Document details

Optics Communications
Volume 398, 1 September 2017, Pages 1-11

Quantum phase fluctuations of coherent and thermal light coupled to a non-degenerate parametric oscillator beyond rotating wave approximation

(Article)

Alam, M.[a], Mandal, S.[a], Wahiddin, M.R.[b]

[a]Department of Physics, Visva-Bharati, Santiniketan, India
[b]Department of Computer Science, Kulliyyah of ICT, International Islamic University Malaysia, Kuala Lumpur, Malaysia

Abstract

View references (62)

The essence of the rotating wave approximation (RWA) is to eliminate the non-conserving energy terms from the interaction Hamiltonian. The cost of using RWA is heavy if the frequency of the input radiation field is low (e.g. below optical region). The well known Bloch-Siegert effect is the out come of the inclusion of the terms which are normally neglected under RWA. We investigate the fluctuations of the quantum phase of the coherent light and the thermal light coupled to a nondegenerate parametric oscillator (NDPO). The Hamiltonian and hence the equations of motion involving the signal and idler modes are framed by using the strong (classical) pump condition. These differential equations are nonlinear in nature and are found coupled to each other. Without using the RWA, we obtain the analytical solutions for the signal and idler fields. These solutions are obtained up to the second orders in dimensionless coupling constants. The analytical expressions for the quantum phase fluctuation parameters due to Carruther's and Nieto are obtained in terms of the coupling constants and the initial photon numbers of the input radiation field. Moreover, we keep ourselves confined to the Pegg-Barnett formalism for measured phase operators. With and without using the RWA, we compare the quantum phase fluctuations for coherent and thermal light coupled to the NDPO. In spite of the significant departures (quantitative), the qualitative features of the phase fluctuation parameters for the input thermal light are identical for NDPO with and without RWA. On the other hand, we report some interesting results of input coherent light coupled to the NDPO which are substantially different from their RWA counterpart. In spite of the various quantum optical phenomena in a NDPO, we claim that it is the first effort where the complete analytical approach towards the solutions and hence the quantum phase fluctuations of input radiation fields coupled to it are obtained beyond rotating wave approximation. To have the feelings of the analytical solutions, we give few numerical estimates of the quantum phase fluctuation parameters relevant to a real experimental situation.

Author keywords

Bloch-Siegert effect | Non-degenerate parametric oscillator | Quantum phase fluctuations | Rotating wave approximation

Indexed keywords

Engineering controlled terms: Coherent light | Differential equations | Equations of motion | Fermi level | Hamiltonians | Nonlinear equations | Quantum optics | Quantum theory

Compendex keywords: Analytical approach | Analytical expressions | Bloch-Siegert effect | Coupling constants | Phase fluctuation | Qualitative features | Quantum phase fluctuations | Rotating wave approximations

Related documents

On the quantum phase fluctuations of coherent light coupled to a degenerate parametric amplifier
Alam, M. , Mandal, S. , Wahiddin, M.R.
(2016) Optik

On the quantum phase fluctuations of coherent light in a chain of two anharmonic oscillators coupled through a linear one
Alam, N. , Mandal, S.
(2016) Optics Communications

Phase fluctuations of coherent light coupled to a driven quantum oscillator with time-dependent mass and frequency
Kumar Singh, S. , Mandal, S.
(2008) Journal of Modern Optics

Engineering main heading: Parametric oscillators

Authors > Keywords >

Funding details

Funding number	Funding sponsor	Acronym	Funding opportunities
F.No.42-852/2013	University Grants Commission	UGC	See opportunities by UGC
1283)/13/EMR-II			
	Council of Scientific and Industrial Research	CSIR	See opportunities by CSIR

Funding text

One of the authors (SM) thanks the University Grants Commission, New Delhi for financial support through a major research project (F.No.42-852/2013(SR). SM also thankful to the Council of Scientific and Industrial Research (CSIR), Government of India for financial support (03(1283)/13/EMR-II).

ISSN: 00304018
CODEN: OPCOB
Source Type: Journal
Original language: English
DOI: 10.1016/j.optcom.2017.04.019
Document Type: Article
Publisher: Elsevier B.V.

References (62)

View in search results format >

All Export Print E-mail Save to PDF Create bibliography

1 Hanle, W.

(1924) *Zeitschrift für Physik*, 30 (1), pp. 93-105. Cited 397 times.
doi: 10.1007/BF01331827

2 Harris, S.E.
Lasers without inversion: Interference of lifetime-broadened resonances

(1989) *Physical Review Letters*, 62 (9), pp. 1033-1036. Cited 1230 times.
doi: 10.1103/PhysRevLett.62.1033

View at Publisher

3 Fry, E.S., Li, X., Nikonov, D., Padmabandu, G.G., Scully, M.O., Smith, A.V., Tittel, F.K., (...), Zhu, S.-Y.
Atomic coherence effects within the sodium D1 line: Lasing without inversion via population trapping

(1993) *Physical Review Letters*, 70 (21), pp. 3235-3238. Cited 267 times.
doi: 10.1103/PhysRevLett.70.3235

