2024

# Modeling-Based Methodology for Electromagnetic Screening of Copper Foils for High-Frequency Applications

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QWED

CF CIRCUIT FOIL

5G_Foil

# Outline

1. Motivation.
2. Measurements.
3. Results.
4. Conclusions.

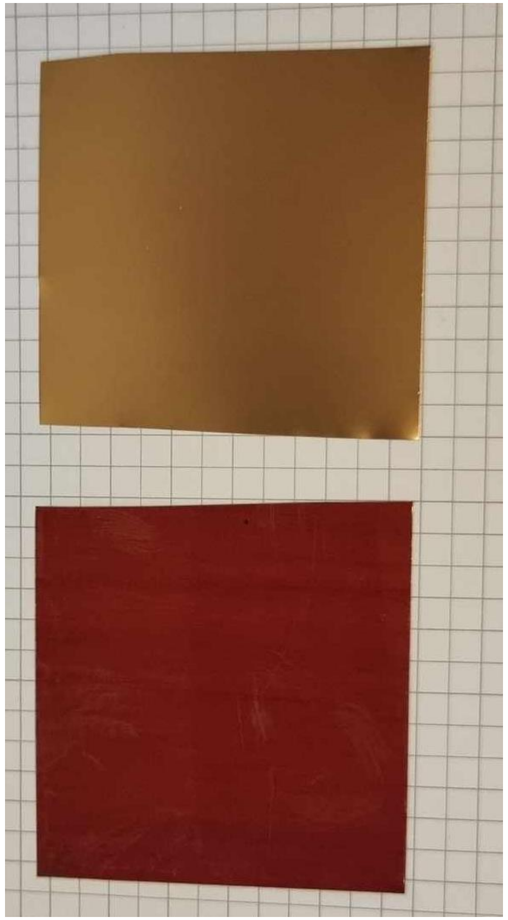
# Motivation

- Need for ultra-low-loss materials in high frequency electromagnetic design and techniques allowing precise determination of such materials.
- Developing microwave and millimetre-wave resonators for stand-alone copper foils samples measurements as an alternative for time-consuming and cumbersome tests of circuit manufactured on a PCB.
- Better understanding of the impact of individual processes in the production of copper foils.

# Measurements

## Samples

- 24 types of copper foils by CFL.
- Each type is different combination of base foil and treatment and also delivered in two thicknesses 35 $\mu m$ and 70 $\mu m$.
- Roughness parameters were measured for each sample by CFL.

