PTB

CALIBRATION OF AC-DC CURRENT TRANSFER STANDARDS BASED ON CALCUABLE THERMAL CONVERTERS ON QUARTZ SUBSTRATE

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Contents

Electrical quantities are defined, realized an maintained at direct current (dc).

For alternating current (ac) calibrations, traceability is given due to ac-dc transfer.

For current, the measured quantity is δ_i, the ac-dc current transfer difference:

$$\delta_i = \frac{I_{ac} - I_{dc}}{I_{dc}}$$

Quartz-PMJTCs

Planar multijunction thermal converters (PMJTCs) on a quartz substrate are used as a calcuable standard

+ Very low conductivity of the substrate

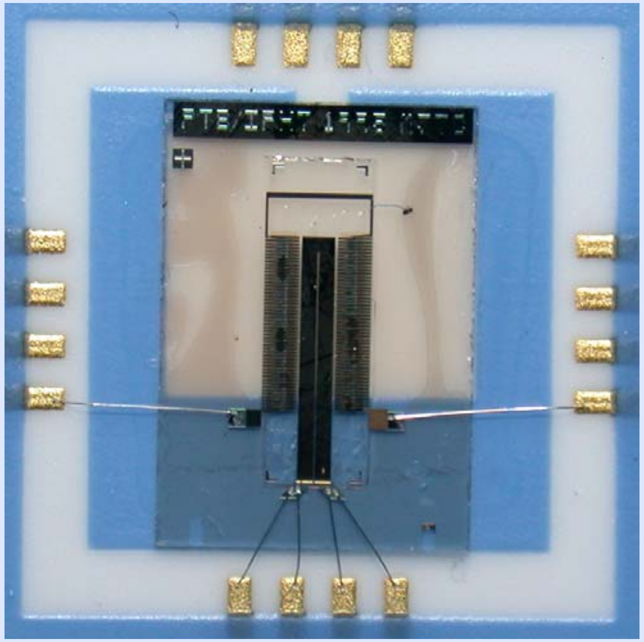
+ Low dielectric constant ε_r

+ Low, calculable transfer difference

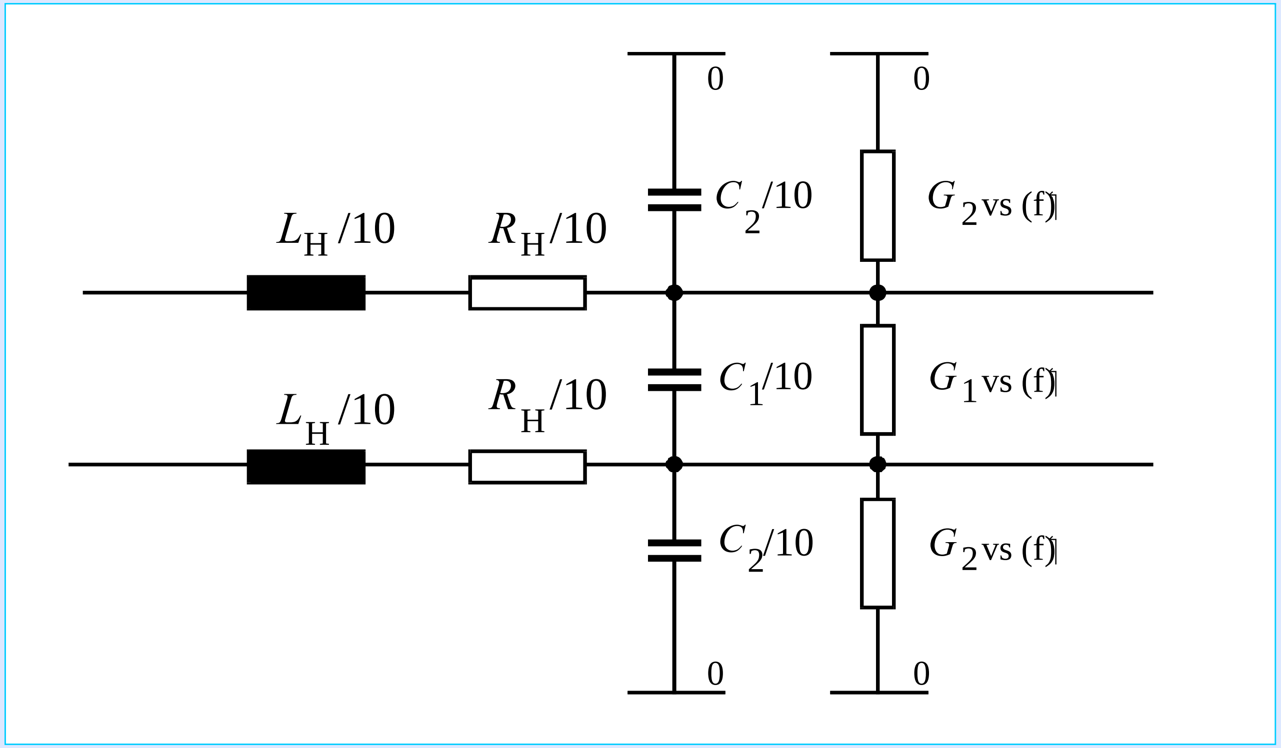
- Difficult to manufacture

- Low thermal time-constant

- Low sensitivity

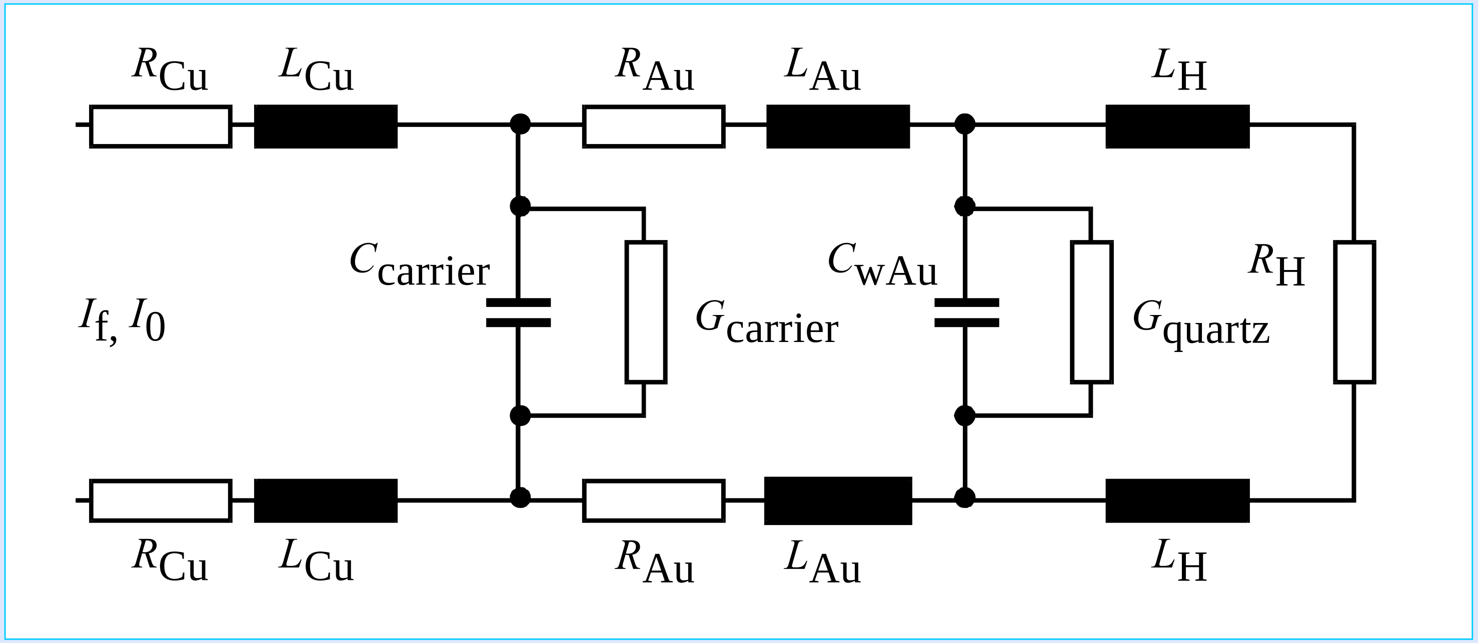


Calculation of δ_i due to heater impedance



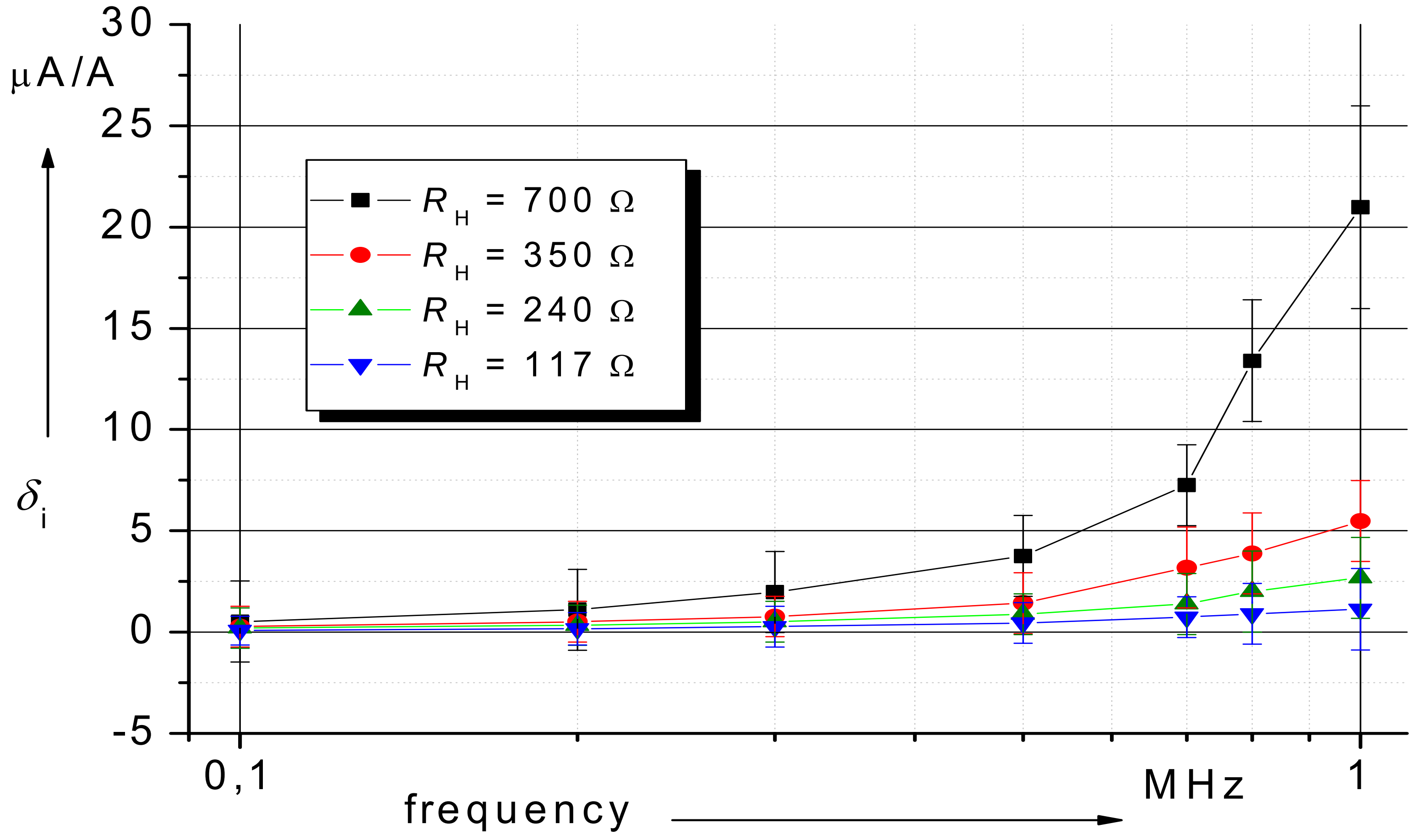
$$\delta_{i1} = \sqrt{\frac{R_H}{\mathrm{Re}\{\underline{Z}\}}} - 1$$