View at Publisher

4 Scully, M.O.
Enhancement of the index of refraction via quantum coherence

(1991) *Physical Review Letters*, 67 (14), pp. 1855-1858. Cited 726 times.
doi: 10.1103/PhysRevLett.67.1855

View at Publisher

5 Gasiorowicz, S.
Quantum Physics
(1974) , p. 222. Cited 664 times.
John Willey & Sons New York

6 Javanainen, J., Yoo, S.M.
Quantum phase of a Bose-Einstein condensate with an arbitrary number of atoms
(1996) *Physical Review Letters*, 76 (2), pp. 161-164. Cited 390 times.
doi: 10.1103/PhysRevLett.76.161
View at Publisher

7 Louisell, W.H.
Amplitude and phase uncertainty relations
(1963) *Physics Letters*, 7 (1), pp. 60-61. Cited 160 times.
doi: 10.1016/0031-9163(63)90442-6
View at Publisher

8 Susskind, L., Glowgower, J.
(1964) *Physics*, 1, p. 49. Cited 620 times.

9 Barnett, S.M., Pegg, D.T.
Phase in quantum optics
(1986) *Journal of Physics A: General Physics*, 19 (18), art. no. 030, pp. 3849-3862. Cited 156 times.
doi: 10.1088/0305-4470/19/18/030
View at Publisher

10 Pegg, D.T., Barnett, S.M.
Unitary phase operator in quantum mechanics
(1988) *EPL*, 6 (6), pp. 483-487. Cited 511 times.
doi: 10.1209/0295-5075/6/6/002
View at Publisher

11 Pegg, D.T., Barnett, S.M.
Phase properties of the quantized single-mode electromagnetic field
(1989) *Physical Review A*, 39 (4), pp. 1665-1675. Cited 752 times.
doi: 10.1103/PhysRevA.39.1665
View at Publisher

12 Lynch, R.
The quantum phase problem: a critical review
(1995) *Physics Reports*, 256 (6), pp. 367-436. Cited 244 times.
doi: 10.1016/0370-1573(94)00095-K
View at Publisher

13 Perinova, V., Luks, A., Perina, J.
Phase in Optics
(1998) . Cited 135 times.
World Scientific Sngapore

14 Tanas, R., Miranowicz, A.
Ts. Gantsog, Progress in Optics, Vol. XXXV, E. Wolf (Ed.), Elsevier, Armsterdam, 1996, p. 355.

15 Noh, J.W., Fougères, A., Mandel, L.
Measurement of the quantum phase by photon counting

(1991) *Physical Review Letters*, 67 (11), pp. 1426-1429. Cited 277 times.
doi: 10.1103/PhysRevLett.67.1426

View at Publisher

16 Noh, J.W., Fougères, A., Mandel, L.
Further investigations of the operationally defined quantum phase

(1992) *Physical Review A*, 46 (5), pp. 2840-2852. Cited 120 times.
doi: 10.1103/PhysRevA.46.2840

View at Publisher

17 Noh, J.W., Fougères, A., Mandel, L.
Operational approach to the phase of a quantum field

(1992) *Physical Review A*, 45 (1), pp. 424-442. Cited 241 times.
doi: 10.1103/PhysRevA.45.424

View at Publisher

18 Pellonpää, J.-P., Schultz, J., Paris, M.G.A.
Balancing efficiencies by squeezing in realistic eight-port homodyne detection

(2011) *Physical Review A - Atomic, Molecular, and Optical Physics*, 83 (4), art. no. 043818. Cited 5 times.
http://oai.aps.org/oai?verb=GetRecord&Identifier=oai:aps.org:PhysRevA.83.043818&metadataPrefix=oai_apsmeta_2
doi: 10.1103/PhysRevA.83.043818

View at Publisher

19 Fan, H.-Y., Zaidi, H.R.
An exact calculation of the expectation values of phase operators in squeezed states

(1988) *Optics Communications*, 68 (2), pp. 143-148. Cited 35 times.
doi: 10.1016/0030-4018(88)90140-X

View at Publisher

20 Gerry, C.C.
On the phase fluctuations of coherent light interacting with an anharmonic oscillator

(1987) *Optics Communications*, 63 (4), pp. 278-280. Cited 38 times.
doi: 10.1016/0030-4018(87)90355-5

View at Publisher

21 Pathak, A., Mandal, S.
Phase fluctuations of coherent light coupled to a nonlinear medium of inversion symmetry

(2000) *Physics Letters, Section A: General, Atomic and Solid State Physics*, 272 (5-6), pp. 346-352. Cited 12 times.
doi: 10.1016/S0375-9601(00)00446-1

View at Publisher

22 Lynch, R.
Phase fluctuations in the coherent light/anharmonic oscillator system via measured phase operators

(1988) *Optics Communications*, 67 (1), pp. 67-70. Cited 19 times.
doi: 10.1016/0030-4018(88)90091-0

View at Publisher

23 Lynch, R.
Phase fluctuations in a squeezed state using measured phase operators

(1987) *Journal of the Optical Society of America B: Optical Physics*, 4 (10), pp. 1723-1726. Cited 31 times.
doi: 10.1364/JOSAB.4.001723

