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ELECTRODYNAMICS AND WAVE PROPAGATION

Reflection of a Surface Mode from the End of a Planar Metamaterial Waveguide

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Abstract—Variational method is used for the analysis of the problem of surface mode reflection from the end of a planar dielectric waveguide fabricated from a metamaterial. The theory is illustrated by the examples of the ends of three-layer symmetric waveguides with piecewise constant profiles of their permittivities and permeabilities.

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INTRODUCTION

Problems of mode scattering by irregularities of dielectric waveguides often arise in the analysis of various microwave and optical systems. Such problems have been adequately analyzed for structures fabricated from "conventional" media (see, e.g., [1–3]). At present, systems made of metamaterials are intensively studied. Such materials are also called left-handed media (LHM) or media with negative refractive indices. Their permittivity ε and permeability μ can simultaneously take negative values [4, 5]. As a rule, such materials are artificial magnetodielectrics (composites). They have some unique properties (for example, negative refraction); in such media, the "inverse" Cherenkov effect is possible.

Modes of regular planar waveguides fabricated from metamaterials were described in [6–9]. At the same time, problems of scattering in such structures are poorly studied. This paper considers the problem of surface mode reflection from the end of a planar dielectric waveguide (PDW) whose center layer is fabricated from a medium with negative values of permittivity ε and permeability μ (Fig. 1). The problem is solved with a variational method [10–12]. Note that, earlier, this problem was analyzed in [12]; however, in that paper, reflections of other modes, the so-called oscillating waveguide modes, were calculated.

Sometimes, photonic crystals [13] and various layered dielectric structures are also assigned to the class of metamaterials. Some properties of these systems differ them from the properties of most composites; nevertheless, many phenomena occurring in all such media are very similar. Below, we limit our analysis to the class of structures (composites) that can be considered as homogeneous media in the chosen frequency band, i.e., we assume dimensions of all inclusions in the media, which are used for fabrication of metamaterials, are substantially less than the wavelength. This assumption will be analyzed below.

1. SURFACE MODES

The geometry of the problem and the coordinate system are shown in Fig. 1; the thickness of the PDW center layer is designated by $2d$. We assume the structure is symmetric, i.e., functions $\varepsilon(y)$ and $\mu(y)$ are even functions of transverse coordinate y. Below, we assume also profiles of the permittivity and permeability are piecewise constant: these parameters are equal to ε_1 and μ_1 in the substrate and the coating (at $|y| > d$) and ε_2 and μ_2 in the center layer (at $|y| < d$), respectively. The first pair of parameter values is positive, and the second pair is negative. Note that the technique is also applicable (with minor changes) to PDWs in which the permittivity and permeability are piecewise continu-

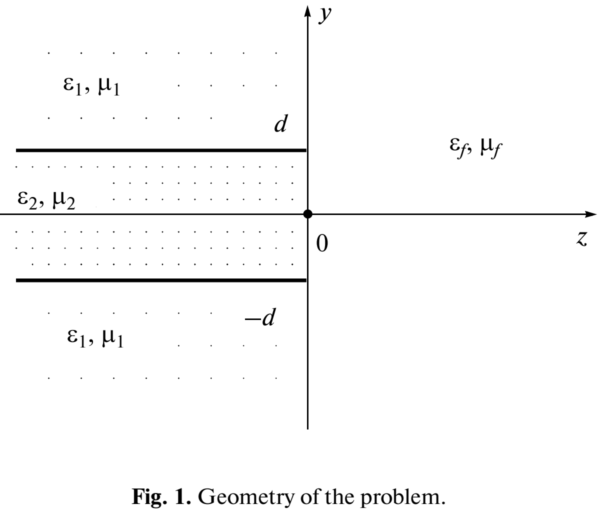

Fig. 1. Geometry of the problem.