Wired Fault Discovery

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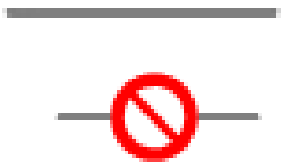
Wire Faults

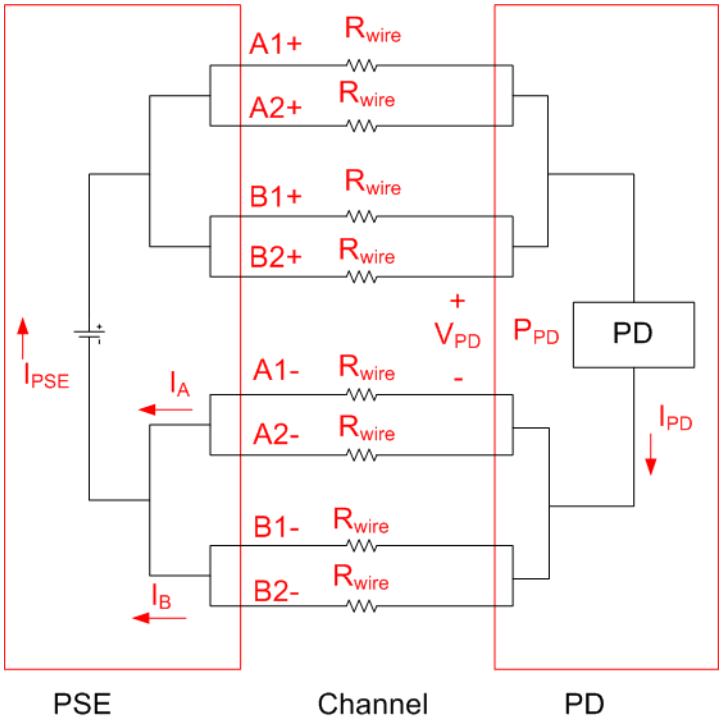
- A **wire fault** causes a significant wire resistance change in the Ethernet channel.
- For example,
  - A broken wire.
  - A broken or loose connection.
- Valid Connection
- Fault



Wire Faults: Reasons to discover

- Wire faults cause
  - Ethernet data errors
  - Excess current to be drawn
  - Unreliable system operation
- Which leads to unhappy customers
  - That call support lines
- Discovering wire faults
  - Permits customers to debug the problem and may results in fewer support calls

Wire Faults: System Circuit

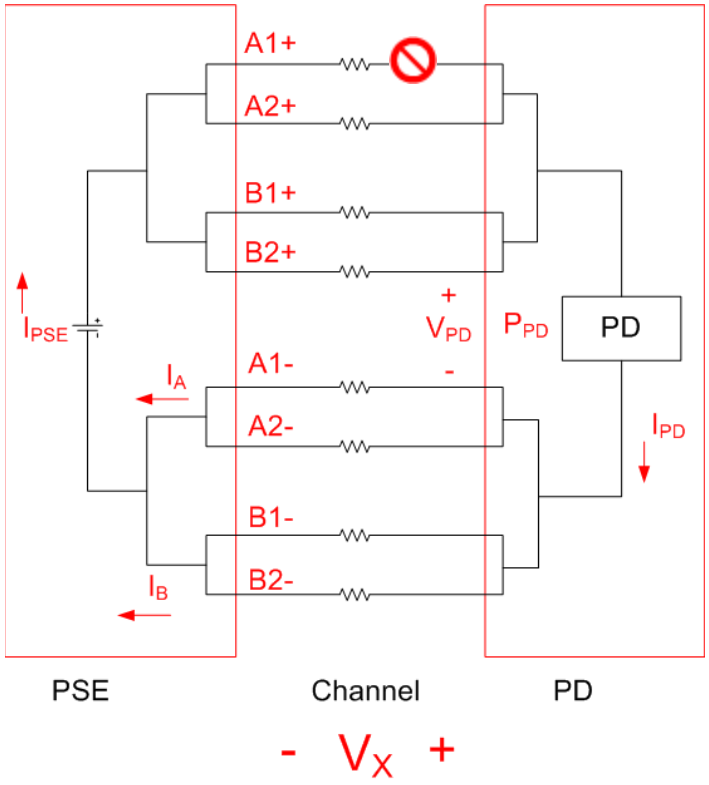


$$R_{Chan} = 2\frac{R_{wire}}{4} = \frac{R_{wire}}{2}$$

Small channel resistance components are ignored.

