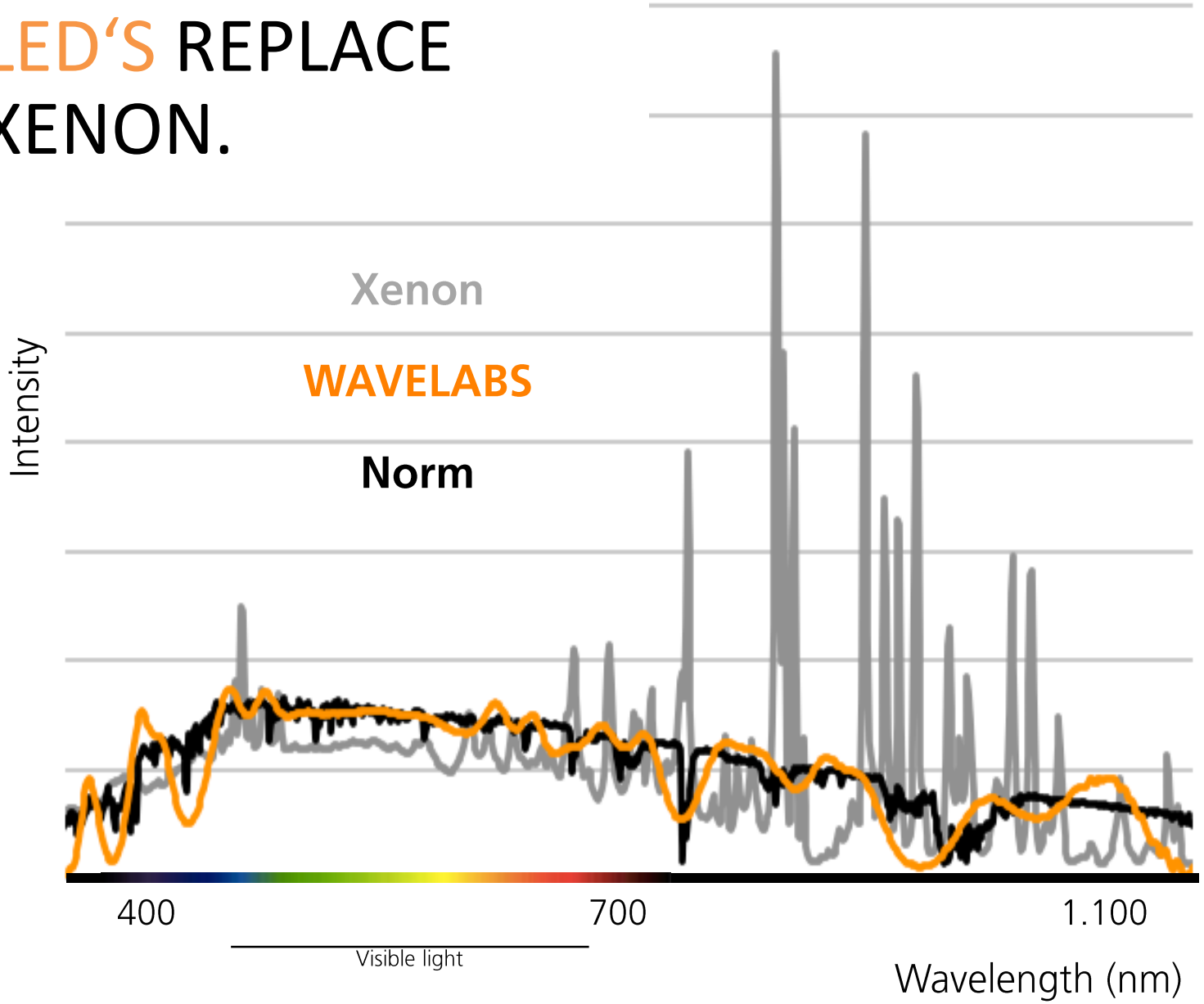
Avoiding Errors in Fill-factor Measurements

Sascha Esefelder, Wavelabs

LED‘S REPLACE XENON.



LED‘S GET REFERENCES.

Fraunhofer

Hanwha

SOLARTRON

SERIS
Solar Energy Research Institute of Singapore

UNSW
THE UNIVERSITY OF NEW SOUTH WALES

CanadianSolar

IF2

Hanwha Q CELLS

pvtools
photovoltaic device analysis

PI Photovoltaik Institut Berlin

King Abdullah University of Science and Technology
KAUST

HEPTAGON
ADVANCED MICRO OPTICS

LSU
LOUISIANA STATE UNIVERSITY

Australian National University

林洋电子
Linyang Electronics

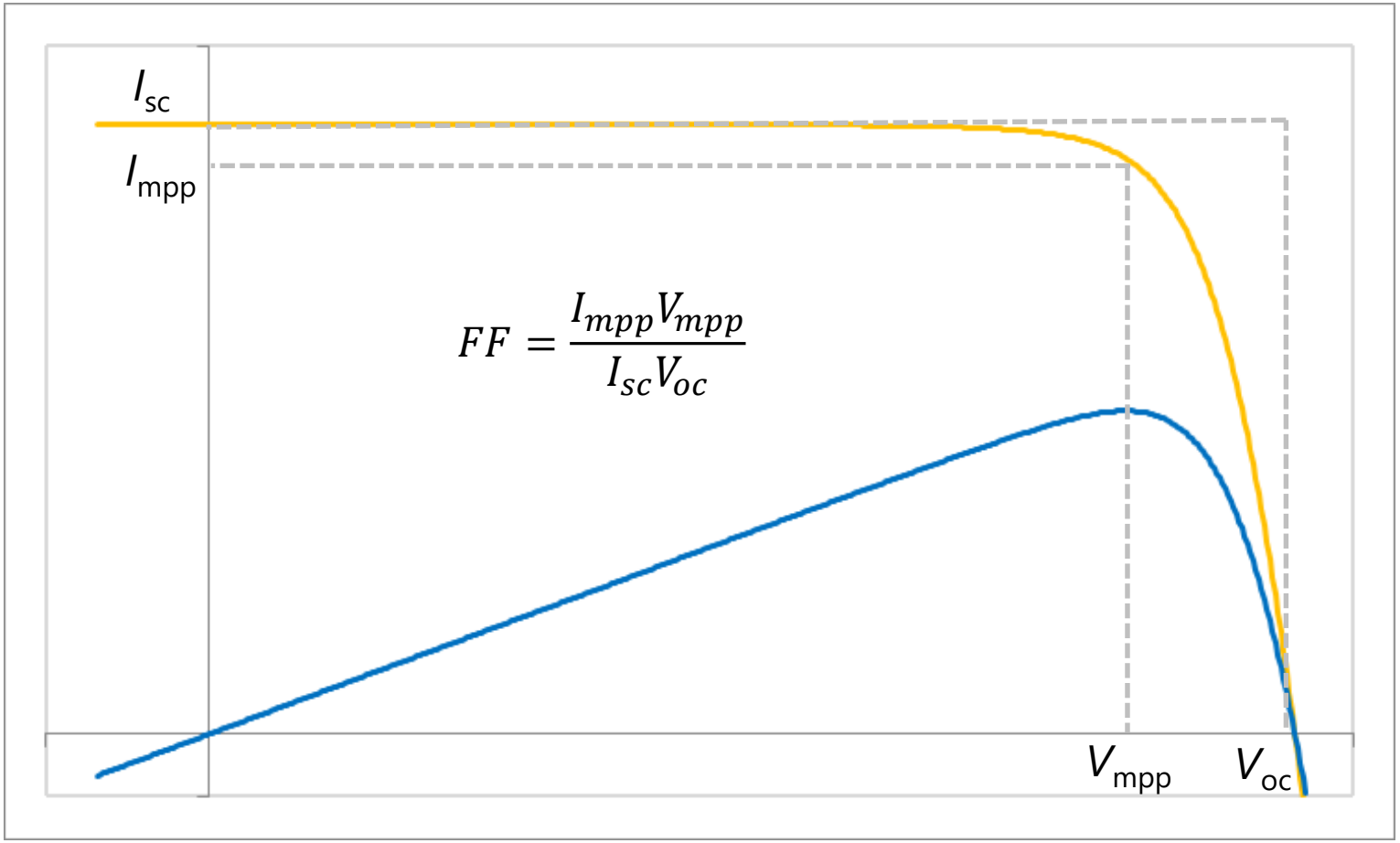
JinKO Solar

HZB Helmholtz Zentrum Berlin

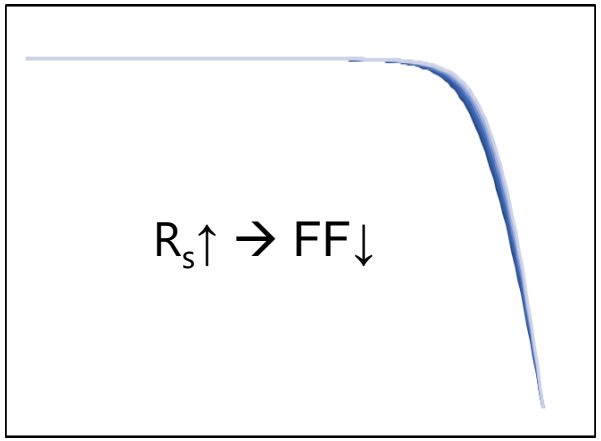
Outline

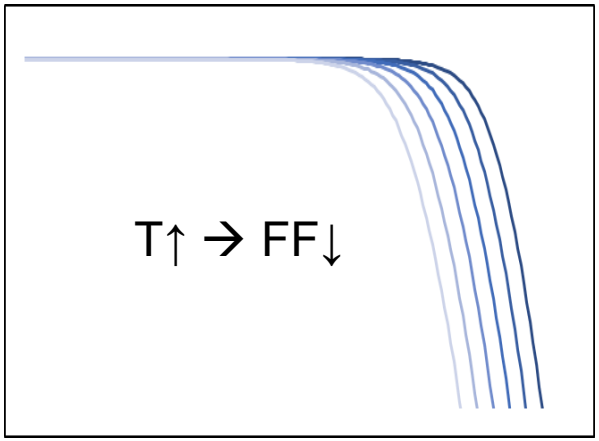
1) Introduction
2) Ensuring STC conditions
3) Nonuniform contact resistance
4) Design of the contact bar
5) Conclusion

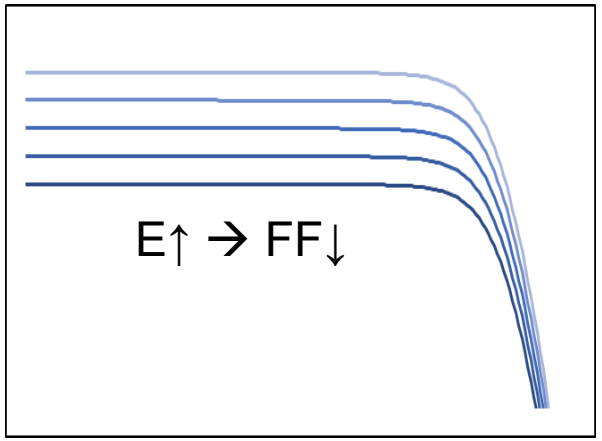
Introduction



Ensuring STC conditions







Laboratory

- 4 point contacting
- Measurement at 25 °C
- Measurement at 1000W/m² including a spectral mismatch correction, shading correction …

Production

- 4 point contacting
- proper calibration on V_{oc} and knowledge of temperature coefficients
- proper calibration on I_{sc} (spectral match between production cell and reference cell)

Nonuniform contact resistance

Table III: Simulated fill factors for measurement schemes with different load contacting and sensing.

