# Easily Designed and Constructed High Impedance Surfaces

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## I. INTRODUCTION

High impedance surfaces are formed using artificial materials that conspire to behave effectively as a magnetic conductor (versus an electric conductor), at least over a limited frequency range. In the case of a perfect magnetic conductor (PMC), the surface boundary condition is

$$\hat{n} \times \bar{H} = 0 \tag{1}$$

When applied in the situation of a uniform plane wave (UPW) normally incident on a PMC plane, this boundary condition produces a reflection coefficient of +1, versus –1 for a conventional perfectly electrically conducting (PEC) plane.

Artificial impedance surfaces are not a new concept, of course. Corrugated planes and cylinders found early use as waveguides for surface wave and end-fire antennas, for example [1, 2]. More recent work by Sievenpiper, Yablonovitch and others, however, has produced artificial magnetic conductors that are quite thin [3, 4]. These narrow bandwidth, high impedance surfaces bring into promise applications for antenna backplanes in cellular telephones, PCMCIA cards and other applications where space may be very limited. Other applications are certainly possible.

Two basic classes of high impedance surfaces have emerged: those based on a volume of artificial material and those based on a surface distribution of inhomogeneities. The tri-layer, mushroom structure of Sievenpiper and Yablonovitch [3, 5, 6] is a member of the first class, as is the combination of split ring resonators (SRRs) and capacitively loaded loops (CLLs) of Ziolkowski [7, 8]. For the second class, surfaces composed of Hilbert space curves as proposed by McVay, et al., is a good example [9].

## II. NEW LUMPED-ELEMENT-LOADED HIGH IMPEDANCE SURFACE

We are proposing a new high impedance surface that is extremely easy to design and fabricate, in contrast to many of the surfaces described above. These new surfaces are formed by properly lumped loading a periodic screen on a metallic-backed substrate. An example of such a surface is shown in Figs. 1 and 2 below. While there are a few useful choices for the type of screen and element loading, we will focus here on capacitively loaded inductive meshes, with a representative geometry shown in Fig. 2.

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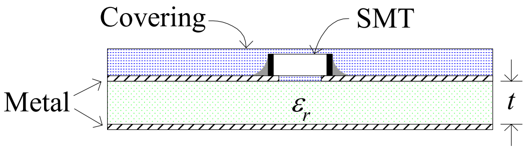

**Fig. 1** Cross-sectional view of a lumped-element-loaded high impedance surface. The substrate thickness *t* is on the order of tens of mils.

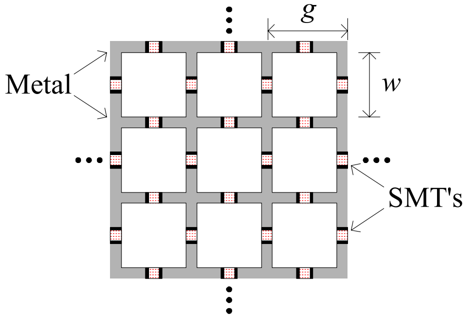

**Fig. 2** Top view of a periodic, lumped-element-loaded inductive screen forming a high impedance surface. Dimensions *g* and *w* are on the order of millimeters.

Provided the radiation wavelength is much larger than the unit cell spacing, it is reasonable to expect that a homogenized boundary condition model for this complicated surface would be valid. In fact, we have successfully applied an impedance sheet model (aka resistive boundary condition) [10] to this surface. Combined with a transmission line (TL) analysis for UPW illumination of the structure, this impedance sheet model provides a simple technique for design and analysis of these new lumped-element-loaded high impedance surfaces.

Considering only normal incidence illumination of the structure in Fig. 2, an approximate TL model for UPW scattering is shown in Fig. 3. Referring to the inductive elements, $L_{me}$ is the homogenized sheet inductance of the mesh while $L_{gp}$ represents inductive effects of the ground plane at the surface of the thin substrate. The capacitive effects are modeled by a parallel combination of $C_{ll}$, which is the homogenized sheet capacitance due to the lumped loading, and $C_{sl}$, which is the homogenized sheet capacitance from the slots in the metallization.

