Alternative Imbalance Specifications

Ken Bennett

Sifos Technologies, Inc.

802.3bt July 2014

Contents

- Introduction
- Pair-to-Pair Resistance Unbalance
- Alternative Specification
- Possible PSE PI Test Method
- Channel P2PRunb
- PD PI Specification
- Rmin Requirement
- Summary

Introduction

- The Resistance Unbalance Ad Hoc continues to study worst case parameters and generate worst case models for End-to-End Pair-to-Pair Runbalance
    - This presentation does not address the content and values used in the models, but the final results of the modeling would be used

- The Ad Hoc is also in the process of defining specifications for the PSE PI and PD PI based upon the worst case models and simulations
    - An alternate PI Pair-to-Pair specification is presented herein

Sifos® Technologies

Introduction – background information

- The goal is to limit pair-to-pair current imbalance
- Resistance unbalance describes current imbalance in purely resistive paths
- P2P Current imbalance includes components that are not purely resistive, so **effective resistance** must be used.
- “Resistance” in this presentation refers to effective resistance.
- Effective resistance is the equivalent resistance needed to cause a Voltage drop in response to current flow. (V/I = Reff)
- Effective resistance includes Voltage offsets due to diodes or any other cause, and Effective resistance may vary with current flow.
- The effective resistances at high currents are the parameters of interest for describing maximum current in a pair.
- Exclusions exist (active balancing, low current PDs, etc.)

Pair-to-Pair Resistance Unbalance

PSE or PD PI P2PRunb doesn't accurately describe its contribution to the End-to-End P2PRunb

- **The following is a Resistive imbalance equation for determining current imbalance between end-to-end pairs**

$$\frac{\sum R_{max} - \sum R_{min}}{\sum (R_{max} + R_{min})}$$

- **This can be separated into contributions of the PSE, PD and Channel:**

$$\frac{R_{pseRmax} - R_{pseRmin}}{\sum (R_{max} + R_{min})} + \frac{R_{CableRmax} - R_{CableRmin}}{\sum (R_{max} + R_{min})} + \frac{R_{pdRmax} - R_{pdRmin}}{\sum (R_{max} + R_{min})}$$

- **PSE PI P2PRunb *contribution* is not the same as PSE PI P2PRunb**

$$\frac{R_{pseRmax} - R_{pseRmin}}{\sum (R_{max} + R_{min})} \neq \frac{R_{pseRmax} - R_{pseRmin}}{R_{pseRmax} + R_{pseRmin}}$$

- **Changes in total resistance can change Runbalance requirements:**
  - **A PI P2PRunb specification does not take this into account**

Alternative Specification

- Resistance limits for each PI can be derived from the worst case End-to-End P2PRunb model and expressed in the form of a linear equation

$$R_{max} = X * R_{min} + Y$$

$$X = \frac{1+ R_{unb}}{1- R_{unb}}$$

For the PSE PI: $$Y = \frac{1+ R_{unb}}{1- R_{unb}} [R_{chmin} + R_{pdmin}] - [R_{chmax} + R_{pdmax}]$$

For the PD PI: $$Y = \frac{1+ R_{unb}}{1- R_{unb}} [R_{chmin} + R_{psemin}] - [R_{chmax} + R_{psemax}]$$

Runb = Worst case **End-to-End P2PRunb**

Rchmax, Rchmin; Rpdmax, Rpdmin; Rpsemax, Rpsemin are Worst case maximum and minimum effective resistances for the Channel, PD and PSE respectively from the worst case **End-to-End P2PRunb** model**.**

- X, Y can be reduced to constants
- Results can be used to determine P2P Effective Resistance limits necessary to meet a worst case E2E P2PRunb:

$$\mathrm{R_{max}} < \mathrm{X} * \mathrm{R_{min}} + \mathrm{Y}, \qquad \mathrm{R_{min}} > (\mathrm{R_{max}} - \mathrm{Y}) / \mathrm{X}$$

Ad Hoc Annex L6: PI Specification Options

Sifos Technologies

P2PRunb:

Ratio. Fully implementation independent .

Need two parameters to solve equation with two variables. Need more research to verify completeness.

This Method:

The next slides show that This In not the case

Complete solution.

Not flexible, Implementation dependent.

P2PRunb with Rmin Requirement:

Complete solution.

Rmin exists anyway.

Rmin is a separate requirement which may be necessary to meet An Acceptable E2E P2PRunb

Not fully Implementation independent but tolerable.

