Design methodology to enhance high impedance surfaces performances

M. Grelier[1*], A.C. Lepage[2], X. Begaud[2*], M. Jousset[3] and S. Mallégol[3]

[1]THALES Communications & Security, 4, avenue des Louvresses, 92622 Gennevilliers Cedex 13, France
[2]Institut Telecom, Telecom ParisTech - LTCI CNRS UMR 5141, 46 rue Barrault, 75634 Paris Cedex 13, France
[3]THALES Systèmes Aéroportés, 10 avenue de la 1ère DFL 29238 Brest Cedex 3, France
*corresponding author, E-mail: Xavier.Begaud@telecom-paristech.fr

Abstract

A methodology is introduced for designing wideband, compact and ultra-thin high impedance surfaces (HIS). A parametric study is carried out to examine the effect of the periodicity on the electromagnetic properties of an HIS. This approach allows designers to reach the best trade-off for HIS performances.

1. Introduction

In recent years, artificial surfaces have been widely studied and used in microwave applications [1]. Within a limited frequency bandwidth, these periodic structures can exhibit an electromagnetic band gap (EBG) in which surface wave propagation is forbidden along the structure but also an high impedance surface (HIS) allowing incident electric field to be reflected without any phase shift. This last property makes them suitable as reflector for reducing the overall antenna thickness [2]. In addition of low profile requirement, some applications need supplementary specifications such as wideband characteristics, compact properties when the allocated area is limited.

All these features may not be satisfied at a time due to intrinsic limitations since the reflection phase feature of an HIS is directly related to its different physical and geometrical parameters: the substrate thickness, its relative dielectric constant, the patch width and the gap width [3]. Furthermore, these parameters are also subject to constraints imposed by the available materials and manufacturing processes. Parametric studies can be useful to quickly reach a solution [4], but most of the time, these studies only focus on one specification like the bandwidth without providing a global view. Moreover, the HIS periodicity is not completely taken into account in these analyses because the effect of each parameter is investigated separately.

In this paper, we propose a design procedure that gathers all needed information for designing low profile, broadband and compact HIS structures as best as possible when compromises must be done.

2. Design considerations

The concept of high impedance surface was first introduced by Sievenpiper [2]. In this study, the considered HIS is presented on Fig. 1. It's composed of a planar array of metallic square patches with no via printed on a grounded dielectric slab with a thickness h and a relative dielectric constant ε_r. The width of each square patch is w, the gap between neighbouring patches is g and the lattice period P=w+g.

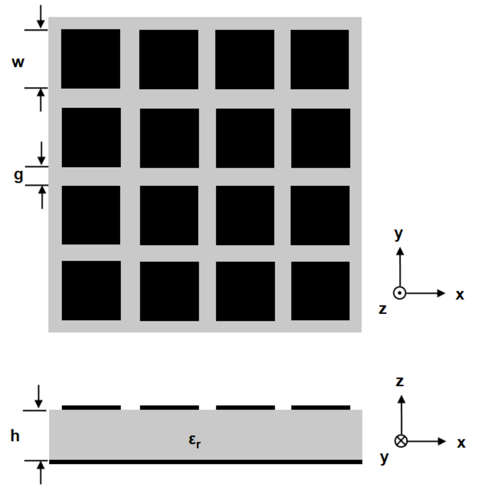

Figure 1: Configuration of the studied HIS

All these physical and geometrical parameters define the electromagnetic properties of the HIS that are commonly obtained by the reflection phase method [4]. This procedure consists in illuminating a unit cell with periodic boundary conditions by an incident plane wave under a normal incidence. Then the phase difference between the reflected and incident electric field at the surface is plotted as function of frequency. Fig. 2 displays the reflection phase diagram with the following parameter set: h=2mm, ε_r=2, w=4mm and g=2mm. Simulations have been performed with CST Microwave Studio® which results have already been verified by measurements [5]. The reflection phase is equal to zero for the resonant frequency f_0=15GHz. Here the HIS bandwidth (Δf) is defined as the frequency range over which the reflection coefficient phase varies from +90° to –90°. Within this band, when an antenna is placed above the HIS, the reflected backward radiation interferes constructively with the forward radiation. Here, the frequency band ranges from 11.3GHz to 19GHz. The HIS compactness, defined by the lattice period, is equal to 6mm.