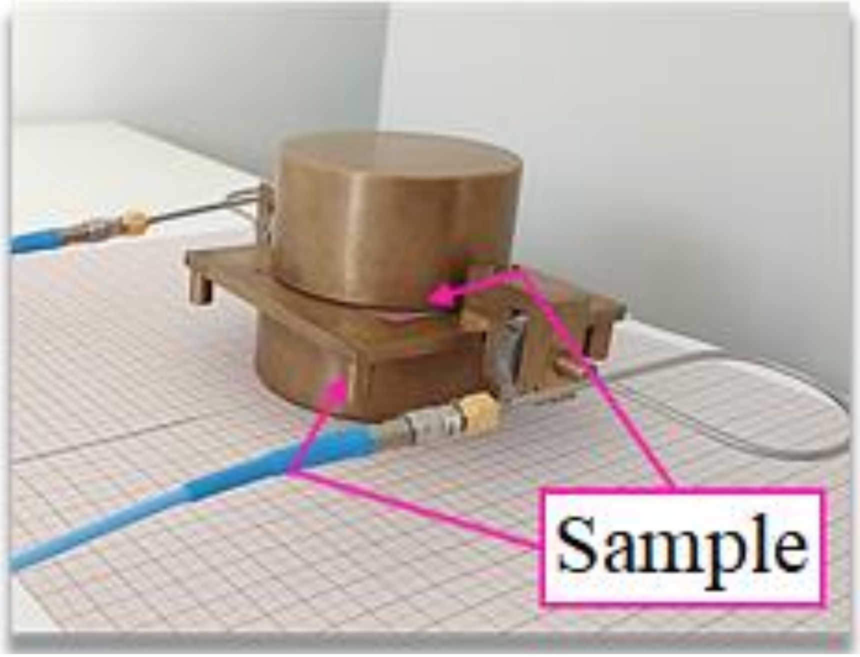


CIRCUIT FOIL

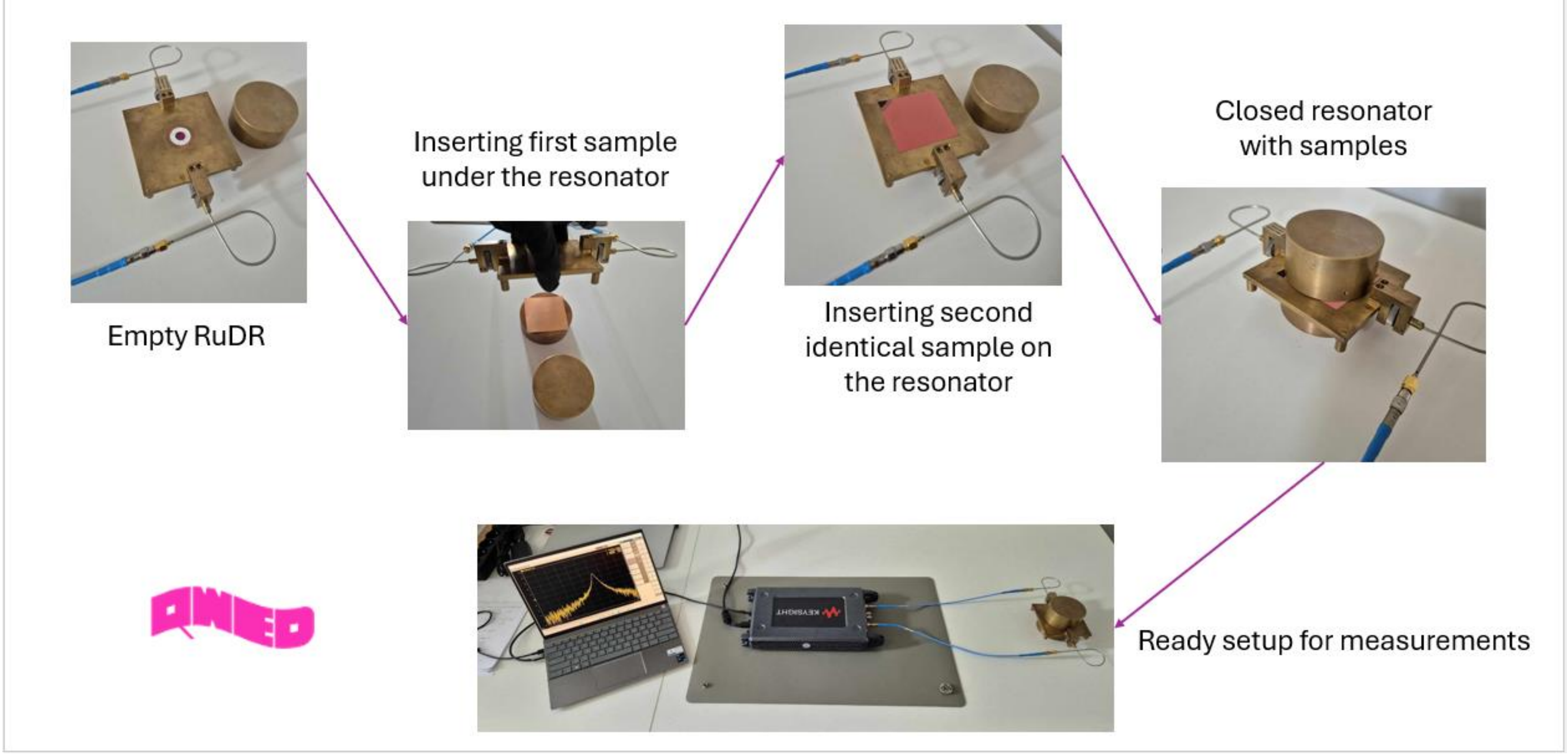
# Measurements

## Ruby Dielectric Resonator (RuDR)

- Foil loss is measured with RuDR operating at 13 GHz.
- RuDD is connected to VNA (Keysight Streamline P5008B), which extracts the 3dB bandwith at the resonance.
- A dedicated application converts this to the Q-factor and then calculates the effective conductivity.



