Chapter 10
Fuzzy Logic Modelling of Nonlinear Metamaterials

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ABSTRACT

Nonlinear metamaterials have interesting properties that could change the way technology works. Modelling the complex behaviour of metamaterials is needed to improve their performance and make new gadgets. This chapter looks at fuzzy logic models for complex effects in metamaterials. This part talks about fuzzy sets, membership functions, fuzzy rules, and inference systems. Metamaterials don't behave in a straight way, so there are problems with describing them. Input factors, membership functions, along with fuzzy rules are talked about in the modelling method of fuzzy logic for nonlinear metamaterials. Acoustic and visual metamaterial case studies show how fuzzy logic models can be used. This part also talks about the latest developments, possible uses, and pros and cons of fuzzy logic models in nonlinear metamaterials. This chapter tells scientists and engineers how to use fuzzy logic to model and understand nonlinear metamaterials.

1. INTRODUCTION

1.1. Overview of Nonlinear Metamaterials

In the past few years, nonlinear metamaterials have attracted a lot of attention due to the exceptional qualities they possess and the potential applications they have in a variety of different domains, such as optics, acoustics, and electronics. These

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materials are engineered composites that exhibit unconventional behaviour not found in natural materials. By designing their structure at the micro- or nano-scale, researchers can manipulate the response of nonlinear metamaterials to external stimuli, leading to exotic phenomena such as negative refraction, cloaking, and nonlinear wave propagation (Smith, Pendry, & Wiltshire, 2004).

Nonlinear effects in metamaterials arise from the inherent nonlinearity of their constituent materials, as well as the engineered nonlinear response at the unit-cell level. These effects manifest as the dependence of material properties on the intensity or amplitude of the excitation signal. Common nonlinear phenomena observed in metamaterials include harmonic generation, parametric amplification, bistability, and self-focusing (Lapine et al., 2014; Liu et al., 2017).

The study and modelling of nonlinear metamaterials play a crucial role in understanding their behaviour and exploiting their unique characteristics for practical applications. Various analytical, numerical, and experimental techniques have been employed to investigate the nonlinear response of metamaterials. However, due to the complex and often non-intuitive nature of nonlinear effects, modelling nonlinear metamaterials remains a challenging task.

To address these challenges, this chapter explores the application of fuzzy logic modelling as an effective tool for capturing and understanding the nonlinear behaviour of metamaterials. Fuzzy logic offers a flexible and intuitive framework for handling imprecise or uncertain information, making it well-suited for modelling complex and nonlinear systems. By integrating fuzzy logic into the modelling process, researchers can gain insights into the nonlinear dynamics of metamaterials and predict their behaviour under various operating conditions (Alù & Engheta, 2017).

1.2. Importance of Modelling in Understanding Metamaterial Behaviour

Modelling plays a crucial role in understanding the behaviour of metamaterials, enabling researchers to unravel complex phenomena, optimize designs, and guide practical applications. By developing accurate and comprehensive models, scientists can gain insights into the underlying physics and mechanisms governing metamaterial behaviour. This section highlights the importance of modelling and its contributions to the understanding of metamaterial behaviour.

(i) **Modelling Complex Phenomena:** Metamaterials exhibit intricate and often counterintuitive behaviour that cannot be easily understood through simple intuition or empirical observation alone. Modelling provides a systematic framework to analyse and explain the mechanisms behind