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DYNAMICAL QUANTUM EFFECTS IN MULTICHANNEL NONLINEAR WAVEGUIDES USING PHASE SPACE REPRESENTATIONS

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ABSTRACT

Squeezed light has a great deal of potential for varieties of quantum technology applications. In order to develop impactful devices reflective of wide application areas, technical difficulties of generating squeezing need to be eliminated or at least minimized. Therefore, in a search for a more flexible way of manipulating squeezing, the quantum effects exhibited by multichannel waveguides driven by coherent excitation are investigated. Four novel designs are considered: multichannel third order nonlinear waveguides, multichannel third order nonlinear waveguides with cavity setup and multichannel second order nonlinear waveguides, both with and without cavity setup. Compared to the multimode interaction in the standard two-channel configuration, the study focuses on developing a more convenient alternative to generate squeezed light via multichannel interaction considering the cross-action nonlinear coupling between the channel waveguides. In these implementations, solutions for the Hamiltonians of the proposed designs are obtained semi-analytically via normal- and symmetrical- ordered Phase Space Representation. Moreover, an effective computational program suitable for simulating dynamics of large quantum systems have been developed. The possibility for extending squeezing is investigated by studying the time development quadrature variances of the field's averages. The results show that multichannel interaction exploiting third order nonlinear effect yields various forms of enhanced squeezing, as compared with the ordinary two-channel system. Maximal squeezing increases with the increase of channel waveguides involved in an interaction. In multichannel systems, there exist new possibilities for correlation between the modes in different channels, i.e. the second-, third- and fourth- order compound-mode. The states of maximal squeezing in the compound-mode depend upon the order of combination of field operators; the strongest squeezing always appears in the highest combination. Parallel squeezing (in all channels) is achievable via quantum state transfer, while the squeezing levels depend on the channels. As opposed to the asymmetrical initialization, symmetrical initial excitation provides a greater degree of squeezing and larger squeezing is possible with a larger input field. Fully quantum analysis of the intracavity dynamics displays a strong transition of photon property between the super-Poissonian and sub-Poissonian statistics. These transitions depend on the state of the cavity detuning. The cavity setup, in addition to the multichannel arrangement, allows different features of squeezing to be generated and enhanced squeezing is obtained for all the considered detuning values with an interesting effect such as leaf-revival-collapsed-like squeezing. In addition, the quantum effects are maximal near cavity resonance. Furthermore, in the case of second order nonlinear effect, the coupled modes can be sub-Poissonian over wide range of interaction length and a witness for bipartite entanglement between the modes in different channels is observed. Optimal entanglement is obtained by keeping the surrounding channels in isolation and the range for which maximal entanglement appear may be controlled by the number of channel waveguides. As such, the multichannel systems developed in this thesis provide complete mathematical models for emulating and extending the quantum effects, particularly squeezing.

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CHAPTER ONE
INTRODUCTION

1.1 Background of Research

"*It would seem appropriate to speak of one of these hypothetical entities as a particle of light, a corpuscle of light, a light quantum, or light quanta, if we are to assume that it spends only a minute fraction of its existence as a carrier of radiant energy, while the rest of the time it remains as an important structural element within the atom...I, therefore, take the liberty of proposing for this hypothetical new atom, which is not light but plays an important part in every process of radiation, the name photon*."

Gilbert. N. Lewis

Back in 1900, due to the failure of classical electromagnetic theory to explain the spectral distribution of blackbody radiation, Max Planck developed the quantum theory of light by deriving the intensity spectral distribution function of discrete energy packets [1]. Einstein accounted the idea, later on, treating the energy packets as real physical particles namely photons and explained the quantized nature of harmonic oscillators [2]. The birth of quantum theory has a very great impact on modern technological development touching nearly every aspect of advanced technology while opening new avenues of research beyond classical limit range from quantum sensing [3, 4] to quantum computing [5, 6] and communications [7, 8]. Quantum optics is one of today's field of interest among researchers due to the rapid progress and major contributions from both theoretical and experimental aspects of light nature as a quantized photon. In quantum optical systems, the need of perceiving the fields in accordance to quantum theory is crucial. Following the law of quantum mechanics, there is no quantum optical system that can escape from the intrinsic statistical aspect of fluctuation [9]. The main disadvantage of quantum indeterminacy is the emergence of white noise which limits the performances of many laser-based applications.