# An Effective Surface Impedance Concept to Model Arbitrary Roughness Profiles on Printed Circuit Boards up to 110 GHz

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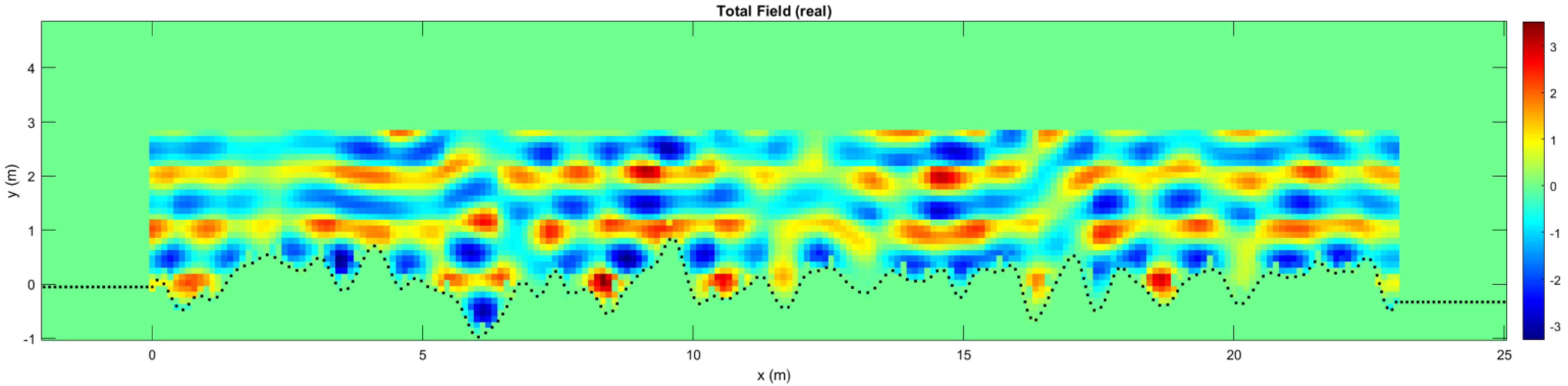
# Introduction

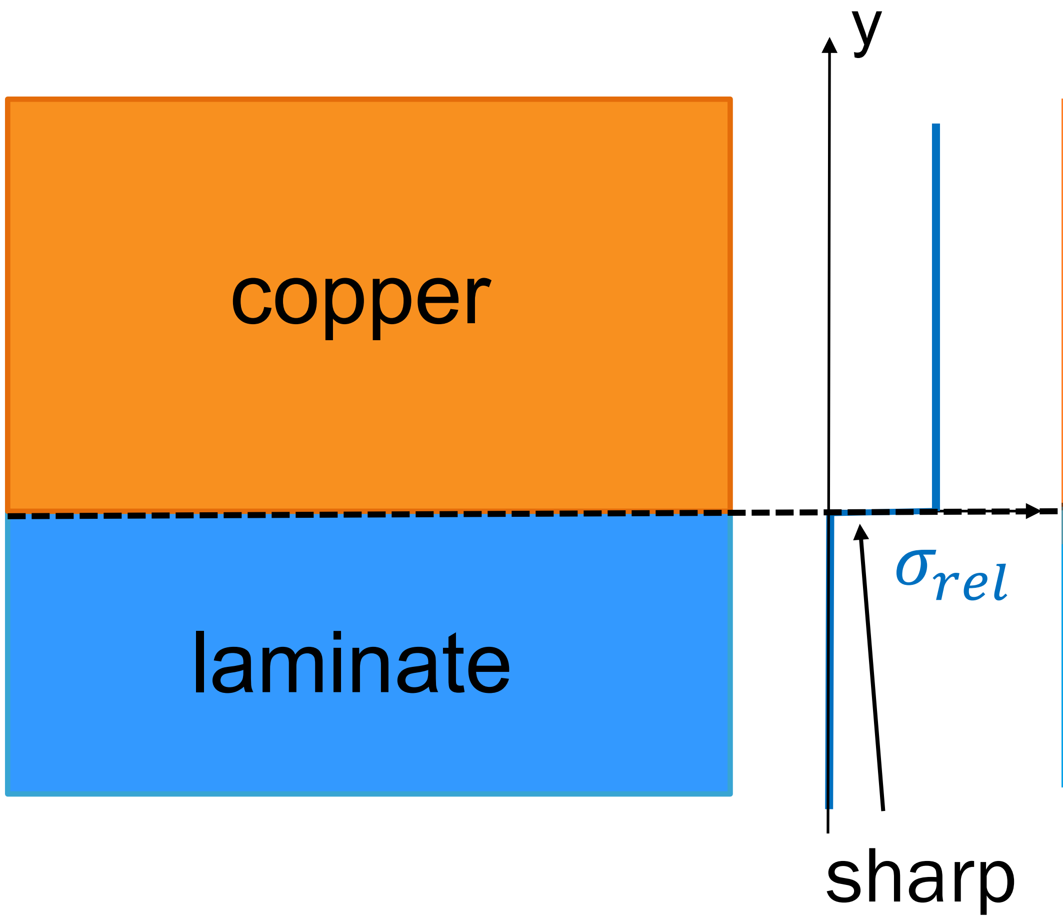
- Many ways to describe impact of rough surfaces on high-frequency signals.
- Famous: H&J, Huray (snowball), full-wave stochastic models, <u>Gradient Model</u>

