A One-Layer Ultra-Thin Meta-Surface Absorber

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1. **Abstract:** In this paper, the design of a one-layer ultra-thin meta-surface absorber having a simple geometry is demonstrated. The absorber is constructed of a periodic array of square patches printed on a dielectric material backed by a PEC. The square patches are coupled to each other through lossy dielectric materials representing lumped resistors. Therefore, at the resonant frequency of meta-surface the structure is equivalent to a resistive sheet where by tuning the value of dielectric loss an impedance match to the free space is successfully accomplished.

2. **A Review of Ultra-Thin Absorbers:** In many radar and tracking applications it is desired to enhance or reduce the Radar Cross Sections (RCS) of an object. A typical approach for reducing the RCS of a structure is to coat it with a lossy material that can absorb the energy in a specified range of frequency. There have been considerable efforts in recent years to present a novel methodology for obtaining a lightweight thin absorber.

One of the most popular approaches for the design of EM absorbers is based on the use of Salisbury screens [1]. This structure consists of a resistive sheet located a quarter wavelength above a PEC back dielectric slab, as shown in Fig. 1. A portion of an incident wave illuminating the Salisbury screen is reflected form the surface, and the remaining part is propagated inside the dielectric and is reflected off the backed PEC plane and goes through the dielectric and resistive sheet. At the frequency that these two reflected waves are 180^0 out of phase they cancel each other, and the reflection coefficient goes to zero. The thickness of the dielectric slab backing the resistive sheet determines the frequency for zero reflection. The main challenge is to reduce the thickness of dielectric slab and provide a lightweight thin absorber.

Kern and Werner in 2003 presented a novel approach for design of an ultra-thin absorber utilizing a GA-optimized metallic pattern printed on a very thin dielectric material backed by the PEC [2]. The metallic pattern is a lossy screen and can significantly absorb the EM energy. The advantage of this method, compared to the Salisbury screen, is that the new design is now a single layer structure that is very thin. However, the GA optimized pattern has a complex configuration, which is difficult for fabrication. Additionally, the designed absorber is sensitive to the polarization state and angle of incident of the illuminating plane wave and is not very suitable for practical applications.

Recently, another concept for achieving a high performance ultra-thin absorber was introduced by Engheta [3]. This method is based on the use of high impedance meta-surfaces. Basically, instead of using a quarter wave distance between the PEC and resistive sheet, a high impedance surface is used just next to the resistive sheet to realize a PMC plane and successfully fulfill the required phase difference for field cancellation. Therefore one does not need to use a quarter wavelength spacer. However, no practical design on this idea has been examined yet.

In this paper, we first propose a simple high impedance meta-surface architecture located next to a resistive sheet to accomplish the above concept and present a thin absorber. Then we will demonstrate how one can obtain an ultra-thin absorber with the use of only high impedance meta-surface without any need of resistive sheet. In the later design, a lossy meta-surface is designed in order to provide free space surface impedance η_0 at the resonance.

3. **RIS-Resistive Sheet Absorber:** In this section, design of an ultra-thin absorber made up of a high impedance meta-surface positioned next to a resistive sheet is investigated. In [4] we demonstrated the concept of a high impedance Reactive Impedance Surface (RIS) accomplished utilizing a periodic array of square patch elements printed on a high dielectric material backed by a PEC. The geometry is shown in Fig. 2(a). The periodic meta-surface is equivalent to a parallel LC circuit (see Fig. 2(b)) with reactive impedance behavior $\eta = j\nu$. A Finite Difference Time

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Domain (FDTD) technique with Periodic Boundary Conditions/Perfectly Matched Layers (PBC/PML) walls [5] is applied to characterize the performance of the high impedance meta-surface illuminated by a normal incident plane wave, and an arbitrary oblique wave with incident angle 30° and linear polarization specified by angle $\psi^i = 60^\circ$ (between the electric field and a reference direction $\hat{\mathbf{k}}^i \times \hat{\mathbf{z}}$). The normalized reactance and reflection phase of the surface are shown in Fig. 3.

It is observed that the surface is inductive at frequencies below resonance, open circuit at the resonance (behaving as a PMC surface with infinite impedance) and capacitive above the resonant frequency. At frequencies much lower than the resonant frequency the surface impedance approaches zero, and the structure behaves as a PEC surface.

Due to the symmetric shape of periodic patches the performance of reactive impedance surface is almost independent of the polarization states (in *x-y* plane). Additionally, since a relatively large dielectric constant is used, according to Snell's law, $\cos\alpha$ (α is transmission angle inside the dielectric material) remains close to unity independent of incidence angle in free space. Therefore, surface reactance of the impedance surface becomes almost invariant to incidence angle and polarization as desired.

The designed meta-surface has very thin thickness of about $0.03\lambda_0$ and as illustrated presents the high impedance performance with zero reflection phase at the resonance. Therefore, if the surface is located next to an impedance matched resistive sheet, as shown in Fig. 4(a), the required phase difference for field cancellation of the reflected waves is fulfilled, and an ultra-thin absorber can be achieved. The performance of meta-surface absorber is shown in Fig. 4(b). Note that although a very good absorption over a relatively wide range of incident angles is observed, it is practically impossible to achieve such an absorber. This is because that the resistive sheet should have certain material values at different incident angles and cannot be accomplished.