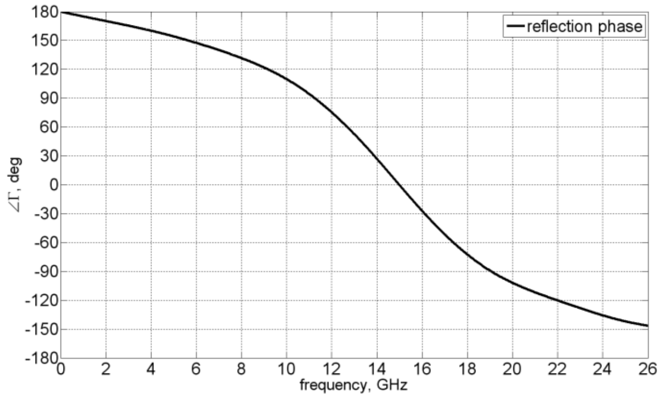

Figure 2: Reflection phase diagram

3. Design methodology

Unlike conventional parametric studies where each parameter is examined one by one while the others are kept constant, we propose to investigate the effects of w and g at the same time. That's why we don't express the period P by a sum but by a product as follows P=w+g=g(1+r) where r is the ratio w/g. Indeed, different combinations of w and g can yield the same value for P without producing the same results on the reflection phase. This decomposition enables to study the influence of P but also to focus on the ratio w/g which has rarely been done. For the sake of clarity, we only study the following cases where the parameters g and r vary by a factor 10: g=0.5mm, 1mm, 2mm, 3mm, 4mm, 5mm and r=1, 2, 5, 10. We extract for each couple (g, r) the resonant frequency, the HIS bandwidth and the HIS compactness from the reflection phase diagram. All these information are then reported in Fig. 3 and Fig. 4.

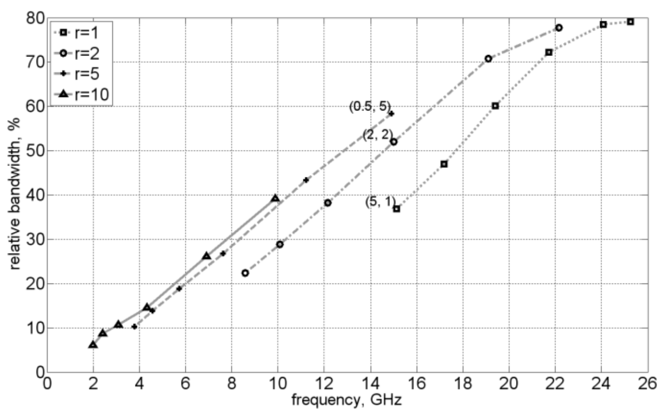

Figure 3: Evolution of the relative bandwidth $\Delta f/f_0$ for h=2mm and ε_r=2

Fig. 3 illustrates the evolution of the HIS relative bandwidth $\Delta f/f_0$ with frequency. Reflection phase feature typically occurs from 2GHz to 26GHz. The relative bandwidth grows when r decreases for a constant g but also when g decreases for a constant r. We notice that several couples (g, r) having the same resonant frequency lead to a different relative bandwidth. For example, the couples (0.5, 5), (2, 2) and (5, 1) exhibit a resonant frequency at 15GHz and present a relative bandwidth $\Delta f/f_0$ respectively of 58%, 52% and 36%. This result can be used to maximize the bandwidth by only modifying the geometrical parameters.

Fig. 4 deals with the relative compactness by representing the evolution of the ratio λ_m/P versus frequency where λ_m is the wavelength in the medium [6]. We observe that for the same resonant frequency, the relative compactness gets better when g decreases and r increases. At f_0=15GHz, the couples (0.5, 5), (2, 2) and (5, 1) present a relative compactness λ_m/P respectively of 5.5, 2.5 and 1.7. These results help to converge more rapidly to the values of w and g in order to optimize the HIS compactness.

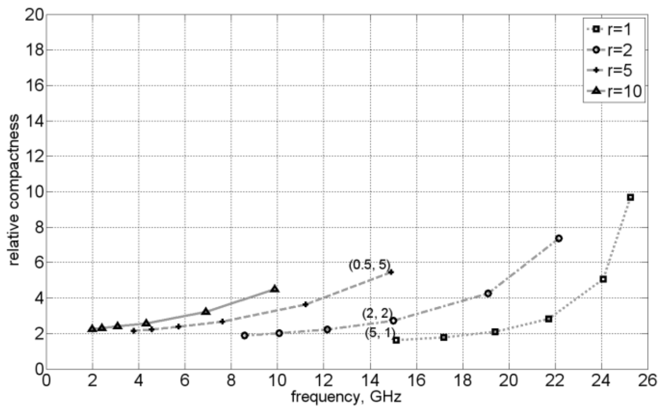

Figure 4: Evolution of the relative compactness λ_m/P for h=2mm and ε_r=2

These two previous graphs allow HIS designers to identify solutions that fulfill their requirements. In addition, they also point out some limitations. For instance, it's difficult to build an HIS whose characteristics are f_0=11.5GHz, λ_m/P=8 and $\Delta f/f_0$>70%. The only way to overcome this physical restriction is to increase either the relative permittivity or the substrate thickness. That is why the methodology is then applied to two other parameter sets: h=2mm and ε_r=8 (Fig. 5 and Fig. 6), h=4mm and ε_r=2 (Fig. 7 and Fig. 8).

