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An absorbing matched layer implementation for the transmission line matrix method

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ABSTRACT

An absorbing matched layer for the Transmission Line Matrix method in acoustics is proposed. So far, existing formulations of absorbing layers for TLM have been obtained from empirical considerations. In the present study, a formulation is proposed on the basis of acoustic equations. The approach is based on the discretization of the propagation wave equation for a dissipative and non-homogeneous medium and from the Perfectly Match Layer formalism of Bérenger. Two solutions are proposed that both give a specific scattering matrix for the Transmission Line Matrix method: one is equivalent to an artificial purely dissipative medium and the other to a non-homogeneous and dissipative artificial medium. The proposed solutions are compared to an existing empirical formulation of absorbing layer. It is shown that the non-homogenous and dissipative solution is less interesting than the purely dissipative one because its efficiency can strongly depend on the receiver location. The purely dissipative solution can outperform the empirical matched connexion law formulation for a large range of incidence angle if an optimized value of the damping factor is used. For the frequency 100 Hz, significant efficiencies better than 28 dB for normal to grazing incidence, and between 30 dB and 50 dB for normal incidence to oblique incidence can be reached, with an absorbing layer thickness of only one wavelength.

1. Introduction

The impact of noise on residents is a major issue and the necessity of having more effective methods for predicting noise levels is a constant need. Many numerical methods can be used to make predictions of sound level in outdoor conditions [1]. During the last decade, time-domain approaches, such as the Finite Difference Time Domain (FDTD) method or the Transmission Line Matrix (TLM) method, have become increasingly popular to study broadband outdoor noise propagation [2–5]. Recent research has focused on taking into account more realistic sound propagation conditions such as meteorological effects [6–8], ground absorption [5,9,10] or complex terrain [11,12]. However, time domain methods still require significant computational effort for the simulation of outdoor long range sound propagation. More especially, a major issue is when a free field condition is required at a boundary of the computational domain. To avoid unwanted reflections from the boundaries, the computational domain is usually enlarged but this solution is often not satisfactory as it increases the computational burden. Thus, other solutions must be considered.

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A first kind of approaches that intends to prevent such unwanted reflections is based on absorbing boundaries (ABs), consisting in imposing absorbing conditions at the boundaries of the computational domain. However, the real impedance condition [13,14] and the boundary operators method [15–18], such as Taylor's series expansion [14–16] and Higdon's operator [17], have shown limited interest for the TLM method in acoustics [14,18].

A second kind of approaches proposes to use absorbing layers (ALs), consisting in adding an extra portion of domain at the boundary in order to gradually dissipate incoming acoustic waves inside the AL. ALs require more substantial computational resources than ABs, but it remains more efficient for the reduction of the reflected field [14]. Two ALs methods have already been tested for the TLM method: the dissipative medium [13] and the matched connexion law [18,19]. De Cogan [19] suggested to use the TLM connexion laws to define a layer that gradually dissipates the incident field, by affecting every connexion laws of the TLM model by an attenuation factor. Guillaume [14] suggested to treat only the connexion law which corresponds to the main direction of the incident pulse (“one-way” approach). He showed that this approach gives significantly better results for the reflection error compared to the original de Cogan's formulation. These methods have shown interesting results for absorbing efficiency but both are based on empirical considerations and none of them have been justified by a rigorous analytical derivation yet.

The Perfectly Matched Layer (PML), suggested by Berenger in electromagnetism [20,21], has been used in several methods for acoustic simulations [22–24] because it has very convincing absorbing performances. Some attempts to implement PML in the TLM method are available in the literature for electromagnetic propagation [25,26], but no PML implementation has yet been proposed for the TLM method in acoustics.

This paper aims at presenting the implementation of an absorbing matched layer for the TLM method in acoustics. The proposed formulation differs from previous works because it is based on a rigorous derivation of acoustics equations and not on empirical considerations. Section 2 presents this implementation for a dissipative and/or non-homogeneous medium using the PML formalism of Bérenger. A presentation of the efficiency of this absorbing layer is then presented in Section 3 and compared to Guillaume's ”one-way” approach.

2. Implementation of an absorbing matched layer for the TLM method

2.1. TLM modeling for a dissipative and non-homogeneous medium

The TLM method has initially been developed for electromagnetism applications by Johns and Beurle [27]. It has first been adapted to acoustics by Saleh and Blanchfield [28], and Kagawa et al. [29] have been the first to investigate systematically the possibilities and limits of the method in acoustics. This numerical method simulates wave propagation of pressure pulses inside a spatial mesh where pressure pulses travel from a node to its neighbors through transmission lines (Fig. 1). At the time t the instantaneous pressure $p(x,y,t)$, denoted by ${}_tp_{(i,j)}$ at the node (i,j) located at (x,y), is given by the sum of all incident pulses ${}_tI^n_{(i,j)}$ coming from its neighbors separated from Δl. The TLM propagation process is modeled as follows [29,30]: first (Fig. 1a), incident pressure pulses at a node are scattered from this node to its neighbors following a matrix relation between incident pulses ${}_tI^n_{(i,j)}$ and scattered pulses ${}_tD^n_{(i,j)}$ (“scattering” step); next (Fig. 1b), incident pulses of adjacent nodes are obtained at next time step $t+\Delta t$ from relations involving scattered pulses at time t (“transmission” step).

Dissipation and non-homogeneous sound speed in the medium can be taken into account by the addition of specific branches at every node of the transmission-line network [29] (Fig. 2). These additional branches have specific modified characteristic impedances Z_0/ζ for dissipation and Z_0/η for non-homogeneous sound speed, where ζ and η are parameters

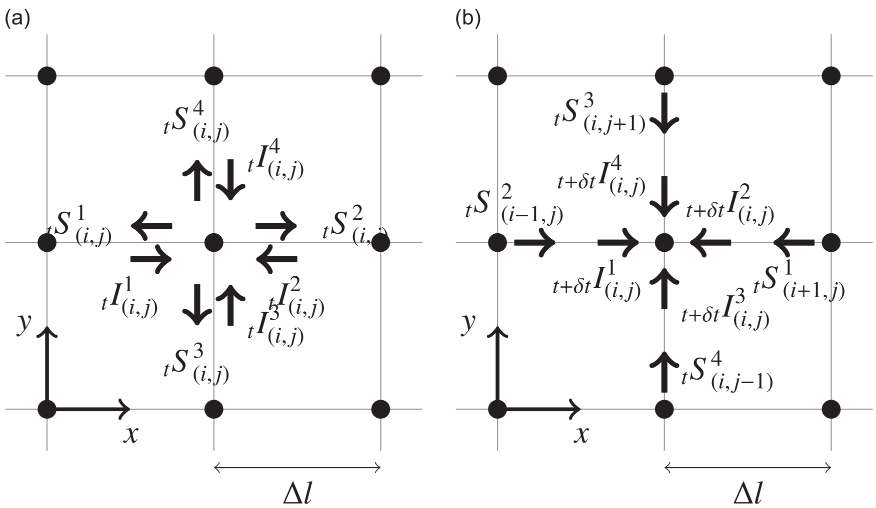

Fig. 1. Incident and scattered pulses at a node (i,j) in the transmission-line network during the scattering step (a) and the transmission step (b).