A Double-Layer Metamaterial-Based Technique for Interference Mitigation and Shielding of Planar Microwave Structures

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Abstract

An efficient cloaking-shielding technique based on the use of a double superstrate-layer overlay is developed in this paper for planar microstrips. The metamaterial-inspired formulation reduces considerably the induced on the strip current and the reflected from the microstrip electric field, thus alleviating the electromagnetic susceptibility of microstrip transmission lines. For this purpose, the mathematical analysis and optimization procedure are founded on a semi-analytic integral equation algorithm, while a set of numerical results certifies its promising merits.

1. Introduction

The controllable confinement of electromagnetic interactions between devices and their environment, thus rendering them invisible and immune to potential interferences, has recently triggered a significant research interest in the microwave regime [1, 2]. Amid diverse devices, microstrip transmission lines, despite their compact and economical structure, are vulnerable to crosstalk and unintentional radiation. Toward this direction, various noteworthy designs have been presented, exploiting different implementation concepts [3, 4]. In this paper, a double superstrate-layer, metamaterial-oriented method is introduced and verified in order to concurrently attain low electromagnetic reflections as well as considerable levels of shielding of planar microwave configurations.

2. The cloaking-shielding method

Let us consider an external, distant noise-source as a z-polarized plane wave with an incidence angle φ_i that impinges on the configuration of Fig. 1. The Green's function expressions for the homogeneous (without the perfect electric conducting (PEC) strip) structure are derived analytically [3], with the secondary part of Green's function in the substrate's layer (region 3) receiving the form of

$$G_3^{\text{sec}}(x,y) = \frac{1}{4\pi}\int_{-\infty}^{\infty} A_1 \cosh\left[(y+w)\sqrt{l^2-k_3^2}\right] + A_2 \sinh\left[(y+w)\sqrt{l^2-k_3^2}\right] dl, \quad (1)$$

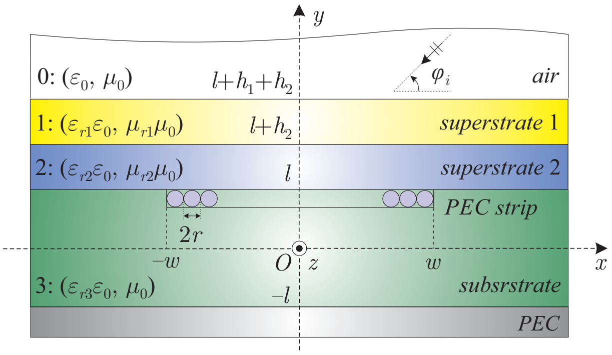

Figure 1: The cloaked microstrip transmission line.

with A_1, A_2 constant coefficients that depend on the relative position of every layer with regard to its source current, thickness, and constitutive parameters. Next, the PEC strip is decomposed into a properly selected large number N of thin cylindrical wires of surface C_n, so that it can be safely assumed that the surface current J_n on each wire is constant. Thus, the scattered electric field in region $i = 0, 1, 2, 3$ can be expressed as

$$E_i^{\text{scat}}(x,y) = -j\omega\mu_0 \sum_{n=1}^{N} J_n \int_{C_n} G_i(x,y)dS. \quad (2)$$

Applying the boundary conditions on the surface of the thin wires, a $N \times N$ linear system results in the form of

$$j\omega\mu_0 \sum_{n=1}^{N} J_n \int_{C_n} [G_1^{\text{pr}}(x,y) + G_2^{\text{sec}}(x,y)]dS = E_3^{\text{ind}}(x_k, w-r), \quad (3)$$

where E_3^{ind} is the induced electric field in region 3 of the strip-free structure, superscripts pr and sec indicate the primary and secondary parts of Green's function in region 3, and $(x_k, w-r)$ are the coordinates of the k_{th} wire center. By solving this linear system, the induced current on the strip and the scattered electric field, through (2), are obtained.

For our analysis, two superstrate layers are overlaid atop the microstrip line. In essence, our objective is two-fold,

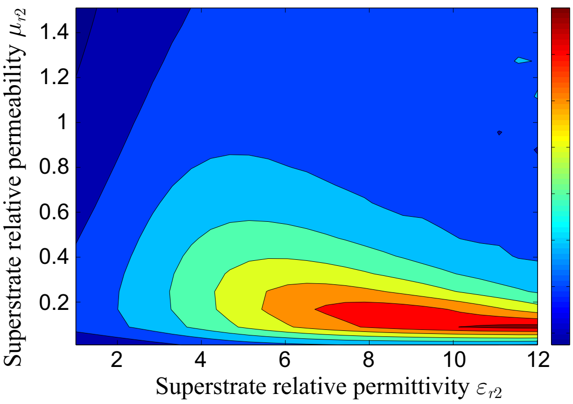

Figure 2: Contour plot of the ratio of the total current induced on the strip for the cloaked to the non-cloaked case, on the map of the superstrate ε_{r2} and μ_{r2}.