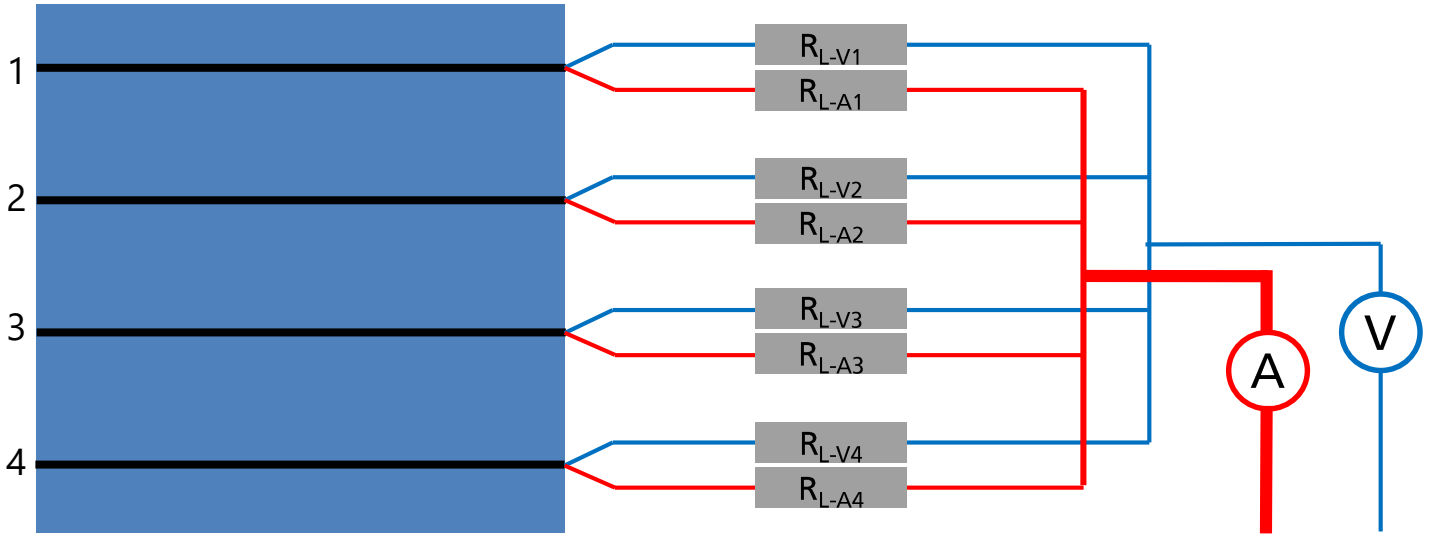
Load contacting scheme	FF_1 / % with V_{BB1}	FF_2 / % with V_{BB2}	FF / % with all BB
Ideal	78.50	78.50	78.50
I	76.99	79.81	77.92
II	66.55	82.11	70.35
III	78.56	78.47	78.53

Geisemeyer et. Al, 29th EUPVSEC 2014, 2BV.8.29

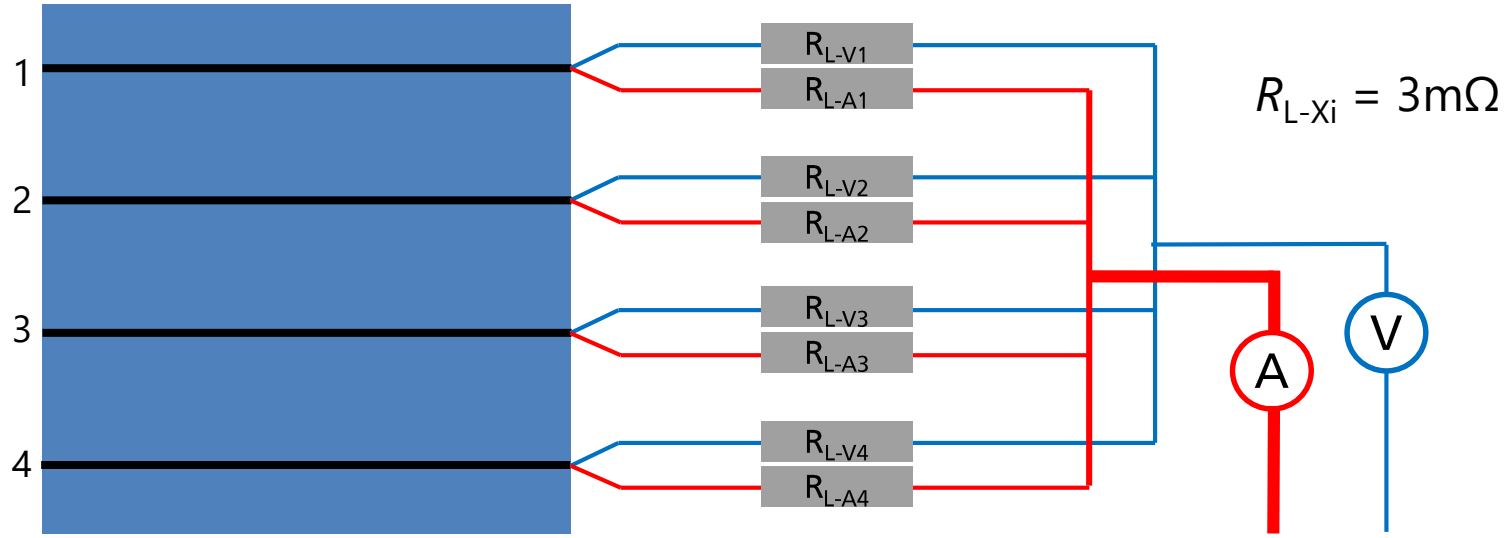
Four terminal sensing

„Separation of current and voltage electrodes eliminates the lead and contact resistance from the measurement. "

Wikipedia.org

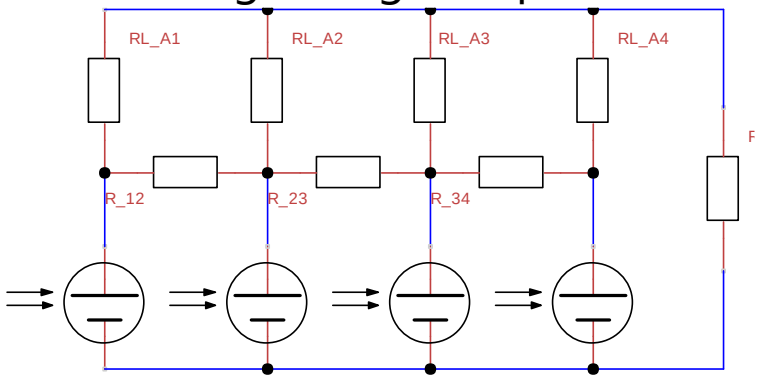


Nonuniform contact resistance – Analytical model

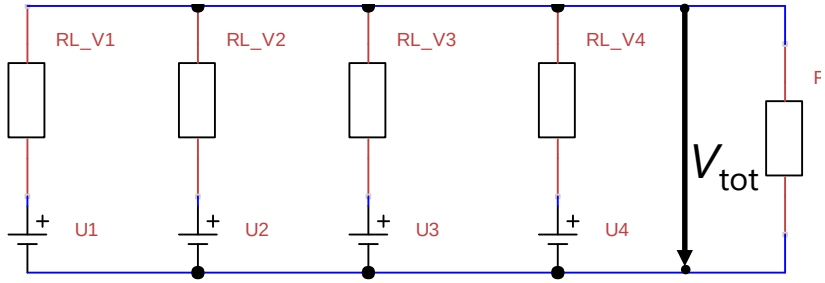


$R_{L\text{-}Xi}$ = 3mΩ

1) Calculate the current flow and resulting voltage drops



2) Calculate V_{tot}



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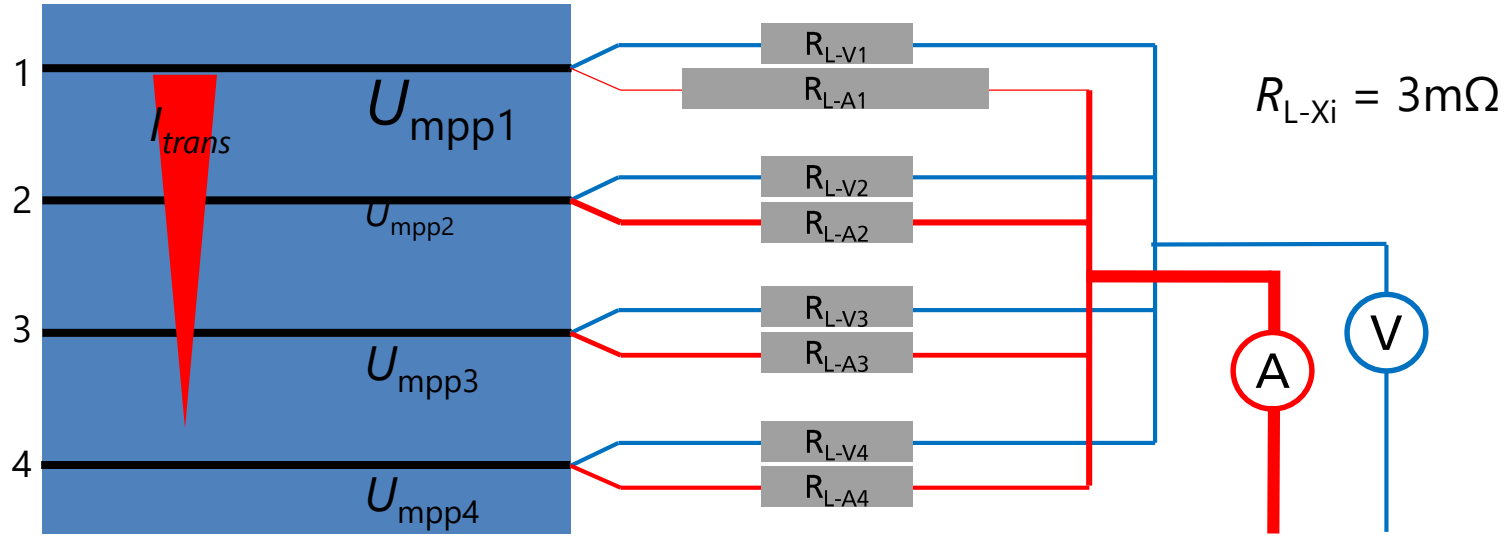


