Follow-up of bench measurement of TCSPM block

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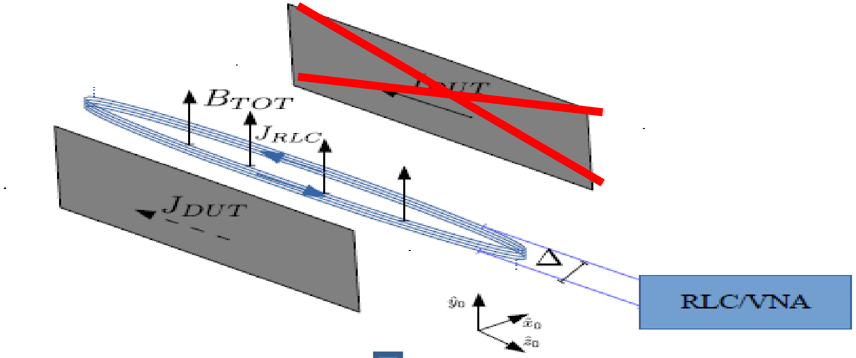
Introduction

Resistivity measurements on collimator blocks routinely performed in the lab.

Date	Bulk	Coating	Treatment	Coating resistivity	Expected resistivity
30 Aug 2017	C	-	-	$(0.87 to 1.3)\,\mu\Omega m$	$1\ \mu\Omega m$
01 Jun 2016	MoGr	Mo	-	(30 to 150) $n\Omega m$	53.5 $n\Omega m$
01 Jun 2016	MoGr	-	-	$(1.5 \pm 0.2)\ \mu\Omega m$	$1\ \mu\Omega m$
18 May 2016	CFC	Cu stripe	-	$(43 \pm 10)\ n\Omega m$	30 $n\Omega m$
18 May 2016	CFC	-	-	$(6.9 \pm 0.5)\ \mu\Omega m$	$5\ \mu\Omega m$
18 May 2016	CFC	Mo stripe	-	$(140 \pm 40)\ n\Omega m$	53.5 $n\Omega m$
18 May 2016	C	-	heat treatment	$(23 \pm 3)\,\mu\Omega m$	$15\ \mu\Omega m$
18 May 2016	C	Mo	heat treatment	$(125 \pm 12)\ n\Omega m$	53.5 $n\Omega m$
18 May 2016	C	-	-	$(27.5 \pm 0.3)\,\mu\Omega m$	$15\ \mu\Omega m$
18 May 2016	C	TiN	-	$(147 \pm 49)\ n\Omega m$	400 $n\Omega m$
18 May 2016	CFC	-	-	$(7.6 \pm 0.8)\,\mu\Omega m$	$5\ \mu\Omega m$
18 May 2016	CFC	TiN	-	$(182 \pm 26)\ n\Omega m$	400 $n\Omega m$
09 Feb 2016	CFC	Mo	after heat treatment	$(75 \pm 6)\ n\Omega m$	53.5 $n\Omega m$
15 Dec 2015	C	Mo	-	$(54 \pm 5)\ n\Omega m$	53.5 $n\Omega m$
08 Dec 2015	CFC	-	-	$(6.8 \pm 0.8)\,\mu\Omega m$	$5\ \mu\Omega m$
08 Dec 2015	CFC	Mo	-	$(68.0 \pm 8.4)\ n\Omega m$	53.5 $n\Omega m$
12 Nov 2015	C	-	-	$(16.7 \pm 3.5)\,\mu\Omega m$	$15\ \mu\Omega m$

Method



$$Z_y^{dip}(\omega) = \frac{j}{Q\Delta}\int_0^L (E(z,\omega) + c \times B(z,\omega))_y \, e^{\frac{j\omega z}{v}} dz$$

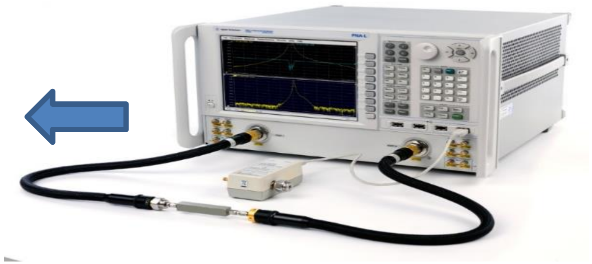
If $\lambda \gg 2\pi D$

$$Z_y^{dip}(\omega) = \frac{j}{Q\Delta}\int_0^L (E(z,\omega) + c \times B(z,\omega))_y dz$$

