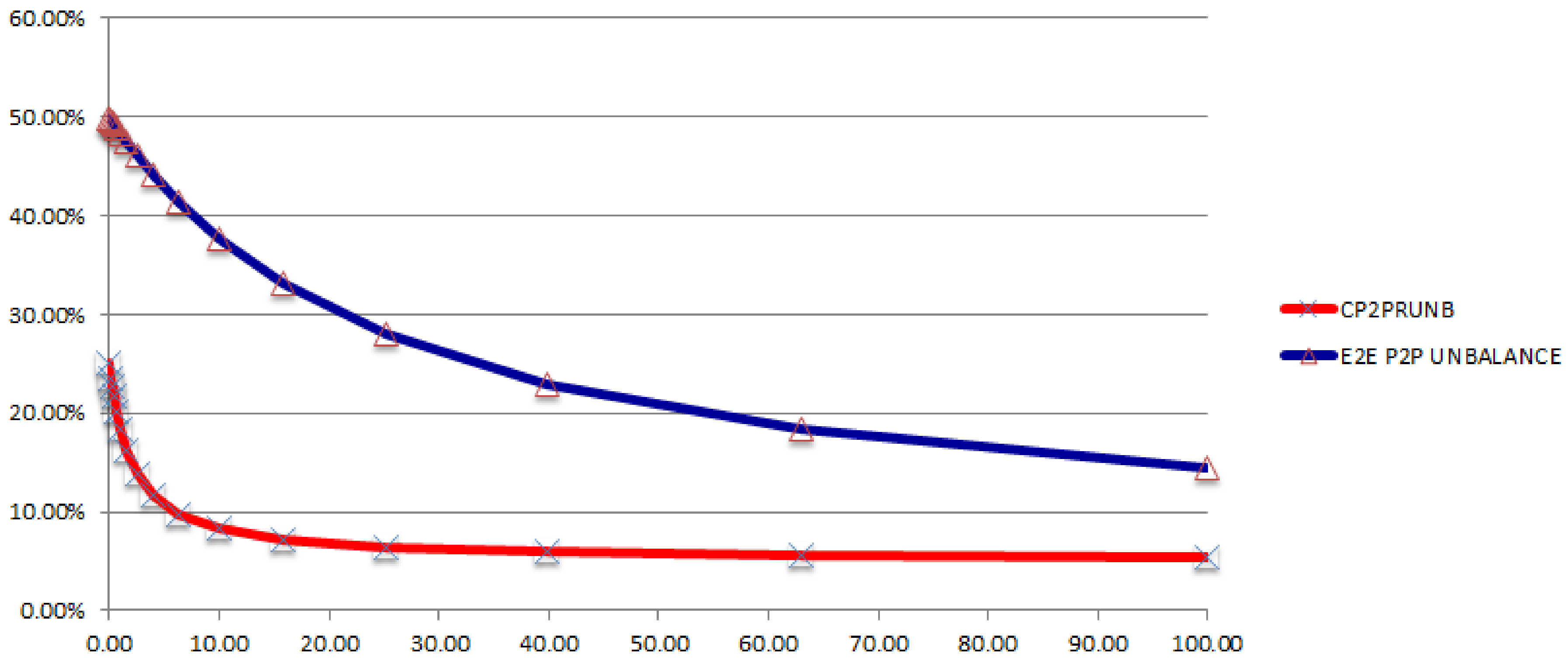
- Examples:
- Rdiff=Rmax-Rmin=0.2=X:
  - P2PRUNB=(0.2-0)/(0.2+0)=100%
  - P2PRUNB=(0.23-0.03)/(0.23+0.03)=77%
  - P2PRUNB=(0.3-0.1)/(0.3+0.1)=50%
  - P2PRUNB=(1-0.8)/(1+0.8)=11%

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

Source: Yair Darshan

Annex R: End to End Channel P2PRUNB vs Channel P2PRUNB

- Using adhoc database values for components. Annex G1.
- The high C_P2PRUNB at short cable at short cable is dominate by PSE PI and PD PI components.



Annex R1: Maximum pair current

- Using adhoc database values for components. Annex G1.
- The high C_P2PRUNB at short cable at short cable is dominate by PSE PI and PD PI components.