Comparison of Methods

Equation for PSE Rmax derived from PI P2PRunb:

$$\boldsymbol{R_{psemax}} = \frac{\mathbf{1 + PI\_P2PRunb}}{\mathbf{1 - PI\_P2PRunb}} \boldsymbol{R_{psemin}}$$

Equation for PSE Rmax derived from E2E P2PRunb:

$$\boldsymbol{R_{psemax}} = \frac{\mathbf{1 + E2E\_P2PRunb}}{\mathbf{1 - E2E\_P2PRunb}} \boldsymbol{R_{psemin}} + \frac{\mathbf{1 + E2E\_P2PRunb}}{\mathbf{1 - E2E\_P2PRunb}} [\boldsymbol{R\_chmin} + \boldsymbol{Rpdmin}] - [\boldsymbol{Rchmax} + \boldsymbol{Rpdmax}]$$

Highlighted Terms reduce to constants based upon the worst case models

(See annex for derivations)

Sifos Technologies

Worst Case Model Values

	Rmax	Rmin
PSE	0.096	0.076
Channel	0.174	0.158
PD	1.632	0.9307
E2E-P2PRunb	0.24042	

PSE PI P2PRunb = 0.11628

PSE PI P2P Rmax = 1.26316 (PSE PI P2P Rmin)

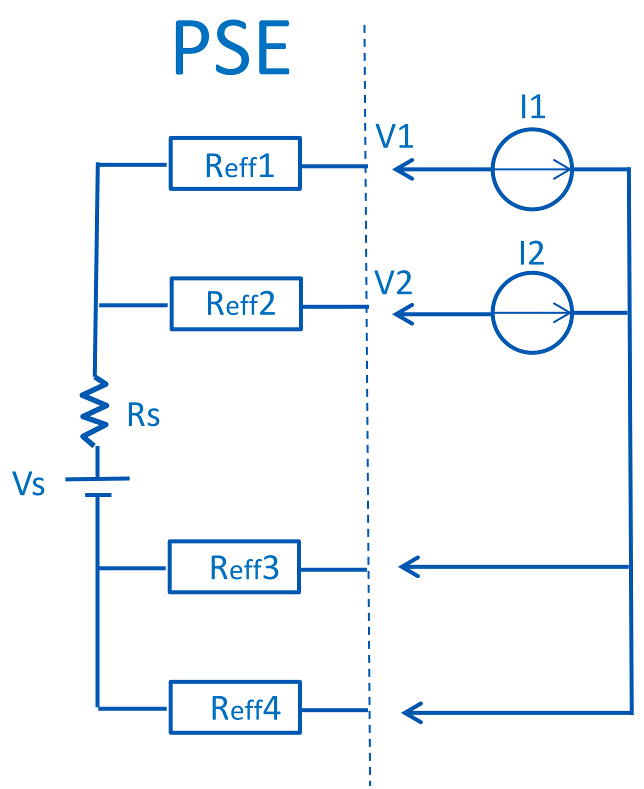
PSE PI P2P Rmax = 1.633 (PSE PI P2P Rmin) - 0.0281

PSE Rmin	PSE Rmax Limit	E2E P2PRunb	PI P2PRunb
0.05	0.0535	*0.2404*	0.0342
0.1	0.1352	*0.2404*	0.1496
0.15	0.2168	*0.2404*	0.1822
0.2	0.2985	*0.2404*	0.1976
0.25	0.3801	*0.2404*	0.2065

PSE Rmin	PSE Rmax Limit	PI P2PRunb	E2E P2PRunb
0.05	0.0632	*0.1163*	0.2428
0.1	0.1263	*0.1163*	0.2383
0.15	0.1895	*0.1163*	0.2340
0.2	0.2526	*0.1163*	0.2300
0.25	0.3158	*0.1163*	0.2263

Possible PSE PI Test Method

Test 1 – Effective Resistance:



Reff# may include fixed Resistances and Nonlinear components, such as ACMPS Diodes

1. Determine $R_{eff}1$
   - $I1 = I_a$, $I2 = I_c$, Measure V1, V2
   - $I1 = I_b$, $I2 = I_c$, Measure V1', V2'
   - $R_{eff}1 = |[(V1-V1')-(V2-V2')]/(I_a - I_b)|$
2. Determine $R_{eff}2$
   - $I2 = I_a$, $I1 = I_c$, Measure V1, V2
   - $I2 = I_b$, $I1 = I_c$, Measure V1', V2'
   - $R_{eff}2 = |[(V2-V2')-(V1-V1')]/(I_a - I_b)|$
3. Determine R_{eff} Compliance
   - $R_{eff}max \leq X * R_{eff}min + Y$
   - (X, Y are Constants derived from the final worst case model)
4. Repeat steps 1-3 for the negative pairs

