ELECTROMAGNETIC BEHAVIOUR OF EMBOSSED CONDUCTIVE FOILS IN MULTILAYER INSULATION STRUCTURES FOR SATELLITE SHIELDING APPLICATIONS

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As highlighted in recent studies addressing electromagnetic compatibility (EMC) challenges in satellite systems, the increasing complexity of onboard electronics has intensified the demand for effective shielding strategies [1]. Multilayer insulation (MLI) materials remain essential not only for thermal regulation [2], but also for electromagnetic interference (EMI) shielding, thanks to their alternating layers of conductive and dielectric materials [3]. The stacking arrangement, material properties, and surface characteristics of these layers can significantly influence shielding behaviour across a broad frequency spectrum. In particular, microstructural features such as interfacial air gaps or surface irregularities can alter both thermal and electromagnetic performances.

The study in [4] investigates the electromagnetic performance of an embossed conductive foil (ECF), composed of a Kapton substrate coated with a thin vapor-deposited aluminum (VDA) layer (Fig. 1(a)). Expanding upon previous research focused on planar conductive foils [3], the focus here shifts to how surface morphology influences shielding effectiveness (SE). The ECF displays a distinct bumpy surface, consisting of embossed areas separated by wrinkle-like depressions (Fig. 1(a)).

To characterize the ECF's electrical properties, Van der Pauw measurements were used to determine sheet resistance and conductivity. Morphological features were analyzed through profilometry and optical microscopy. For modeling purposes, the surface of the ECF was divided into unit cells that capture the recurring shape and structure of the embossed pattern (Fig. 1(a)). These unit cells constituted the reference geometry for developing a 3D simulation model (Fig. 1(b)). Electromagnetic simulations were performed using CST Studio Suite and validated through coaxial waveguide measurements up to 4 GHz.

Initial simulations focused on the ECF in a single-layer configuration. CST results were obtained using the full 3D model, including the embossed morphology, while the analytical Transmission Line (TL) model was applied to a simplified planar (non-embossed) foil consisting of a 100-nm-thick VDA layer on a 26 μm Kapton substrate. Results demonstrated that the localized embossing features introduce only marginal variations in SE.

Subsequently, the analysis was extended to assess whether the embossed morphology affects SE when the foil is integrated into a MLI configuration. The MLI sample under consideration consisted of a flat Kapton-VDA foil [3] placed on top of the ECF. To evaluate the electromagnetic response of this layered system, again both CST simulations and TL modelling were carried out. In the TL model, the ECF was modelled as non-embossed VDA-Kapton foil sandwiched between two dielectric spacer layers. The wrinkle-induced separation between the conductive surfaces is considered by the first spacer layer (Gap 1) positioned above the embossed surface. The second dielectric layer (Gap 2) was included to represent the space facing free space, although it has negligible impact on SE (see inset of Fig. 1(c)). Gap 1 and Gap 2 were estimated to be approximately 120 μm and 300 μm, respectively. The results, shown in Fig. 1(c), were compared against experimental measurements. Simulations that neglect gap layers show clear mismatches with experimental results, especially at high frequencies, highlighting the need to include interlayer spacing in electromagnetic models. At lower frequencies, discrepancies are further amplified due to measurement challenges and capacitive effects in complex multilayer setups. These issues, combined with the real-world variability of gap thicknesses in unattached MLI layers, underscore the critical impact of gaps on shielding performance. The findings of this study offer valuable insights into how microstructural features influence electromagnetic shielding in MLI architectures.

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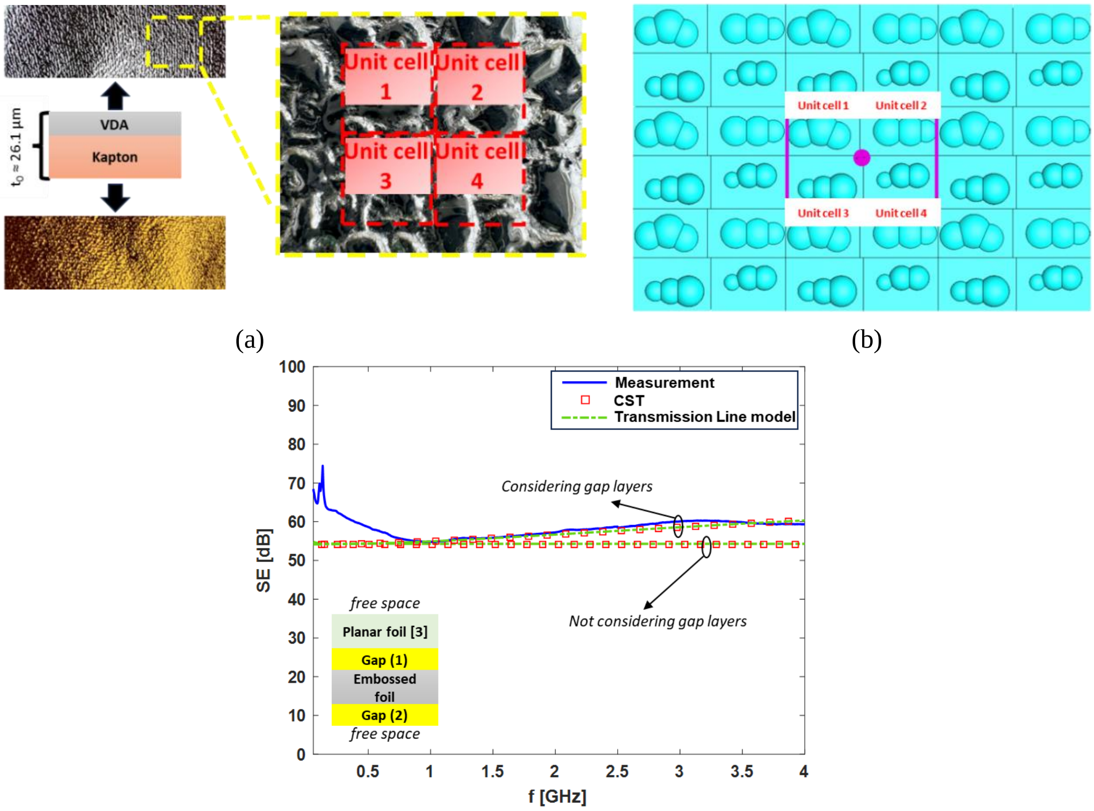

Figure 1. (a) Kapton substrate with VDA coating and a zoomed-in view of the embossed surface, highlighting wrinkle patterns and representative unit cell regions used for modeling. (b) Grid of unit cells extracted from the embossed topology, serving as the geometric basis for CST electromagnetic simulations. (c) SE comparison for the full MLI structure: measured data (blue solid line), CST simulation (red squares), and TL model (green dashed line), with insets illustrating the sketch of the simulated structure. [4]

References

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