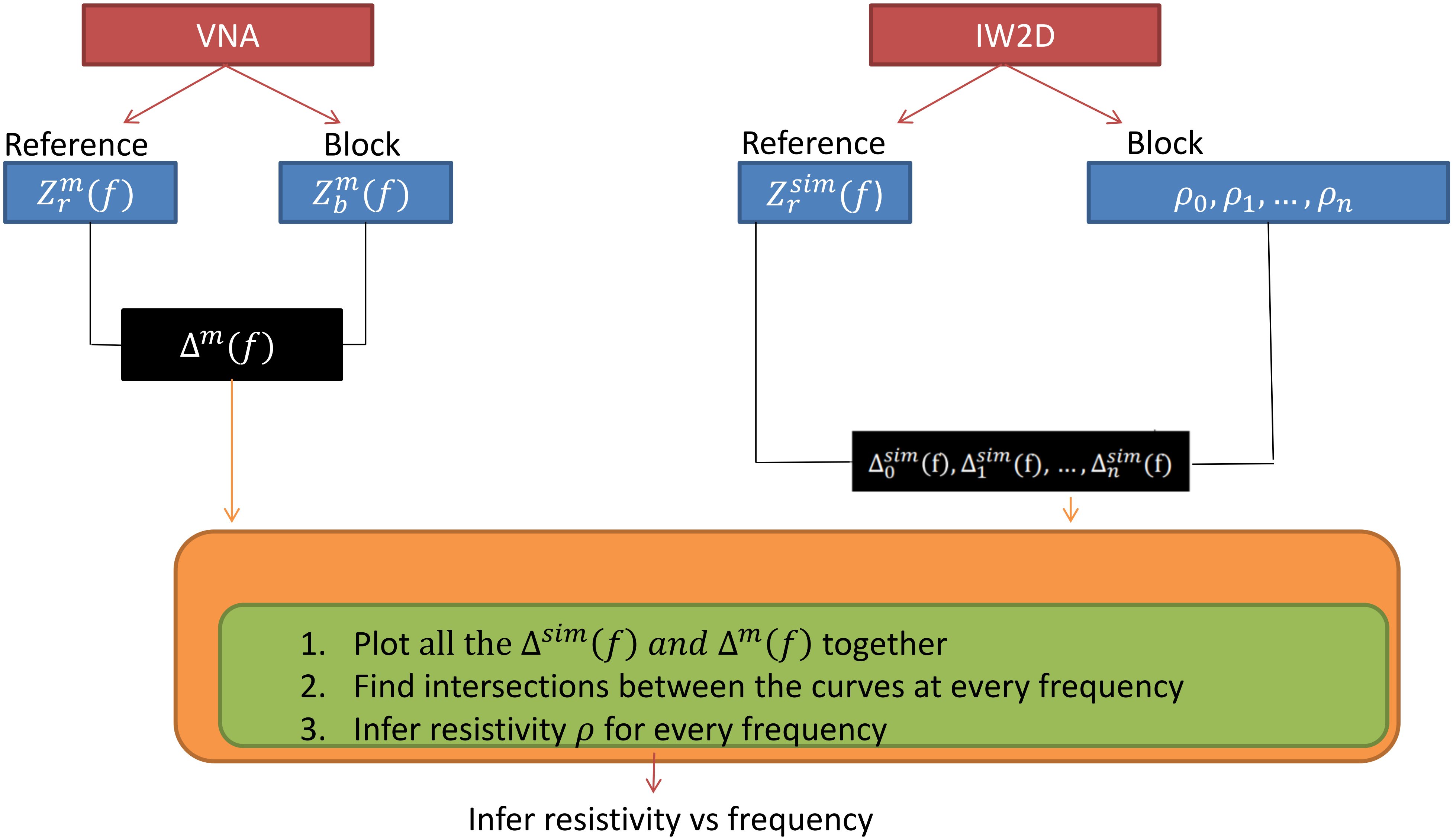
(Quasi - Magnetostatic approximation)

$$Z_y^{dip}(\omega) = \frac{c}{\omega}\frac{Z_{VNA}}{N^2\Delta^2}$$

$$V_{VNA} = I_{VNA} Z_{VNA} \cong j\omega B_y N \Delta L$$



$$\Delta^m(f) = \frac{c}{2\pi f}\frac{Z_{VNA}{}^{block} - Z_{VNA}{}^{ref}}{N^2\Delta^2}$$


