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Experimental verification of analytical model for high impedance surfaces

O. Luukkonen, P. Alitalo, C.R. Simovski and S.A. Tretyakov

A simple yet accurate analytical model for a high impedance surface comprising an array of capacitive patches over a grounded dielectric slab is experimentally verified. The results are compared for the oblique incidence reflection phase obtained with the analytical model and commercial simulation software with the results of free-space measurements. It is shown that the analytical and simulation results are in very good agreement with the experimental results. To the authors' knowledge, this is the first time the results of the analytical model in question have been experimentally verified.

Introduction: In general, the notion of an artificial impedance surface or high impedance surface covers a wide variety of surfaces. Basically any surface with an engineered structure that can be characterised in terms of its surface impedance on the air interface of the structure falls into this group. Therefore, different types of structures, such as corrugated surfaces [1] or mushroom structures [2] can all be categorised as artificial impedance surfaces no matter how different the principles of their operation might seem. The high impedance surface considered in this Letter is composed of a capacitive patch array on top of a grounded dielectric slab (see Fig. 1). In contrast to the mushroom-type high impedance surface proposed in [2], there are no vertical metallic vias in the case studied here. Accurate analytical models for the structure proposed in [2] are available in [3, 4].

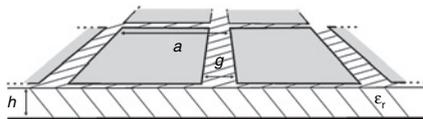


Fig. 1 Studied high impedance surface

There are no metallic vias embedded in substrate
 Notations: a = square patch array, g = gap between adjacent patches, h = height of dielectric substrate, ϵ_r = relative permittivity of substrate

The possibility to use artificial impedance surfaces to improve the performance of conventional applications, or even for completely new applications, has been widely studied in recent literature after [2]. Despite the considerable interest towards high impedance surfaces, a physically sound model capable of predicting the response of the surface shown in Fig. 1, especially for oblique incidence of waves, was not derived until [5]. In [5] the results of the derived analytical model were compared with numerical simulations. To the best of the authors' knowledge the model in [5] has not been verified against experimental results. Validation of analytical results against simulations, particularly with simulations conducted independently with more than one tool, is often considered to be adequate. However, the experiments are the last stage of verification. This serves as motivation for this Letter.

Analytical model: The main point of comparison in this Letter is the analytical model presented in [5] for high impedance surfaces comprising a capacitive patch array over a grounded dielectric slab. The model describes the high impedance surfaces in terms of surface impedances. These surface impedances read for the TE and TM fields, respectively [5]:

$$Z_s^{TE} = \frac{j\omega\mu \tan(\beta h)/\beta}{1 - k_0^2(\epsilon_r + 1)a/\pi \times \tan(\beta h)/\beta \ln[\sin^{-1}(\pi g/2a)](1 - \sin\theta/\epsilon_r + 1)} \quad (1)$$

$$Z_s^{TM} = \frac{j\omega\mu \tan(\beta h)/\beta \cos^2\theta_2}{1 - k_0^2(\epsilon_r + 1)a/\pi \times \tan(\beta h)/\beta \ln[\sin^{-1}(\pi g/2a)] \cos^2\theta_2} \quad (2)$$

where ω is the angular frequency, μ is the permeability of the dielectric substrate ($\mu = \mu_0$ in our case), $\beta = \sqrt{k_0^2\epsilon_r - k_t^2}$ is the propagation constant along the normal direction of the substrate, $\epsilon_r = \epsilon_r' - j\epsilon_r''$ is the relative permittivity of the dielectric substrate, k_t is the tangential component of the wave vector as imposed by the incident wave, θ is the incident angle, and $\theta_2 = \arcsin(\sin(\theta)/\sqrt{\epsilon_r})$. Furthermore, h is the height of the dielectric slab, a is the period of the square patch array, and

g is the gap between the adjacent patches. The expressions for the surface impedance in (1) and (2) are valid for the cases when $w \ll a$ and $k_0\sqrt{(\epsilon_r + 1)}/2 \ll 2\pi$.

In the model shown in [5] the incident plane wave impinges on the patch array creating a capacitive response. The patch array re-radiates the plane wave to the grounded dielectric slab. The electrical thickness of the slab is chosen so that its response to the incident plane wave on the surface on which the patch array lies is inductive in the given frequency region. The capacitive response of the patch array and the inductive response of the grounded dielectric slab together form a parallel resonant circuit.

Methods: The analytical results are compared with experimental and simulation results. The experimental results are obtained from free-space reflection measurements in an anechoic chamber, as illustrated in Fig. 2. The measured high impedance surface sample (approximately 19.5×28.5 cm) was positioned on a rotation unit with an accuracy of 0.03° . The position of the receiving antenna was checked using two mirrors and a laser. The laser was directed along the normal direction of the transmitting antenna towards the sample. The mirrors were positioned both on the surface of the sample and on the receiving antenna. The mirror on the receiving antenna was facing directly towards the sample. It was confirmed that the laser point from the transmitting antenna was reflected by the mirrors all the way to the receiving antenna and back to the sample. The transmitting and receiving horn antennas have a gain of 20 dB over the X-band (8–12 GHz). The transmission between the two horn antennas was measured with a HP8722C network analyser.

