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Article

The True Significance of Wave Mechanics Theory in Microwave Absorption Research: Redirecting Scientific Inquiry Toward Meaningful Theoretical Advancement

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Abstract

The establishment of wave mechanics theory in microwave absorption research carries significance that transcends mere error correction. While refuting impedance matching theory eliminates false explanatory frameworks, the deeper contribution of wave mechanics theory lies in fundamentally redirecting research methodology and objectives. This essay argues that the true value of wave mechanics theory emerges not from what it negates—the impedance matching framework, the treatment of return loss (*RL*) as material property, the attribution of film thickness effects to material structure—but from what it enables: a reoriented research paradigm that investigates optimal relationships between complex permittivity, complex permeability, frequency response characteristics, and microwave absorption performance. The profound contribution of wave mechanics theory is methodological: it transforms microwave absorption research from a descriptive cataloging of material structures into a rigorous investigation of how material composition and structural design influence the frequency response characteristics of electromagnetic properties. This reorientation represents the genuine theoretical advancement that the field requires.

Keywords: wave mechanics theory; microwave absorption; complex permittivity; complex permeability; frequency response; theoretical paradigm shift; research methodology; material design principles; electromagnetic property optimization; scientific reorientation

1. Introduction: Error Correction Versus Theoretical Advancement

The relationship between error correction and scientific progress is often misunderstood. Identifying and correcting false theories constitutes necessary but insufficient conditions for theoretical advancement. A field can successfully eliminate erroneous frameworks while simultaneously failing to advance genuine understanding.

Consider a hypothetical scenario: suppose the impedance matching theory in microwave absorption research is definitively refuted. Researchers henceforth cease discussing impedance matching, abandon the notion of return loss (*RL*) as an intrinsic material property, and recognize that film thickness effects cannot be attributed to material structure alone. The field has achieved theoretical correction. Yet what follows?

Without replacement theoretical frameworks, the field enters an intellectual vacuum. Research continues—researchers synthesize materials, measure return loss, observe performance variations—but without coherent theoretical guidance. Observations accumulate without integration into meaningful understanding. Structure-property relationships are cataloged without explanatory principle. The field becomes descriptively correct but theoretically impoverished.

This scenario, while perhaps exaggerated, captures a genuine danger in paradigm-challenging work. Demonstrating what is false does not automatically establish what is true. The true significance

of wave mechanics theory emerges only when it provides not merely correction but reorientation—not simply what to abandon, but what to investigate.

2. From Impedance Matching to Wave Mechanics: The Epistemological Transition

The transition from impedance matching theory to wave mechanics theory represents more than substitution of one theoretical framework for another. It embodies a fundamental shift in how microwave absorption phenomena should be conceptualized and investigated.

Impedance Matching Framework:

- Assumes a specific material property ("impedance") that determines absorption behavior
- Treats return loss as a material characteristic
- Attributes observed absorption peaks to material structure-induced impedance matching
- Searches for structural designs that achieve "optimal impedance matching"
- Interprets film thickness effects as material structure manifestations

This framework operates within severe conceptual constraints. It reduces a complex electromagnetic phenomenon to a single material parameter. It presumes that absorption performance can be explained through quasi-static material properties rather than dynamic electromagnetic processes. It confuses film thickness effects (electromagnetic consequences) with material structure effects (compositional consequences).

Wave Mechanics Framework:

- Conceptualizes microwave absorption as electromagnetic wave propagation in lossy media with frequency-dependent material properties
- Recognizes that electromagnetic behavior emerges from the dynamic interaction between complex permittivity, complex permeability, incident frequency, and material thickness
- Treats return loss as a phenomenon dependent on the entire electromagnetic system, not a material property
- Explains absorption maxima through constructive interference of electromagnetic processes
- Distinguishes film thickness effects (electromagnetic pathway length dependence) from material structure effects (frequency response characteristic dependence)

The epistemological transition is profound. Rather than searching for material properties that satisfy a predetermined matching condition, wave mechanics theory asks: what combinations of electromagnetic properties, across what frequency ranges, with what material thicknesses, produce optimal absorption? This reframing opens entirely new investigative pathways.