VNA
Reference
Block
$Z_r^m(f)$
$Z_b^m(f)$
$\Delta^m(f)$
IW2D
Reference
Block
$Z_r^{sim}(f)$
$\rho_0, \rho_1, \dots, \rho_n$
$\Delta_0^{sim}(f), \Delta_1^{sim}(f), \dots, \Delta_n^{sim}(f)$
1. Plot all the $\Delta^{sim}(f)$ and $\Delta^m(f)$ together
2. Find intersections between the curves at every frequency
3. Infer resistivity ρ for every frequency
Infer resistivity vs frequency

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Measurement of Mo coating not fully understood

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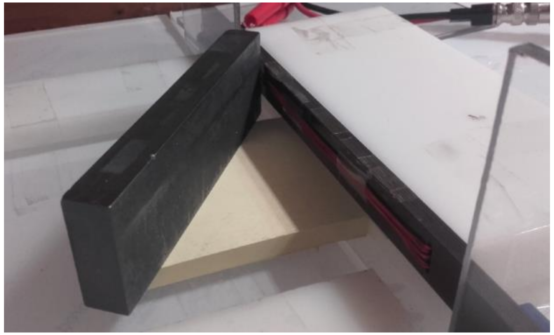
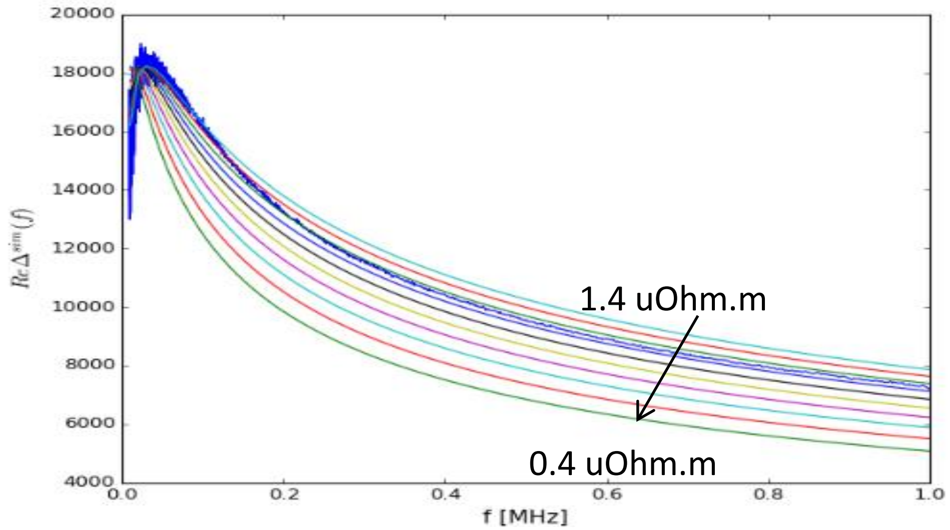
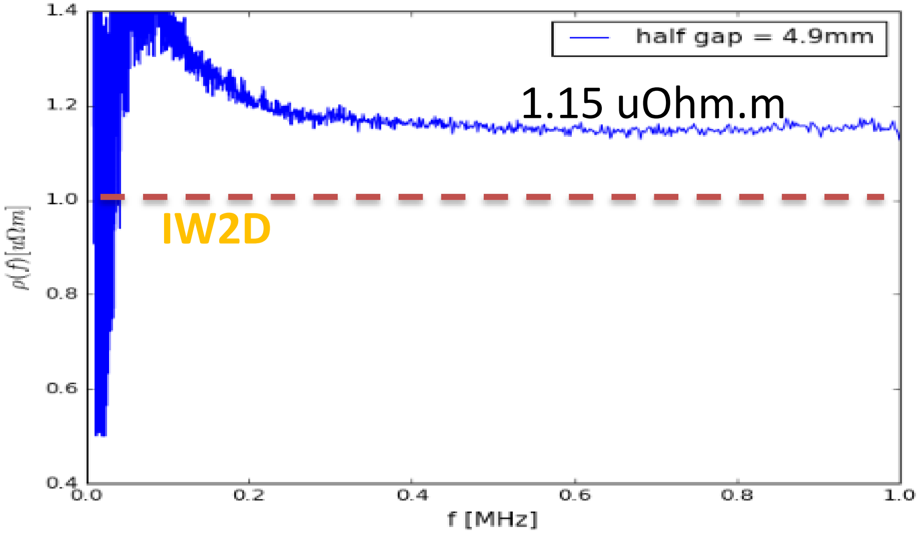
- In the past the setup was very rough and prone to systematic errors.
- Setup improvement performed: use of plastic spacer to fix block and loop in reproducible way.