Current Levels

$I_a \geq 90\%$ Capacity

$I_b = 70\%$ (Nominal example)

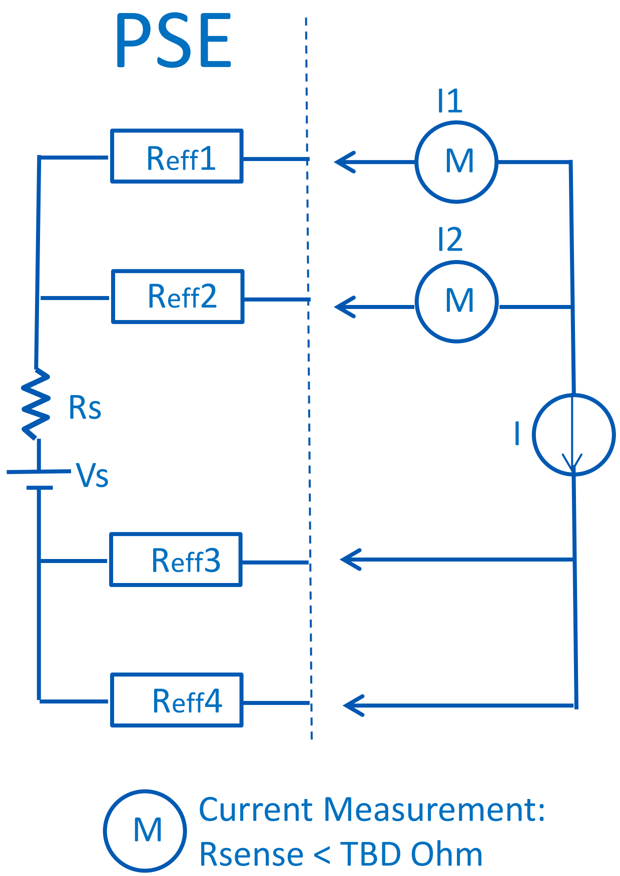
I_c = a constant value, eg: 10mA

- If ongoing Ad Hoc simulations indicate that effective resistance measurements inadequately describe behavior in the presence of a balanced condition…
  - For example, Diode forward Voltage variation with current and temperature causing current balance to changes

- Then *measurements* from the Effective Resistance test and the Ad Hoc simulation results can further provide parameters for a current balance specification and/or test:
  - PI P2P Current Unbalance Limit:

$$\mathbf{I_{unb\_max}} = [(\mathbf{R_{max}} - \mathbf{R_{min}}) / (\mathbf{R_{max}} + \mathbf{R_{min}})] + \mathbf{N}$$

  - Where the P2PRunb at the PI sets a baseline limit for expected current unbalance, and N is a parameter that would account for balanced-state effects



Current imbalance:

1. Determine R_{eff} unbalance:
   $R_{eff\_unb} = |(R_{eff}1 - R_{eff}2)/(R_{eff}1 + R_{eff}2)|$
   (R_{eff} values are from Test 1)
2. Determine I_{unb}:
   Set I ≥ 90% Capacity, Measure I1, I2
   $I_{unb} = |(I1 - I2)/(I1 + I2)|$
3. Determine I_{unb} Compliance
   $I_{unb} \leq R_{eff\_unb} + N$
4. Repeat steps 1-3 for the negative pairs

Notes:

I_{unb} caused by R_{eff_unb} is expected
- Test 2 provides confirmation of test 1 results

N is TBD and provides margin for:
- Temperature induced imbalances (ie: Diode Vf)
- Other influences (if any)