R_{L-Xi} = 3mΩ

$\Delta U_{BB1-2} = I_{trans} * R_{BB1-2}$

R_{L_A1} = 13mΩ → I_{trans} = 0.6A, **ΔU_{BB1-2} = 12 mV** für R_{BB1-2} = 20mΩ

$U_{mpp1} \neq U_{mpp2}$

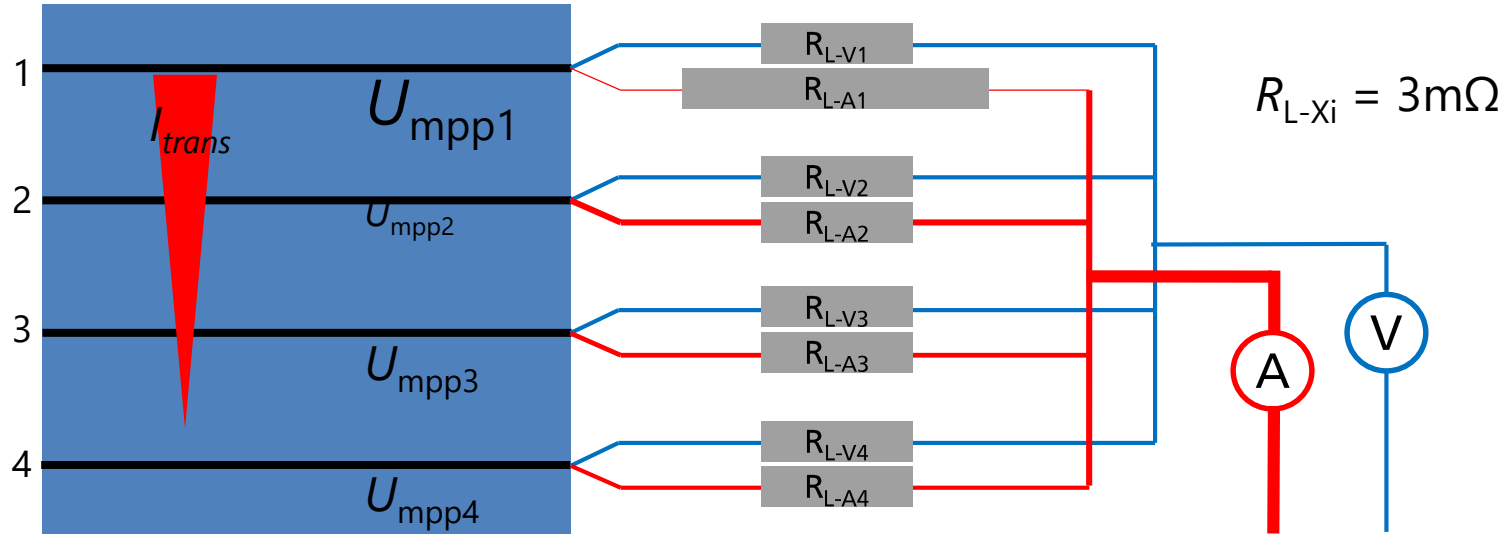
$U_{mpp1} = U_{mpp3}$ + 6 mV, $U_{mpp2} = U_{mpp3}$ - 6 mV

$U_{mpp} = ¼ \sum U_{mppi}$

$U_{mpp}(R_{L-Ai} \neq \text{const}) = U_{mpp}(R_{L-Ai} = \text{const})$

Only for R_{L-Vi} = const)

Nonuniform contact resistance – Analytical model



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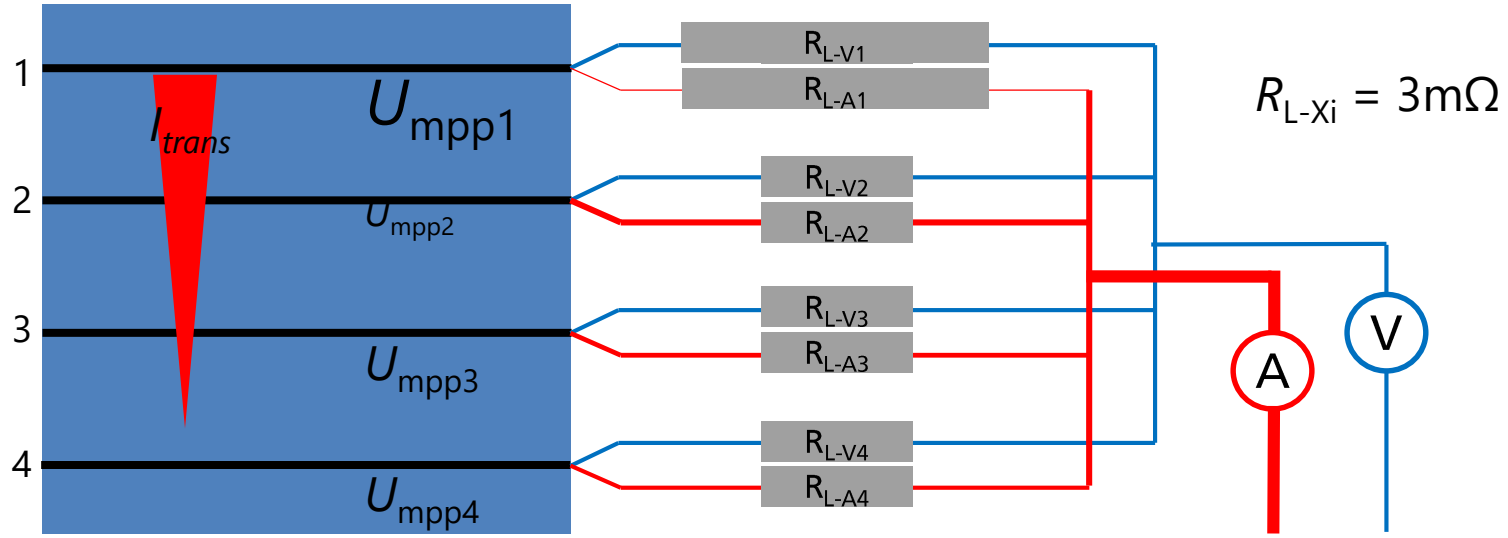
R_{L-V1-4}	LLLL					
ΔU_{mpp} [%] *	0.0					

L = 3mΩ, H = 13mΩ

*using Kirchhoff's circuit laws

Nonuniform contact resistance – Analytical model



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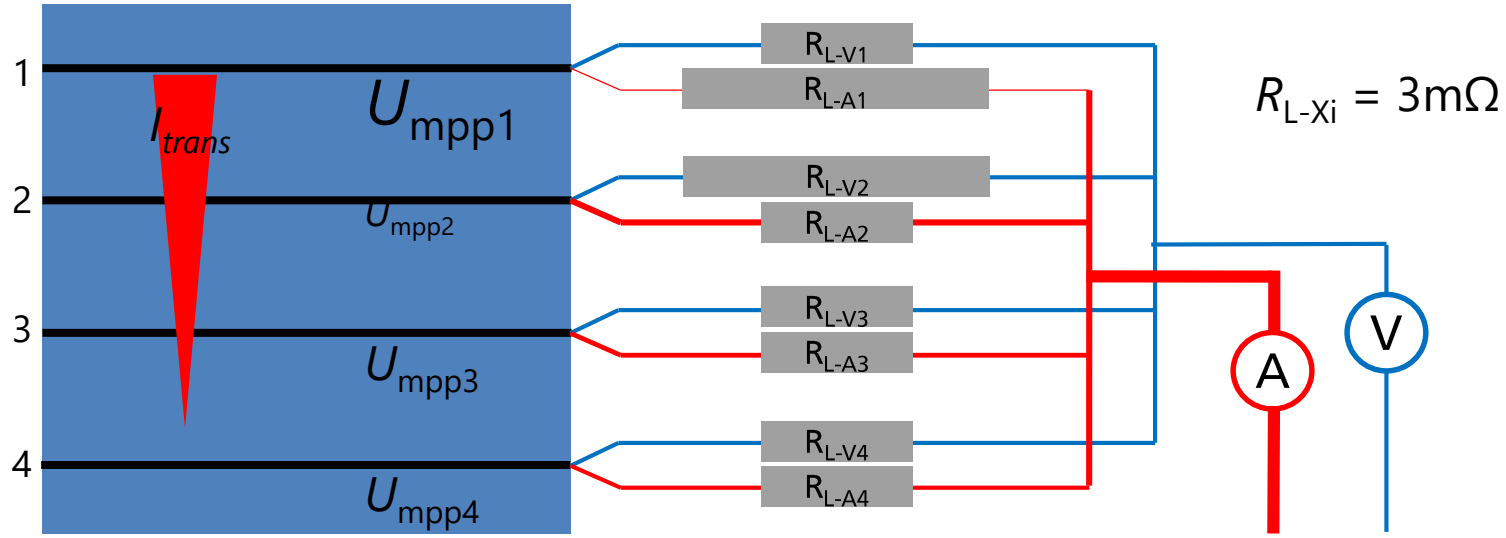
R_{L-V1-4}	LLLL	HLLL				
ΔU_{mpp} [%] *	0.0	-0.26				

L = 3mΩ, H = 13mΩ

*using Kirchhoff's circuit laws

Nonuniform contact resistance – Analytical model



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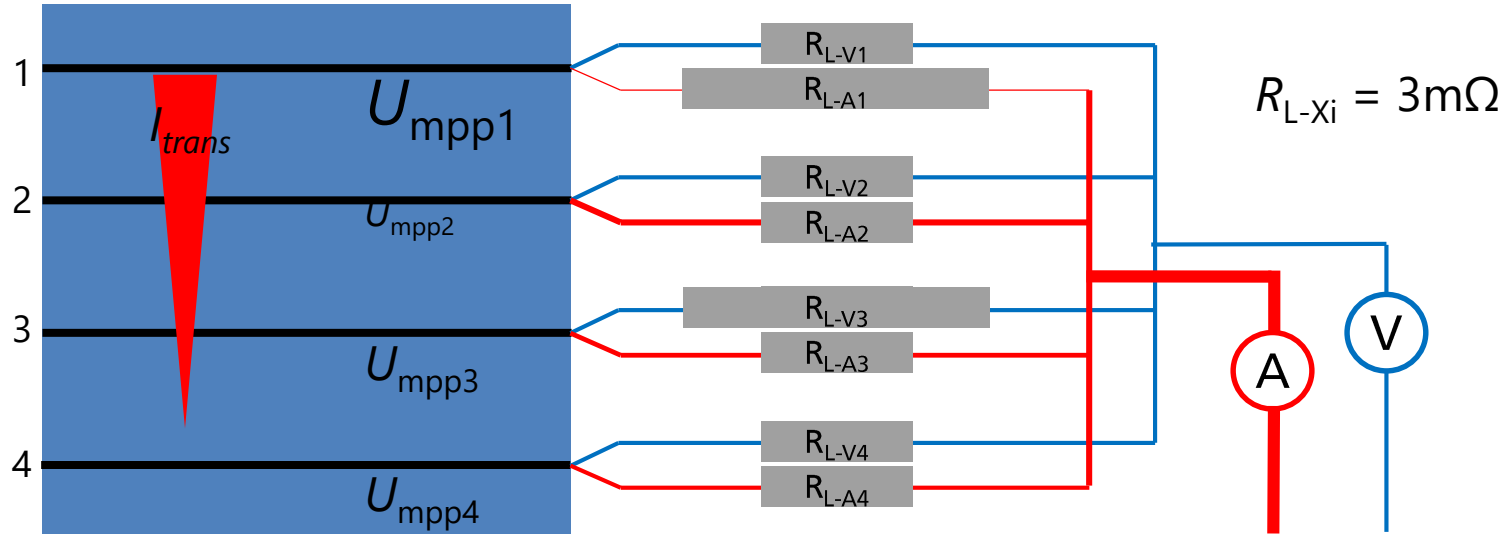
R_{L-V1-4}	LLLL	HLLL	LHLL			
ΔU_{mpp} [%] *	0.0	-0.26	0.23			