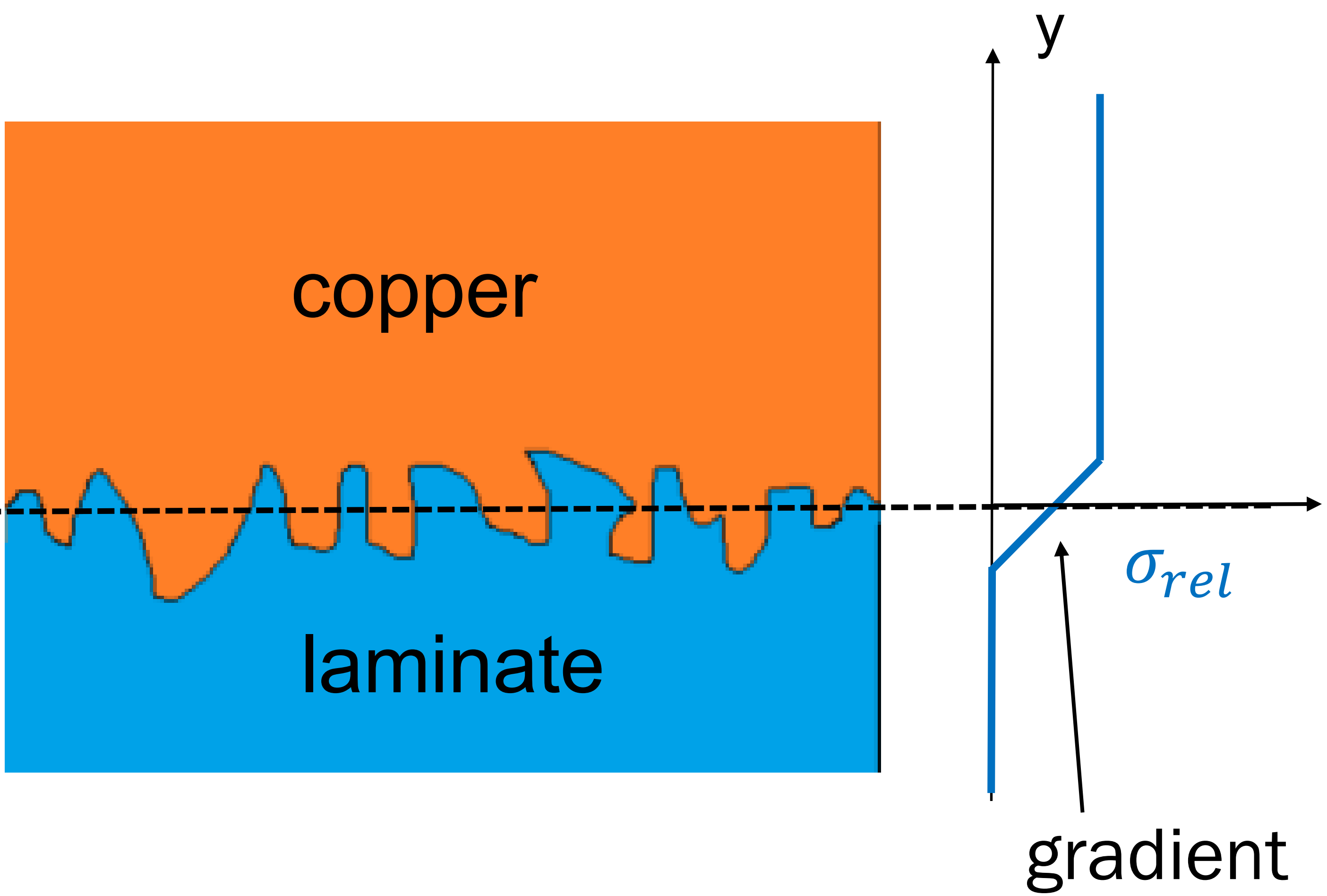


# Gradient Model



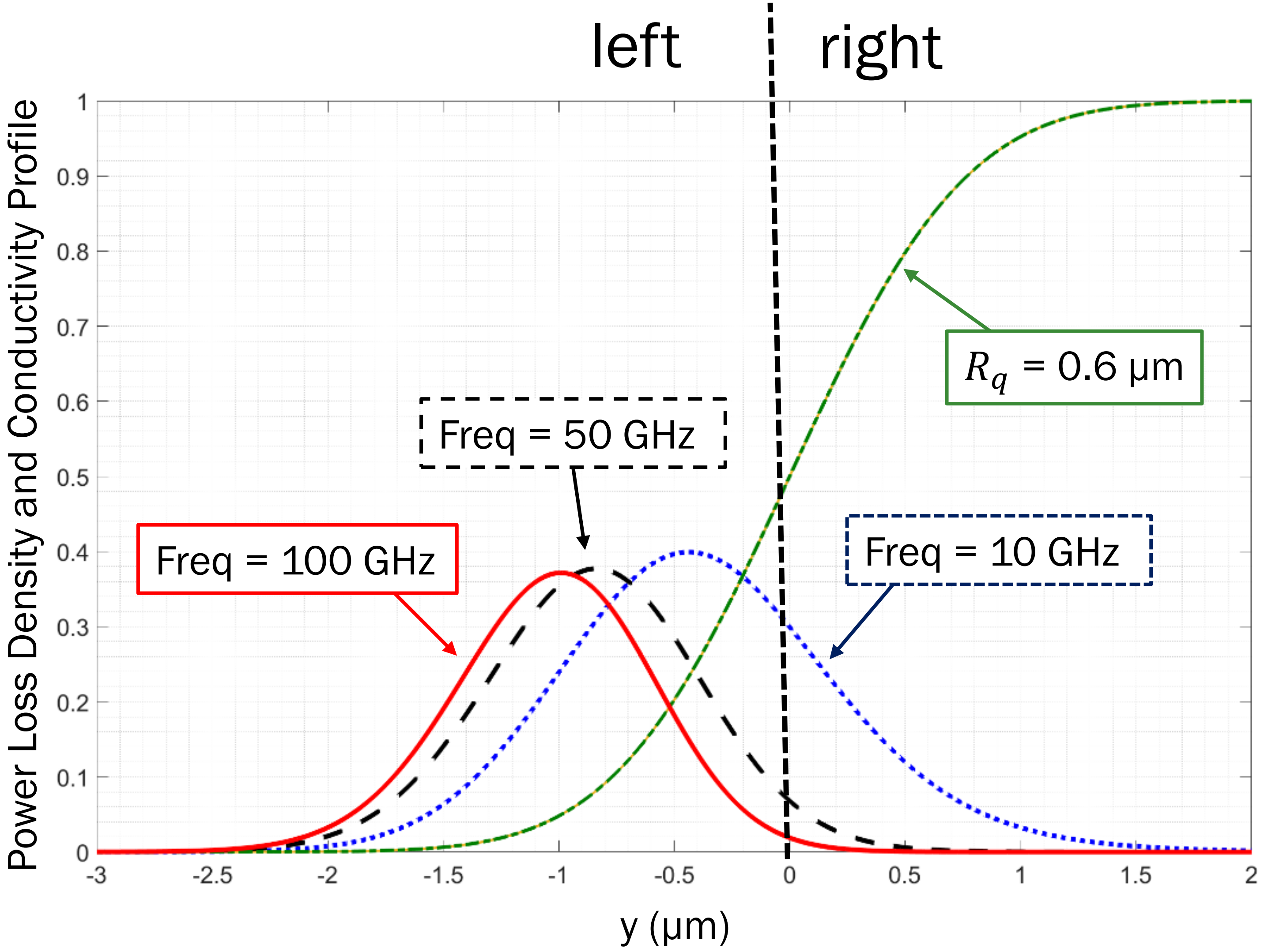
**Classic skin effect:** → **Gradient Model:**



