Absorption Characteristics of Periodic Arrangements of Infinite Helices

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Abstract—**The absorption properties of periodic arrangements of lossy, infinite helices are investigated. The helices are assumed to be embedded in free space and backed by a p.e.c. plane. The method of moments is used to solve for the scattering parameters of a single layer, and a multiscattering technique is used to form a composite matrix that describes the scattering due to several layers. The resistivity of the wire, the pitch to length ratio of the helix, and the thickness of the layer are shown to affect the power absorbed.**

I. Introduction

CHIRAL structures, e.g., helices, randomly embedded in a host dielectric have been shown to affect the electromagnetic characteristics of the composite medium [1]. Such inclusions can be used to create media that exhibit excellent absorption characteristics [2]. The purpose of this letter is to investigate the absorption properties of layers of periodic arrangements of lossy, infinite helices backed by a p.e.c. plane. It will be demonstrated that varying the pitch to length ratio and the resistivity of the wire helices significantly affects the reflection characteristics. It will also be shown that as the thickness of the layers changes, the pitch to length ratio of the helices that results in the most absorbed power also changes.

II. Problem Formulation

The periodic geometry under investigation in this letter is shown in Fig. 1. The layered structure consists of a finite number of slabs backed by a p.e.c. plane. A single layer, shown in the perspective view, is comprised of a periodic arrangement of infinitely long helices. The thickness of the layers, dz, is chosen equal to the period of separation, dy, so that the helices are equally spaced in both the y- and z-directions. Two layers backed by a p.e.c. plane are shown in the top view, where the circles represent the cross-sections of the helices when viewed along their axes. The structure can be analyzed by considering a single turn of the helix, so that the periodicity of the structure along the axis of the helix, dx, corresponds to the pitch, P, of the helix. The length of a single turn, L, is defined in terms of the pitch, P, and the radius, r, of the helix as $L = \sqrt{(2\pi r)^2 + P^2}$. In cases considered in this letter, the radius of the helix, r, is chosen to be three-tenths of the period of separation, dy. A pitch to length ratio of one, which corresponds to a straight wire, is realized by setting $r = 0$. The medium surrounding the helices in a layer is chosen to be free space and as shown in Fig. 1, normally incident plane waves with the electric field oriented parallel to the axes of the helices are used to illuminate the slabs.

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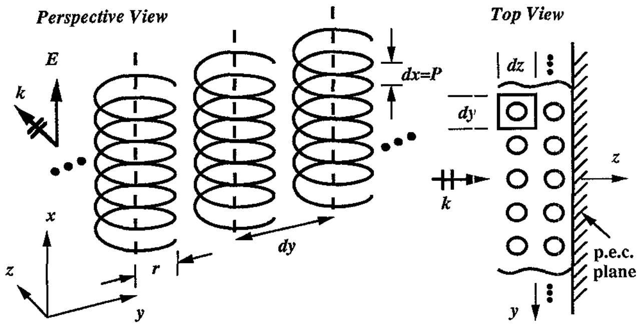

Fig. 1. Perspective view (left) of single layer of periodic arrangement of infinite helices with axes parallel to the x-axis. Period of separation is dy in the y-direction, and dx in the x-direction. Top view (right) of two layers of periodic helical geometry backed by a plane of perfect electric conductor. Normally incident plane wave with electric field oriented parallel to the axes of the helices.

An electric field integral equation (EFIE) is formulated in terms of the electric current density on the wire scatterer within a single reference cell, and is solved via the method of moments [3]. Various approximations are used in order to calculate the potential integrals and the moment method inner product integrals [4]. Acceleration techniques are employed in order to efficiently evaluate the periodic Green's function, as detailed in [5].

The single layer composed of the periodic array of scatterers is described in terms of a scattering matrix. When more than one layer is present, the composite scattering matrix is found using a multiscattering scheme [6]. The validity of the multiscattering approach was verified by directly analyzing the multiple layer structure using a unit cell comprised of multiple layers. These different approaches yielded identical results.

III. Numerical Results

The results presented in this section will show the effect of varying the pitch to length ratio of the helices, the resistivity of the helices, and the thickness of the layers. The reflected power is plotted as a function of the number of layers of helices. Due to the brevity of this presentation, only a representative sample of the different cases investigated may be shown here.

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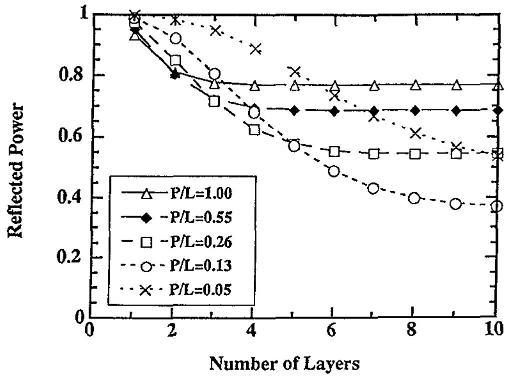

Fig. 2. Reflected power vs. number of layers, with period $dy = 0.05\ \lambda$, resistance per wavelength $R/\lambda = 1000\ \Omega/\lambda$, and varing pitch to length ratio P/L.