L = 3mΩ, H = 13mΩ

*using Kirchhoff's circuit laws

Nonuniform contact resistance – Analytical model



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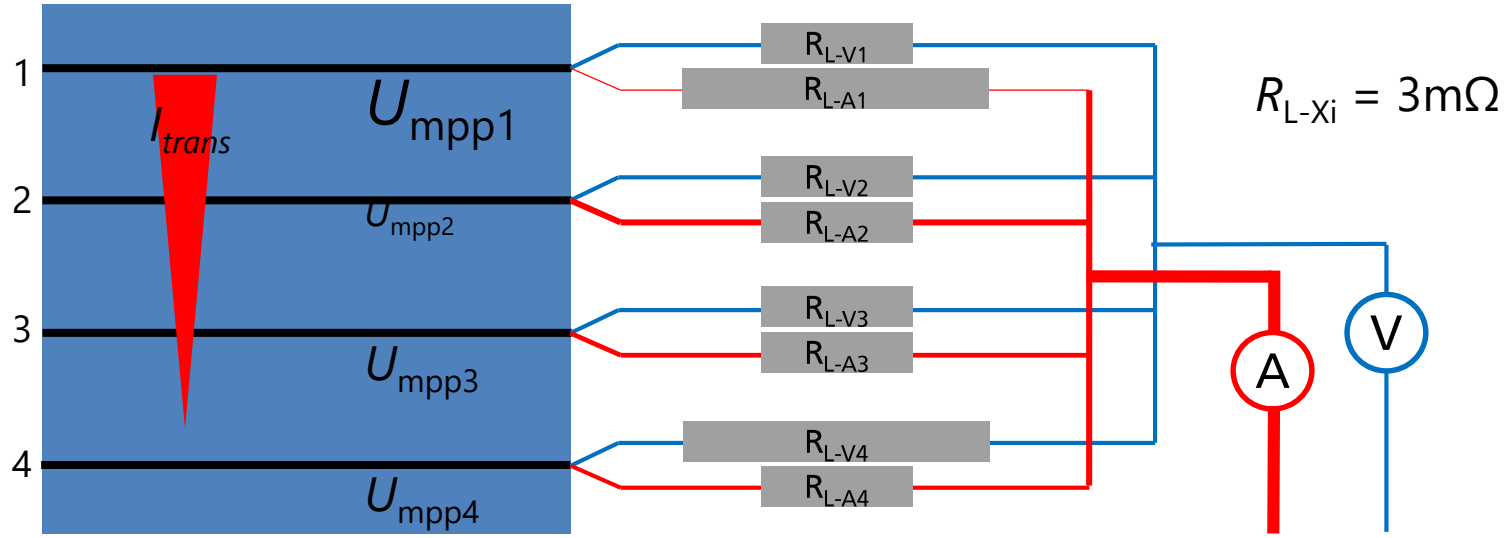
R_{L-V1-4}	LLLL	HLLL	LHLL	LLHL		
ΔU_{mpp} [%] *	0.0	-0.26	0.23	0.03		

L = 3mΩ, H = 13mΩ

*using Kirchhoff's circuit laws

Nonuniform contact resistance – Analytical model



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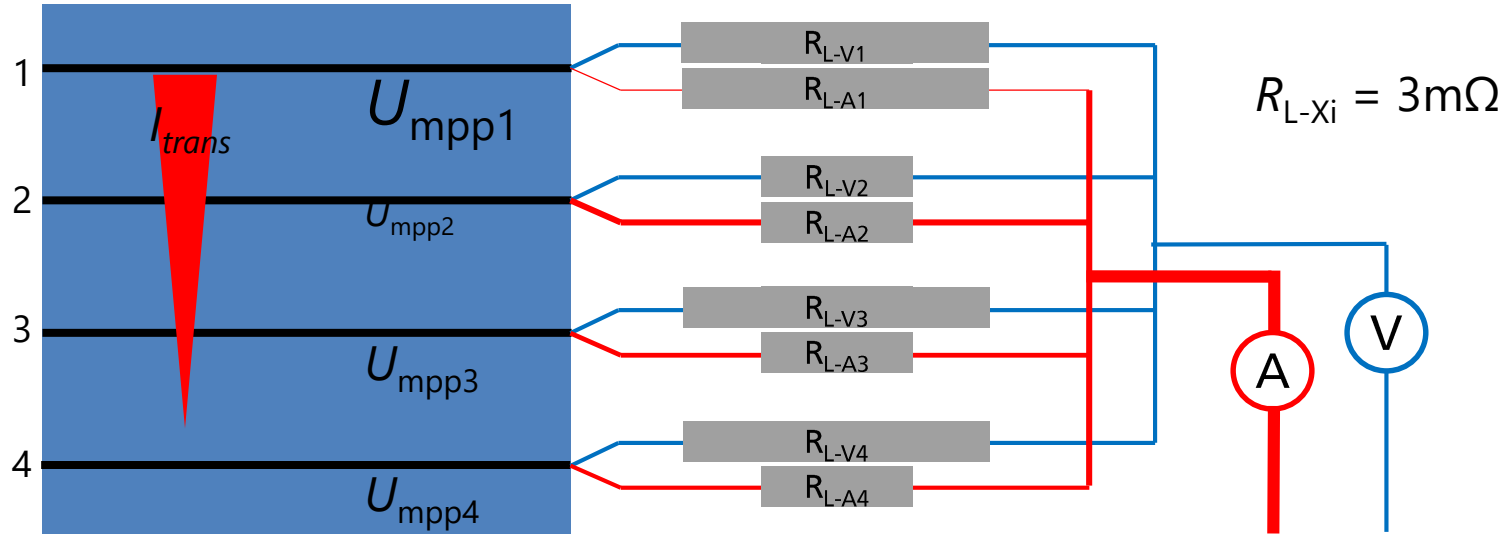
R_{L-V1-4}	LLLL	HLLL	LHLL	LLHL	LLLH	
ΔU_{mpp} [%] *	0.0	-0.26	0.23	0.03	0.0	

L = 3mΩ, H = 13mΩ

*using Kirchhoff's circuit laws

Nonuniform contact resistance – Analytical model



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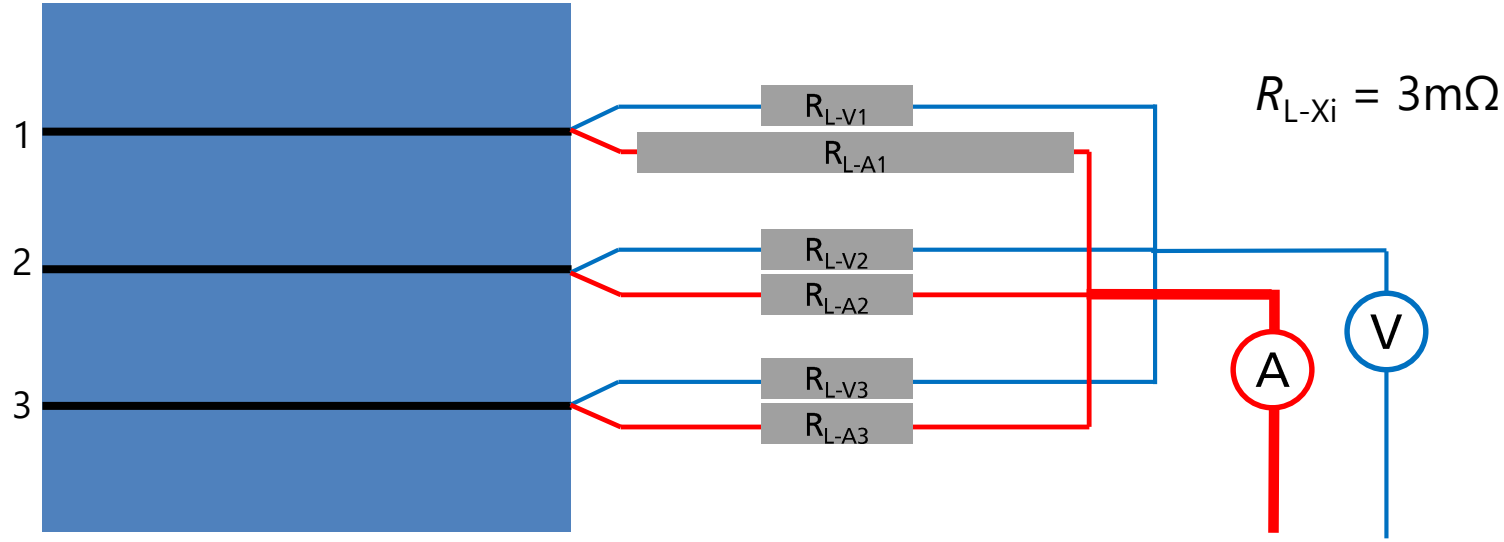
R_{L-V1-4}	LLLL	HLLL	LHLL	LLHL	LLLH	HLHH
ΔU_{mpp} [%] *	0.0	-0.26	0.23	0.03	0.0	-0.44