R_{wire} is the resistance of a channel wire and connectors between the PSE and PD.

Wire Faults: System Circuit



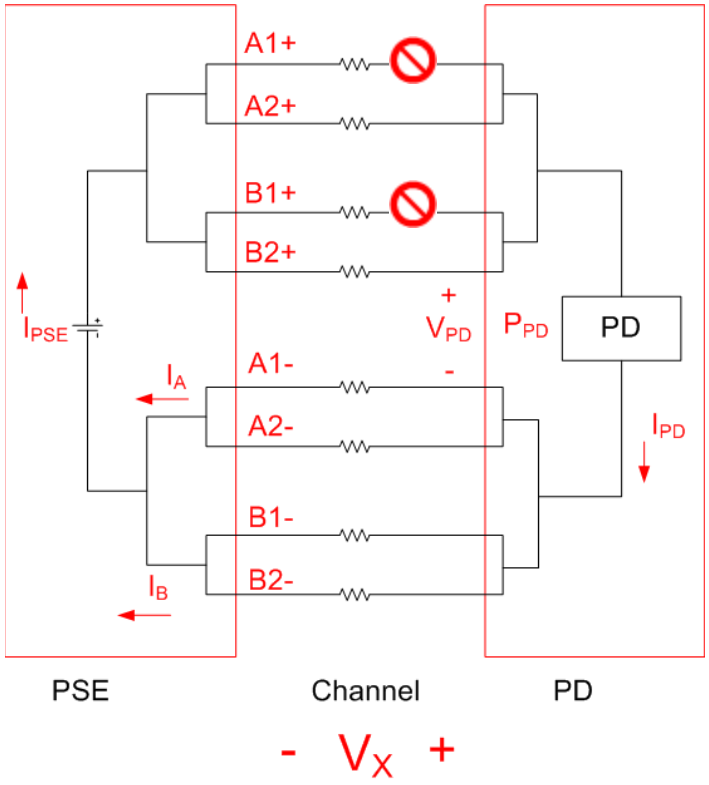
$$R_{Chan} = \frac{R_{wire}}{3} + \frac{R_{wire}}{4} = \frac{7R_{wire}}{12}$$

Channel resistance increases
V_{PD} decreases
I_{PD} increases
I_A and I_B increase equally

$$I_A = I_B = \frac{V_x}{\frac{R_{wire}}{2}} = \frac{2V_x}{R_{wire}}$$

$$I_A + I_B = I_{PSE} = I_{PD}$$

Wire Faults: System Circuit



$$R_{Chan} = \frac{R_{wire}}{2} + \frac{R_{wire}}{4} = \frac{3R_{wire}}{4}$$

Channel resistance increases
I_{PD} increases
I_A and I_B increase equally

$$I_A = I_B = \frac{V_x}{\frac{R_{wire}}{2}} = \frac{2V_x}{R_{wire}}$$

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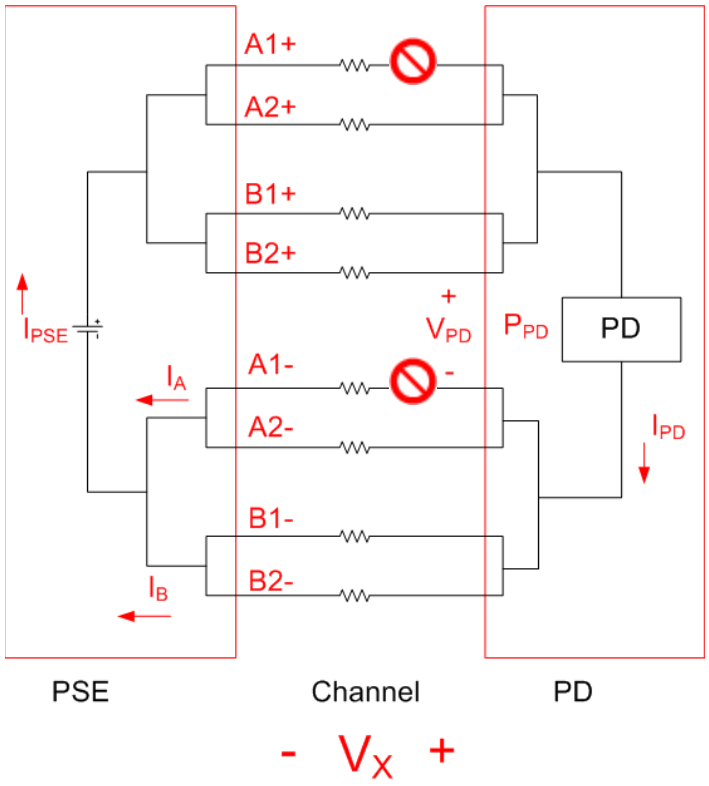
Wire Faults: System Circuit



