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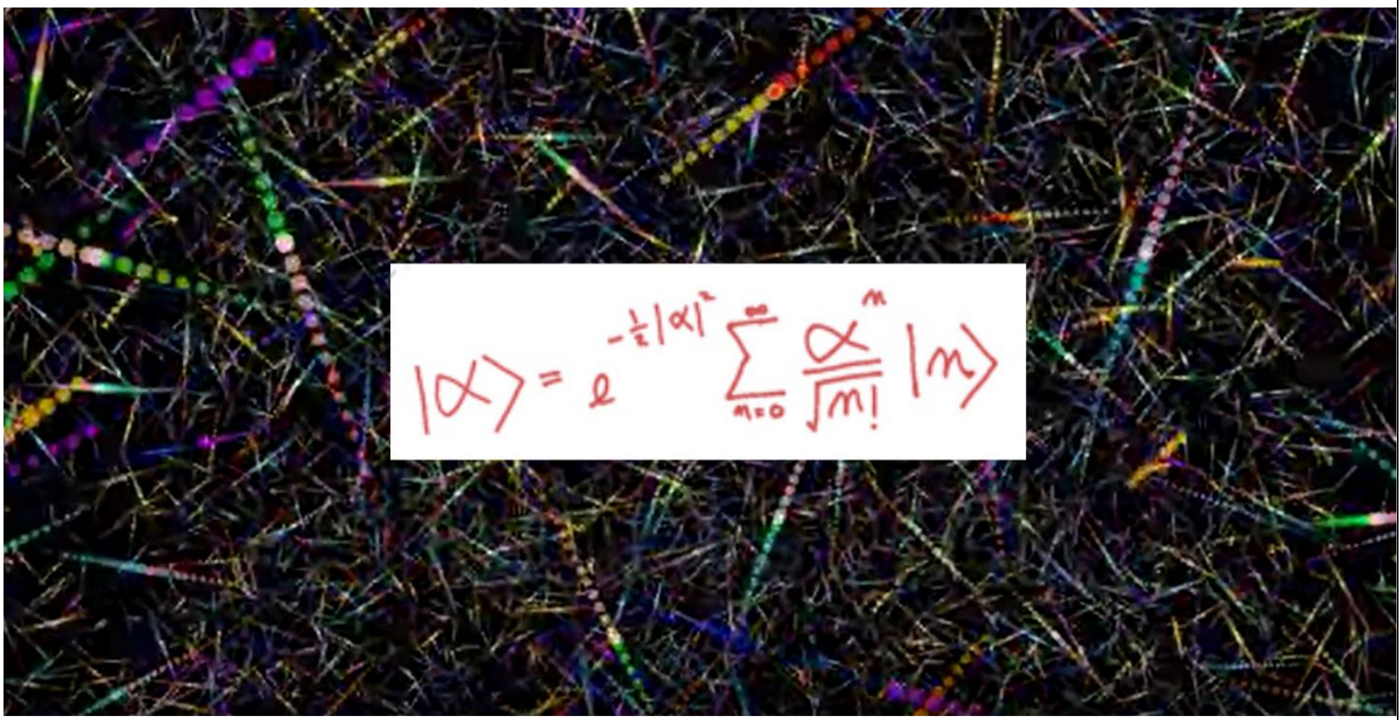
Quantum antenna theory

Abstract

The quantization effect of electromagnetic energy is widely known to explain effects such as Planck's Law or the photoelectric effect. There are many electromagnetic phenomena that can only be explained by a quantum radiation theory such as the Casimir effect or the noise receivers that work with weak power signals. In addition, quantum technologies are significantly increasing their technological maturity: quantum communications, quantum cryptography, quantum radar, etc. This course aims at addressing a quantum explanation of the radiation emitted by a source, giving rise to solutions of Maxwell's equations in the limit, producing, however, non-classical states of light with enormous applications.

