

Time-Varying Systems, Causality, and Fundamental Limits in Applied Electromagnetics

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Using time as an additional degree of freedom in electromagnetism, photonics, and wave physics is attracting significant research interest, motivated by the possibility to explore new physical phenomena and create efficient electromagnetic and photonic devices, potentially surpassing various well-established performance limits on electromagnetic absorption, emission/radiation/scattering, time delay, impedance matching, among others (Z. Hayran, and F. Monticone, "Using Time-Varying Systems to Challenge Fundamental Limitations in Electromagnetics: Overview and Summary of Applications," *IEEE Antennas and Propagation Magazine*, vol. 65, pp. 29-38, 2023). Many of these physical limits are derived under the assumptions of linearity and time-invariance, and are deeply related to the principle of causality, raising interesting questions at the intersection of these concepts.

In this talk, I will briefly review these ideas, opportunities, and challenges, and will then discuss some of our latest research efforts, with a focus on our recent work demonstrating enhanced broadband absorption of electromagnetic waves using periodic temporal modulations, breaking one of the key theoretical limitations of linear time-invariant absorbers (M. Ciabattini, Z. Hayran, and F. Monticone, "Observation of broadband super-absorption of electromagnetic waves through space-time symmetry breaking," *Science Advances*, vol. 11, no. 3, pp. eads7407, Jan. 2025.).

Recent advances in this area, by our group and several others worldwide, provide new insights to challenge existing paradigms on the physical limits of electromagnetic systems and may pave the way to the development of devices that operate in a regime fundamentally beyond the reach of linear time-invariant systems.

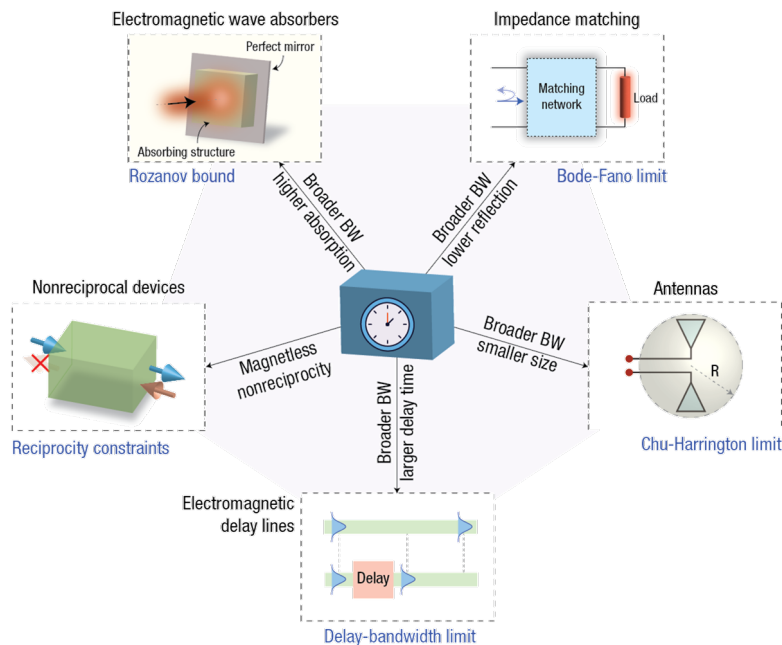


Figure 1. Examples of performance limits and application domains that can be impacted by time-varying systems.