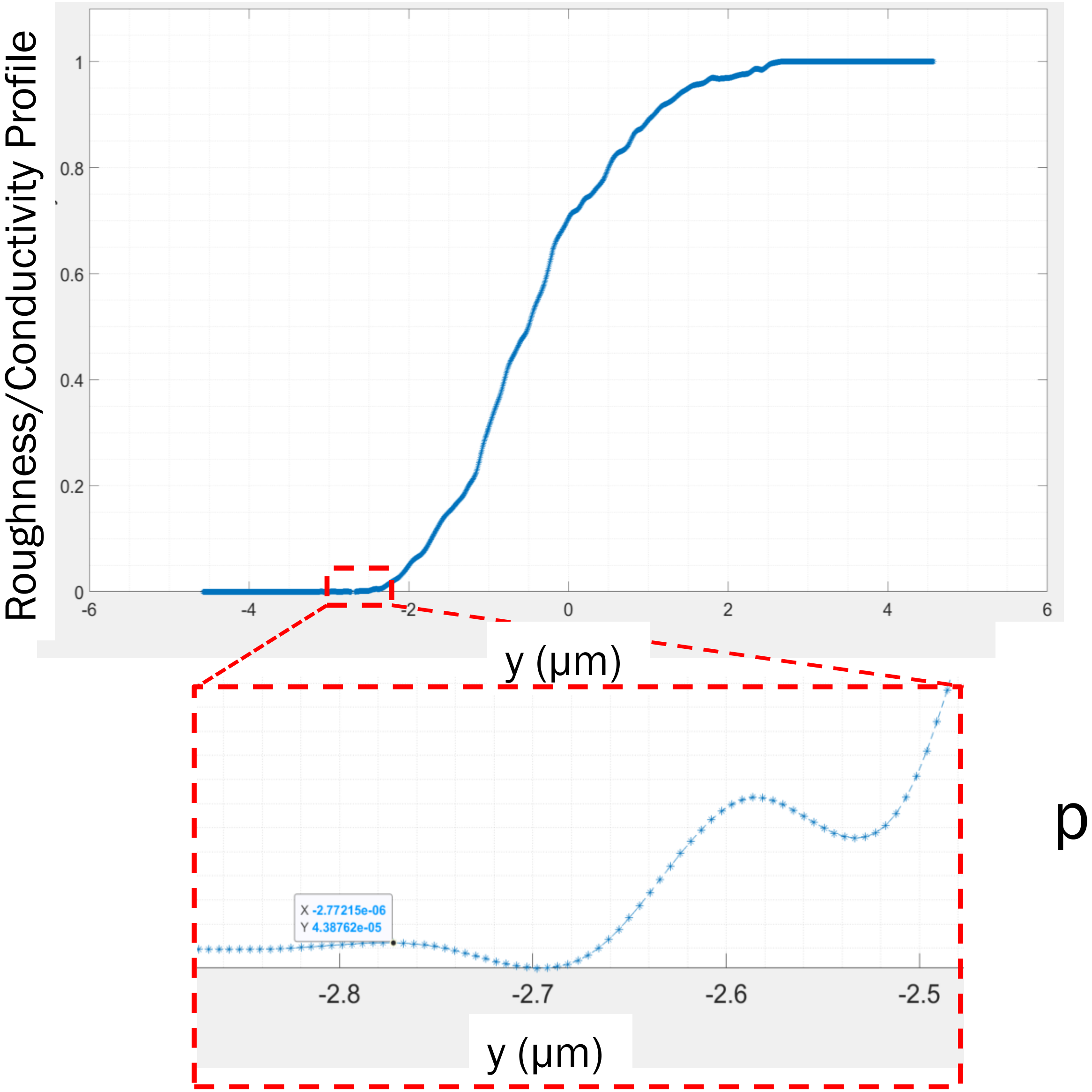
# Typical Profile Approximation

Roughness profiles often approximated as CDF of a gaussian bell curve with gradient $R_q$:




Most of the power loss on left side of Profile!