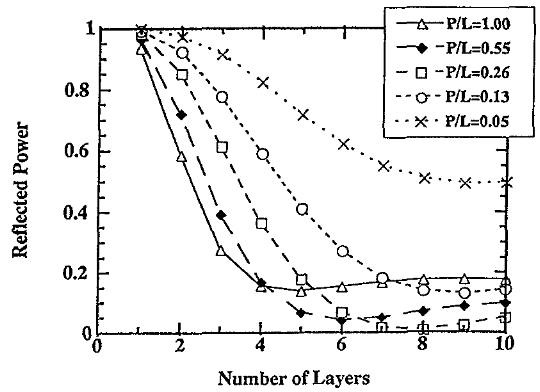

Fig. 3. Reflected power vs. number of layers, with period $dy = 0.05\ \lambda$, and resistence per wavelength $R/\lambda = 10\,000\ \Omega/\lambda$, and varying pitch to length ratio P/L.

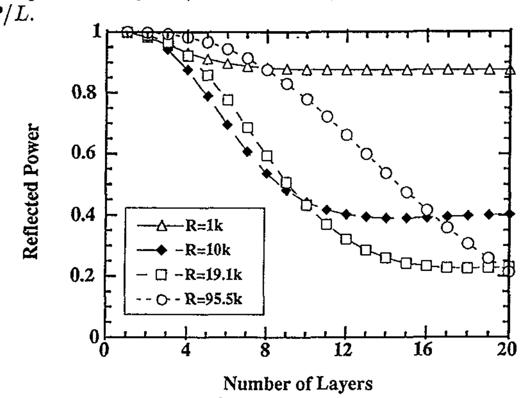

Fig. 4. Reflected power vs. number of layers, with period $dy = 0.01\ \lambda$, pitch to length ratio $P/L = 0.13$, and varying resistence per wavelength R/λ.

The first result, shown in Fig. 2, is for a structure comprised of layers that are 0.05 λ thick. The resistivity of the helices is fixed at $R/\lambda = 1000\ \Omega/\lambda$ while the pitch to length ratio varies. The curves in this plot show that as P/L decreases, more layers are required for the reflected power to reach a minimum value, and the minimum values of reflected power are lower for the smaller P/L. Next, the resistivity is increased to $R/\lambda = 10\,000\ \Omega/\lambda$ while the thickness of the layers remains constant at 0.05 λ. The results for this case, displayed in Fig. 3, show that while it still takes more layers for the smaller pitch to length ratio curves to reach minimum values, these minima do not necessarily decrease as P/L decreases. This is clearly shown by the $P/L = 0.26$ curve, which achieves excellent absorption characteristics at eight layers with a value of virtually zero reflected power, while the minimum value of reflected power is at 15% for the $P/L = 0.13$ curve.

The thickness of the layers also effects the absorption characteristics, as shown in Fig. 4. In this plot, $P/L = 0.13$ while the thickness of the layers is 0.01 λ and the resistivity varies. Comparing the $R/\lambda = 10\,000\ \Omega/\lambda$ curve of Fig. 4 with the $P/L = 0.13$ curve in Fig. 3 and the $R/\lambda = 1000\ \Omega/\lambda$ curve of Fig. 4 with the $P/L = 0.13$ curve in Fig. 2, it is evident that for this pitch to length ratio the structure with thicker layers exhibits better absorption properties. Focusing on the curves of Fig. 4 alone, we see that as the loss increases, more layers are required to achieve the minimal amount of reflected power. For the cases considered here, the more lossy the helix, as expected, the lower the minimum value of total reflected power.

IV. Conclusion

In this letter, the reflection properties of periodic arrangements of lossy, infinite helices backed by a plane of perfect electric conductor were investigated. It was shown that as the pitch to length ratio decreases, more layers are required for the reflected power to reach a minimum value. It was also demonstrated that decreasing P/L values do not always result in minimal reflected power. For a fixed pitch to length ratio and layer thickness, it was shown that as the resistivity increased, more layers were required to improve absorption.

The effects of embedding periodic arrangements of helices in lossy and lossless dielectric is currently being investigated. Using the results of the dielectric study and the results presented here, we are currently developing a method to extract effective constitutive parameters that can be used to describe the scattering characteristics of the composite medium. This will lead to a clear physical interpretation of the effects of the varying parameters, and will be reported shortly.

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