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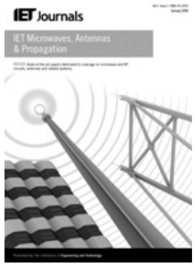

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# Mathematical formulation for zero reflection from multilayer metamaterial structures and their notable applications

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**Abstract:** The behaviour of bilayer structures composed of common materials and metamaterials (MTMs) under oblique incidence of plane waves is investigated by exact analytical methods. The TE, TM and elliptical polarisations are analysed. There are several combinations of double positive (DPS), double negative (DNG), epsilon negative (ENG) and mu negative (MNG) media for the bilayer structures, but only DPS−DPS, DPS−DNG and ENG−MNG bilayers with TE, TM and circular polarisations are analysed in detail. For homogeneous and isotropic MTM media, exact mathematical relations are derived for the design of reflectionless bilayer structures as a function of their geometry (thickness) and electric and magnetic parameters. Frequency dispersion is included in the formulations. It is shown that bilayers composed of common materials are not effective for the construction of zero reflection bilayer surfaces, whereas the application of MTMs is required to realise reflectionless phenomena. For the design of zero reflection bilayer structures, their thicknesses and values of $\varepsilon$ and $\mu$ are determined. Finally, the performance of forward and backward notch filters observed by MTM bilayer structures are studied in detail and their designs and applications are investigated. The bandwidth of lossy MTMs increases considerably.

## 1 Introduction

The reduction of radar cross-section of objects has long been of interest, which has been realised by various methods, such as the applications of radar absorbing materials. Such materials have other applications, such as covering the inside walls of anechoic chambers, design of antennas with low-side lobe levels, protection against electromagnetic interference in high-speed circuits and so on.

In this paper, we intend to apply metamaterials (MTMs) to reduce reflections from objects.

Common materials called double positive (DPS) have both the real parts of their permittivities ($\varepsilon$) and permeabilities ($\mu$) positive. On the other hand, MTMs are classified as double negative (DNG) where both the real parts of their ($\varepsilon$) and ($\mu$) are negative [1–4]. They are called epsilon negative (ENG) and mu negative (MNG), where only their $\varepsilon$ and only their $\mu$ are negative, respectively. MTMs are mostly realised by periodically embedding conducting wires [thin wires (TWs)] and split ring resonators (SRRs) inside the dielectric media.

It should be noted that the selection of correct signs of the real and imaginary parts of $\varepsilon$, $\mu$, $k$ (wave number) and $\eta$ (intrinsic impedance) of common materials and various types of MTMs is necessary in their mathematical treatment.

We consider here a multilayered structure composed of common materials and MTMs on each side of which are half spaces filled up by dissimilar materials.

It is assumed that a plane wave of arbitrary polarisation (TE, TM, circular or elliptical) is obliquely incident on the structure. Several analytical methods have been developed for the analysis of plane wave incidence on multilayered structures and also for the propagation of waves inside