3. The Inadequacy of Mere Error Correction

Research that merely corrects impedance matching theory without advancing positive theoretical frameworks operates at a disadvantage. Such work accomplishes important intellectual housekeeping—it eliminates misleading explanatory structures—but it fails to redirect inquiry toward productive investigation.

Consider what "error-corrective" research in the post-impedance matching era might look like:

- Papers that demonstrate RL is not an intrinsic material property
- Studies showing that film thickness cannot be explained through impedance matching logic
- Critiques of literature claiming structure-induced optimal impedance matching
- Empirical demonstrations that the impedance matching framework mispredicts absorption behavior

This work has value. It clears intellectual debris. Yet it remains largely negative—it establishes what is not true without establishing what investigation should pursue. Researchers reading such work understand that impedance matching is incorrect, but they lack guidance regarding what productive research directions remain.

Furthermore, error-corrective research inherently operates defensively. It must continuously respond to impedance matching assumptions embedded throughout the literature. Each new paper citing impedance matching logic requires renewed demonstration of error. The field becomes locked in reactive debate rather than advancing through new inquiry.

Wave mechanics theory transcends this limitation. It operates affirmatively—it establishes not merely what is false but what should be investigated, how that investigation should be conducted, and what questions constitute meaningful scientific inquiry.

4. The True Research Direction: Optimal Electromagnetic Property Combinations

The genuine significance of wave mechanics theory lies in redirecting attention toward a fundamental question: **What combinations of complex permittivity, complex permeability, frequency response characteristics, and material thickness produce optimal microwave absorption, and how can material composition and structural design be engineered to achieve these combinations?**

This question encompasses multiple dimensions of inquiry:

4.1. Electromagnetic Optimization

The first dimension asks: across what frequency ranges, with what permittivity and permeability values, and at what material thicknesses, does optimal absorption occur? This is fundamentally an electromagnetic question. It requires investigation of how dielectric loss, magnetic loss, their frequency dependencies, and material thickness interact to determine electromagnetic field evolution through the material.

Classical transmission line theory provides the theoretical foundation. However, applying this theory to optimize absorption performance requires systematic investigation of parameter space. How does varying complex permittivity across frequency ranges affect absorption? How does permeability frequency dependence interact with permittivity? At what thickness do multiple absorption peaks emerge? How do standing wave patterns within the material create destructive versus constructive interference of loss mechanisms?

These questions structure a coherent research program. Unlike impedance matching theory, which presumes a specific matching condition, wave mechanics theory opens parameter space for systematic exploration. Research becomes directed toward understanding the relationships between electromagnetic parameters and absorption performance rather than verifying predetermined matching conditions.

4.2. Material Property Design

The second dimension asks: how can material composition be engineered to achieve target complex permittivity and permeability characteristics across specified frequency ranges? This transitions from electromagnetic investigation to materials science investigation—but with crucial distinction from previous approaches.

Previous research, operating within impedance matching frameworks, investigated material structure seeking to achieve "optimal impedance matching." Structure-property relationships were conceptualized as mechanisms for impedance adjustment. Dielectric fillers were chosen to achieve specific permittivity values. Magnetic particles were incorporated to generate permeability. But these choices were guided by impedance matching logic rather than by systematic understanding of how composition determines frequency-dependent electromagnetic properties.

Wave mechanics theory reorients this investigation. Rather than asking "what structure achieves optimal impedance matching," researchers ask "what composition produces the target complex permittivity and permeability frequency response?" The question remains structure-property investigation, but with clarified objectives and theoretical guidance.

This reorientation has profound consequences for research design. Instead of synthesizing materials that empirically show high absorption then post-hoc attributing performance to impedance matching, researchers can strategically design materials toward predetermined electromagnetic targets. The investigation becomes hypothesis-driven rather than empirically exploratory.