$$R_{Chan} = \frac{R_{wire}}{3} + \frac{R_{wire}}{3} = \frac{2R_{wire}}{3}$$

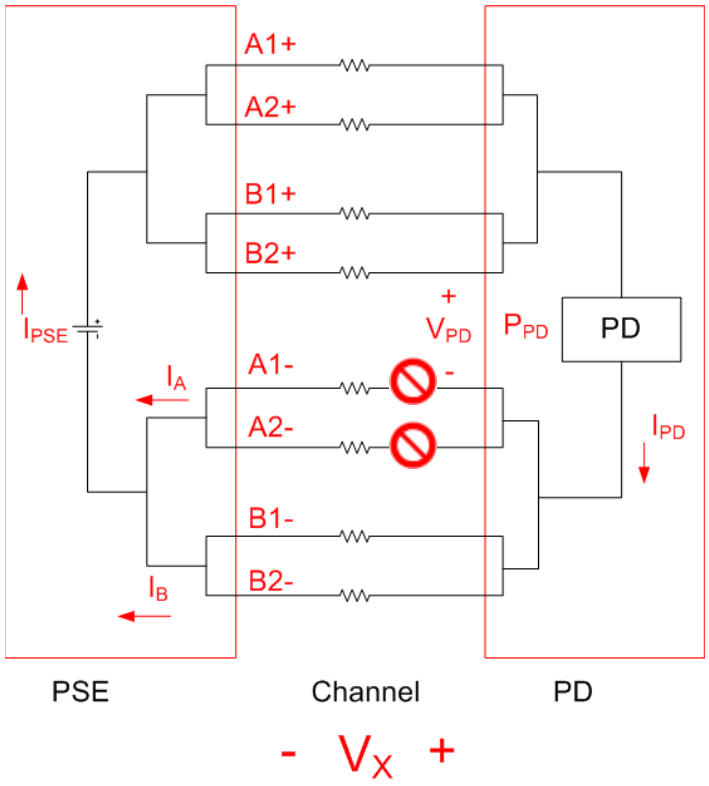
Channel resistance increases

I_{PD} increases

I_B is 2x I_A

$$I_A = \frac{V_x}{R_{wire}}, I_B = \frac{V_x}{\frac{R_{wire}}{2}} = \frac{2V_x}{R_{wire}}$$