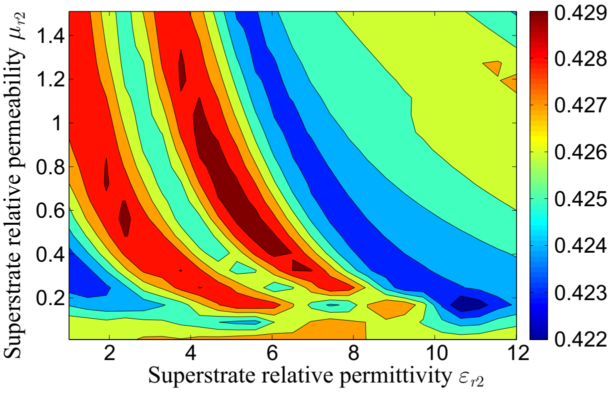

Figure 3: Contour plot of the ratio of the electric field reflected from the structure for the cloaked to the non-cloaked case, on the map of the superstrate ε_{r2} and μ_{r2}.

namely the reduction of the reflected from the structure electric field and the mitigation of the induced current on the strip, so that the electromagnetic interference from external sources to a nearby microwave structure is decreased. To this goal and based on the above formulation, an extensive optimization process that involves the dimensions and electromagnetic parameters of the two layers is conducted. A key asset of the featured technique is its ability to provide fast and precise estimations of the induced on the strip current and the structure's reflected field. Therefore, for our optimization procedure, we can safely select the frequency spectrum of [6 GHz,10 GHz] and a range of incidence angles $\varphi_i \in [15^\circ, 90^\circ]$ for the external noise-source. Moreover, an FR-4 substrate is employed with a thickness of $2w = 1.5\,\mathrm{mm}$ and a relative permittivity of $\varepsilon_{r3} = 4.3 - j0.0966$, while the dimensions of the conducting strip are $1.5\,\mathrm{mm}\times 48.4\,\mu\mathrm{m}$.

Initially, the dimensions and material parameters of the first layer (region 1) are determined. Our selections refer to values that correspond to typical dielectric boards, so that the final structure can be easily manufactured. In particular, thickness is chosen as $h_1 = 298\,\mathrm{mm}$, whereas $\varepsilon_{r1} = 2.8 - j0.042$ and $\mu_{r1} = 1$. Then, the characteristics of the second superstrate layer (region 2) are specified. A common board thickness of $h_2 = 5\,\mathrm{mm}$ is selected, while extensive numerical simulations are conducted, as shown in Figs. 2 and 3, to define a pair of optimal and realizable media parameters. Two solutions are preferred: (i) $(\varepsilon_{r2}, \mu_{r2}) = (1.0, 1.0)$, corresponding to an air-gap or synthetic polymer and (ii) $(\varepsilon_{r2}, \mu_{r2}) = (11.48, 0.72)$, corresponding to a μ-near-zero (MNZ) metamaterial. The significant reduction of the induced current is shown in Fig. 4 for both designs.

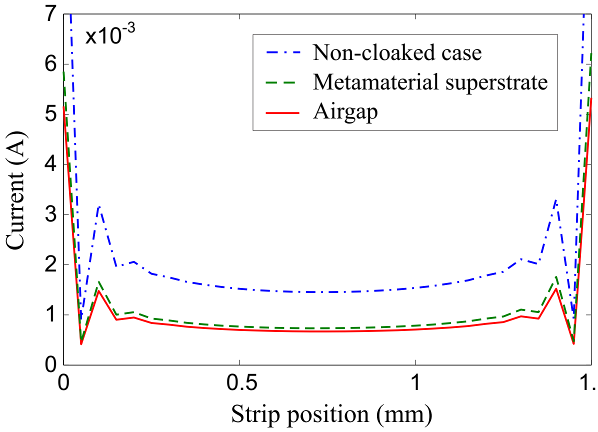

Figure 4: Current along the conducting strip.

3. Conclusions

A novel method for the cloaking-shielding and interference mitigation of planar microstrips, that involves a double-layer overlay atop of the strip, is proposed in the current work. Its effectiveness and design is examined through meticulous numerical simulations of the featured algorithm.

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