4.3. Frequency Response Engineering

The third dimension addresses a typically neglected question: how should complex permittivity and permeability *change across frequency ranges* to optimize absorption over bandwidth rather than at isolated frequencies?

Impedance matching theory, by presupposing a wrong matching condition, implicitly assumes that film properties as material properties. This assumption is demonstrably false. Actual absorbers display frequency-dependent permittivity and permeability. Yet previous research frameworks offered no theoretical principle for understanding how frequency dependence should be engineered.

Wave mechanics theory enables systematic investigation of frequency response design. How should permittivity decrease with frequency to maintain absorption as frequency increases? At what rates should permeability decline to preserve loss mechanisms across bandwidth? How do relaxation processes in magnetic and dielectric components interact across frequency ranges? What composite material architectures—multilayer structures, gradient compositions, dispersed inclusions—optimally produce target frequency response characteristics?

These questions constitute frontier research in microwave absorption. They require integration of electromagnetic theory, materials science, composite design principles, and frequency-dependent material characterization. They demand intellectual rigor and sophisticated investigation. Yet they represent the genuine theoretical challenges that microwave absorption research should address.

5. From Cataloging to Understanding: The Methodological Transformation

The reorientation enabled by wave mechanics theory transforms microwave absorption research from cataloging toward understanding.

5.1. The Cataloging Approach

Previous research, operating within impedance matching frameworks, operated largely as cataloging:

- Synthesize material with composition X and structure Y
- Measure return loss spectrum
- Observe absorption peak at frequency f
- Attribute performance to "impedance matching at frequency f "
- Conclude that composition X and structure Y "achieve optimal impedance matching"
- Catalog the results in literature

This approach produces enormous literature volumes. Thousands of papers employ this methodology, each reporting materials with slight compositional variations, each claiming impedance matching achievement, each contributing incremental observations to an ever-expanding catalog. The literature becomes comprehensive in breadth but shallow in depth. Questions about *why* particular structures produce absorption at specific frequencies remain unanswered. Understanding of underlying electromagnetic mechanisms remains absent.

5.2. The Understanding Approach

Wave mechanics theory enables a fundamentally different research methodology:

- Identify target electromagnetic properties (complex permittivity and permeability values, frequency dependencies) required for optimal absorption at specified frequency and thickness
- Investigate material compositions that produce target electromagnetic properties

- Characterize frequency-dependent permittivity and permeability of candidate materials
- Integrate electromagnetic and materials science investigation to explain *how* composition determines frequency response
- Systematically vary composition and structure to refine alignment between actual and target electromagnetic properties
- Advance understanding of composition-property relationships

This approach produces qualitatively different research outcomes. Each investigation contributes to systematic understanding rather than accumulating descriptive catalogs. Subsequent researchers can build upon established structure-property principles rather than merely cataloging additional examples. The literature becomes increasingly coherent as understanding integrates individual observations.

5.3. Theoretical Depth Versus Experimental Breadth

A crucial distinction emerges: cataloging approaches maximize experimental breadth—they survey diverse materials and structures. Understanding approaches prioritize theoretical depth—they rigorously characterize structure-property relationships for specific material systems.

Impedance matching theory, by providing convenient (wrong) pseudo-explanation for any observed absorption, implicitly encouraged breadth-focused research. Every new material could be claimed to "achieve impedance matching," producing publishable results with minimal theoretical investment. Literature grew quantitatively while theoretical understanding stagnated.

Wave mechanics theory reverses these incentives. Research gains intellectual value through rigorous investigation of structure-property relationships rather than through accumulation of material examples. A single materials system investigated with sophisticated electromagnetic and structural characterization, understood through rigorous application of wave mechanics principles, contributes more theoretical advancement than fifty hastily synthesized materials with impedance matching attribution.