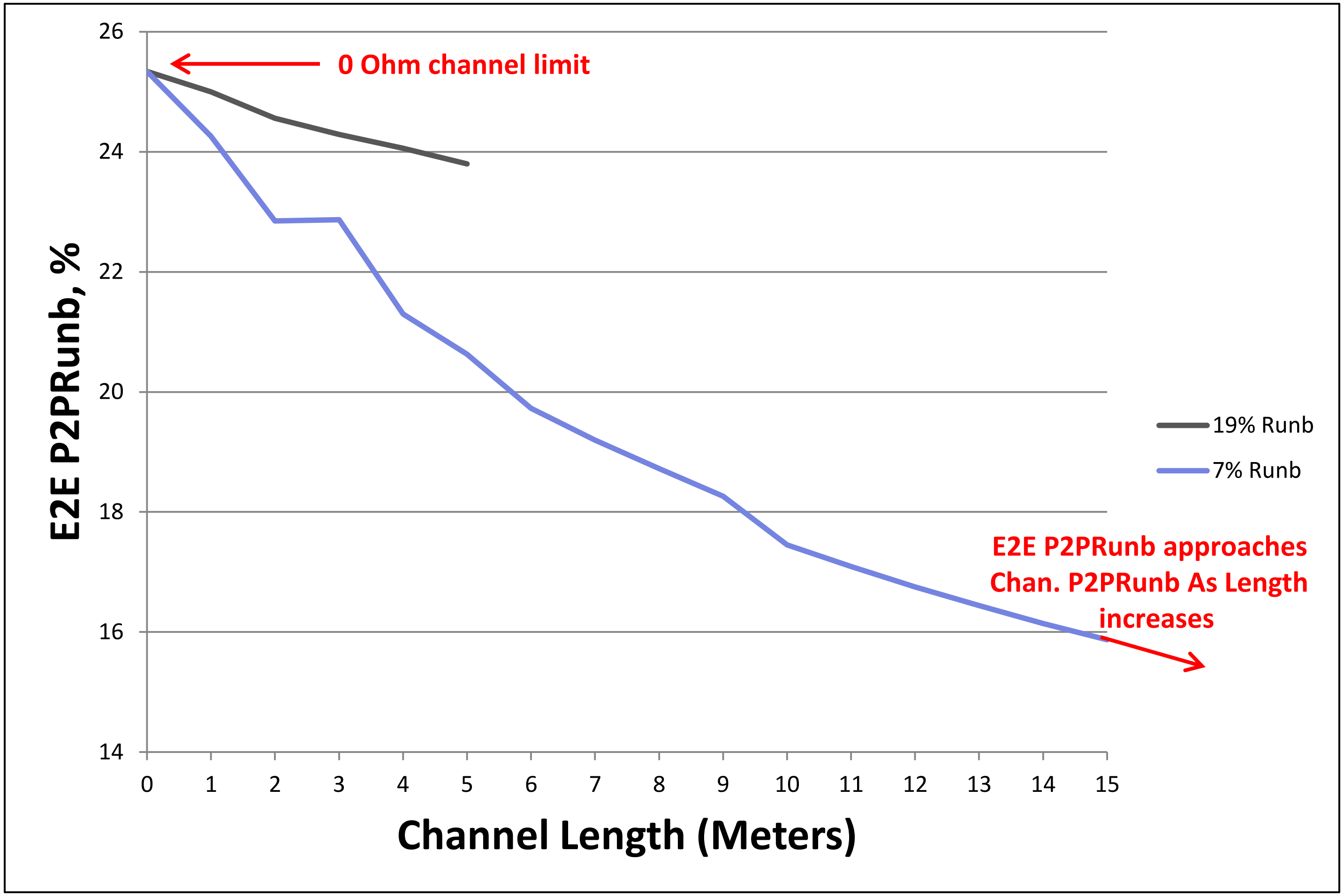
Channel P2PRunb

Channel P2PRunb Specification

- Important for long cables
  - E2E P2PRunb approaches channel P2PRunb as length increases
  - More likely to be run in bundles, where cable heating limits are specified
  - A Reference for installers, generally met using standard cables

- Short cables with 1 or more connectors:
  - Worse than long cables, shouldn't have the same specification
  - Less influence on E2E P2PRunb
  - A compliance requirement and test is impractical
    - Short cables are frequently installed by non-technical users
    - Cognizance of a channel P2PRunb requirement may not exist
    - A non-technical user can't be expected to measure channel resistances

Channel P2PRunb – short channels have higher P2PRunb, but have less influence on E2E P2PRunb



Data is consistent with Ad Hoc channel use cases and examples used in worst case simulations, however may not contain the latest updated values

Sifos Technologies

Channel P2PRunb Specification

- Don’t need a fixed value for Channel P2PRunb for all cases
    - Specify channel P2PRunb only for cables exceeding some distance
    - If TIA defines it, then we may want to simply follow that specification
- For short cables:
    - Could Specify number of connectors per unit length
        - Possibly guides non-technical users
    - Or No Specification at all
        - just simulate the worst use case so that it’s accounted for in the worst case E2E P2PRunb Model