# Measurements



Empty RuDR

Inserting first sample under the resonator

Inserting second identical sample on the resonator

Closed resonator with samples

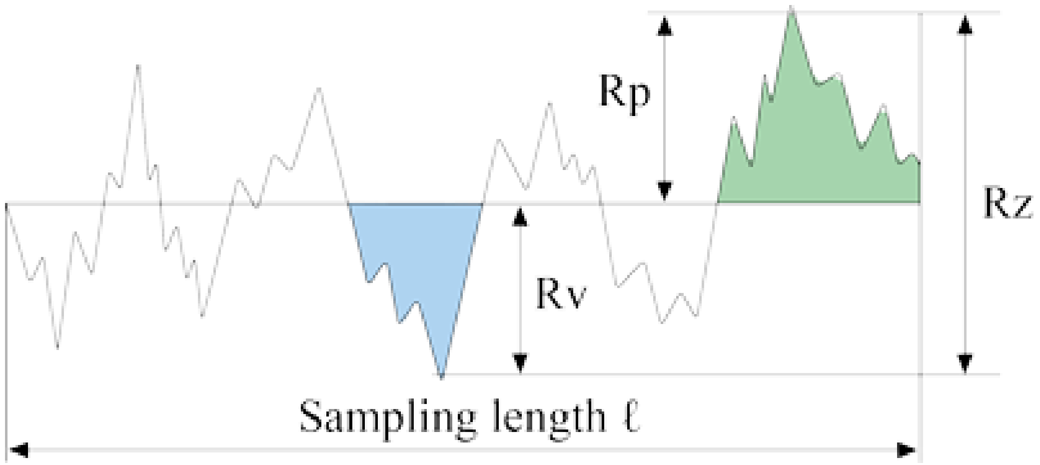
Ready setup for measurements

# Results

## Roughness parameters (contact stylus profilometre)

Maximum Height (Rz)

$$Rz = Rp + Rv$$



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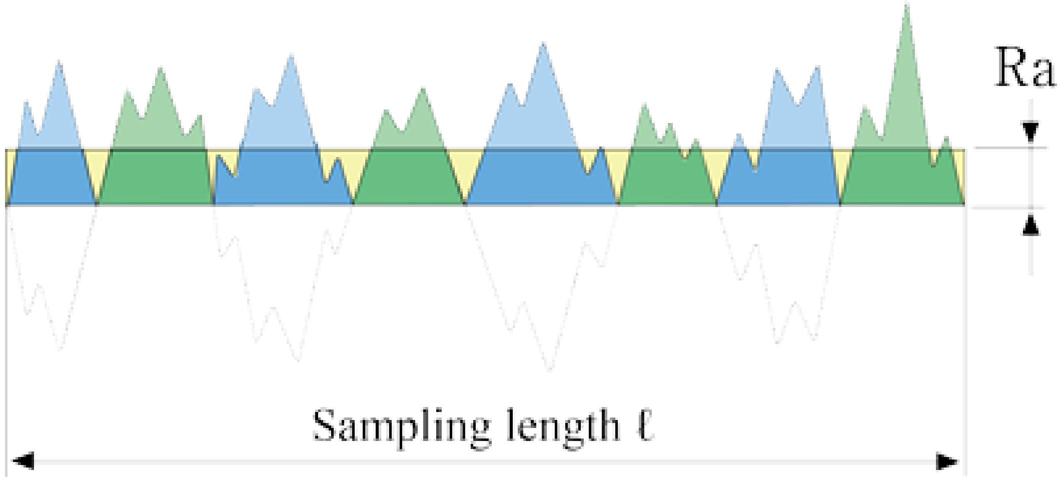
Arithmetical Mean deviation (Ra)