Calculation of δ_i due to stray capacitances

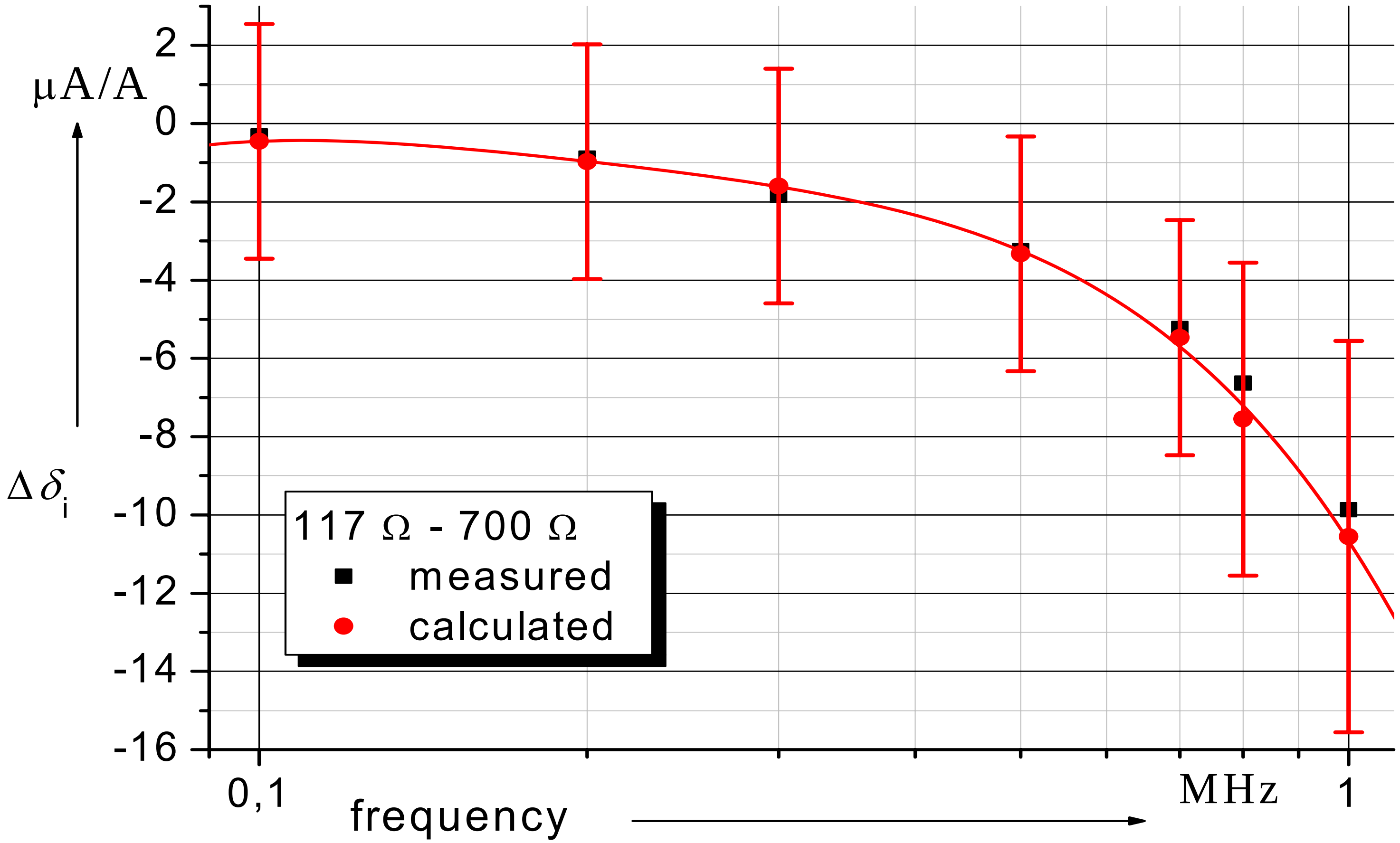


$$\delta_{i2} = \frac{\left|\underline{Z}_2 \cdot (\underline{Z}_3 + \underline{Z}_4)\right|}{\left|\underline{Z}_3 \cdot (2 \cdot \underline{Z}_1 + \underline{Z}_2)\right|} - 1$$