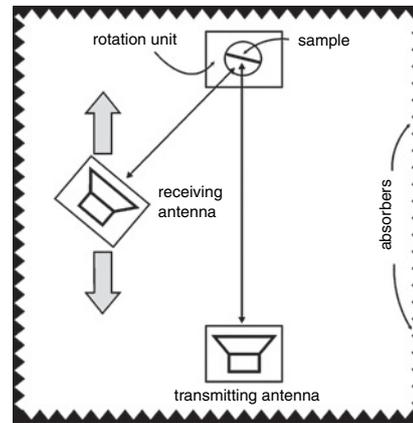


Fig. 2 Measurement setup

Owing to the finite sample size, two samples were measured: a high impedance surface sample and a metal plate with exactly the same outer dimensions as the high impedance surface sample. According to the physical optics approximation, the currents induced to these surfaces by the incident field differ only by the factor corresponding to their reflection coefficients. Therefore, the reflection coefficient of an infinitely large high impedance surface is calculated from the measurement results as $R = -A/B$, where A is the reflection coefficient of the high impedance surface sample and B is the reflection coefficient of the metal plate. The measurements for the high impedance surface and the metallic plate were conducted twice. After the first measurements, the measurement setup was disassembled completely and constructed again for the second measurements. The final experimental reflection phase result is the average of the two measurements that were conducted.

The simulation results were obtained using Ansoft's HFSS [6]. The reflection coefficient of an infinitely large high impedance surface can be easily simulated by using the software's intrinsic periodical boundary condition properties, which has been described in detail in [7].

Results and discussion: The high impedance surface was etched on an FR4 substrate. Following the notations in Fig. 1, the structural parameters of the studied high impedance surface are the following: $a = 5.113$ mm, $g = 0.33$ mm, $h = 1.54$ mm, and $\epsilon_r = 4.4(1 - j0.02)$. The reflection phase diagrams for the TE and TM fields for the incident angle of 30° are shown in Figs 3a and b, respectively. There is good agreement between the analytical, simulation and experimental results.

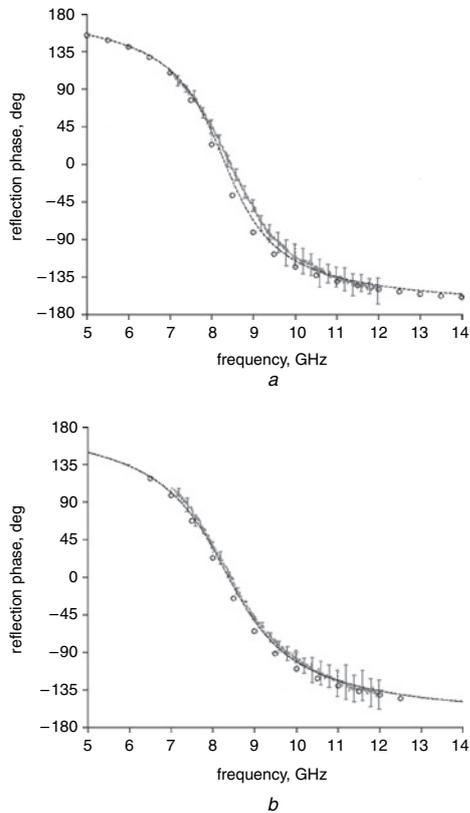


Fig. 3 Reflection phase results

a TE fields

b TM fields

Analytical results are denoted with dashed line, experimental results denoted with solid lines, with error bars denoting standard deviation. Simulation results denoted with circles

According to the analytical and simulation results for the incidence angle of 30° the reflection losses of the sample at resonance $f_r = 8.4$ GHz, are 1.3 and 1.1 dB for the TE and TM fields, respectively. Agreement between the analytical and numerical results is very good. Owing to the large electrical size of the sample, even a slight misalignment in either one of the antennas or the sample can produce a significant error of this magnitude. Because of this, the losses of the sample were not measured with this measurement setup. The measurements for the reflection phase are much less sensitive to errors in alignment of the antennas or sample.

Conclusions: In this Letter the analytical results of [5] are experimentally verified in terms of reflection phase. The experimental results are also compared with simulation results. There is good agreement between the analytical, simulation and experimental results.

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References

- 1 Kildal, P.-S.: 'Artificially soft and hard surfaces in electromagnetics', *IEEE Trans. Antennas Propag.*, 1990, **38**, (10), pp. 1537–1544
- 2 Sievenpiper, D., Zhang, L., Broas, R.F.J., Alexopoulos, N.G., and Yablonovitch, E.: 'High-impedance electromagnetic surfaces with a forbidden frequency band', *IEEE Trans. Microw. Theory Tech.*, 1999, **47**, (11), pp. 2059–2074
- 3 Luukkonen, O., Simovski, C.R., Räsänen, A.V., and Tretyakov, S.A.: 'An efficient and simple analytical model for analysis of propagation properties in impedance waveguides', *IEEE Trans. Microw. Theory Tech.*, 2008, **56**, (7), pp. 1624–1632
- 4 Luukkonen, O., Silveirinha, M., Yakovlev, A., Simovski, C.R., Nefedov, I.S., and Tretyakov, S.A.: 'Effects of spatial dispersion on reflection from mushroom-type artificial impedance surfaces', *IEEE Trans. Microw. Theory Tech.*, accepted for publication
- 5 Luukkonen, O., Simovski, C., Granet, G., Goussetis, G., Lioubtchenko, D., Räsänen, A.V., and Tretyakov, S.A.: 'Simple and accurate analytical model of planar grids and high-impedance surfaces comprising metal strips or patches', *IEEE Trans. Antennas Propag.*, 2008, **56**, (6), pp. 1624–1632
- 6 Ansoft's homepage: <http://www.ansoft.com/>
- 7 Application note: 'Analysis of photonic bandgap surfaces using Ansoft HFSS', http://www.ansoft.com/news/articles/analysis_of_photonic_bandgap_surfaces.pdf