STUDY OF LASER INTENSITY FLUCTUATIONS IN RANDOM AND NONLINEAR MEDIA

By

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C E R T I F I C A T E

This is to certify that the thesis entitled, "STUDY OF LASER INTENSITY FLUCTUATIONS IN RANDOM AND NON LINEAR MEDIA" which is being submitted by Mr. V.R. Subrahmanyam to the Indian Institute of Technology, New Delhi, for the award of the degree of 'Doctor of Philosophy' in physics, is a record of bonafide research work carried out by him under my guidance and supervision.

The thesis has reached the standard, fulfilling the requirements of the regulations relating to the degree. The results obtained in the thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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IN LOVING MEMORY OF

MY MOTHER

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ABSTRACT

Fluctuations in physical systems have always attracted scientists and engineers. Every optical field found in the nature has certain statistical features as it is associated with fluctuations and represents a 'statistical dynamic system'. In recent years, photon statistics has received much attention for statistical description of fluctuations expressed in terms of correlation functions. The success of this approach opened several areas of research. This subject enjoyed rapid growth after the development of laser, modern fast detectors and fast data processing techniques.

Steady and systematic research is going on the study of statistical properties of radiation in random media. The radiation passing through this medium is modified by the fluctuations in the medium. This can serve as the source of information about the properties of the medium. This technique is applied to laser light scattering where recent focus is in the study of biological studies because of its unique features like non-contact measurements and fast response to fluctuating velocity fields.

Due to the enormous field intensities available, exciting new phenomena including nonlinear optics are observed, in spite of the weak nonlinear response of

matter. Most of these processes operate only above a certain critical threshold. There is a remarkable growth of interest in far from equilibrium phenomena. In the threshold regime, these systems are susceptible to external perturbations.

The thesis is devoted to the study of intensity fluctuations in different random and nonlinear media. The present work consists of theoritical and experimental parts. The chapters are also divided as nonlinear and random parts. Chapters 2 and 3 are devoted for nonlinear optics of our interest. The latter chapters deal with random media which includes experimental work also. The chapterwise breakup of the thesis as follows :

Chapter 1 : This is an introductory chapter, giving the idea of statistical properties of radiation and relevant historical growth of the subject under investigation.

Chapter 2, is devoted to the phenomenon of optical bistability, in which the light intensity transmitted through a nonlinear system exhibits a hysteresis cycle under appropriate conditions. This subject has received great attention due to its potential applications in designing optical switches and memories for future computers. Theoritically, it is an interesting example of a system driven far from equilibrium exhibiting first order phase transition.

In this chapter, we study the recently described semiclassical model under plane wave and mean field approximations on two-photon optical bistability in a Fabry-Perot cavity filled with large permanent dipole molecules. First, we deal with the catastrophe theory of optical bistability giving threshold conditions and means of control the bistable characteristics.

Then, we study the statistical properties of this system with the external laser intensity fluctuations to be the main source of noise. We studied two different cases (i) degenerate and (ii) non-degenerate. In latter case, multistability is possible.

In the bistable region, we obtain two values of fluctuation parameters for a given value of input intensity. This produces interesting hysteresis effects. The statistical properties for double bistability in non-degenerate case are also studied where higher branches are found to be unstable.

<u>Chapter 3</u>: The self-focusing in a nonlinear medium has been one of the most interesting subjects in nonlinear optics. Even though, it is a fundamental problem, it is

important for practical applications. It has been shown experimentally that filaments are related to certain amplitude or phase fluctuations present in the incident beam. In situations where an intense laser beam travelling through nonlinear medium result in multiple filament formation, there is one-to-one correspondance between filaments and intensity spikes riding over the incident laser beams. The fact that intensity perturbations in the incident laser beams are responsible for beam breaking into filaments was also confirmed by superimposing known perturbations on the laser beam.

This chapter deals with the numerical calculations concerning the growth of large-scale spikes riding axially over a Gaussian profile of an intense laser beam. We find the relative intensity in spikes becomes a critical parameter of their development due to the counteracting behaviour of self-focusing and depletion effects of the main beam. Thus, the initial relative intensity in the spikes determines, in a critical way, the final energy, size, and quasi stabilization.

Chapter 4 : In many optical experiments, it is interesting to investigate the photon statistics which are modified by the temporal behaviour of the intensity. There are experimental observations reported in the literature where time dependent relaxation of the optical signal shows a marked deviation from the exponential law. For such cases, the intensity follows a time dependent function proportional to $\exp(-(t/\tau)^{\beta})$, $0 < \beta \leq 1$ where β expresses the departure from exponential law.

In this chapter, we derive the photon counting distribution and other related statistical parameters for the above mentioned non exponential decays and focus on β values pertaining to the recent experiments.

Chapter 5 and 6 : These two chapters have been devoted to experimental investigations.

In Chapter 5, reviewing briefly the different approaches to experimental studies of photon correlations, we describe our design and fabrication of microprocessor based correlator. This correlator is applicable equally to Gaussian as well as non-Gaussian signals unlike clipped versions. It is versatile yet cost effective correlator with 128 channels and scanning capacity upto 65,535 cycles for good signal-to-noise ratio. Sampling times can be from internal clock (1 μs to 1 ms) or from an external clock. The design features are dealt in this chapter.

Chapter 6, describes the performance of the correlator by some investigations in random media. Experiments have been carried out on rotating ground glass and translating ground glass and investigation of the coherence and correlation properties of laser light through optical fibres. Then the general application areas are described where the correlator can be applied with particular emphasis on biological studies.

Finally, the Appendix gives the features of 8085 microprocessor used for the construction of correlator.