Measurement on MoGr bulk

Position: **behind the Mo stripe**
N = 7 -> self coil resonance ~ 3 MHz
Δ = **6.2 mm (*)**
Half gap =4.9 mm
Coil core width = 6 mm
Wire winding diameter = 6 mm
Spacer width = 1.3 mm



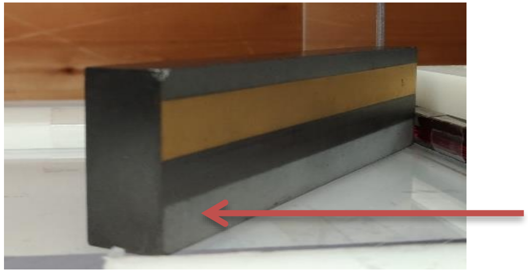


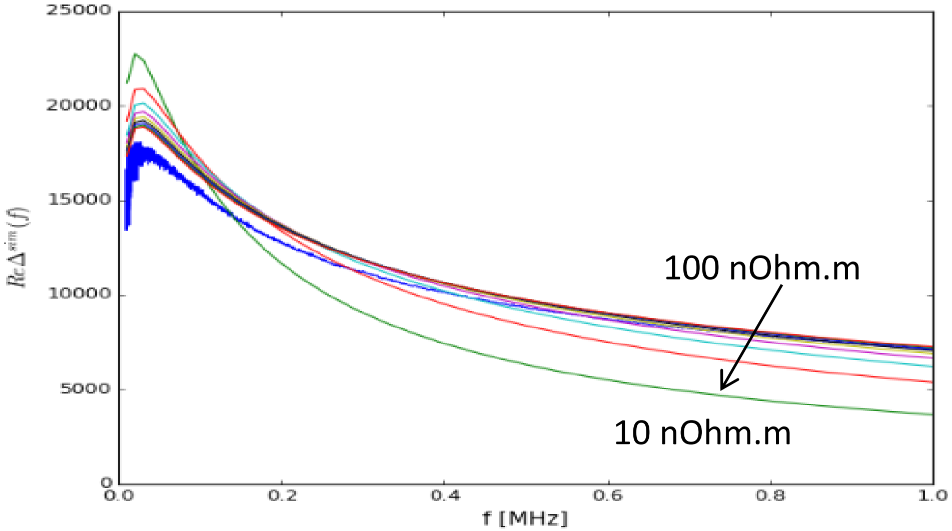


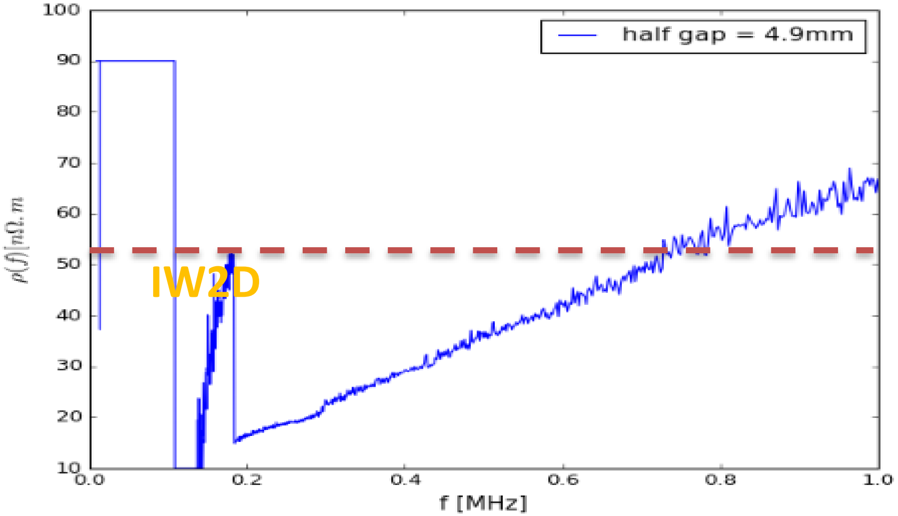
(*) We infer Δ in order to match the curve peak to the simulated curve peak as it does not seem to be dependent on conductivity -> calibration.

Measurement on Mo

Position: **Mo stripe**
N = 7 -> self coil resonance ~ 3 MHz
Δ = **6.2 mm**
Half gap =4.9 mm
Coil core width = 6 mm
Wire winding diameter = 6 mm
Spacer width = 1.3 mm
Bulk resistivity assumed: 1.15 uOhm.m







- Non flat behavior.
- Inferred resistivity, only above 200 kHz, tends to vary with frequency.

