Transfer matrix method for the analysis of space-time-modulated media and systems

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Wave propagation in systems where the material parameters or structures are varying in both space and time is both complex and useful. Space-time modulation adds another powerful degree of freedom to the manipulation of classical wave systems, opening the door for control of wave behavior beyond the reach of stationary systems, such as nonreciprocal wave transport and realization of gain media. However, many theoretical methods for characterizing space-time varying systems are limited to systems that are modulated sinusoidally, computationally expensive, and limited in accuracy since the effect of higher order modes are neglected. We will present our recent work on creating create a general framework to solve wave propagation problems in arbitrary assembly of time-varying components in acoustic, electromagnetic, and electric circuit systems by the generalization of the transfer matrix method. Compared with existing methods, the proposed method (i) is capable of handling systems with arbitrary spatial modulation profile (ii) considers and quantifies the influence of high-order harmonics, and (iii) is computationally efficient, especially for large systems. We demonstrate the capability of the proposed method with three examples: optimization of nonreciprocal sound transmission under geometric constraints, parametric amplification in the gain medium, and optimized unidirectional amplification with two modulated elements. The proposed method provides a versatile approach for the study of general space-time-varying systems, which allows any number of time-modulated elements with an arbitrary modulation profile, facilities the investigation of high-order modes, and provides an interface between space-time-modulated systems and other stationary or dynamic systems. Its computation efficiency allows optimization of system parameters for specific target functionalities.

References

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