# Real Roughness Profiles




original: $$\frac{\partial^2 \underline{B}_x^L}{\partial y^2} - j\omega\mu\sigma \underline{B}_x^L - \frac{\partial}{\partial y}\ln(\sigma(y))\frac{\partial \underline{B}_x^L}{\partial y} = 0$$

$$\ln(0) = -\text{inf}\,!!$$

E-field formular: $$\frac{\partial^2 \underline{E}_x^L}{\partial y^2} - j\omega\mu\sigma(y)\underline{E}_x^L = 0$$

power loss: $$P_v = \int \sigma(y)\left|\underline{E}_x^L\right|^2 dy$$

current : $$\underline{I} = \int \sigma(y)\underline{E}_x^L dy$$

$$\underline{R} = \frac{P_v}{\underline{I}^2}$$

# Effective $R_q$ Concept



Calculate $\underline{R}$ for a given profile and desired frequency

Estimate, which gaussian CDF with gradient $R_{q,eff}$ has same $\underline{R}$ as calculated from the real profile

# Problems with Curve Approximations

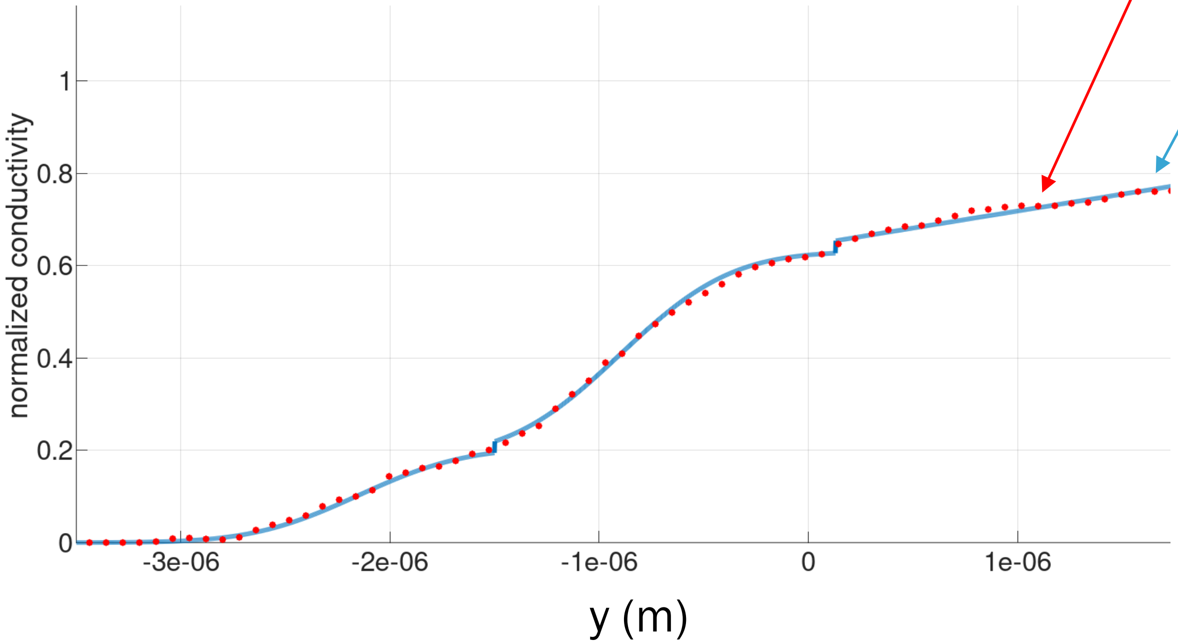


cross-section:

Measurement

Approximation with 3 gaussian CDFs

Fit with single, gaussian CDF




$$R_q = \sqrt{\frac{1}{L}\int_0^L h(x)^2 dx}$$

$R_{q,eff,single\ CDF} = 2.39\ \mu m$

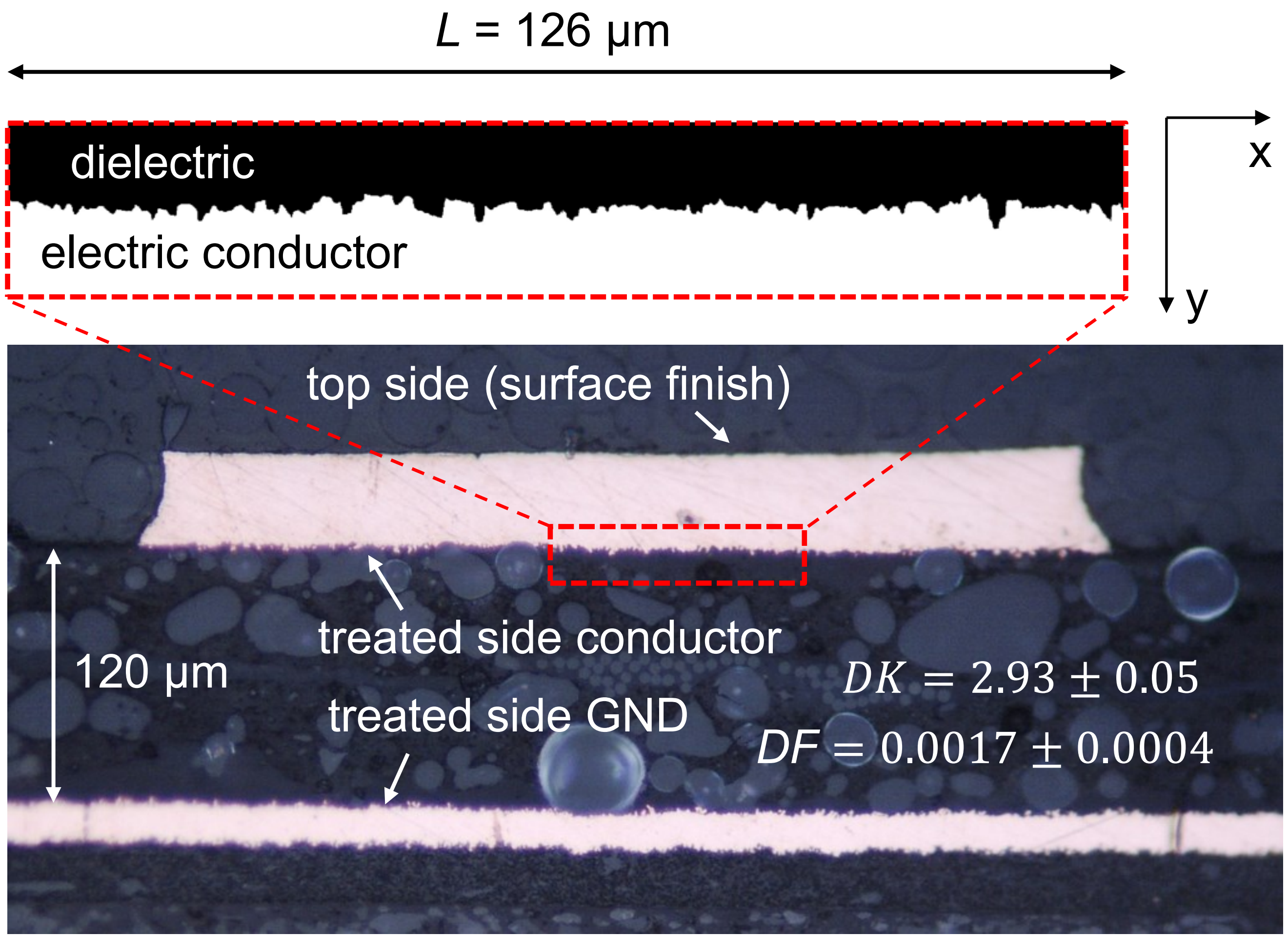
$R_{q,eff\ DIN\ EN\ ISO\ 4287} = 2.45\ \mu m$