$$Ra = \frac{1}{\ell}\int_0^{\ell} |Z(x)|\,dx$$



Olympus*

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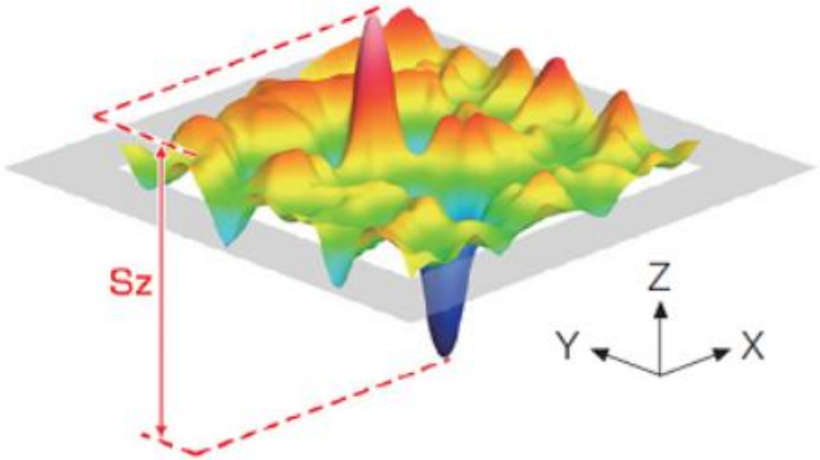
* https://www.olympus-ims.com/en/metrology/surface-roughness-measurement-portal/parameters/#!cms[focus]=cmsContent14708

# Results

## Roughness parameters (noncontact laser interferometry)

### Maximum Height (Sz)

$$Sz = Sp + Sv$$



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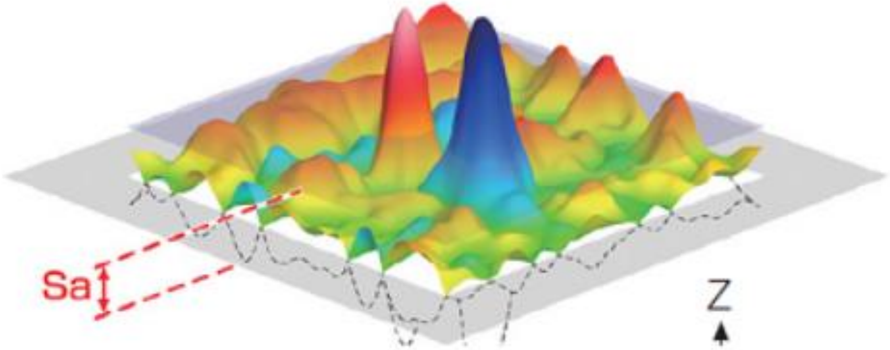
### Arithmetical Mean Height (Sa)

$$Sa = \frac{1}{A}\iint_A |Z(x,y)|\,dxdy$$



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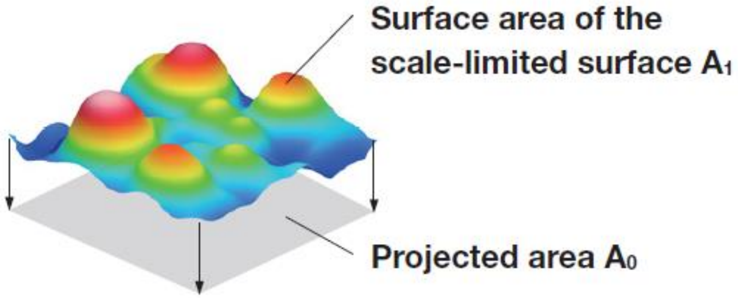
* https://www.olympus-ims.com/en/metrology/surface-roughness-measurement-portal/parameters/#!cms[focus]=cmsContent14708