4. One-Layer Lossy Impedance Surface Absorber: The objective here is to demonstrate how a one-layer ultra-thin absorber can be effectively obtained with the use of only a lossy impedance surface. Fig. 5(a) illustrates the RIS designed in Fig. 2(a), where the dielectric materials between the square patches are now lossy ($\tan\delta = 1.23$), representing lumped resistors. The equivalent circuit model is shown in Fig. 5(b). It is observed that at the surface resonance the structure is equivalent to a resistor. The value of R is chosen equal to the free space impedance η_0. Therefore at the resonance the surface is matched to the free space and completely absorbs the incident wave. The characteristic impedances and reflection coefficients of the surface for the normal and oblique waves are determined in Figs. 6 and 7. A significant absorption in the range of incident angles is successfully demonstrated.

References

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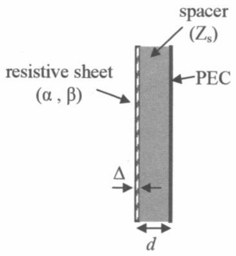
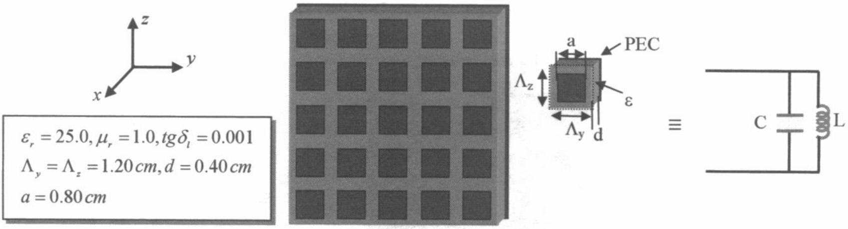
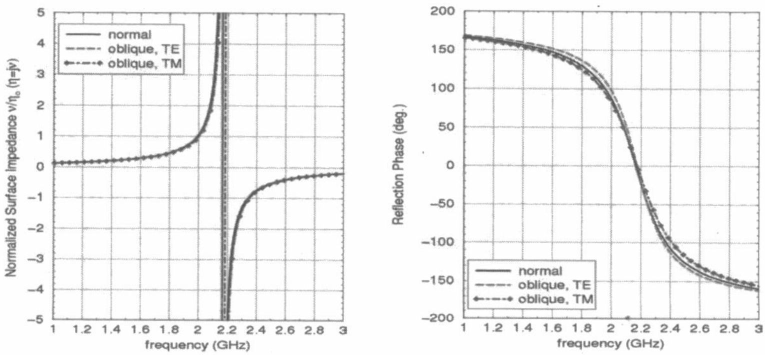


Fig. 1. Salisbury screen composed of a resistive sheet in front of a quarter wavelength dielectric spacer backed by a PEC.



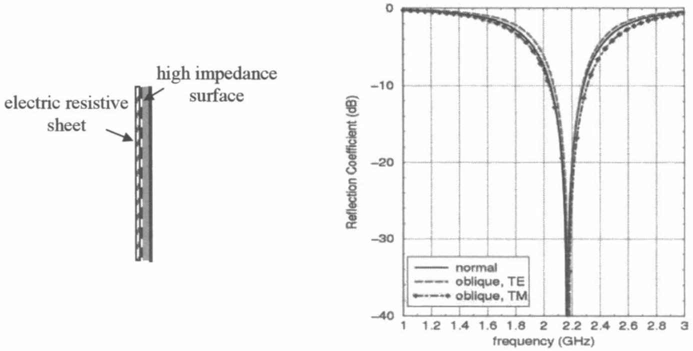
(a) (b)

Fig. 2. (a) The geometry of reactive impedance surface and (b) its equivalent circuit model.



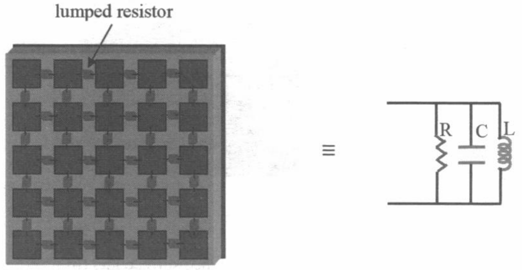
(a) (b)

Fig. 3. The performance of reactive impedance surface. (a) Surface impedance characteristic, (b) Reflection phase.



(a) (b)

Fig. 4. (a) Meta-surface absorber constructed of RIS and resistive sheet and (b) its reflection coefficient.



(a) (b)

Fig. 5. (a) The geometry of lossy impedance surface and (b) its equivalent circuit model.

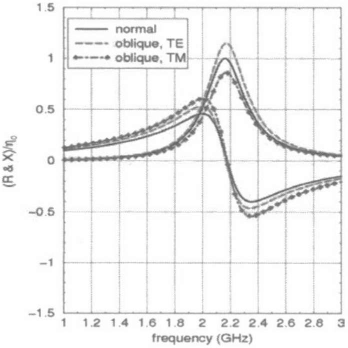


Fig. 6. Characteristics of lossy impedance surface.

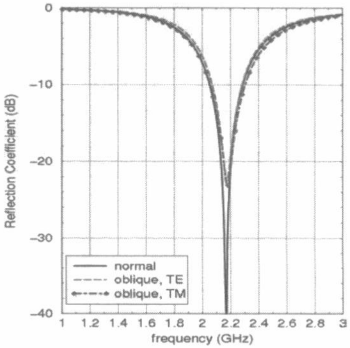


Fig. 7. Reflection coefficient of lossy impedance surface.