L = 3mΩ, H = 13mΩ

*using Kirchhoff's circuit laws

Nonuniform contact resistance – Experimental verification



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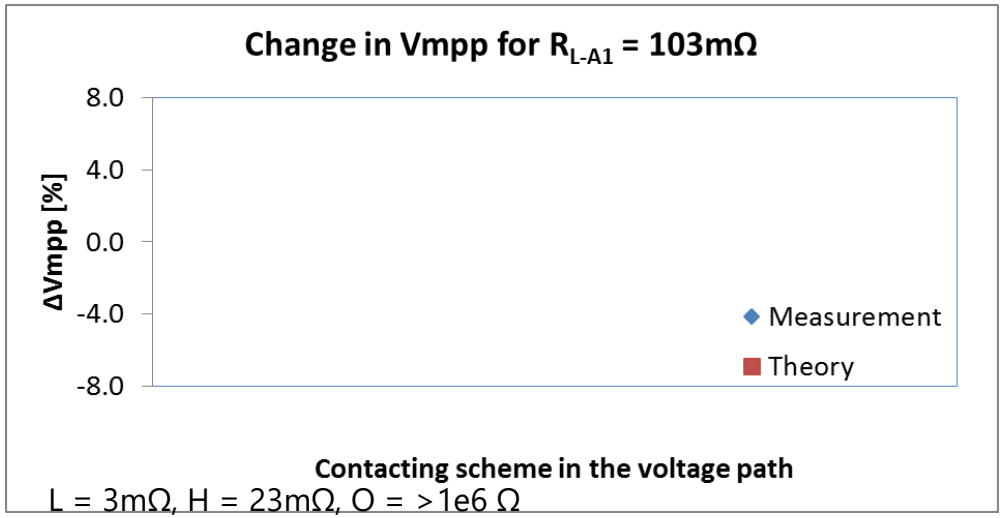
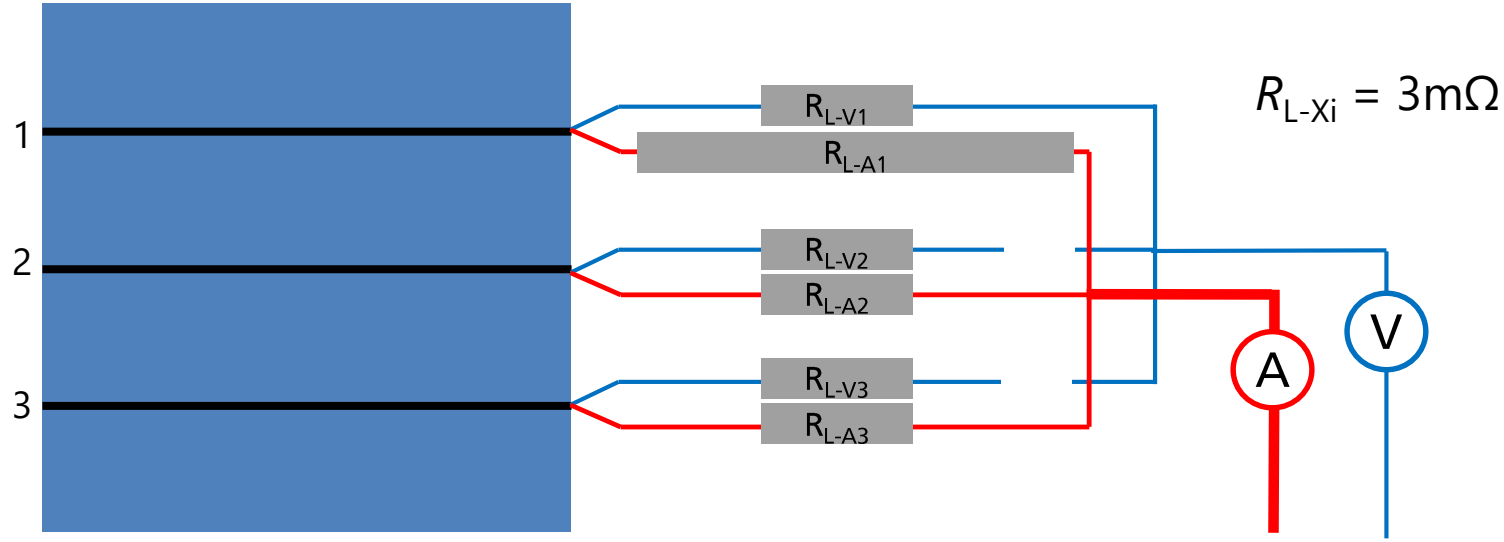


L = 3mΩ, H = 23mΩ, O = >1e6 Ω

Nonuniform contact resistance – Experimental verification



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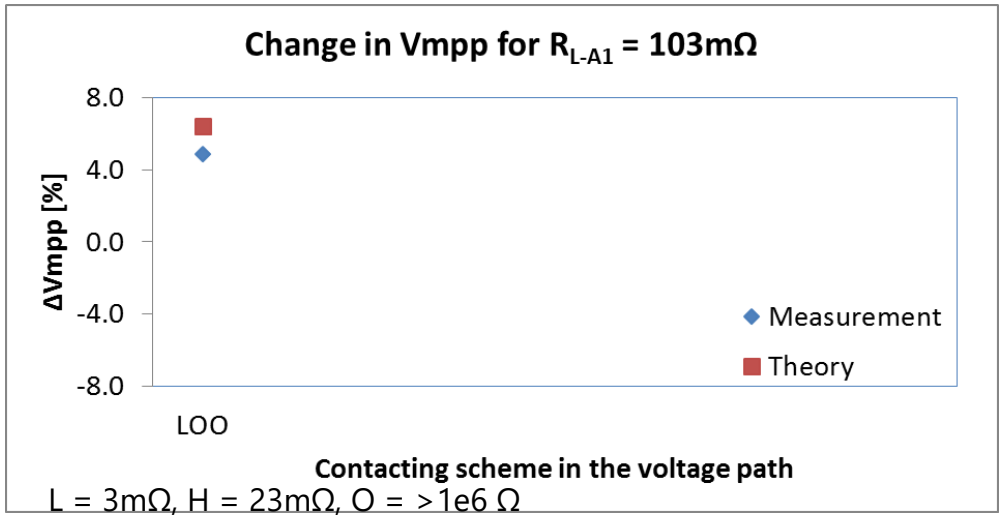

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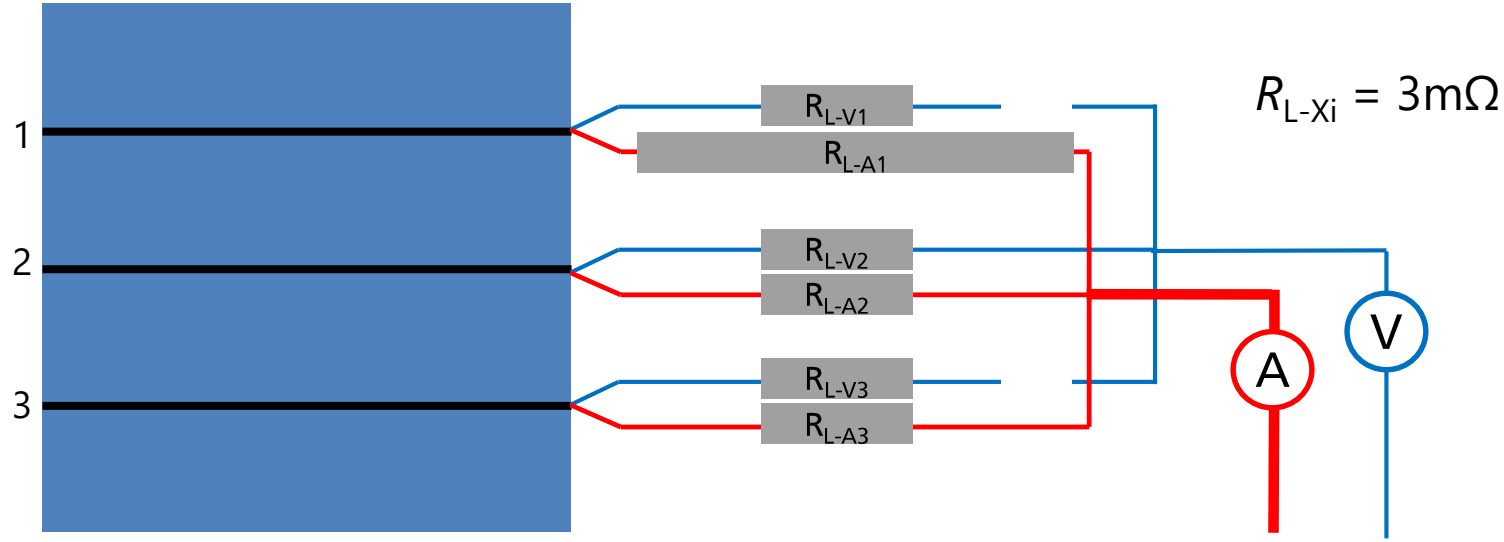

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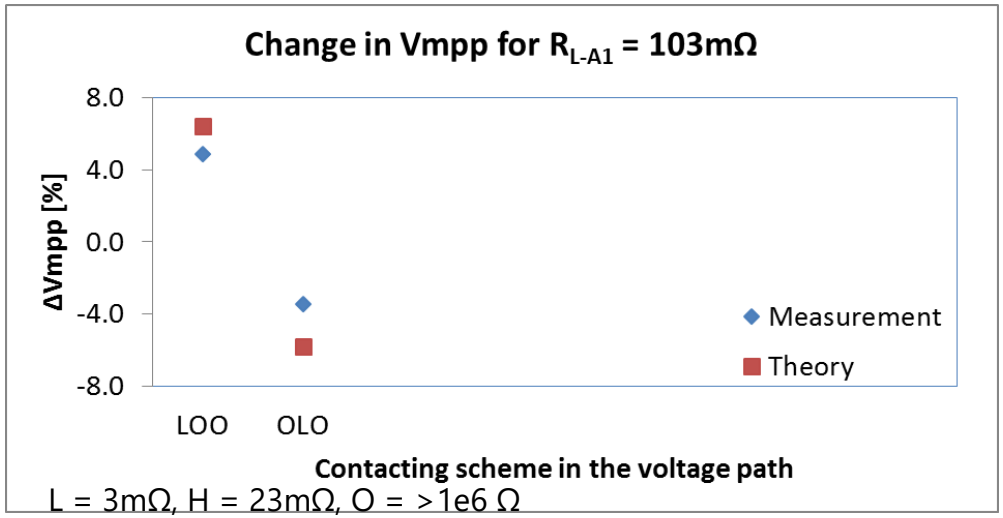

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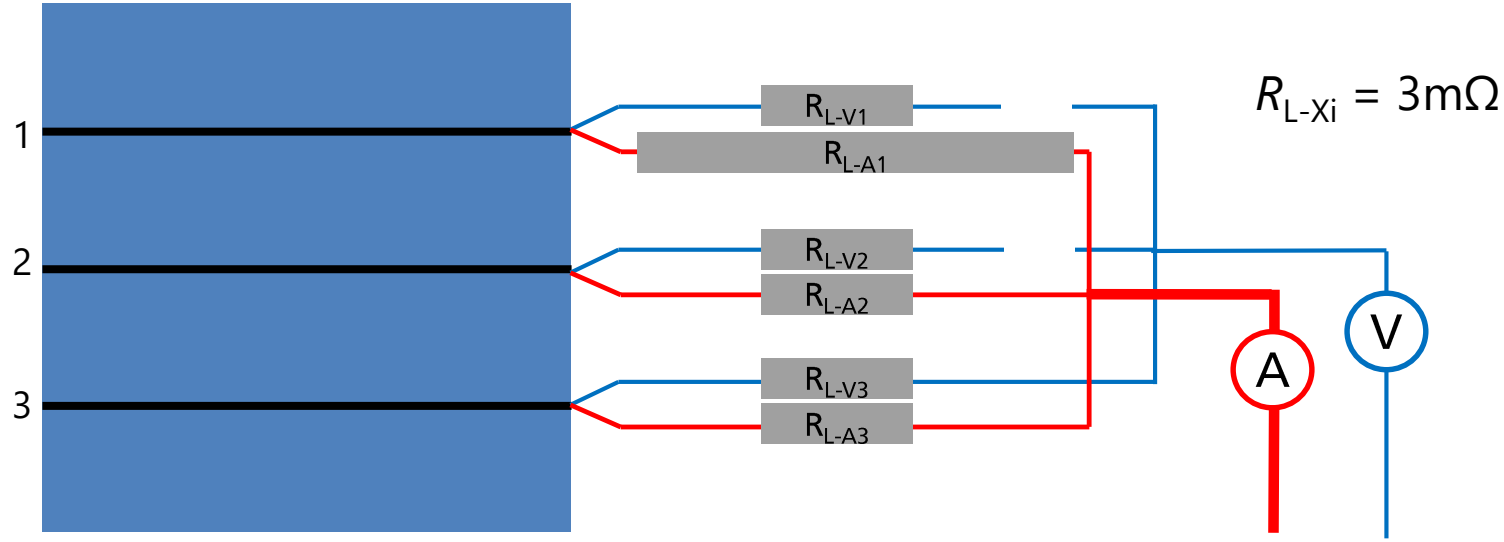