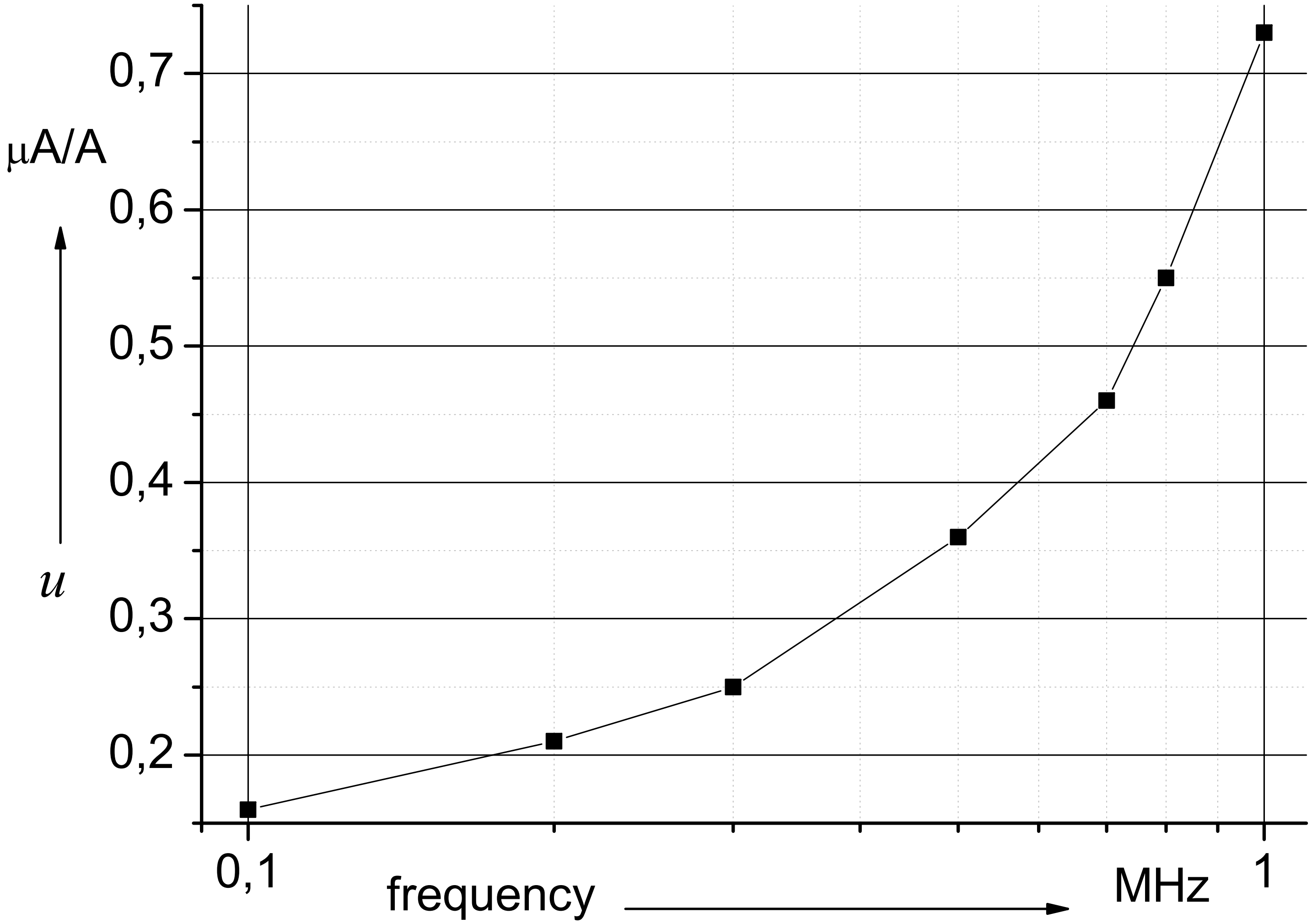
Current transfer differences



Validation of the calculation



Uncertainties using built-in Tee



Measurement setup using driven guards

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