Wire Faults: System Circuit



$$R_{Chan} = \frac{R_{wire}}{4} + \frac{R_{wire}}{2} = \frac{3R_{wire}}{4}$$

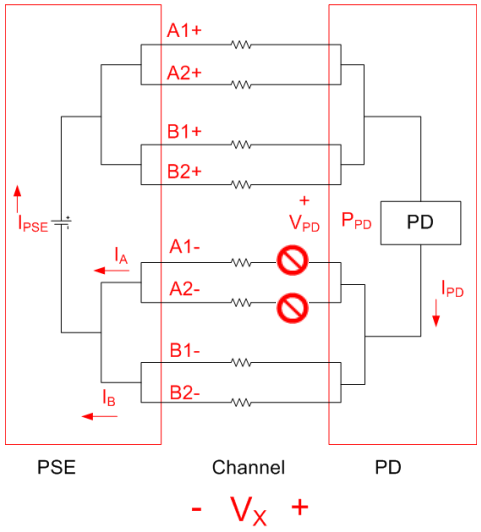
Channel resistance increases

I_{PD} increases

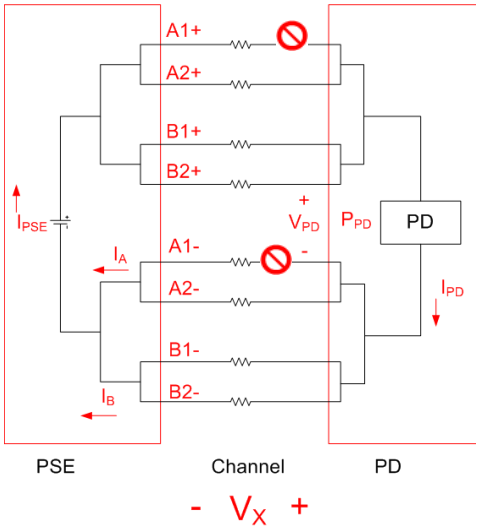
I_A = 0

I_B = I_{PSE} = I_{PD}

Wire Faults: Review 1



I_A = 0
$I_B = I_{PD}$
This is considered a **major I_{unbal}**



I_B is 2x I_A
This is considered a **minor I_{unbal}**

Current will be used to discover wire faults.
It may be easier to discover a major I_{unbal} compared to a minor I_{unbal}.

A 10-bit ADC can discover a minor current unbalance.

Wire Faults: Review 2

A wire fault increases the channel resistance.

A constant power PD load will increase I_{PD} and reduce V_{PD} to keep the load constant.

Wire faults may be discovered when I_A and I_B are affected differently.

		2P	4P	PSE Power (W)		Vpd (V)	
Ppd (W)	Faults	Rchan (Ω)	Rchan (Ω)	2P	4P	2P	4P
25.5	0	12.5	6.25	30	27.4	42.5	46.6
25.5	1	18.8	7.29	34.3	27.7	37.1	46.0
25.5	2	25.0	9.38	motor boat	28.6	motor boat	44.6
51	0	NA	6.25	NA	60.0	NA	42.5
51	1	NA	7.29	NA	62.3	NA	40.9
51	2	NA	9.38	NA	68.7	NA	37.1

Cable is CAT 5, worst-case channel, V_{PSE} = 50V
The worst-case 2-fault case is shown.
Motor boat = PD moves between power on and power off states.

Wire Fault: Customer View

ALT-A 2-pair systems with a wire fault

- No data
- Invalid power

DATA	Power	Description
Valid	Valid	System may operate in specification
Valid	Invalid	**Not possible**
Invalid	Valid	**Not possible**
Invalid	Invalid	2-pair invalid data and power

A wire fault results in a data link error.

Wire Fault: Customer View

ALT-B 2-pair systems and 4-pair systems using both power alternatives with a wire fault

- System operation is unreliable
- Systems have 2x more problems and are more difficult to debug compared to ALT-A systems

DATA	Power	Description
Valid	Valid	System may operate in specification
Valid	Invalid	**2-pair impared power path**
Invalid	Valid	**2-pair or 4-pair system impared data path**
Invalid	Invalid	2-pair or 4-pair invalid data and power

A wire fault does not always result in a data link error.

Wire Fault: Customer View

- 4-pair system operation is unreliable with a wire fault
  - Power demand increases, which is not green
  - PSE power may exceed operating limit
    PSE may remove power
  - PD may reach its minimum operating voltage
    PD may disconnect, because of UVLO
  - Data may not be reliable due to increased Iunbal.
  - Cable current is higher than recommended

Wire Fault: Data & 4P Current

- Faults on Alternative-A are **caught by all data rates**.
- Faults on Alternative-B **are not caught by data rates**, 10BASE-T, 100BASE-T.
- If data is valid, current may be used to catch faults,

Cases with Valid Data	IPSE	Major Unbalance	Minor Unbalance
IA, IB	Combined	One is 0	One is 2x other
Detected	0	4	12
Missed	15	11	3
Coverage	**0%**	**27%**	**80%**