$R_{q,eff,three\ CDF} = 0.74\ \mu m$

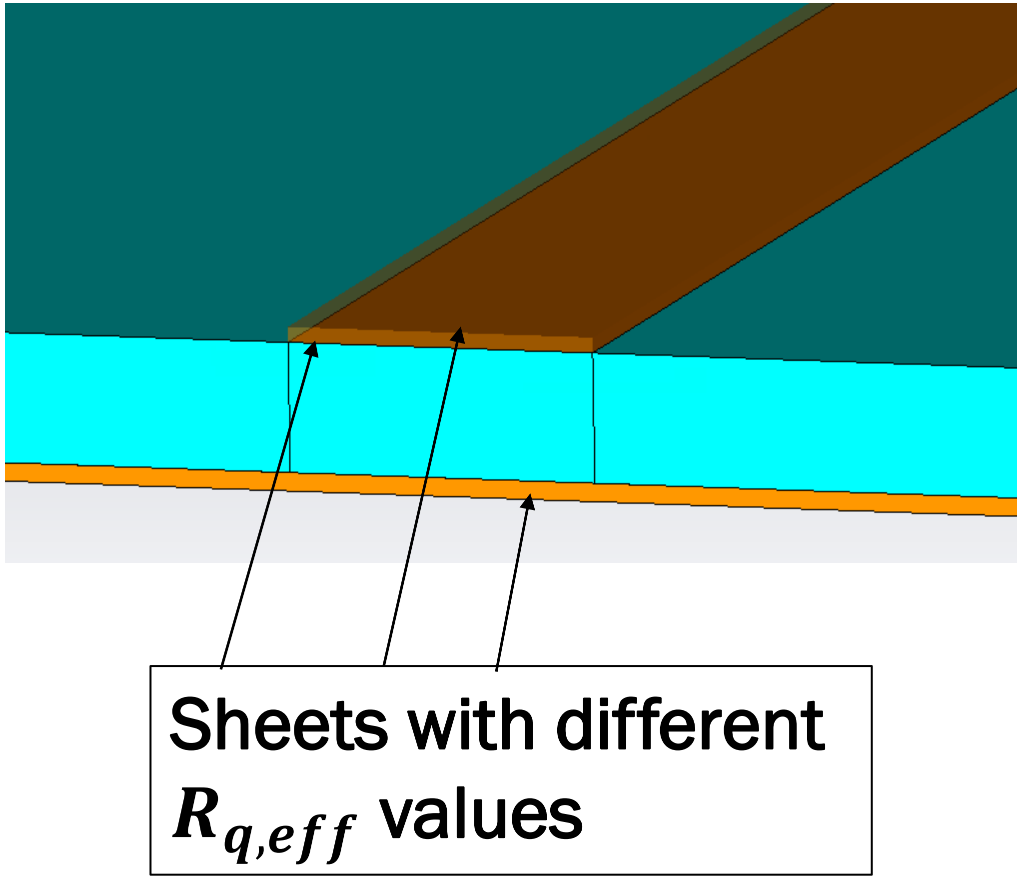
3 different approximations with total different results (@ 50 GHz)!!