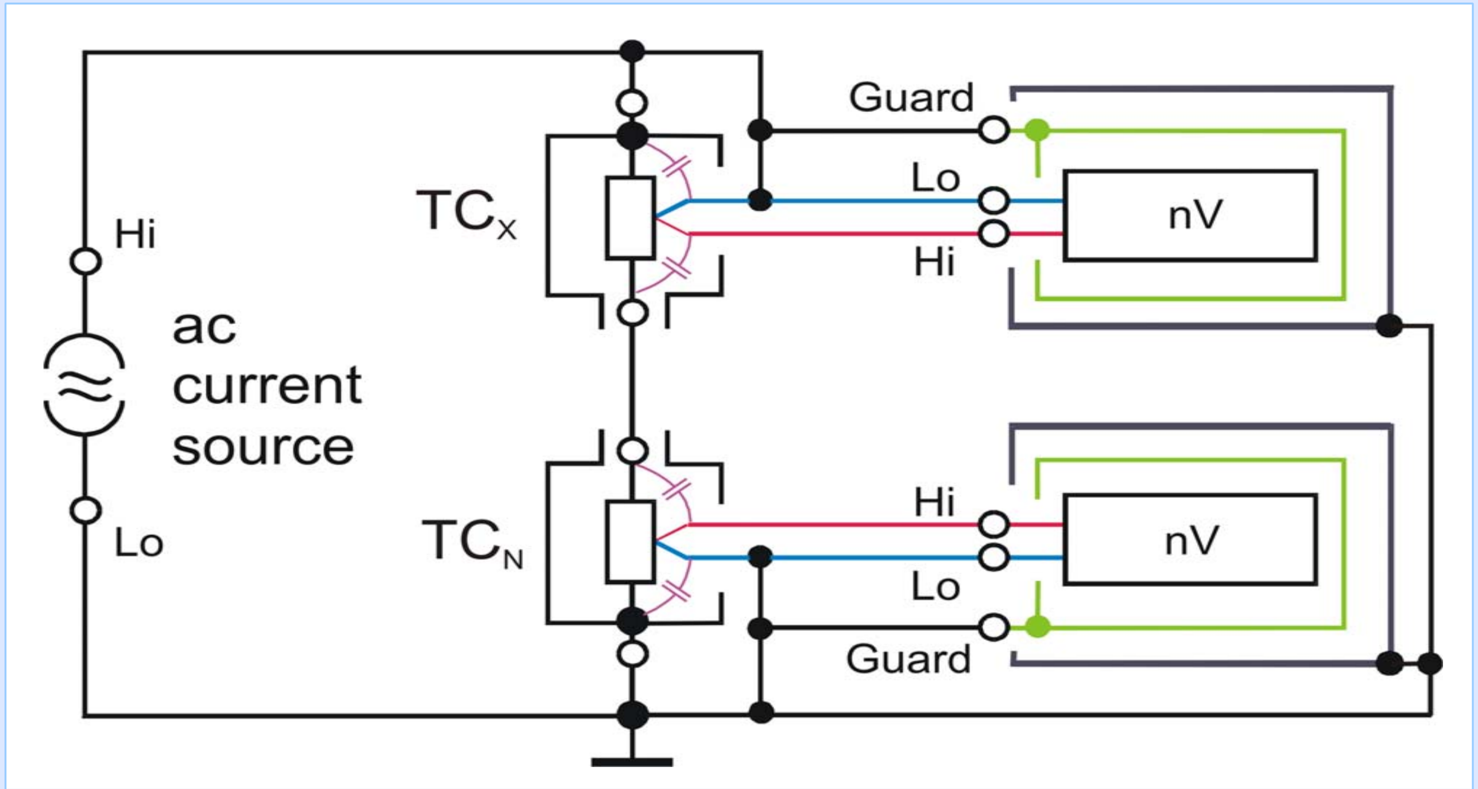


- **Symmetrical setup**
- **Upper standard connected „upside down“**
- **Constant voltage across parasitic capacitances => equal transfer differences in “upper position” and “lower position”**