Liu, Yue and Liu, Ying and Drew, Michael G. B., The Fundamental Distinction Between Films and Materials: How Conceptual Confusion Led to Theoretical Errors in Microwave Absorption (September 17, 2025). Available at SSRN: <https://ssrn.com/abstract=5498078> or <http://dx.doi.org/10.2139/ssrn.5498078>

6. The Challenge and Significance of Reoriented Research

Research directed toward understanding optimal electromagnetic property combinations and how material composition achieves those combinations constitutes genuinely challenging scientific inquiry. It demands intellectual rigor at multiple levels:

6.1. Electromagnetic Rigor

Researchers must move beyond qualitative impedance matching logic to quantitative electromagnetic analysis. Transmission line equations must be solved for specific permittivity and permeability values. Electromagnetic field distributions within lossy materials must be calculated. Absorption mechanisms must be understood not through matching conditions but through field energy dissipation dynamics. This requires familiarity with electromagnetic theory at levels typically absent from materials science training.

6.2. Materials Science Integration

Simultaneously, researchers must understand how material composition determines electromagnetic properties. Why does magnetic particle incorporation increase permeability? How does particle size affect frequency-dependent response? Why do certain dielectric fillers shift permittivity while others induce loss? How do interfacial interactions modify effective

electromagnetic properties? This requires integration of electromagnetic response theory with materials characterization and composite physics.

6.3. Structural Design Sophistication

Research must advance beyond simple material mixtures to sophisticated structural architectures. How can layer-by-layer composition gradients optimize frequency response? How do core-shell particle morphologies modify electromagnetic behavior? Can three-dimensional lattice structures produce target electromagnetic characteristics unattainable through homogeneous mixtures? Can metamaterial design principles enhance absorption efficiency? These questions demand sophisticated materials engineering vision.

Yue Liu, Ying Liu, Michael G. B Drew, *Wave Mechanics of Microwave Absorption in Films: Multilayered Films*, Journal of Electronic Materials, 2024, 53, 8154–8170, doi: 10.1007/s11664-024-11370-9; The wave mechanics for microwave absorption film-Part 3: Film with multilayers, Preprint, Research Square, 13 Aug, 2023, Supplemental file, scite

6.4. Systematic Characterization

Reoriented research requires rigorous electromagnetic characterization. Permittivity and permeability must be measured across frequency ranges with precision sufficient for understanding frequency-dependent behavior. Measurements must be validated through multiple techniques. Systematic variation of composition and structure must be characterized to establish quantitative structure-property relationships. This demands experimental sophistication beyond conventional return loss measurement.

7. Scientific Progress Through Reorientation Rather Than Correction

The deepest significance of wave mechanics theory emerges through understanding scientific progress as reorientation rather than mere correction. Paradigm-challenging theories contribute most profoundly not by eliminating errors but by redirecting inquiry toward productive investigation domains.

Consider historical examples:

Heliocentrism: The significance was not merely correcting geocentric geometry but enabling systematic investigation of orbital mechanics, celestial physics, and gravitational principles. The theory reoriented inquiry toward productive domains.

Quantum Mechanics: Beyond correcting classical mechanics errors, quantum theory redirected investigation toward atomic structure, particle physics, and quantum field theory. The reorientation enabled entirely new scientific domains.

Plate Tectonics: Beyond correcting static earth models, plate tectonics reoriented geological research toward mantle dynamics, seafloor spreading, seismic mechanisms, and paleomagnetic principles.

Each paradigm shift carried power not primarily through error correction but through reorientation. Wave mechanics theory in microwave absorption follows this historical pattern. Its significance emerges through redirecting research from impedance matching verification toward electromagnetic property optimization—from defensive error correction toward affirmative theoretical investigation.

8. The Threshold for Meaningful Theoretical Advancement

A critical insight emerges from this analysis: theoretical advancement requires not merely the elimination of false theories but the establishment of research frameworks that enable rigorous investigation of fundamental questions.

Impedance matching theory, despite its falsity, possessed one advantage: it provided researchers with conceptual scaffolding, however misleading. Researchers had clear objectives—achieve impedance matching. They had interpretive frameworks—attribute absorption to impedance matching. They could write papers within established conventions.