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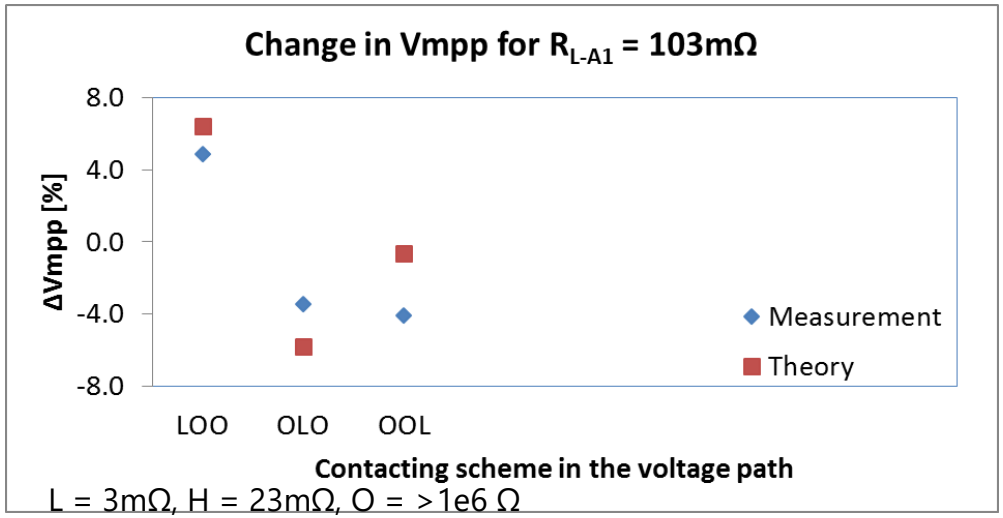

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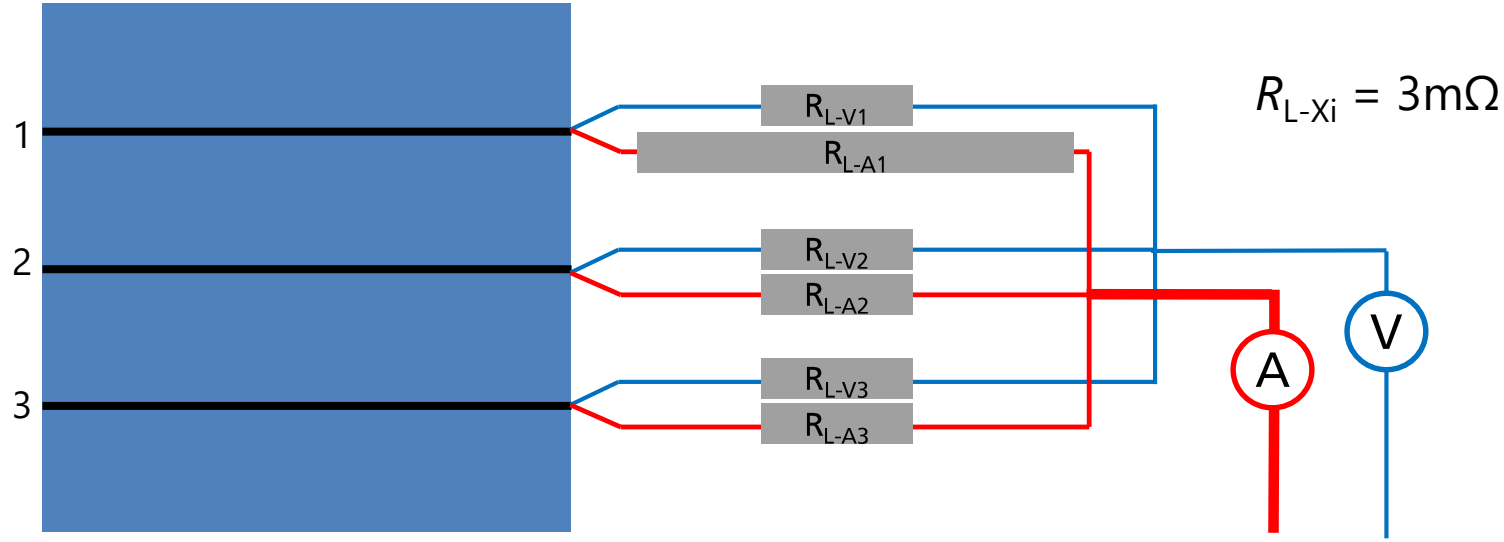

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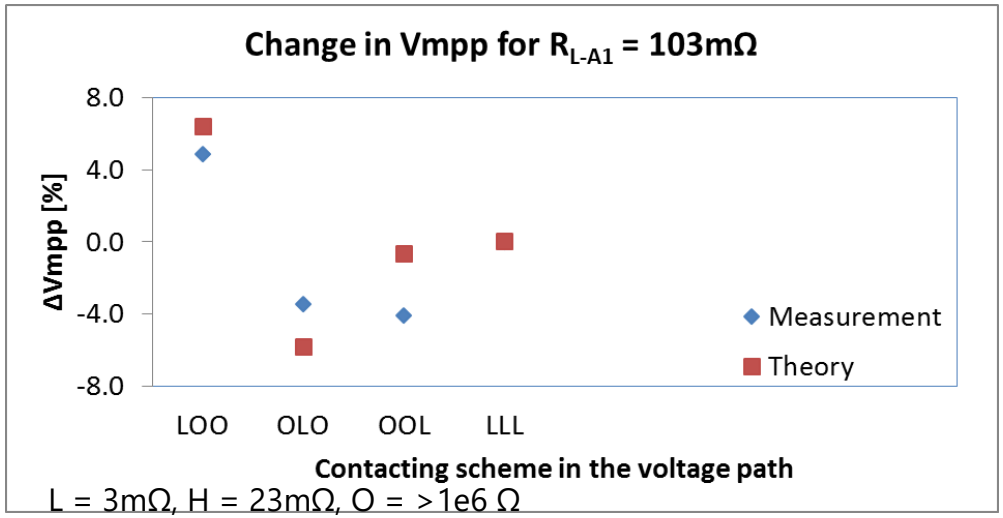

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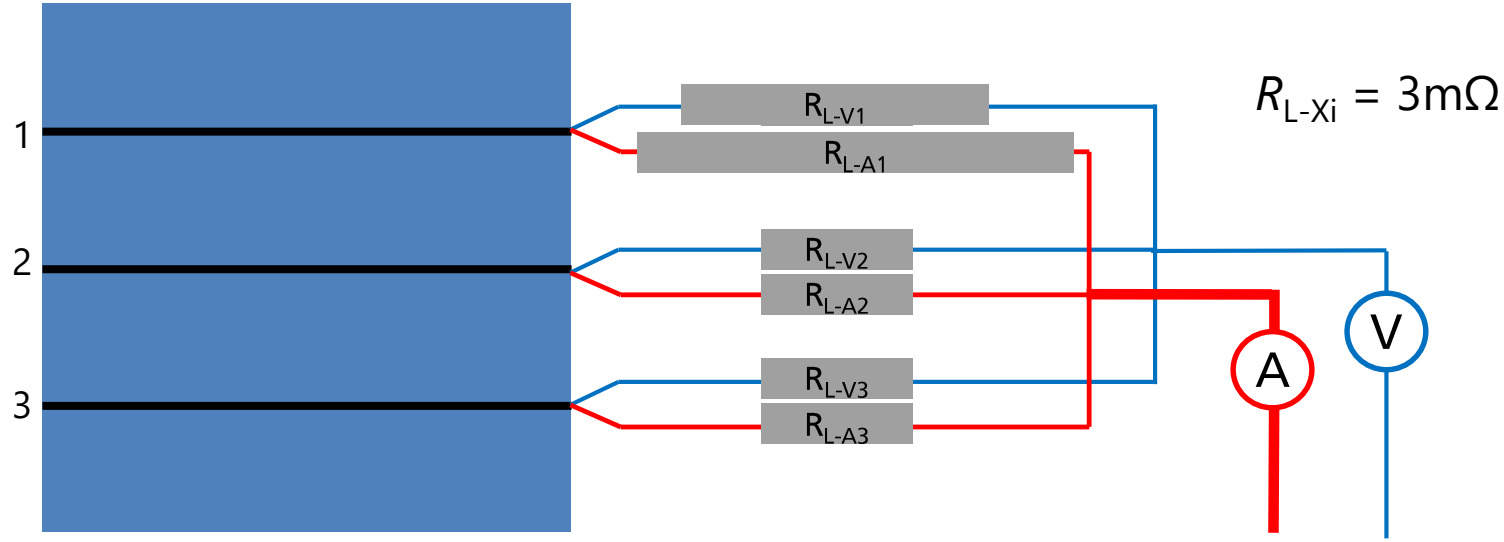

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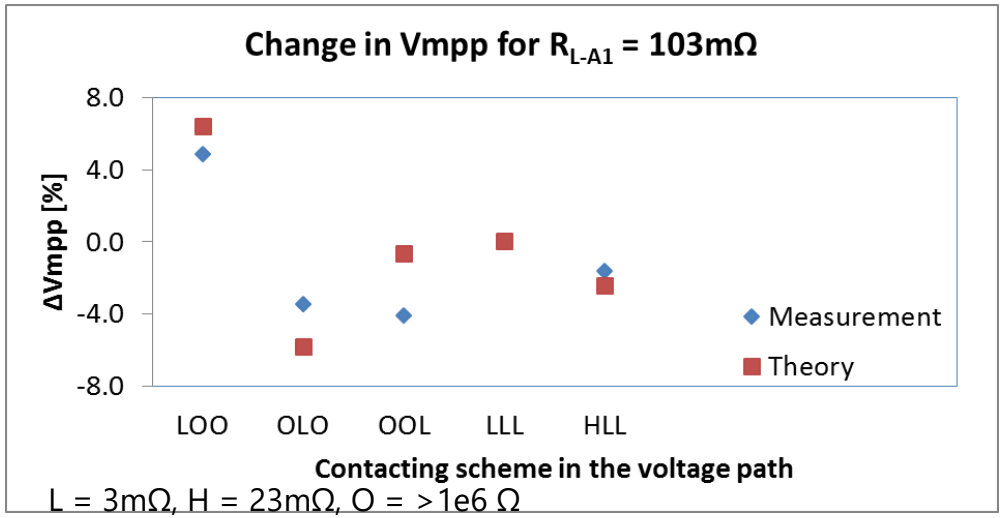