- **Low currents:** PMJTC with low heater resistance

  Problem: Technology limits 90 Ω < R_H < 900 Ω

- **Medium currents:** Shunt + PMJTC

  Problems: Shunt inductance
  Current dependence

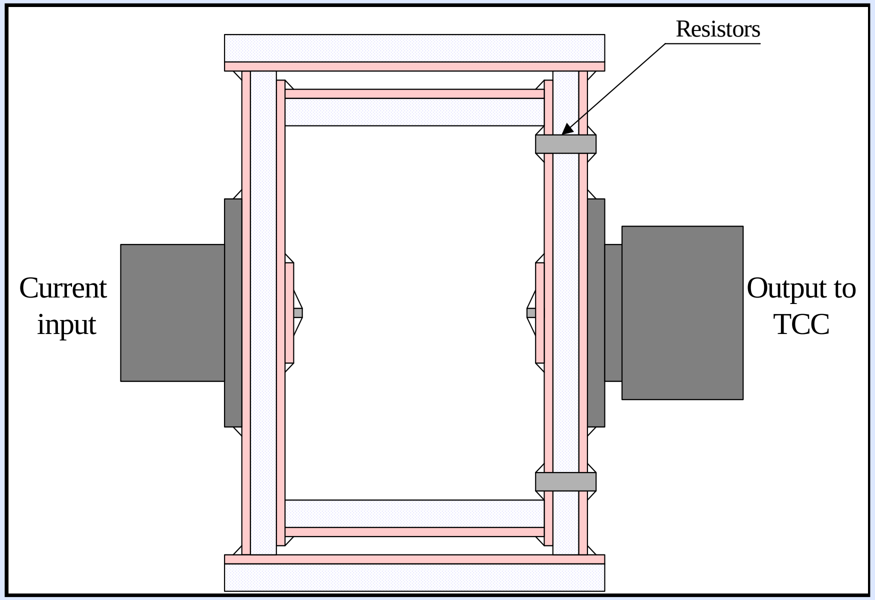
- **High currents:** Cooled shunt + PMJTC

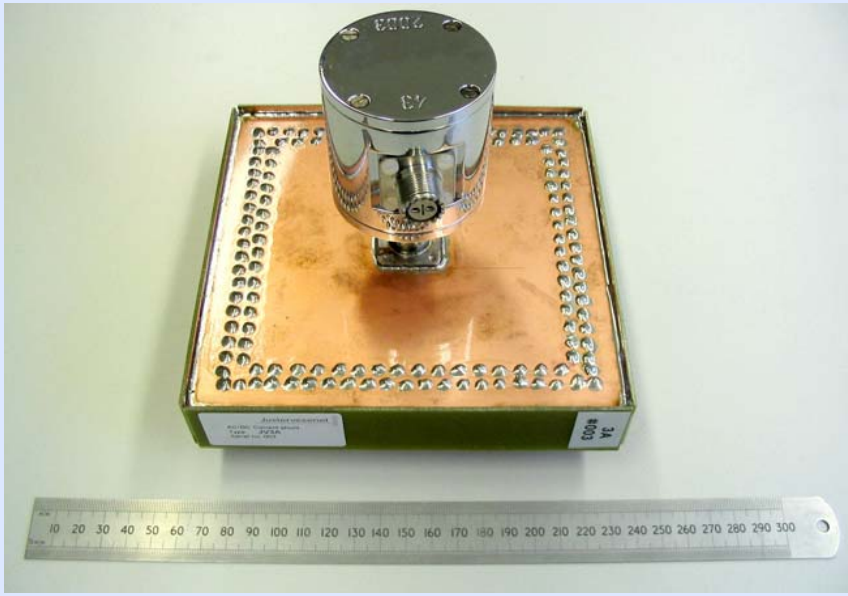
  Problems: Shunt inductance
  Current dependence
  Compliance voltage of current source

Shunts used at PTB

Up to 300 mA:	**PTB design**	**(top)**
500 mA to 5 A:	**Holt design**	**(middle)**
10 A and 20 A:	**Fluke design**	**(bottom)**