Wire Fault: Midspans

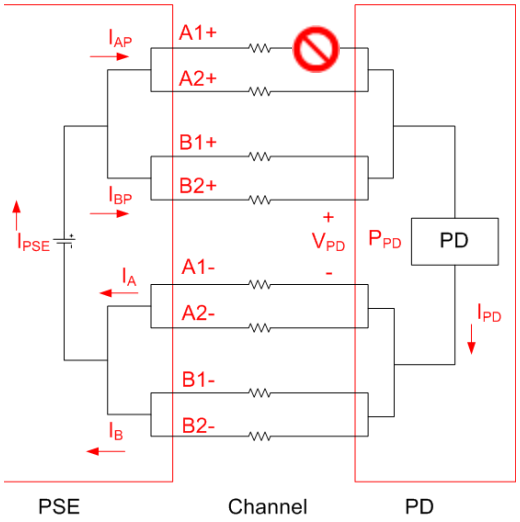
Midspans do not have easy access to data status.

If current is used to catch all wire faults,

All Cases	IPSE	Major Unbalance	Minor Unbalance
IA, IB	Combined	One is 0	One is 2x other
Discover	31	121	185
Missed	224	134	70
Coverage	**12%**	**47%**	**73%**

Wire Faults: System Circuit

More wire faults cases are discovered by making additional current measurements.



Normally $I_{AP} = I_{BP}$ = **positive path currents**

$I_A = I_B$ = **negative path currents**

$I_{AP} = I_{BP} = I_A = I_B$

With the fault shown,

$I_{BP} = 2I_{AP}$

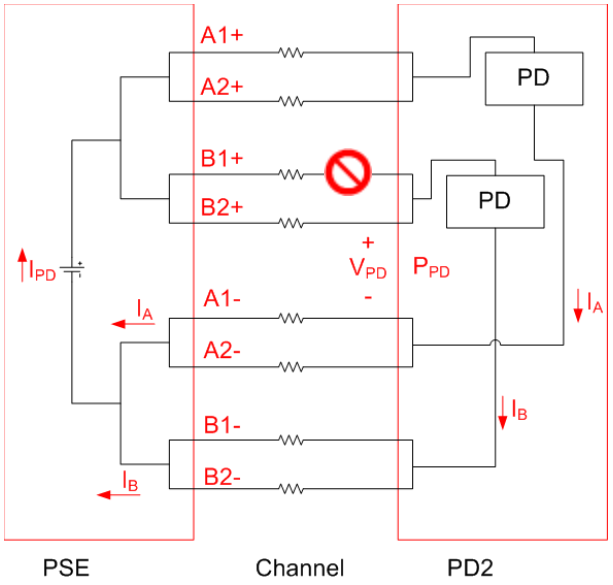
$I_{PSE} = I_{PD} = 2I_{AP} + I_{AP} = 3I_{AP} = I_A + I_B$

$$I_A = I_B = \frac{3}{2} I_{AP}$$

Wire faults are evaluated by comparing measured currents.

Cases using IA, IB, and	and IAP or IBP	and IAP and IBP	and IAP or IBP and valid data
Discover	235	235	255
Missed	20	20	0
Coverage	**92%**	**92%**	**100%**