# Results

## Roughness parameters (noncontact laser interferometry)

Developed interfacial area ratio (Sdr)

$$\mathrm{Sdr} = \frac{1}{A}\left[\iint_A \left(\sqrt{\left[1+\left(\frac{\partial z(x,y)}{\partial x}\right)^2+\left(\frac{\partial z(x,y)}{\partial y}\right)^2\right]}-1\right)dxdy\right]$$



**Sdr**$=\{(A_1/A_0)-1\}\times 100\,(\%)$

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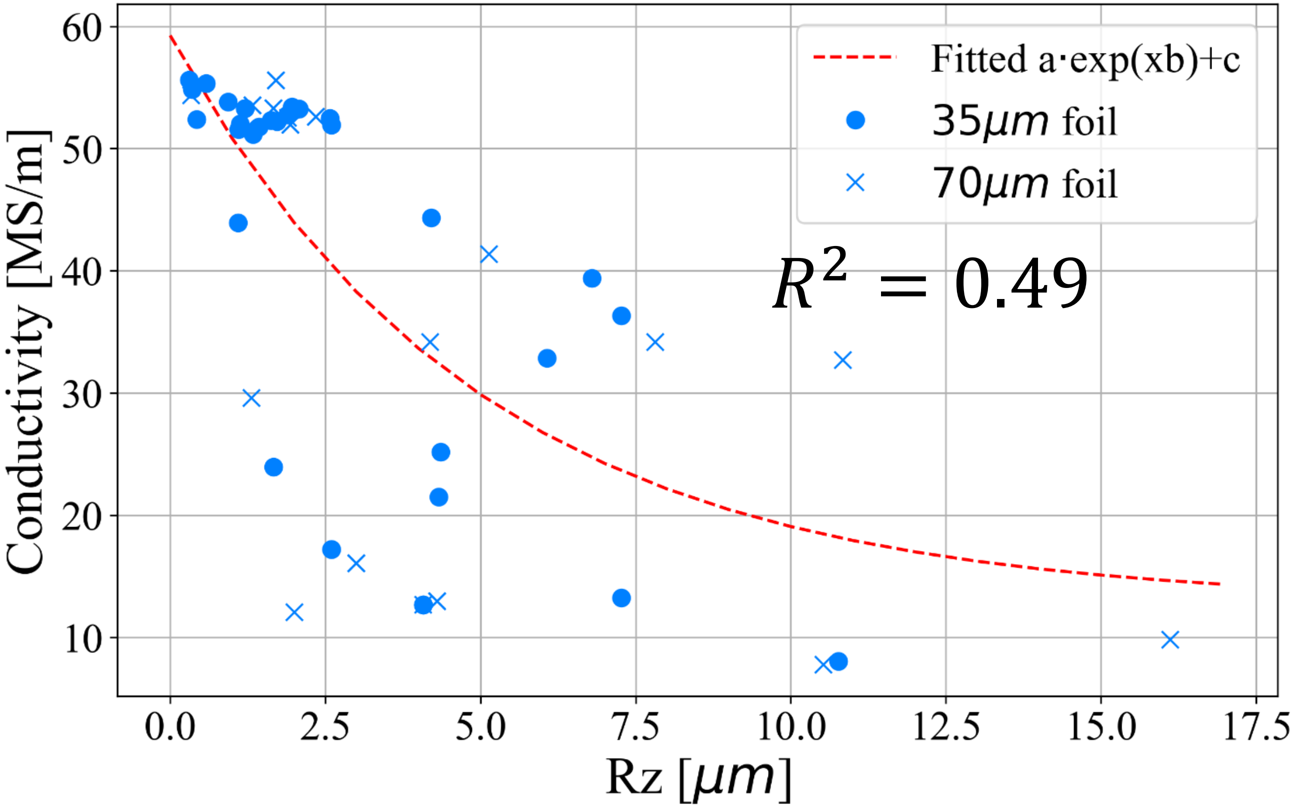
* https://www.olympus-ims.com/en/metrology/surface-roughness-measurement-portal/parameters/#!cms[focus]=cmsContent14708

