URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Nonlocal Antenna Theory and the Problem of Directivity in Quantum Radiating Systems: Fundamental Considerations

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Quantum antennas are a cutting-edge technology within the field of quantum engineering and quantum information processing that have emerged in recent years [1]. They have a wide range of applications, including quantum sensing [2], meteorology, quantum communications [3], nanoscale information processing, energy harvesting, and intrachip data transfer. Quantum antennas have some similar directive radiative properties as classical antennas, but they also have unique characteristics, such as the ability to generate non-classical and entangled states of electromagnetic radiation [4, 5]. In this paper, we focus on developing a theory to characterize the directivity of a generic radiating quantum system with the main application in mind being quantum communications [6]. Two main difficulties arise in this endeavor: first, quantum antennas are in the most general case nonlinear, whereas classical antennas are always linear [2], with nonlinearity ultimately being due to the many-body interaction structure of quantum field theories [7]; and second, due to the massless nature of photons, quantum radiation cannot be localized [8], making quantum antennas inherently nonlocal [7]. The theory of nonlocal classical antennas was developed for sources that radiate in nonlocal metamaterials [9], and it showed that directivity can be constructed in momentum space instead of spacetime [10]. This approach may also be applied to quantum antennas because radiation in quantum field theory also occurs in momentum space [7]. In this talk, we will explore the connection between quantum nonlocality and nonlocality in classical metamaterials and present formulas for quantum antennas in momentum space. We will also discuss antennas in massive electromagnetism, where photons with non-zero mass can be emitted [11], and consider the relationship between nonlocal classical and quantum systems.

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