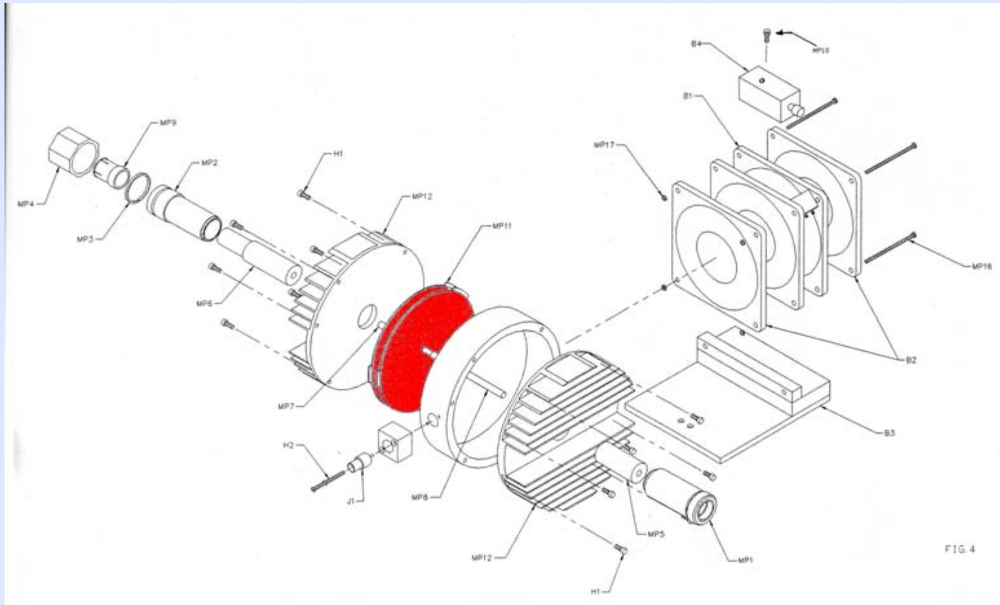
Shunts in Justervesenet design





Justervesenet

- + **Low cost materials**
- + **Large number of resistors ensure equal current distribution**
- + **Very small area of current path yields low inductive coupling**
- - **No case**



EL-9800

(NIST Design)

Set of four shunts:

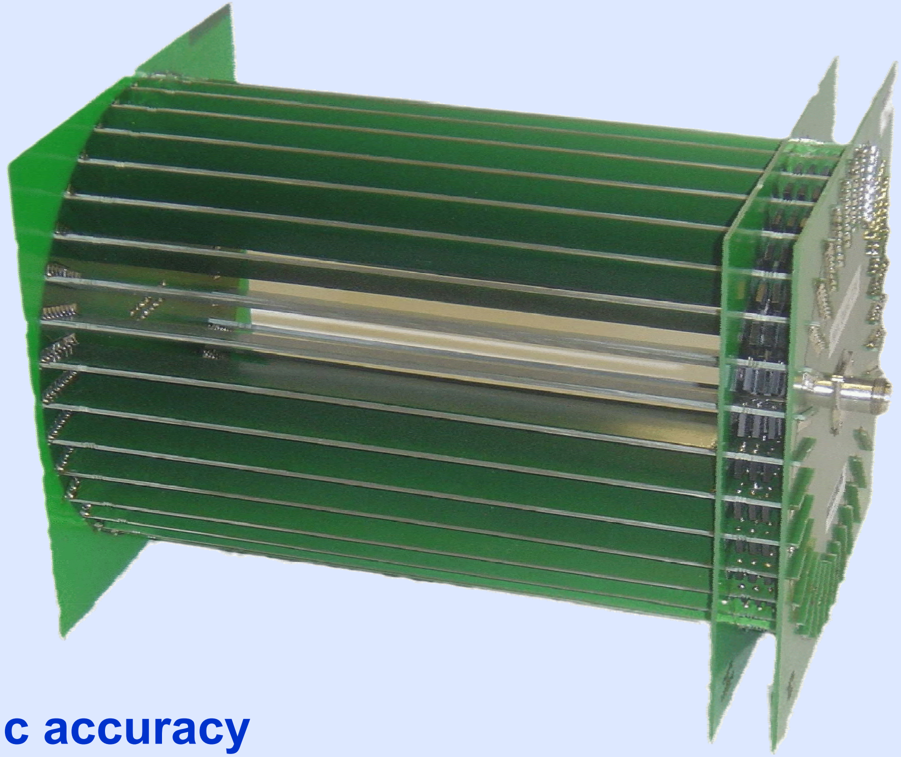
- 10 A to 30 A (25 mΩ)
- 30 A to 50 A (10 mΩ)
- 50 A to 80 A (5 mΩ)
- 80 A to 100 A (3 mΩ)

New high current shunts

Proven design scaled for higher currents

800 mV nominal output voltage

Available up to 100 A



+ Precision resistors provide also dc accuracy
+ Large number of resistors ensure equal current distribution
+ Small area of current path yields low inductive coupling
- No case
- Quite expensive

Step-up chains using different standards

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Step \ Chain	A	B	C
start	20 mA	30 mA	30 mA
1	50 mA	100 mA	100 mA
2	100 mA	500 mA	300 mA
3	200 mA	1 A	1 A
4	500 mA	5 A	3 A
5	1 A		5 A
6	2 A		
7	5 A		

Chains A & B: Self-made and Holt shunts

Chain C: Justervesenet-Shunts (two sets)

Comparison of the chains: 1 A at 1 MHz: $\Delta < 10$ µA/A

5 A at 100 kHz: $\Delta < 5$ µA/A

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Assumption:

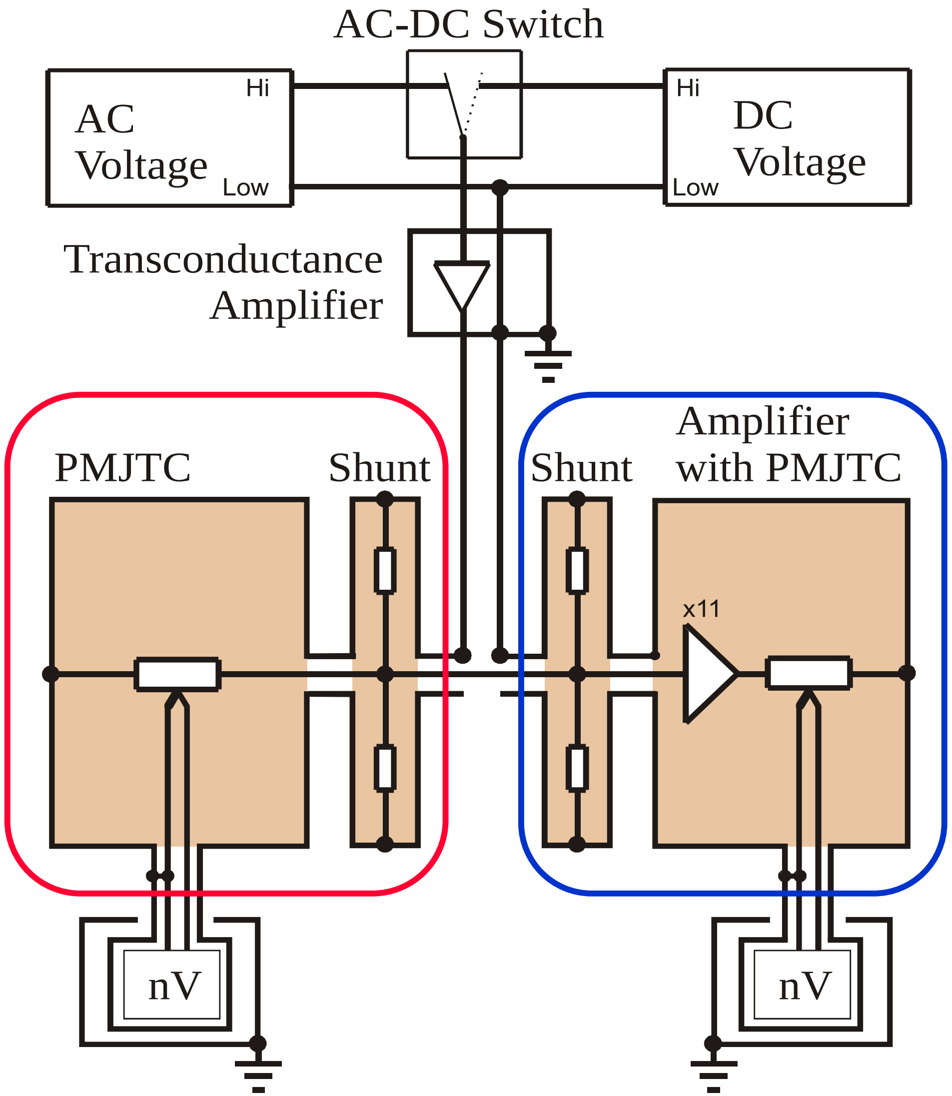
Current level dependence of shunts
results from self-heating

Measurement approach:

Shunt with low voltage drop used as a standard

- => Low power => low self-heating => low current level dependence
- Low voltage drop => voltage-amplifier necessary to operate PMJTC

Measurement setup: Shunt with Amplifier



Device under test

Standard

The following sources of uncertainty of the step-up procedure can be identified for each step:

u (δ_{std}) Standard uncertainty of the (calculable) transfer difference of the standard used, i.e. uncertainty of previous step

u (δ_{C}) Standard uncertainty of the comparison procedure

u (δ_{A}) Type A standard uncertainty, i.e. the standard deviation of the mean

u (δ_{Lev}) Standard uncertainty due to the current level effects in the shunt

u (δ_{LF}) Standard uncertainty due to PMJTC low frequency effects, which are level dependent

Improvements in measurement uncertainties

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Current	Expanded uncertainty of measurement in µA/A at the frequencies					
	10 Hz	1 kHz	10 kHz	100 kHz	500 kHz	1 MHz
30 mA	5 1	5 1	5 1	10 1	- 1	- 2
100 mA	5 2	5 2	5 2	10 2	- 2	- 5
300 mA	10 2	10 2	10 2	20 2	- 3	- 5
1 A	10 4	10 3	10 3	30 4	- 6	- 10
3 A	20 4	20 4	20 4	60 8		
10 A	25 12	25 12	25 12	80 25		
30 A	- 30	- 30	- 60	- 120		
100 A	- 40	- 40	- 80	- 150		

Red : old (2002)

Blue: (2006)

Conclusions

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- PMJTCs on quartz substrate developed at PTB are well suited for current transfer at low current up to 1 MHz
- Potential driven guarding reduces the uncertainty of the comparison measurements
- New shunts with low current level dependence and low transfer difference allow further reduction of the step-up procedure's uncertainty
- New approaches for the determination of the current level dependence allow for corrections and therefore for further reduction of the uncertainty

Thank you for your attention!

Torsten Funck