# Results

## Correlation Between Effective Conductivity and Surface Roughness

Roughness ↑

Conductivity ↓



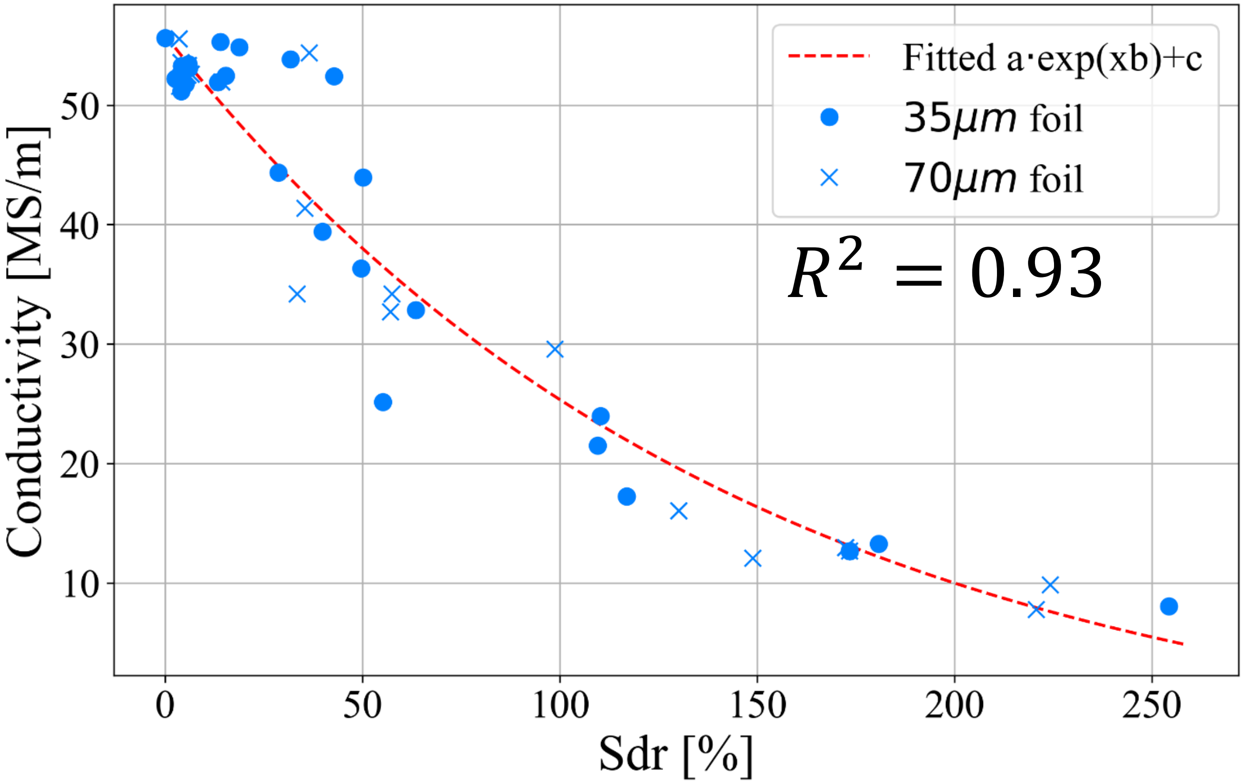
48 measurements (shown here)

