ECE770 T14/QIC 885: Quantum Electronics & Photonics

Lecture 10

Winter 2013, University of Waterloo, Instructor: A. H. Majedi

Abstract and Objectives of Lecture 10

By reviewing the photon number state (Fock state) and elaborating a single photon in Fock state, we do the formal quantization of multi-mode EM radiation for various modes designated by their wavevectors and polarizations. We establish the concept of Fock space for multi-mode EM field similar to Fock space for many-body quantum systems. The coherent state of EM field is then discussed in detail and its properties such as orthogonality and photon statistics are addressed. By introducing the field quadrature fluctuation we will then focus on the Heisenberg uncertainty of quadrature components in the EM field and introduce the squeezed state of the light briefly. The focus then will placed on the Dirac formulation of photon number state by introducing short-hand notation of $|\mathbf{k}\lambda\rangle$ and also polarization states. Using the rotation of polarization state, the concept of total angular momentum of a photon will be addressed. Photon statistics of various EM radiation will be categorized based on the coherent state of EM radiation as Poissonian, Super-Poissonian, such as thermal radiation and sub-Poissonian such as photon number state. In the last part of this lecture, we will discuss the second order correlation function of the EM radiation for various quantum states. In light of the Hanbury Brown and Twiss (HBT) experiment, the EM radiation fall into three categories as Bunched, coherent and anti-bunched ones. Anti-bunching in a typical HBT experiment is discussed in more detail and ways to achieve that is briefly highlighted.

Topics of Lecture 10

7-13) Single Photon in Photon Number State

7-14) Quantization of Multi-mode EM Field

7-15) Dirac Formulation of Photon Number State

7-16) Total Angular Momentum of Photon

7-17) Coherent State of EM Field

7-18) Squeezed State of EM Field

7-19) Photon Statistics

7-20) Photon Anti-bunching

References & Suggested Readings

1- P.W. Milonni, *The Quantum Vacuum, An Introduction to Quantum Electrodynamics*, AP, 1994, Chapter 2. 2- J. C. Garison, R.Y. Chiao, *Quantum Optics*, Oxford, 2008, Chapter 2, Appendix B. 3- H. Bachor and T.C. Ralph, *A Guide To Experimental Quantum Optics*, 2^{nd} ed., 2004. 4- M. Fox, *Quantum Optics, An Introduction*, Oxford, 2006, Chapters 5 and 6.

5- B.E.A. Saleh and M.C. Teich, *Fundamentals of Photonics*,2^{nd} ed., JW, 2007, Chapter 12.

6- C.C. Gerry and P.L. Knight, *Introductory Quantum Optics*, Cambridge, 2005, Chapters 2 and 5.

7- C. W. Gardiner and P. Zoller, *Quantum Noise*, 3^{rd} ed., Springer, 2004, Chapter 4.

8- Ph.A. Martin and F. Rothen, *Many-Body Problems and Quantum Field Theory*, 2^{nd} ed., Springer, 2004, Chapters 1 and 8.

9- P. Strange, *Relativistic Quantum Mechanics with Applications in Condensed Matter and Atomic Physics*, Cambridge, 1998, Chapter 12.