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Modeling the Dispersion of Waves in a Multilayered Inhomogeneous Membrane with Fractional-Order Infusion

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Introduction

The study of wave dispersion in materials is a crucial aspect of material science, particularly for designing structures that need to absorb, transmit, or dissipate mechanical waves. In the context of membranes, such as those used in membranes for medical devices, musical instruments, or engineered acoustic materials, the dispersion of waves plays a significant role in understanding how waves propagate through different layers with varying properties. A multilayered membrane with inhomogeneous material properties adds another layer of complexity to the problem, which is particularly challenging to model using traditional methods. A relatively new and exciting avenue of research in wave propagation is the inclusion of fractional calculus to describe materials that exhibit non-local and memory effects. This is especially relevant when dealing with materials that show complex, non-linear, or viscoelastic behavior. In this article, we explore the modeling of wave dispersion in multilayered inhomogeneous membranes with fractional-order infusion, providing a comprehensive overview of the theoretical framework, mathematical modeling, and potential applications of this approach [1-3].

Description

Fractional calculus is a powerful mathematical tool that generalizes traditional calculus by incorporating non-integer derivatives and integrals. It is particularly useful for modeling systems that exhibit memory or hereditary effects, such as viscoelastic materials, anomalous diffusion, and systems with non-local interactions. In the case of wave propagation, fractional-order differential equations can be employed to model damping, dispersion, and other complex behaviors that are difficult to describe with traditional integer-order models. For instance, in viscoelastic materials, the relationship between stress and strain is often better described by a fractional order derivative rather than a simple linear model. This fractional approach introduces a non-local element into the material behavior, where the response at a given point depends not only on the current state but also on past states, which is reflective of memory effects. In the context of wave propagation, fractional-order infusion refers to modifying the standard wave equation by incorporating fractional derivatives in time or space. For example, in viscoelastic layers of a membrane, a fractional derivative with respect to time may be used to account for the memory effect in the material response, and a fractional derivative with respect to space could capture the inhomogeneities or complex structures of the medium. The dispersion relation, which characterizes how wave frequency and wavenumber kkk are related in the system, can be derived from the modified wave equation. In a fractional medium, the dispersion relation will depend on both the material properties and the fractional orders, and it will show different characteristics from traditional wave propagation in integer-order media [4,5].

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Conclusion

Modeling wave dispersion in multilayered inhomogeneous membranes with fractional-order infusion provides a powerful framework for analyzing complex wave propagation in materials with non-local or memory effects. By incorporating fractional calculus into the wave equations, it becomes possible to describe the intricate behavior of waves in systems that exhibit viscoelasticity, anomalous dispersion, and complex material inhomogeneities. This approach holds great promise for a range of applications, from acoustic metamaterials to medical devices, seismic studies, and non-destructive testing, offering more accurate models for real-world materials and structures that traditional models cannot fully capture. The use of fractional-order models is an exciting frontier in material science, and its potential for revolutionizing wave propagation theory and its applications is immense.

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Conflict of Interest

None.

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