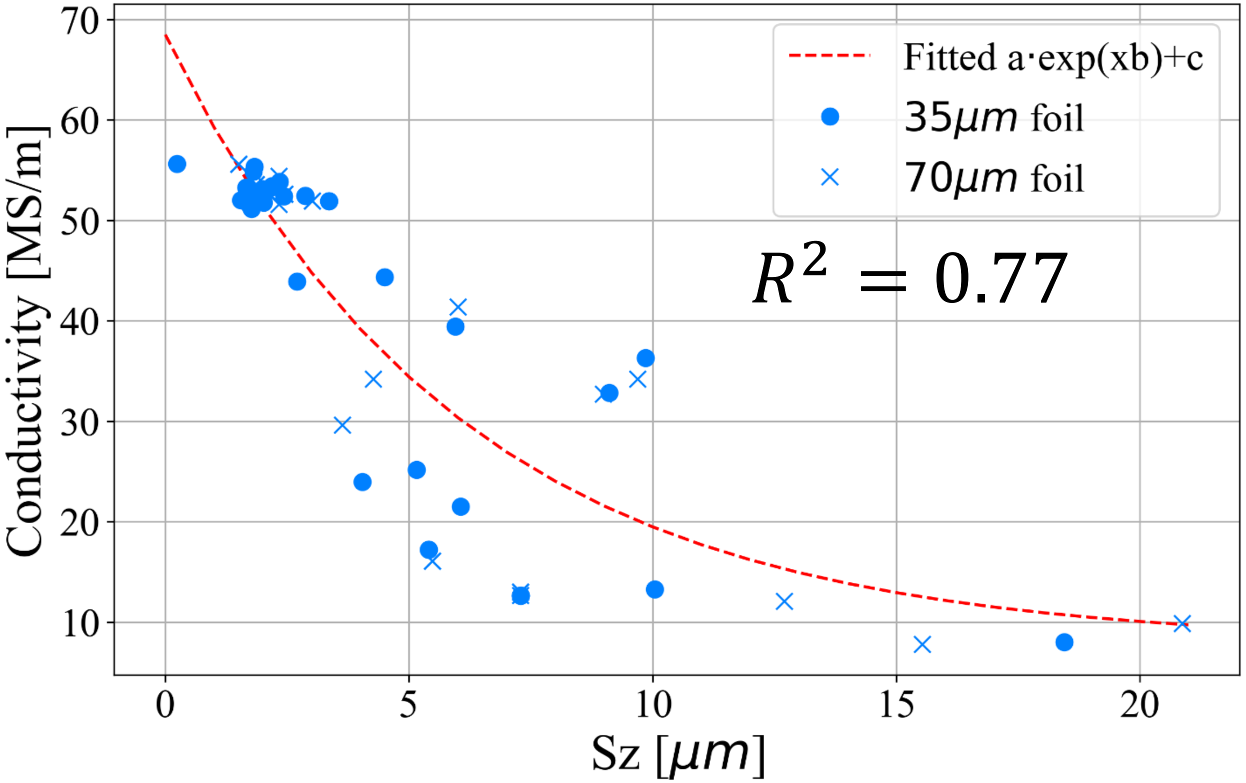
Measurement time 2 min per sample (without repeatability study)

- Effective conductivity decreases (loss increases) with increasing roughness
- But there is no one-to-one realtion between Rz and loss
- Exponential curve: (a=4.65 MS/m, b=−0.2 1/um, c=12.8 MS/m) $R^2 = 0.49$

# Results

## Correlation Between Effective Conductivity and Surface Roughness





(a=61.4 MS/m, b=-6.87*$10^{-3}$, c=-5.59 MS/m)

(a=60.7 MS/m, b=-0.16 1/um, c=-7.82 MS/m)

Better fit with noncontact pamateres (than wth Rz on previous slide)
But still not perfect fit.

# Conclusions

- We have confirmed that increasing roughness leads to higher loss.
- However we have also shown that roughness-to-loss is not represented by a closed-form formula.
- Sz or Sdr (from non-contact roughness measurement) give higher correlation to loss, than Rz (from contact measurement).
- It is recommened to measure foils before their application in mm-Wave circuit design.
- As further expected in view of the electromagnetic considerations, foil thickness is irrelevant (as long as it exceeds several time the penetration depth).

# Acknowledgment

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