Graphical abstract



Recommended prerequisites

The course is intended for researchers who have training in antenna theory and electromagnetic fields. The mathematical apparatus that will be used is linear and matrix algebra, although a small part of the course will be devoted to making it self-contained in this sense. Basic training in potential auxiliary radiation vectors of electrodynamics will be required. Lagrangian and Hamiltonian mechanical concepts will be used, which will also be briefly defined during the course for those who are not completely familiar with them.

Learning objectives

During the course, radiation will be explained from a quantum perspective. The solutions offered by the quantization of the electromagnetic field will be in the limit similar to solutions of Maxwell's equations. However, quantum phenomena will give rise to non-classical radiation states with enormous applications in fields such as communications, cryptography, radiometry, etc. These states are the "squeezed light", "chaotic light" and "Glauber coherent states", which will be explained in detail.

The quantization of the electromagnetic field and its consequences in the radiation theory will be explained. An explanation of the radiation emitted by a classical source will be studied from a quantum perspective, as well as the quantum concepts of light intensity, energy, number of photons, etc. The quantum effects of radiation can be observed precisely when dealing with low-power electromagnetic signals. This problem is addressed, for instance, in radiometers with high sensitivity or noise in low power RF receivers.

A connection will be made between the classical electromagnetic definitions and the concepts of quantum theory, highlighting quantum properties that have no classical analogues. Finally, we will show the application of these effects in disruptive applications such as quantum radar, quantum communications, and cryptography.

Course outline

0. Introduction and motivation:
We will explain why it is necessary to resort to a quantum theory of radiation to explain many phenomena of electromagnetism. In a similar way, the main disruptive and novel applications that quantum technologies are providing in recent years will be summarized.

1. Postulates of quantum mechanics:
We will present a summary of the basic principles of quantum mechanics as well as of the mathematical apparatus and nomenclature necessary to understand it.

2. Quantization of the electromagnetic field
The quantization of radiation is explained by making use of the quantization of the harmonic oscillator. We will introduce the concepts of electromagnetic field, Poynting vector, light intensity, optical coherence, etc., from the quantum point of view.

3. Radiation states.
The states of radiation to which the quantization of light gives rise will be exposed. Its classical analogous will be also presented, paying special attention to those states that do not have analogous classical states.

4. Radiation emitted by a classical source
We will address the problem of what is the radiation emitted by a classical source of electron current density from the quantum point of view. At the working limit, the solution should be equal to that provided by Maxwell's equations. However, quantum effects without classical analogous will appear when the number of photons emitted by the antenna is not so massive. This can have important consequences both in highly sensitive receivers that work with very weak signals, as well as in quantum communications, cryptography and quantum internet systems. All these issues are now being widely exploited by the scientific community.

5. Applications.
We will describe the main applications of quantum technologies from the point of view of electromagnetic radiation. The quantum entanglement phenomenon will be explained, which will give rise to exceptional, novel applications without a classical analogue, such as quantum radar, quantum computing, cryptography and quantum communications.

Instructor – biography

Luis Enrique García-Muñoz is currently Full Professor with the Carlos III University of Madrid, Madrid, Spain. He has managed or participated in six national and European research projects on areas such as antennas, THz and array designs. He has managed 6 national funded projects and has coauthored 67 articles in international journals, holding 6 international patents. His current research interests include mm and sub-mm antennas, quantum electrodymanics, electrodynamics in general relativity and radio astronomy instrumentation. Developing radio astronomy instrumentation has been the main line of research for the last 25 years, with particular emphasis on the work on a receiver with maximum sensitivity (photon counting) in the microwave range frequency working at room temperature. This work required the coordination of an international team composed by researchers from the Max Planck Institute for Radio Astronomy (Germany), Observatorio Astronómico Nacional (Spain), Friedrich-Alexander Erlangen-Nürnberg University (Germany) and the University of Otago (New Zealand.).

Key bibliography

[1] “The Principles Of Quantum Mechanics”, (International Series Of Monographs On Physics) by P. A. M. Dirac, 1988.

[2] “The Feynman Lectures on Physics, Vol. III: The New Millennium Edition: Quantum Mechanics”, by R. Feynman, 2011.

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