Curves follow the same behaviour with a change of scale from a substrate configuration to another one. We can find a couple to satisfy the previous condition on the relative compactness with (0.5, 2) on Fig. 6 and with (1, 2) on Fig. 8. However, Fig. 5 and Fig. 7 demonstrate that the relative bandwidth condition is only achieved with the couple (1, 2) of the last parameter set. On the one hand increasing the relative permittivity reduces significantly the relative bandwidth. On the other hand increasing the HIS height runs counter to low profile requirement since h is doubled. This example illustrates the trade-offs that are involved in HIS design and highlights the advantages of the proposed methodology. Thanks to this procedure, it is possible to quickly know if the whole specification is achievable with the chosen material. Otherwise, it enables to determine which parameters have to be modified to obtain the best compromises.

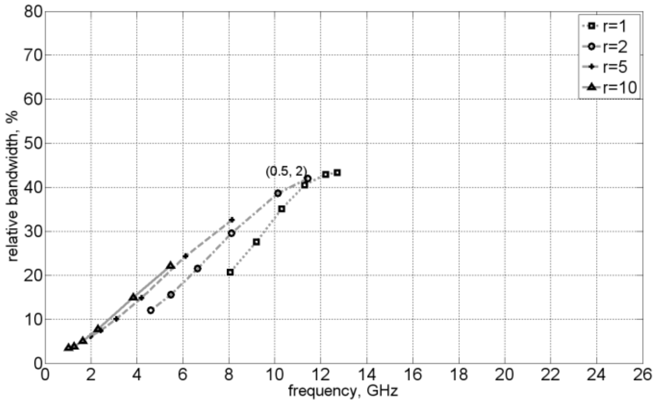

Figure 5: Evolution of the relative bandwidth $\Delta f/f_0$ for h=2mm and ε_r=8

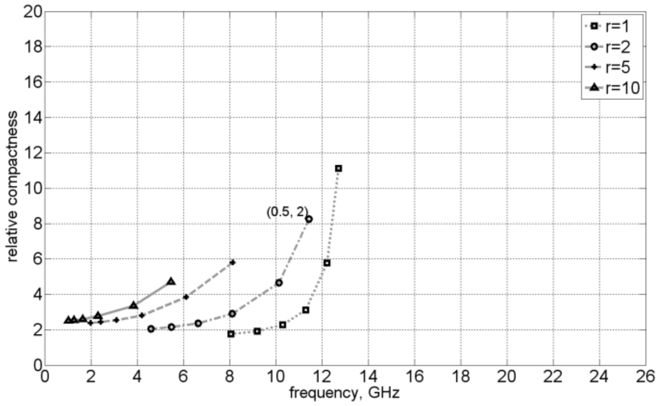

Figure 6: Evolution of the relative compactness λ_m/P for h=2mm and ε_r=8

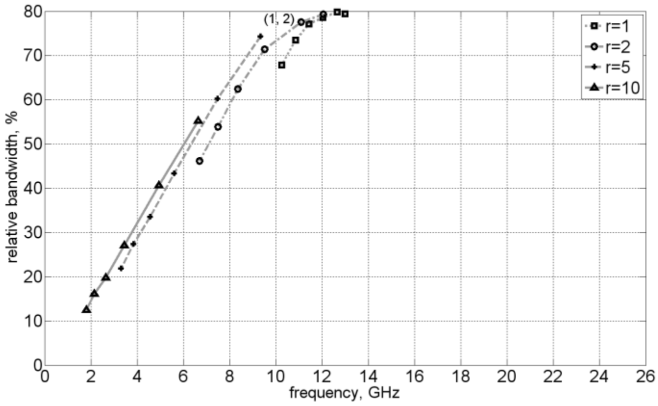

Figure 7: Evolution of the relative bandwidth $\Delta f/f_0$ for h=4mm and ε_r=2

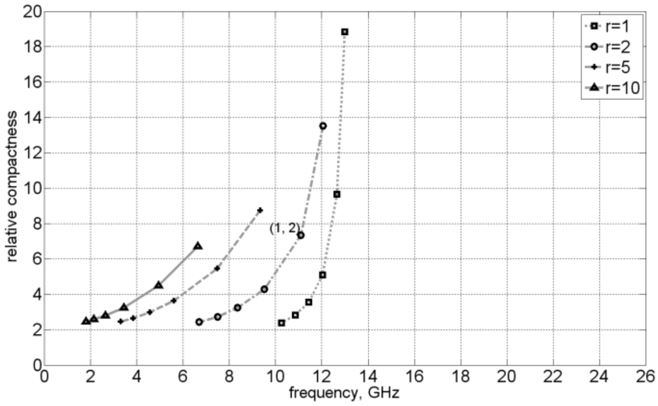

Figure 8: Evolution of the relative compactness λ_m/P for h=4mm and ε_r=2

4. Conclusions

A design procedure has been proposed for HIS relative bandwidth and relative compactness considerations. The adopted methodology provides guidelines for HIS designers and gives them an overview of which performances can be reached for a certain parameter set. Moreover the results of such analysis are reusable for further studies since the parameter set is entirely characterized. This principle can be extended for any HIS shape or any other characteristics such as relative thickness or EBG properties.

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