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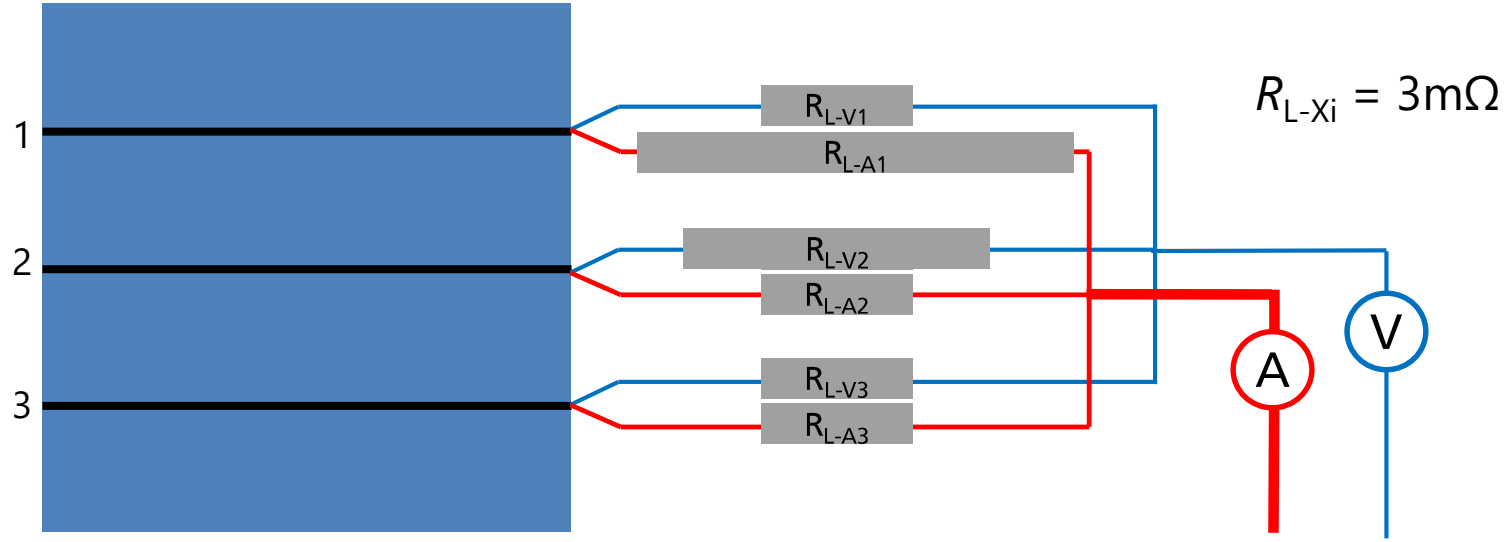

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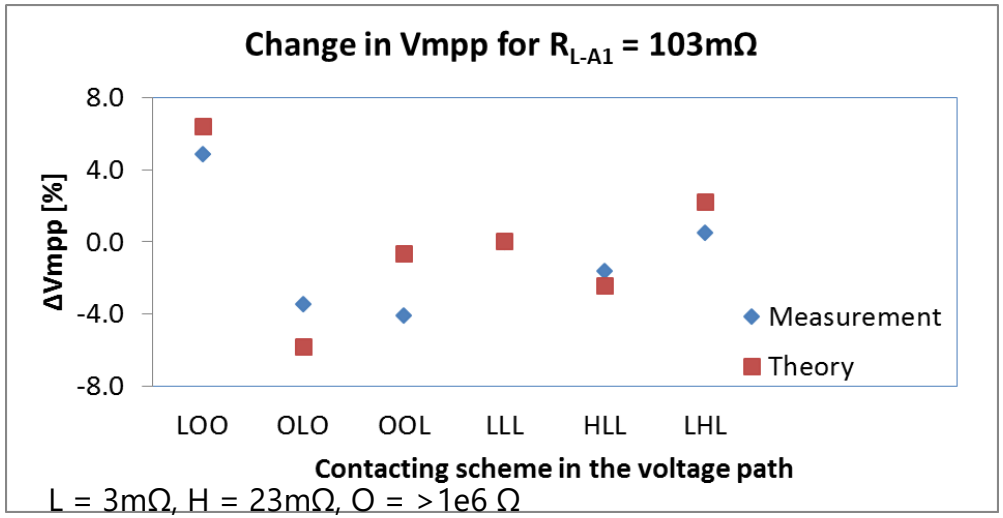

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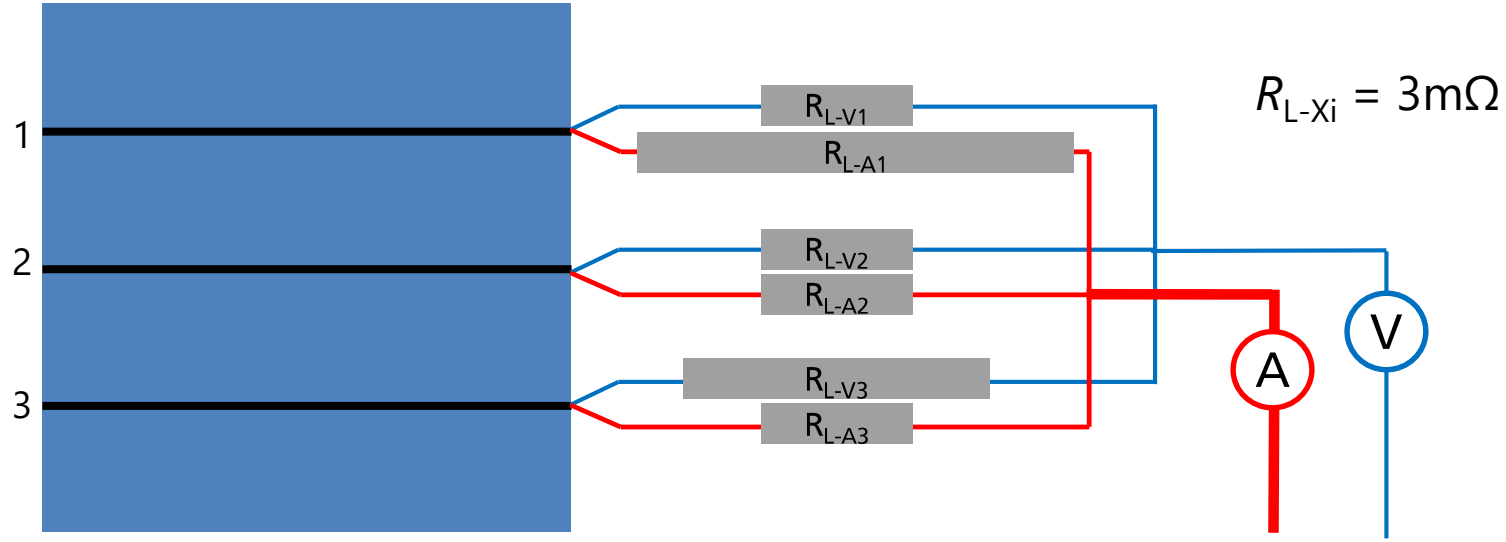

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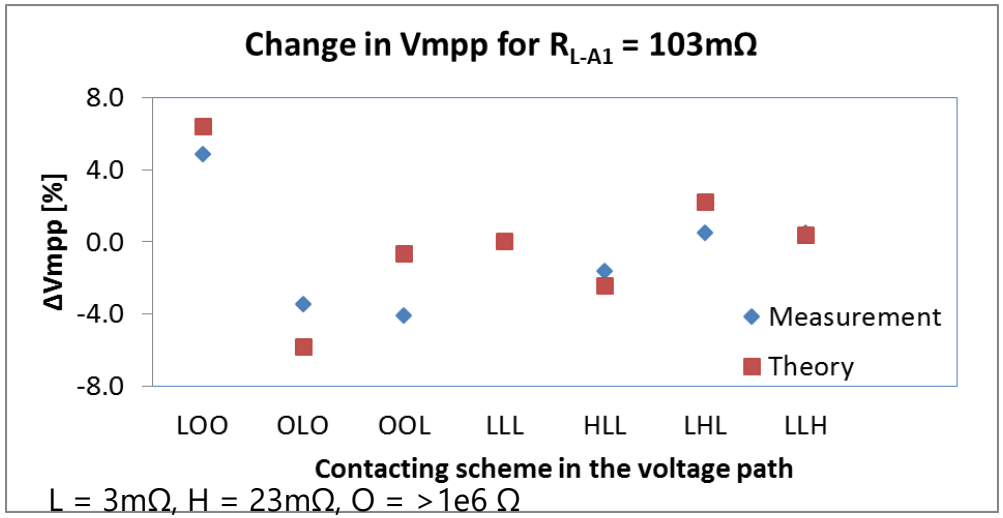