# Considered Materials

## Real world Microstrip Line (cross-section):

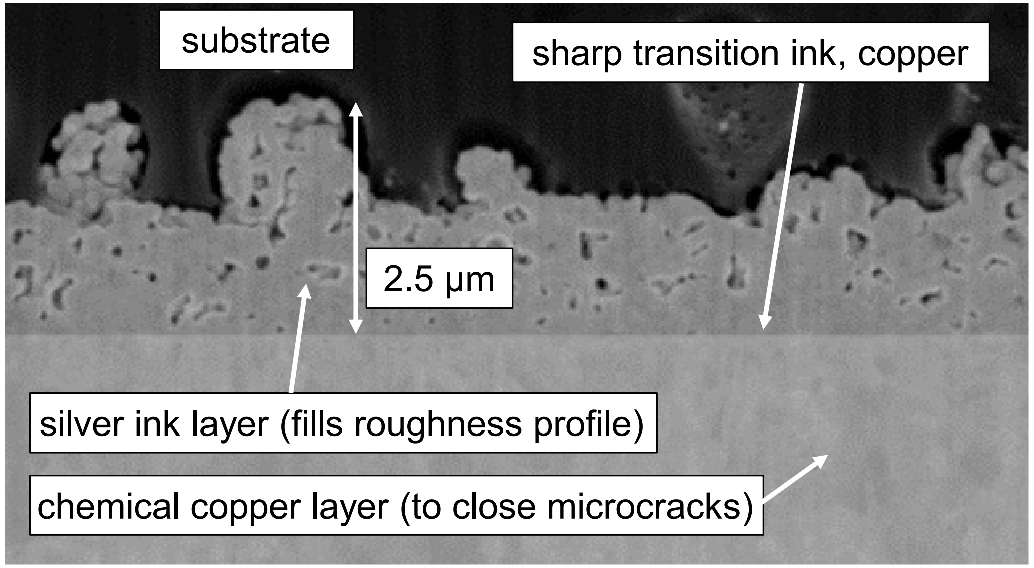



## Simulation model:

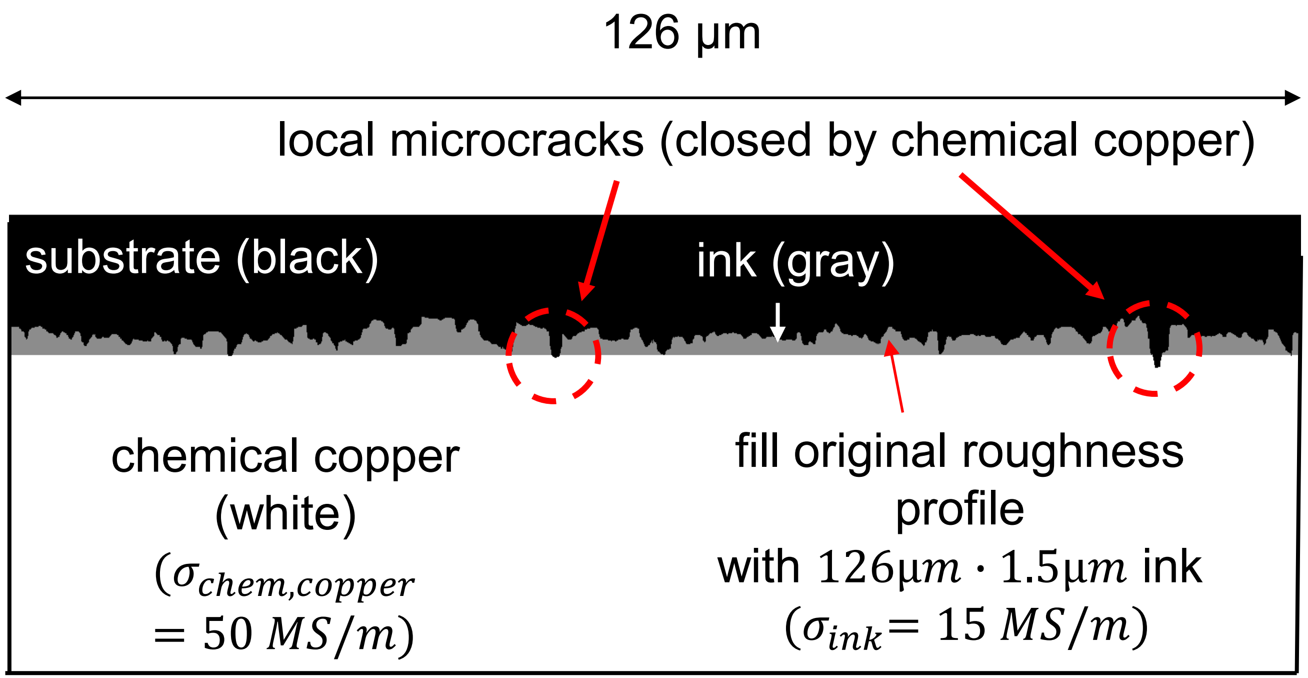


# Same Substrate, Different Conductor

## FIB-Cut of an ink/chemical copper layer-stack:




## model:



# Insertion Loss of 1.57 inch long MS

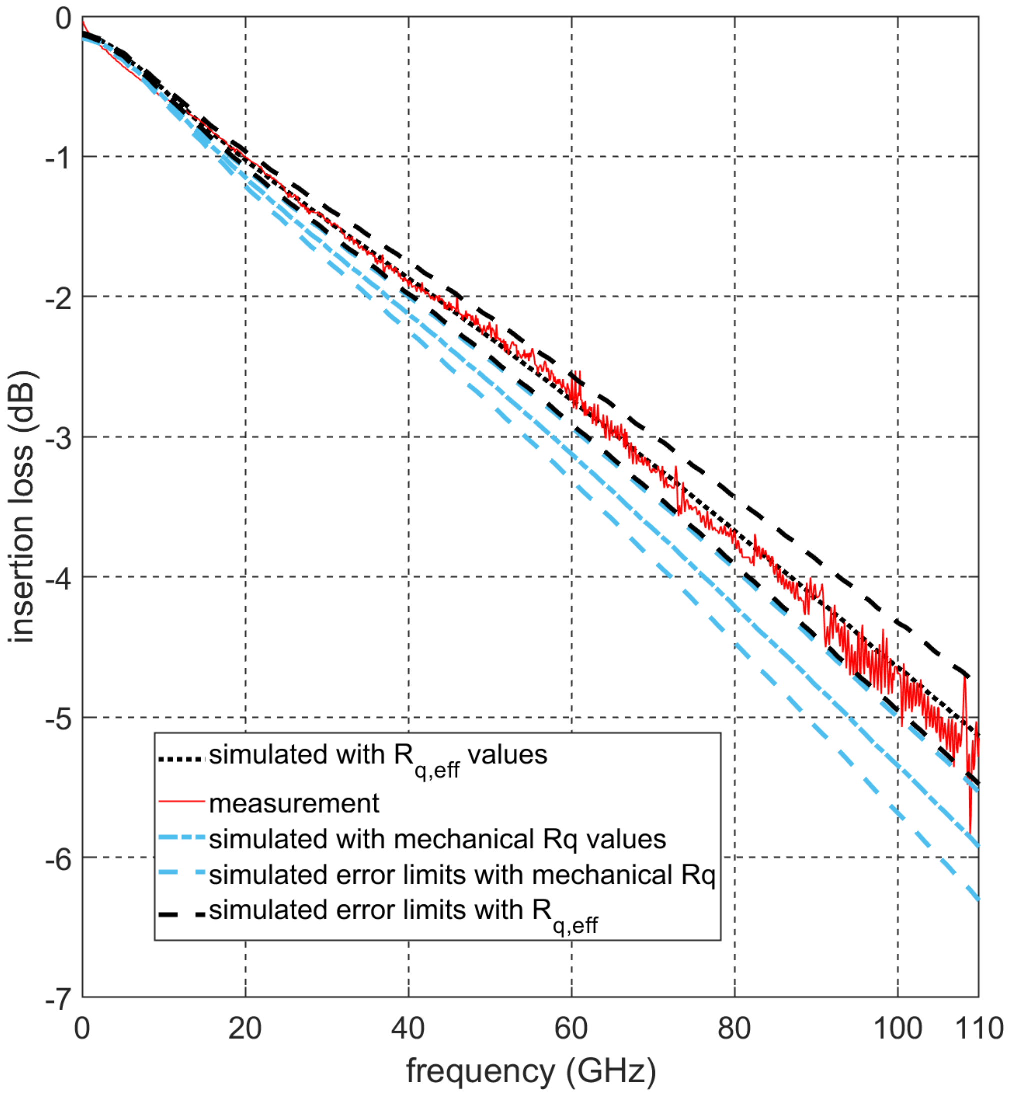


Conductor = pure copper (trace height = 50 µm):

$$R_{q,treated,side} = \sqrt{\frac{1}{L}\int_0^L h(x)^2 dx} = 0.85\mu m \pm 0.1\mu m$$

$$R_{q,eff,treated\ side} = 0.65\mu m \pm 0.1\mu m$$
$$R_{q,eff,top\ side} = 0.25\mu m \pm 0.05\mu m$$

Only with $R_{q,eff}$ plausible simulation results!!