Can we deduce a flat resistivity curve for a simpler material?

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Possible paths for explanation:

- Do we have still some issue related with the measurement setup?
- Is it due to the small stripe width?
- Is it a feature of Mo?

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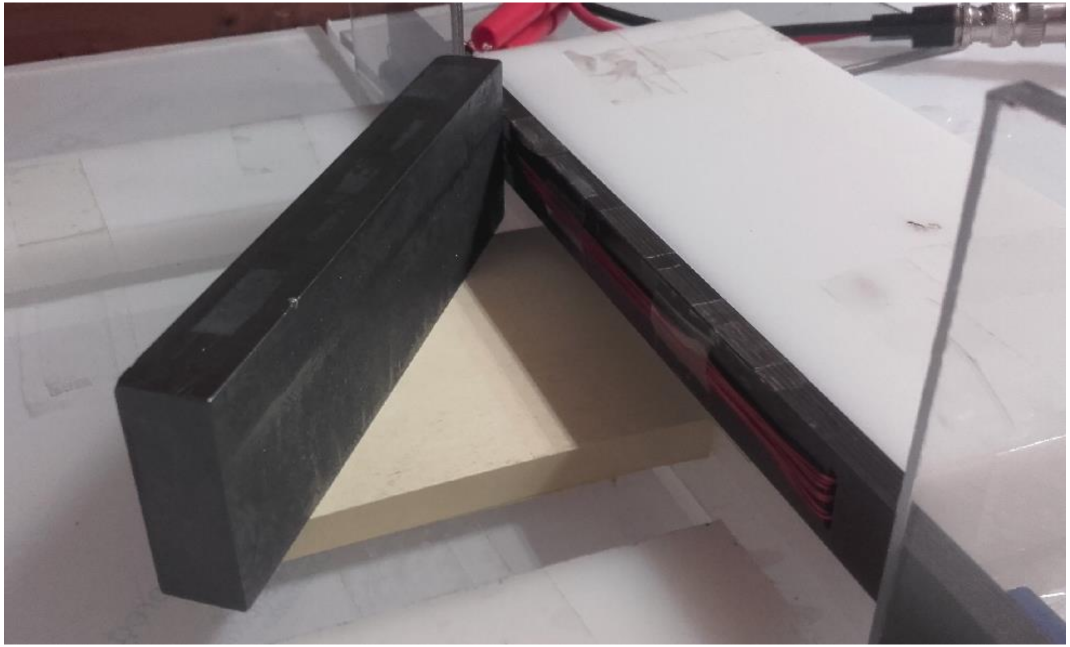
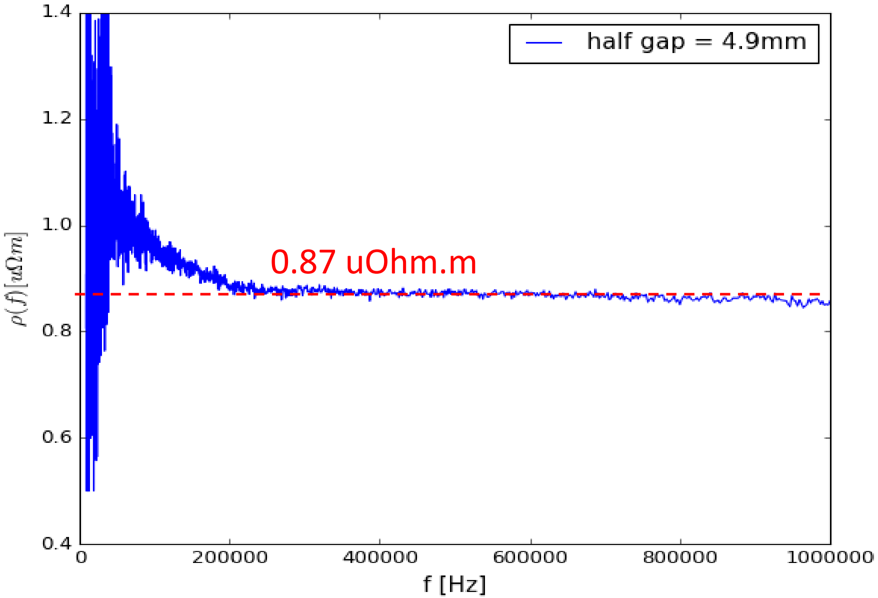
Measurement on MoGr

