Electromagnetic modelling of metallic materials for applications in manufacturing of circuit foils

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***Abstract*— An novel scheme for conducting a full-wave electromagnetic simulation, aimed at characterizing the effective electrical conductivity of copper foils with a rough surface, is presented in this paper. In the proposed approach, the conductivity of copper foils is estimated based on the reflection coefficient of plane wave illuminating the surface of the real life conductor. Proposed approach enables the extraction of the effective conductivity of the rough metal sheet based on the atomic force microscopy (AFM) of real foil sample.**

Keywords*— *surface roughness, copper foil, electromagnetic simulation, finite element method, shape deformation

I. Introduction

In millimeter-wave and high-frequency electronic circuits—such as those enabling next-generation 5G wireless systems—the surface roughness of conductive materials plays a critical role in systems' performance. Due to the skin effect, electrical currents at these frequencies are confined to extremely shallow layers on a conductor's surface. As a result, even minor surface roughness can lead to significant increases in conductor losses, degrading signal integrity and limiting circuit efficiency. The effective conductivity of real-life, rough conductors is not a fixed property—it varies with both frequency and the specific profile of surface roughness. At high frequencies, direct measurements of these effects are often noisy, difficult to interpret, and insufficient for drawing clear design conclusions. This slows down innovation and complicates the development of new materials and products. A promising way forward lies in the development of advanced numerical models that simulate the behavior of rough conductors. Such models can serve as powerful tools for interpreting experimental data, predicting material performance, and testing new concepts virtually. By reducing dependence on costly and time-consuming prototyping, they offer a more agile and cost-effective solution to estimate the component performance. In the following section, we present early results from a project funded under the Eureka/Eurostars programme, entitled "New millimeter-wave techniques for the experimental characterization and computational modelling of metallic materials and applications in advanced manufacturing of circuit foils in Europe." This research project covers the outlined challenges by advancing both experimental and computational techniques for high-frequency material characterization—ultimately supporting the development of more efficient and reliable circuit technologies.

II. Simulation Scenario

In this work, a full-wave electromagnetic simulation scenario involving plane illumination (normal incidence) of bulk metal with given DC conductivity and surface roughness profile has been developed. Based on the calculation of the reflection coefficient |Γ| of reflected electromagnetic wave, one can extract a frequency-dependent effective conductivity of the material, assuming the wave is reflected by a metal with corresponding surface impedance. The simulation scenario is combined with shape deformation technique [1,2], that enables to construct a numerical model of a rough conductor surface based on real-life copper foil profile measurements, for example based on atomic force microscopy scan (AFM). An example simulation result of real-life rough conductor surface is shown in Fig.1, illustrating its extracted conductivity vs. frequency corresponding to a model of rough copper sample. Such simulations gives a good insight into predicted performance of the given copper foil in final system.

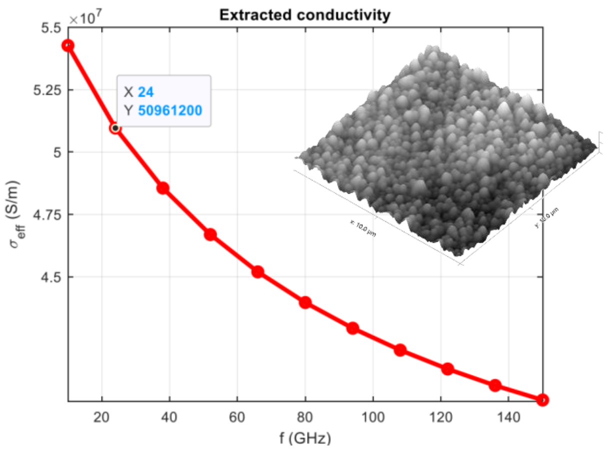

Fig. Simulated effective conductivity from real life copper foil sample.

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IV. References

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