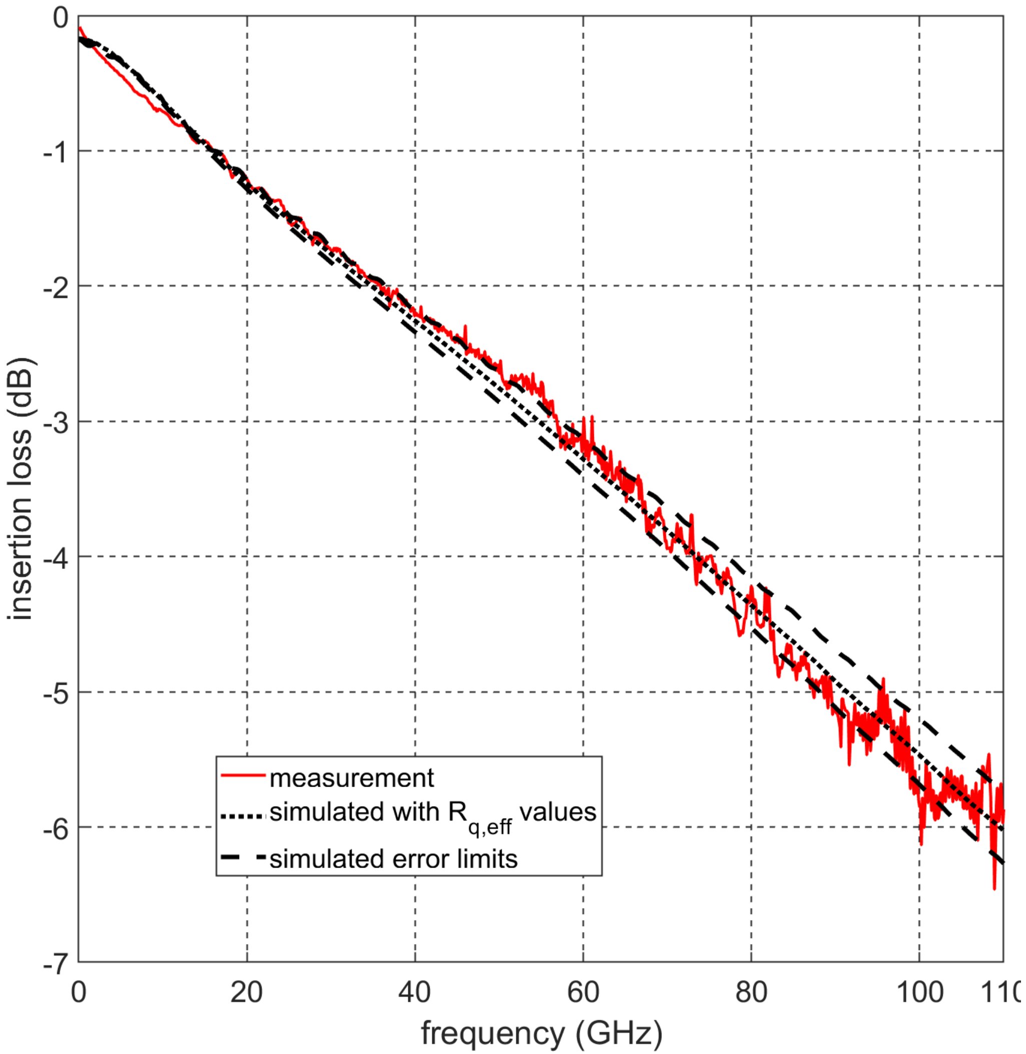


# Insertion Loss of 1.57 inch long MS

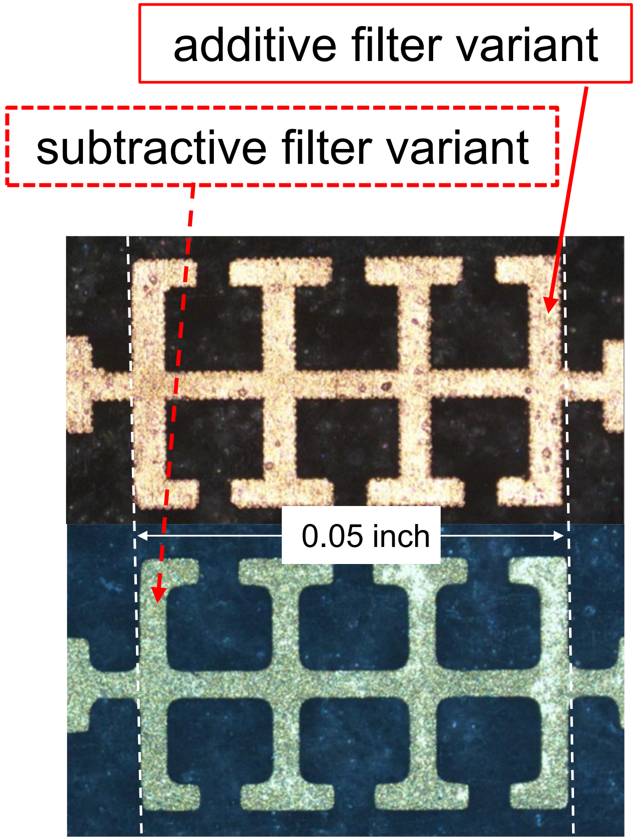
Conductor = ink/chem. Copper layerstack (trace height = 5µm):

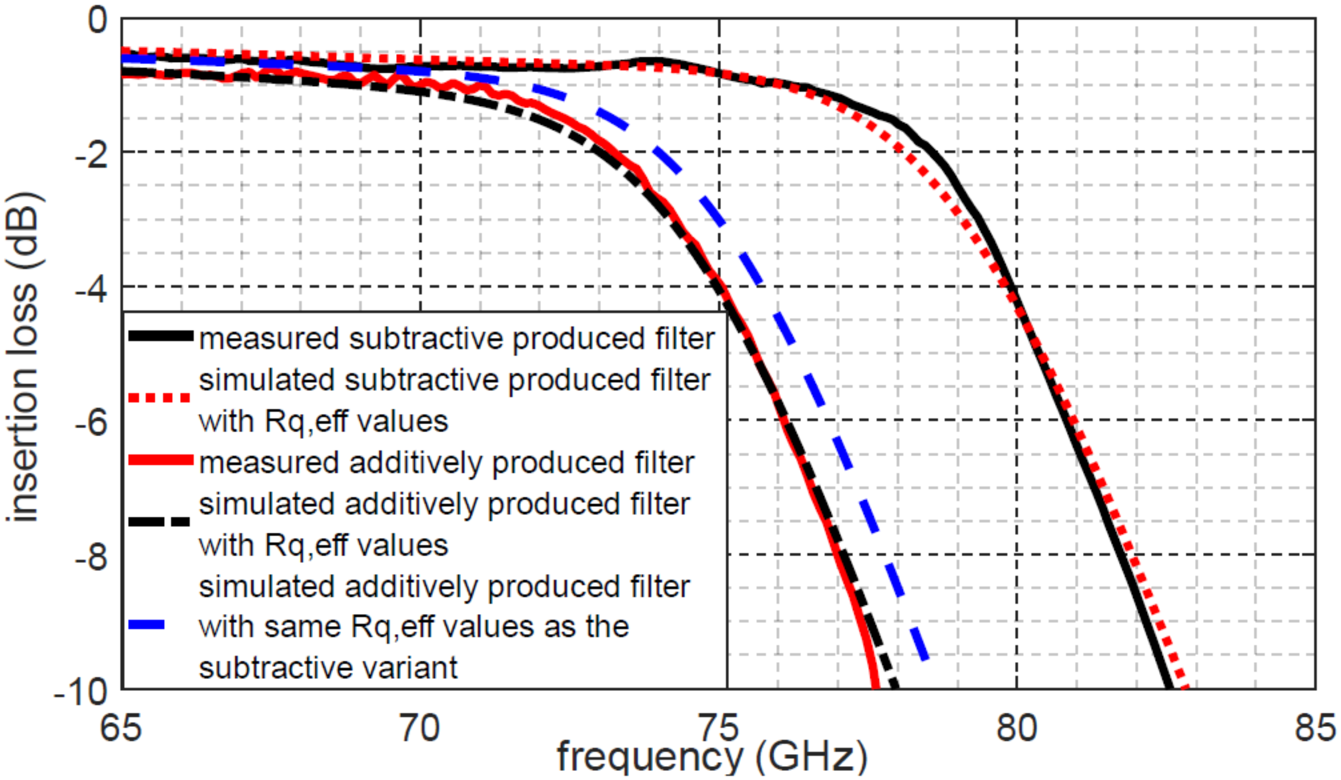
$$R_{q,eff,treated} = 0.86\mu m \pm 0.1\mu m$$
$$R_{q,eff,top\ side} = 0.44\mu m \pm 0.11\mu m$$

Excellent agreement between measurement and simulation



# Low-Pass Filters



# Summary

Main idea of the Gradient Model is adopted
Surface impedance is calculated from real profiles
An effective surface roughness parameter is introduced
Profile approximations become obsolete
Efficiency shown for additive/subtractive produced MS and filters

# Thank you! Questions?