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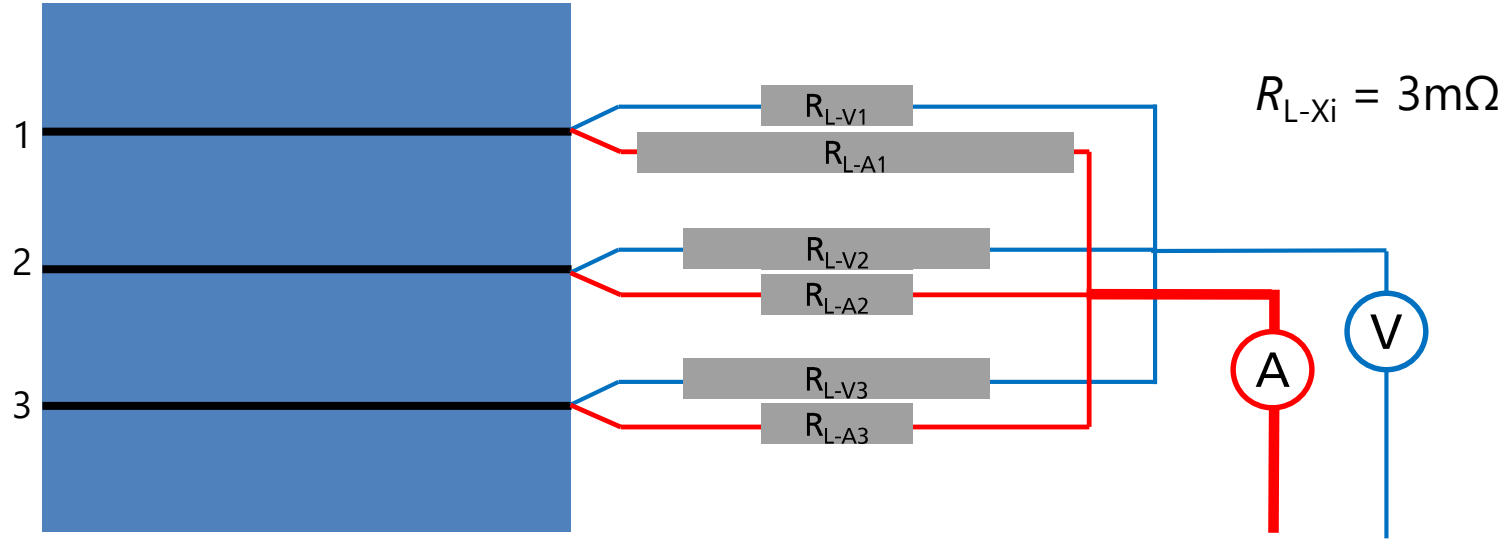
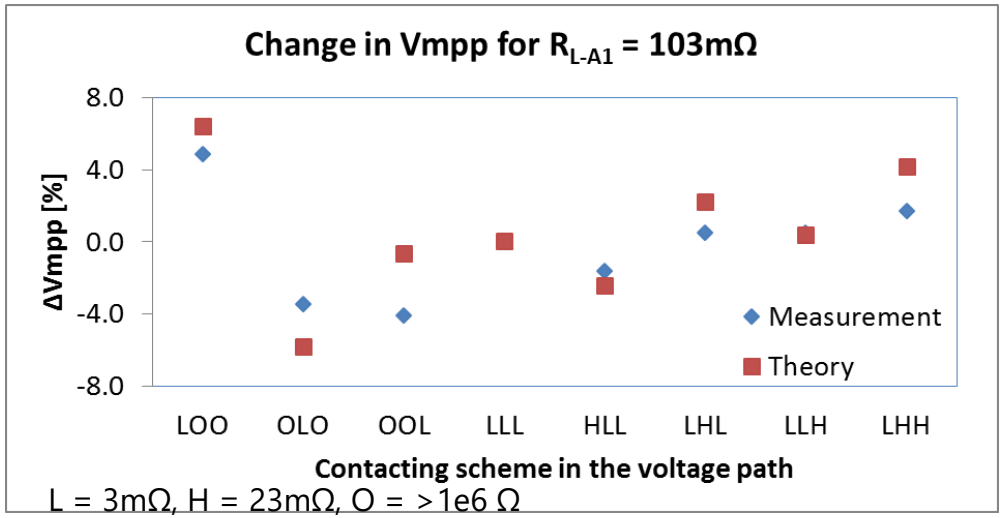
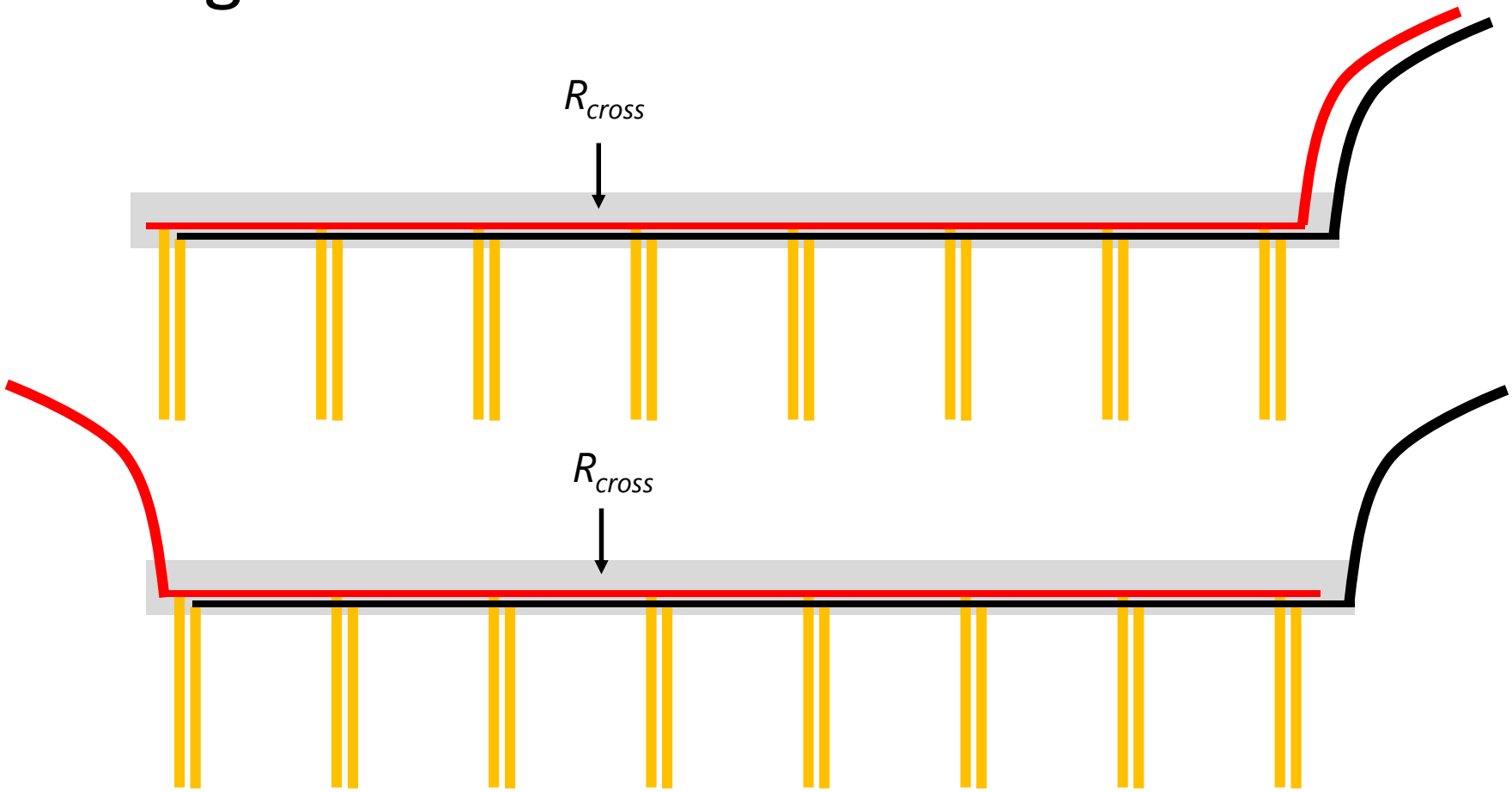




- **Arbitrary *FF* for different contacting resistance possible**
- **Balanced resistance in the voltage path sufficient to get correct *FF***

Design of the contact bar



- Influence of the resistance of the cross connector?

Design of the contact bar

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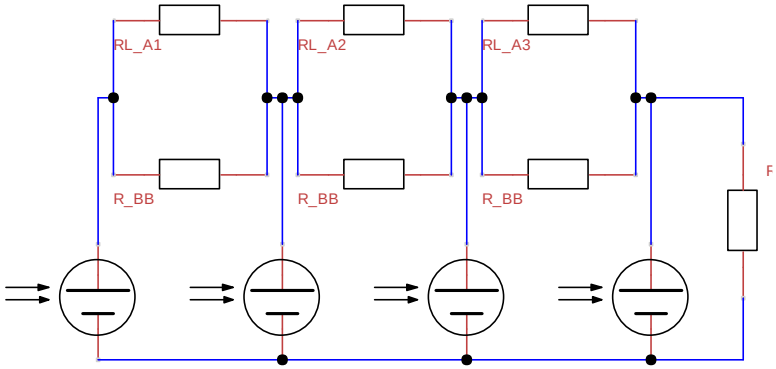
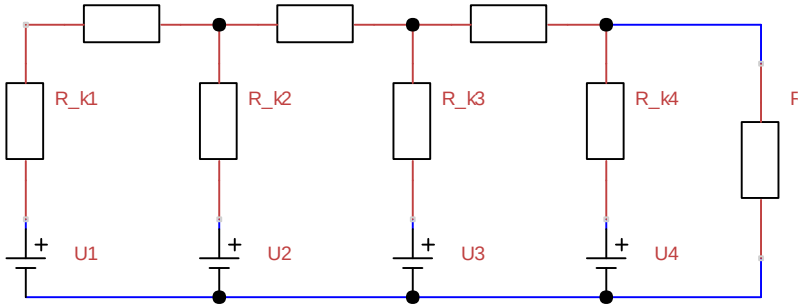
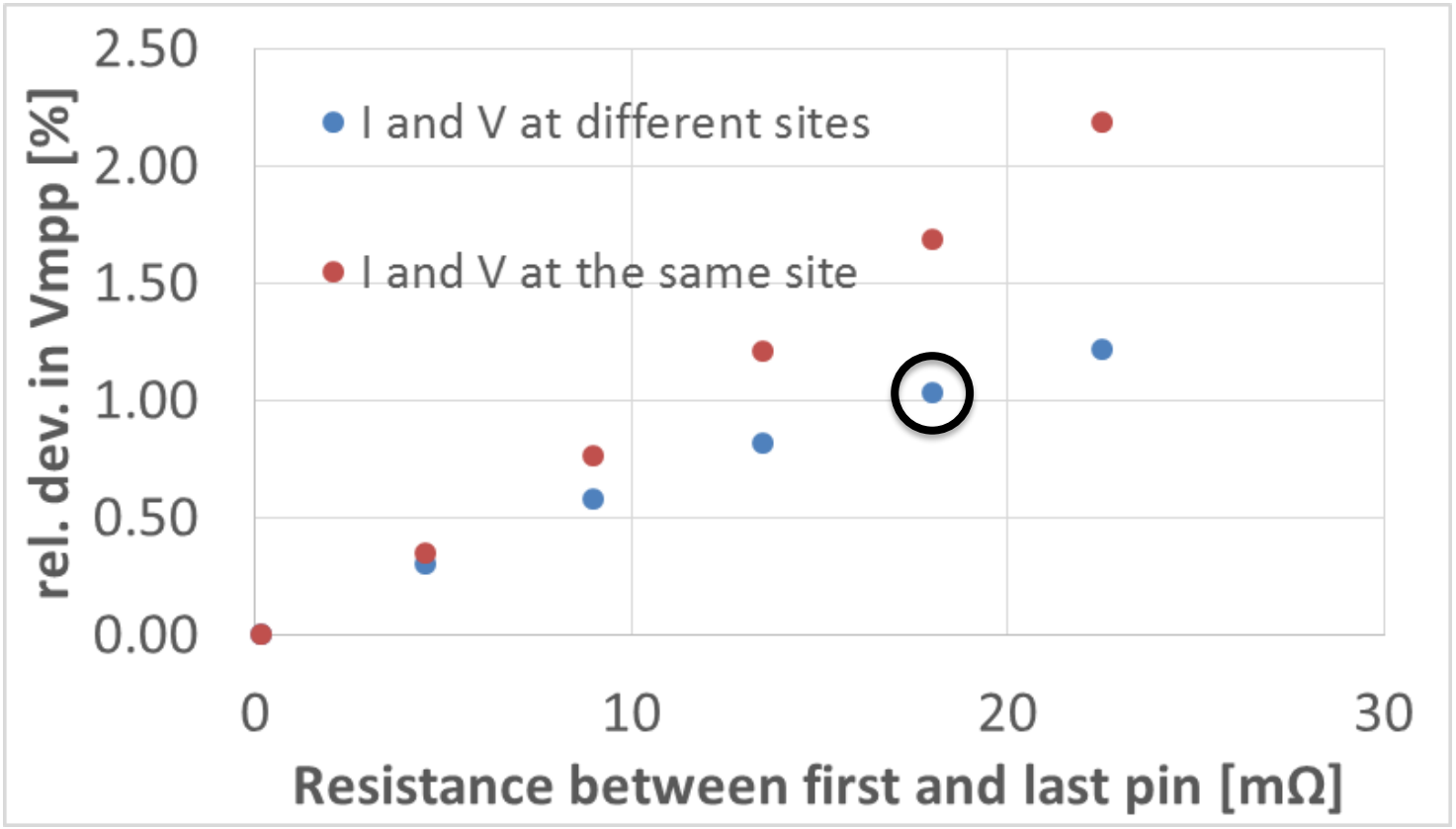


2) Calculate V_{tot}



Influence of R_{cross}



- R_{cross} can add a significant "gain" in *FF*

Conclusion

- Nonuniform contact resistance changes *FF* arbitrarily
- Balanced resistance in the voltage path is sufficient
- Use additional resistors in the current path to compensate small differences
- Avoid significant R_{cross}