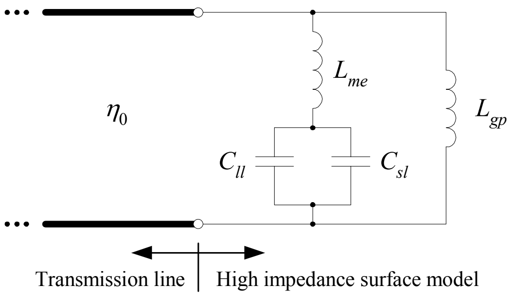

**Fig. 3** Approximate transmission line model for the inductive mesh of Fig. 2 lumped loaded using discrete capacitors.

Simple, but approximate, analytical expressions for all of these homogenized elements in the TL model of Fig. 3 are available. For example, it is easy to show that

$$L_{gp} \approx \mu_0 t \qquad \mathrm{H}/\square \tag{2}$$

while from [11] and simplifying for low frequencies,

$$L_{me} \approx \frac{\mu_0 g}{2\pi} \ln\left[\csc\left(\frac{\pi a}{g}\right)\right] \qquad \mathrm{H}/\square \tag{3}$$

where $a = (g - w)/2$.

Examining the equivalent TL model in Fig. 3, it is apparent that the load forms a parallel resonant circuit. Consequently, at the resonant frequency the voltage (i.e., electric field) reflection coefficient is +1. In other words, this structure forms an open circuit termination (in a TL sense), which is equivalent to a perfect magnetic conductor or a high impedance surface for an electromagnetic wave impinging on the surface of Figs. 1 and 2.

## III. REPRESENTATIVE RESULTS

Typical results from this lumped loading of inductive meshes are shown in Fig. 4. For these results, $g = 5$ mm, $w = 4.75$ mm, $\varepsilon_r = 3.2$ and $d = 30$ mil, with the lumped loading $C = 1.2$ pF. No covering material is included in this example. In addition to predictions using our TL model, also shown in Fig. 4 are phase angles computed using *CST Microwave Studio*, which is a finite integration time domain solver [12]. For these latter results, the metallization thickness of the inductive surface was 50 μm, while in the TL model, it was assumed infinitely thin. In both cases, the metal was assumed PEC. The magnitude of the reflection coefficient (not shown) was found equal to one in both cases.

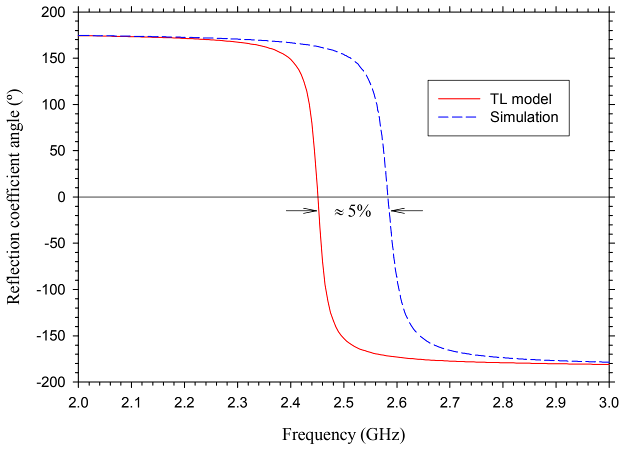

**Fig. 4** Reflection coefficient phase angle for a UPW normally incident on the capacitively lumped-loaded inductive mesh shown in Fig. 2. The phase reference plane is located at the top of the substrate.

It is apparent from these results that the capacitively loaded inductive surface behaves as a high impedance surface – at least within a narrow frequency band near 2.6 GHz. This is true since the reflection coefficient magnitude is one while the phase angle is zero. There is an approximately 5% difference in the predicted resonance frequency, which is quite good considering the approximations used in the TL model. We have exercised this model over various loadings and practical inductive screen sizes and have found similar agreement, which testifies to the usefulness of this simple model in not only designing these high impedance surfaces, but also in understanding their behavior.

## IV. CONCLUSIONS

Lumped loading of metallic screens on a grounded substrate can result in an extremely effective high impedance surface. In particular, we have shown here that capacitive lumped-element loading of a periodic inductive screen is an easily designed and effective surface that would be inexpensive to fabricate. For practical unit cell sizes on the order of a few millimeters, capacitors on the order of a few picofarads are all that is needed to operate this high impedance surface in the commercial wireless communications bands (0.9-6 GHz). Such capacitors are cheap, readily available and will operate nearly to 10 GHz.

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