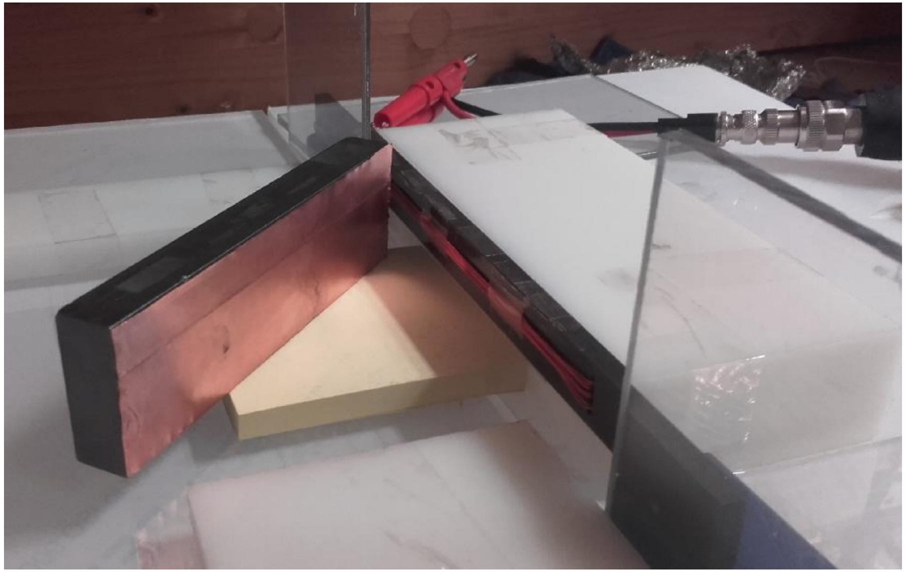
- Re-measured the uncoated part of the TCSPM block
- Measurement taken as reference before a Cu-tape "coating" is applied

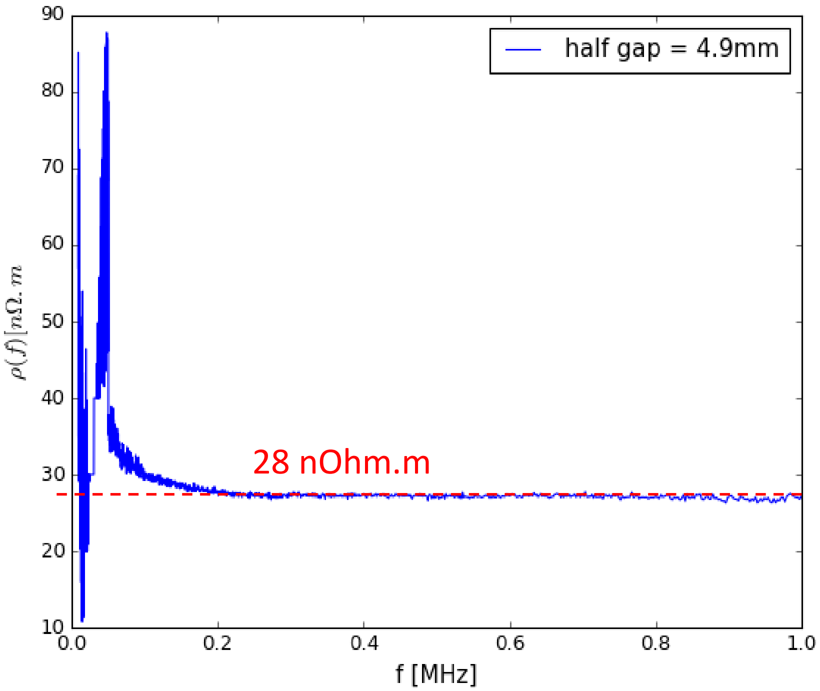




Measurement on Cu “coating”

- Re-measured the uncoated part of the TCSPM block
- Measurement taken as reference before a Cu-tape “coating” is applied
- Good flatness of resistivity achieved at ~28nOhm.m: setup reliability proved!





Conclusions and Next steps

Benchmark measurement proves:

- Reliability of the setup
- Capability of inferring resistivity from IW2D simulations for ~50um Cu layer
- Flat behavior of resistivity as expected
- Potential to deduce Mo on MoGr/CFC, Cu on MoGr/CFC in accurate way

Next steps:

- Coating the full face of the block with 5um Mo to clear out the effect of stripe width.
- Performing similar measurements on CFC and coated CFC.