WAVE PROPAGATION IN LONGITUDINALLY SYMMETRIC METAMATERIALS THAT ARE ISOREFRACTIVE WITH FREE SPACE

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ABSTRACT

Two isorefractive materials have the same speed of light, but different wave impedances. Isorefractive material have definite advantages for transient applications, as they can support non-dispersive TEM modes that propagate parallel to the interface between two materials. It has been shown previously that such materials can significantly impact the efficiency of impulse radiating antennas by increasing the power concentration inside the aperture of the antenna. IN this paper, we will explore the performance of longitudinally symmetric artificial materials that are isorefractive with free space. Specifically, we will examine the performance of anti reflection coatings designed to operate in the time domain at the termination of the artificial material.

INTRODUCTION

A new class of metamaterial was recently presented that is composed of longitudinally symmetric (two-dimensional) inclusions supported in an external host medium [1]. The inclusions are symmetric in the direction of wave propagation (either a Cartesian direction for plane wave propagation or in the radial direction for spherical wave propagation). The effect of such a medium is to create a multi-conductor transmission line with many undriven electrodes (the inclusions). Such a structure can support a TEM mode, which is nondispersive and has a phase velocity equal to that of the host material. If the host medium is a tenuous dielectric (such as a low dielectric constant foam), then the new metamaterial can be nearly isorefractive with free space, i. e. the metamaterial has a lower wave impedance but the same speed of light as free space.

The primary motivator for the proposal of such materials was for use in transient radiators such as impulse radiating antennas (IRAs). IRAs are fundamentally low-aperture efficiency devices due to the open nature of the TEM mode that propagates on their feeds. It has been proposed that the use of low-impedance materials in the portion of the feed that excites the aperture can reduce the percentage of the power that spills over the aperture, thereby increasing aperture efficiency. For most such IRAs, the metamaterial should have conical symmetry.

The fundamental assumption that went into the analysis of these new media is that only the TEM mode is propagating. For time-domain applications, the structure can be expected to be overmoded at the highest frequencies, and hence capable of supporting non-TEM modes. The presence of discontinuities – the beginning and ending of the inclusions – can in principle excite these higher-order modes and reduce the effectiveness of the new medium. In an IRA, it is expected that the metamaterial will fill the region inside the throat of the TEM feed. However, the inclusions must be terminated at the aperture (since radiation is typically into free space), and the conical symmetry cannot be carried all the way to the feed of the antenna due to practical limitations. For plane wave propagation, it will be necessary to form a slab of the metamaterial perpendicular to the direction of propagation, and the corresponding beginning and ending points of the inclusions will provide a mechanism for higher-order mode excitation. In order to transition into or out of the metamaterial in either of the above applications, it is necessary to develop “time-domain anti-reflection coatings” that allow for a gradual transformation of the TEM mode in the metamaterial to that in the surrounding medium. Such anti-reflection coatings will take the form of a tapering of the inclusions over a length that is long when compared with the corresponding time scales of the time-domain waveform, e.g. the risetime or pulsewidth. At late times, there will still be an impedance discontinuity, but if this discontinuity can be delayed sufficiently long enough, the majority of the high-frequency components will have radiated, and the lower frequencies that remain will not be overmoded.

METHOD

In this paper, we will present a series of simulations and measurements that investigate the propagation of electromagnetic waves parallel to the symmetry axis of these metamaterials. Models for the construction of these metamaterials will be presented for both microwave and optical frequencies. As microwave frequencies, the metamaterial will be constructed by supporting rigid inclusions at discrete locations by foam support structures. Such a material has the potential to be extremely light, as the inclusions can be hollow. At optical frequencies, these metamaterials might be fabricated by micro- and nano-fabrication techniques that allow the growth of metallic inclusions either inside or above the surface of a dielectric substrate. Full wave simulations will be used to explore the propagation inside the "bulk" of these materials, as well as explore the effects of medium discontinuities on the electromagnetic mode structure.

In order to realize the benefits of isorefractive materials for impulse radiating antennas, it is necessary to terminate the longitudinally symmetric structure at the end of the aperture. At such a termination, the currents flowing on the inclusions will abruptly stop, and a reflection will occur. It is well known that layered structures can be developed that will prevent or minimize reflections at a specific frequency or across a well-defined frequency range – these are termed anti-reflection coatings. In the time domain, these coatings need to "match" the impedance of the multi-conductor transmission line that makes up the artificial material to the impedance of free space. This is done here by tapering the inclusions to provide a smooth transition to free space. The effect is to delay any large reflections until a clear time, after which the response of the antenna no longer matters.

REFERENCES

[1] J. S. Tyo, "A Class of Artificial Materials Isorefractive With Free Space," accepted for publication in IEEE Transactions on Antennas and Propagation, April 2002