PD PI Specification

PD PI Specifications and Testability

- The proposed PI specifications could apply to PD PI's as well as PSE PI's,

- However Testability is a problem with any PD PI specification
  - PDs aren't controllable like PSEs
    - Current consumption is dynamic and unpredictable
    - Special controls or support equipment may be required to establish operation near maximum power
    - Tests would be needed on all mixes of polarities
    - Blocking diodes in the bridges prevent the equivalent Resistance tests recommended for PSEs
    - DC-DC power conversion can interfere with tests

PD PI Specifications and Testability

- Effective Resistances at the PD PI may be provided as design guidance rather than a specification subject to general compliance testing
- A direct Iunbalance test may be necessary
    - P2P Current measured simultaneously during PD operation
- A test will be critical and may be more complicated if anything is imposed at the PD PI for the purpose of improving the balance relative to the worst case model

Rmin Requirement

If Worst Case E2E P2PRunb is too high…

- Resistance will need to be added, or a minimum limit imposed, in order to provide ballast
- If this is the case, implementing it at the PSE is recommended, because:
  - PSE's can be easily tested and verified for compliance. PD testability is limited and may be subject to misinterpretation
  - PSE-based Resistance would help balance current in PDs that are thought to be compliant, but aren't
  - Non-compliant PD's will likely outnumber non-compliant PSE's
    - PD vendors and variants outnumber PSE vendors and variants and some percentage will not be focused on the details in the standard
    - PD costs are often lower than PSE costs and compliance to the standard is not always at the same priority level
  - Would help balance Type 1,2 PDs which are powered 4 pair

Summary

Summary

- A specification has been proposed for effective resistance limits for PI P2P Balance, which
  - Defines a relative P2P effective resistance necessary to meet a worst case E2E P2PRunb
  - Can be proven mathematically
- A potential compliance test method has been presented
- Channel P2PRunb specifications have been discussed
  - Define only for channels exceeding TBD Length
- It has been recommended that any Resistance ballast, if necessary to meet a desired E2E P2PRunb, be imposed in the PSE

Questions and Comments

Thank You

Annex

Derivation of PSE Resistance Limit

Let $R_{\propto} = R_{chmax} + R_{pdmax}$, $R_{\beta} = R_{chmin} + R_{pdmin}$:

$$\frac{R_{psemax} - R_{psemin} + R_{\propto} - R_{\beta}}{R_{psemax} + R_{psemin} + R_{\propto} + R_{\beta}} = R_{unb}$$ ← **E2E P2PRunb Equation**

$$R_{psemax} - R_{psemin} + R_{\propto} - R_{\beta} = R_{unb}\left[R_{\propto} + R_{\beta}\right] + R_{unb}\left[R_{psemax} + R_{psemin}\right]$$

$$R_{psemax} - R_{psemin} - R_{unb}\left[R_{psemax} + R_{psemin}\right] = R_{unb}\left[R_{\propto} + R_{\beta}\right] - [R_{\propto} - R_{\beta}]$$

$$[1 - R_{unb}]R_{psemax} - [1 + R_{unb}]R_{psemin} = R_{unb}\left[R_{\propto} + R_{\beta}\right] - [R_{\propto} - R_{\beta}]$$

$$[1 - R_{unb}]R_{psemax} = [1 + R_{unb}]R_{psemin} + R_{unb}\left[R_{\propto} + R_{\beta}\right] - [R_{\propto} - R_{\beta}]$$

$$R_{psemax} = \frac{1 + R_{unb}}{1 - R_{unb}} R_{psemin} + \frac{R_{unb}\left[R_{\propto} + R_{\beta}\right] - [R_{\propto} - R_{\beta}]}{1 - R_{unb}}$$

$$R_{psemax} = \frac{1 + R_{unb}}{1 - R_{unb}} R_{psemin} + \frac{1 + R_{unb}}{1 - R_{unb}} R_{\beta} - R_{\propto}$$

Derivation of PSE Resistance Limit Using PI P2PRunb

$$\frac{R_{psemax} - R_{psemin}}{R_{psemax} + R_{psemin}} = R_{unb}$$

← **PSE PI P2PRunb Equation**

$$R_{psemax} - R_{psemin} = R_{unb}\left[R_{psemax} + R_{psemin}\right]$$

$$R_{psemax} - R_{psemin} - R_{unb}\left[R_{psemax} + R_{psemin}\right] = 0$$

$$[1 - R_{unb}]R_{psemax} - [1 + R_{unb}]R_{psemin} = 0$$

$$[1 - R_{unb}]R_{psemax} = [1 + R_{unb}]R_{psemin}$$

$$R_{psemax} = \frac{1 + R_{unb}}{1 - R_{unb}} R_{psemin}$$