Wave mechanics theory, by contrast, requires researchers to grapple with genuine complexity. Optimization across multiple electromagnetic parameters, systematically characterized composition-property relationships, rigorous electromagnetic analysis—these demand intellectual effort that impedance matching pseudo-explanations displaced.

This creates a risk: researchers might abandon impedance matching while failing to advance wave mechanics investigation. They might write papers demonstrating impedance matching errors without establishing positive theoretical frameworks. They might achieve philosophical correction without scientific advancement.

The significance of wave mechanics theory depends upon this transition being completed. Merely ceasing to discuss impedance matching, while maintaining research methodology unchanged, accomplishes nothing. True significance emerges only through reorienting investigation toward the genuine theoretical challenges that wave mechanics theory illuminates.

9. From Consensus Suppression to Methodological Revolution

Earlier analysis identified how peer review systems suppress paradigm-challenging theories through invocation of consensus. Yet suppression operates not merely through rejection of new theories but through obstruction of reoriented research methodologies.

If journal systems permit wave mechanics theory while continuing to reward impedance matching cataloging, then paradigm substitution occurs without research reorientation. Papers that cite wave mechanics rather than impedance matching emerge, creating appearance of theoretical revolution while research methodology remains unchanged. False theories are replaced by correct ones, yet the field continues producing shallow, atheoretical literature.

Genuine revolution requires systemic change. Journals must establish review standards that reward rigorous investigation of structure-property relationships and electromagnetic optimization rather than accumulation of material examples with superficial theoretical attribution. Researchers must adopt investigation frameworks that demand electromagnetic sophistication and materials science integration. Communities must evaluate research through understanding depth rather than experimental breadth.

This systemic reorientation faces obstacles as substantial as those suppressing paradigm-challenging theories. It demands intellectual sophistication from both researchers and reviewers. It reduces publication productivity—rigorous investigation of single material systems yields fewer papers than rapid cataloging of dozens. It requires interdisciplinary expertise that traditional materials science training may not provide.

Yet without this reorientation, the field's response to paradigm-challenging research will constitute mere paradigm substitution rather than genuine theoretical advancement.

10. Conclusions: Significance as Reorientation

The true significance of wave mechanics theory in microwave absorption research transcends error correction. While eliminating impedance matching misconceptions and recognizing film thickness electromagnetic dependence constitute necessary achievements, they remain insufficient for theoretical advancement.

The genuine contribution of wave mechanics theory lies in reorienting microwave absorption research toward fundamental questions: What combinations of complex permittivity, complex permeability, frequency characteristics, and material thickness optimize absorption? How can material composition and structural architecture be engineered to achieve target electromagnetic

properties? How do relaxation processes and structural features determine frequency-dependent electromagnetic response?

These questions constitute frontier scientific inquiry. They demand integration of electromagnetic theory, materials science, and structural design principles. They reward theoretical rigor and sophisticated characterization rather than empirical cataloging. They enable systematic investigation of genuine structure-property relationships rather than pseudo-explanation through impedance matching logic.

Research that merely abandons impedance matching while continuing conventional methodology accomplishes correction without advancement. Research that embraces wave mechanics theory while reconstituting investigation methodology toward electromagnetic optimization and systematic structure-property understanding realizes the theory's true significance.

The field stands at a juncture: it can achieve paradigm substitution without intellectual revolution, or it can undergo genuine reorientation toward the theoretical challenges that constitute legitimate scientific inquiry. The significance of wave mechanics theory depends entirely upon which path the research community pursues.

Liu, Yue, The Right to Academic Freedom: Why Scholarly Articles Should Not Require Citations and the Critique of the Academic Gaming System (September 06, 2025). Available at SSRN: <https://ssrn.com/abstract=5452134> or <http://dx.doi.org/10.2139/ssrn.5452134>

The key to science is speculation and asking the correct question: rethinking evidence, citation, iteration, and innovation in an age of gatekeeping -- The Tyranny of Data: How Modern Scientific Orthodoxy Suppresses Foundational Innovation

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