Wire Faults: System Circuit



Dual PD

Dual PD Equipment

$I_A \neq I_B$

Faults discovered with a current measurement only

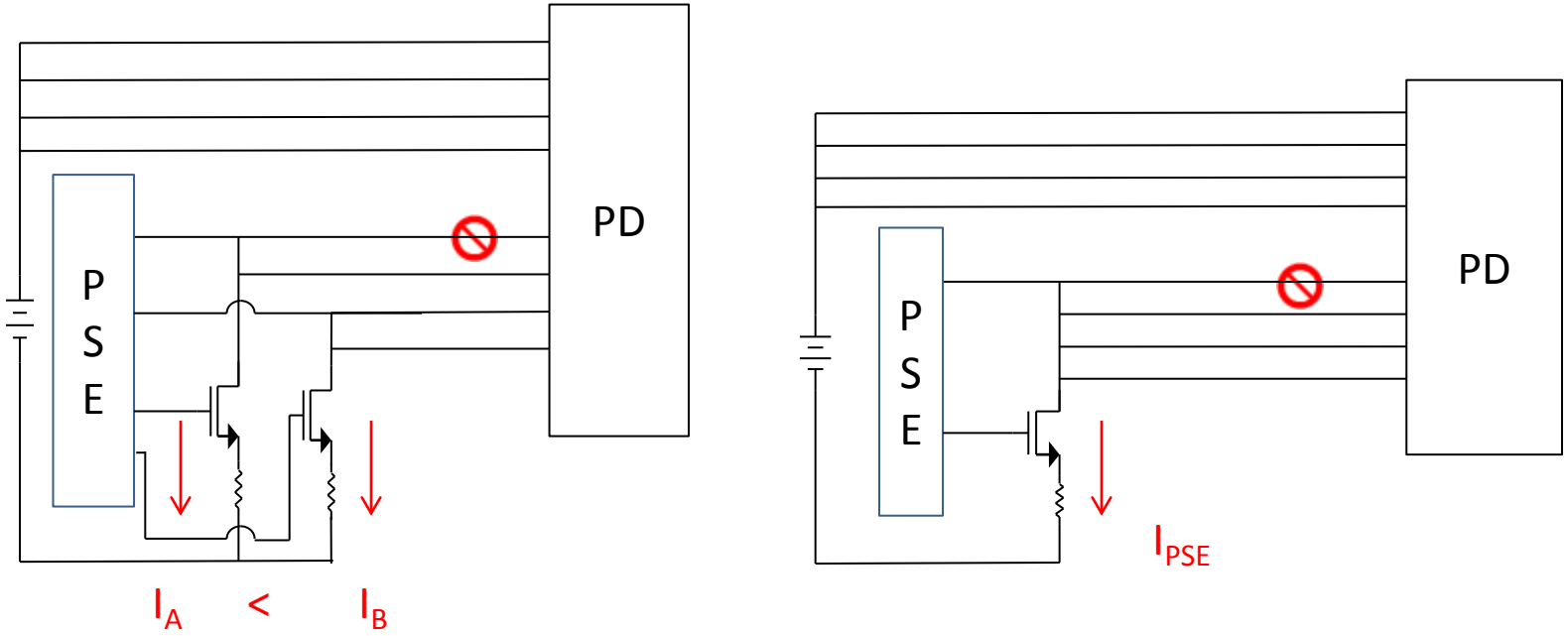
All Cases	IPSE	Major Unbalance	Minor Unbalance
IA, IB	Combined	One is 0	One is 2x other
Discover	31	175	235
Missed	224	80	20
Coverage	**12%**	**69%**	**92%**

Faults discovered when data is valid

Cases with valid data	IPSE	Major Unbalance	Minor Unbalance
IA, IB	Combined	One is 0	One is 2x other
Discover	0	7	15
Missed	15	8	0
Coverage	**0%**	**47%**	**100%**

Either the PSE or the PD may measure currents used to discover wire faults.

Wire Faults: measuring current



PSEs with two hot-swap circuits are capable of measuring current on both alternatives.

PSEs with one hot-swap circuit need extra circuits to measure current on both alternatives.

Conclusion

- Discovering wire faults permits corrective action.
- Wire faults cause measurable current unbalance
  - A PSE with two hot-swap circuits measures current unbalance.
  - A PSE with one hot-swap circuit requires extra circuitry to measure current unbalance.
- Measuring current unbalance provides significantly more wire fault coverage than measuring IPSE alone.
  - 4x coverage with major current unbalance
  - 6x coverage with minor current unbalance
- PSEs that measure current unbalance achieve 92% to 100% inclusive, wire fault coverage by,
  - Measuring one positive path alternative current or, by
  - Powering a 4-pair, dual-PD.
- 100% wire fault coverage is possible when data is considered.

Definitions + Expansion

Wire Fault, slide 2

R_{wire} , slide 4

Current unbalance, slide 9

Using **positive path currents**, slide 16

UVLO, slide13, under voltage lockout

If a 10-bit ADC with a 1A reference is used to measure current. A minor unbalance detects a 1mA difference which is less than the link maintenance current. Power-on currents are expected to be greater than 100 mA. Sense resistor tolerance does not significantly affect current ratios used to discover wire faults.

Expansion

This presentation focuses on using current to discover wire faults. In many cases the wire fault is visible using other means:

- P_{PSE} , and I_{PSE} exceed limits
- R_{chan} exceeds a limit
- V_{PD} is below a limit
- P_{PD} , exceeds a limit
- The above issues may result in the system motor boating.