View at Publisher

24 Vaccaro, J.A., Pegg, D.T.
Phase properties of squeezed states of light

(1989) *Optics Communications*, 70 (6), pp. 529-534. Cited 100 times.
doi: 10.1016/0030-4018(89)90377-5

View at Publisher

25 Yao, D.-m.
Phase properties of squeezed states of light

(1987) *Physics Letters A*, 122 (2), pp. 77-83. Cited 20 times.
doi: 10.1016/0375-9601(87)90780-8

View at Publisher

26 Boyd, R.W.
Nonlinear Optics
(2006) . Cited 6759 times.
2nd edition Academic Press New York

27 Yariv, A.
Quantum Electronics
(1988) . Cited 4459 times.
3rd edition John Wiley & Sons New York

28 Perina, J., Hradil, Z., Jurco, B.
Quantum Optics and Fundamentals of Physics
(1994) . Cited 122 times.
Kluwer Academic Publishers Dordrecht

29 Ficek, Z., Wahiddin, M.R.B.
Quantum Optics: Fundamentals and Applications, International Islamic University Malaysia, Kuala Lumpur, 2004.

30 Ficek, Z., Wahiddin, M.R.
Quantum optics for beginners

(2014) *Quantum Optics for Beginners*, pp. 1-335. Cited 8 times.
http://www.panstanford.com/books/9789814411752
ISBN: 978-981441176-9; 978-981441175-2
doi: 10.4032/9789814411769

View at Publisher

31 Franken, P.A., Hill, A.E., Peters, C.W., Weinreich, G.
Generation of optical harmonics

(1961) *Physical Review Letters*, 7 (4), pp. 118-119. Cited 1308 times.
doi: 10.1103/PhysRevLett.7.118

View at Publisher

32 White, D.R., Louisell, W.H.
Noise calculations for optical parametric oscillators
(1970) *Physical Review A*, 1 (5), pp. 1347-1356. Cited 11 times.
doi: 10.1103/PhysRevA.1.1347
View at Publisher

33 Yariv, A., Louisell, W.H.
5A2—Theory of the Optical Parametric Oscillator
(1966) *IEEE Journal of Quantum Electronics*, 2 (9), pp. 418-424. Cited 54 times.
doi: 10.1109/JQE.1966.1074087
View at Publisher

34 Wu, L.A., Xiao, M., Kimble, H.J.
Squeezed states of light from an optical parametric oscillator
(1987) *Journal of the Optical Society of America B: Optical Physics*, 4 (10), pp. 1465-1475. Cited 215 times.
doi: 10.1364/JOSAB.4.001465
View at Publisher

35 Alge, W., Gheri, K.M., Marte, M.A.M.
The non-degenerate optical parametric oscillator in the strong-coupling regime
(1997) *Journal of Modern Optics*, 44 (4), pp. 841-855. Cited 7 times.
doi: 10.1080/09500349708230699
View at Publisher

36 Bloembergen, N., Shen, Y.R.
Quantum-theoretical comparison of nonlinear susceptibilities in parametric media, lasers, and Raman lasers
(1964) *Physical Review*, 133 (1A), pp. A37-A49. Cited 183 times.
doi: 10.1103/PhysRev.133.A37
View at Publisher

37 Gordon, J.P., Louisell, W.H., Walker, L.R.
Quantum fluctuations and noise in parametric processes. II
(1963) *Physical Review*, 129 (1), pp. 481-485. Cited 98 times.
doi: 10.1103/PhysRev.129.481
View at Publisher

38 Louisell, W.H., Yariv, A., Siegman, A.E.
Quantum fluctuations and noise in parametric processes. I.
(1961) *Physical Review*, 124 (6), pp. 1646-1654. Cited 451 times.
doi: 10.1103/PhysRev.124.1646
View at Publisher

39 Watanabe, K., Yamamoto, Y.
Quantum correlation and state reduction of photon twins produced by a parametric amplifier
(1988) *Physical Review A*, 38 (7), pp. 3556-3565. Cited 33 times.
doi: 10.1103/PhysRevA.38.3556
View at Publisher

40 Zhang, Y.
Generation of non-classical states from an optical parametric oscillator/amplifier and their applications

(2008) *Frontiers of Physics in China*, 3 (2), pp. 126-152. Cited 3 times.
doi: 10.1007/s11467-008-0018-y

View at Publisher

41 Anwar, J., Zubairy, M.S.
Effect of squeezing on the degenerate parametric oscillator

(1992) *Physical Review A*, 45 (3), pp. 1804-1809. Cited 35 times.
doi: 10.1103/PhysRevA.45.1804

View at Publisher

42 Wong, N.C.
Gravity-wave detection via an optical parametric oscillator

(1992) *Physical Review A*, 45 (5), pp. 3176-3183. Cited 12 times.
doi: 10.1103/PhysRevA.45.3176

View at Publisher

43 Allen, L., Eberly, J.H.
Optical Resonance and Two-level Atoms
(1987) . Cited 3920 times.
Dover Publications New York

44 Plastina, F., Liberti, G., Carollo, A.
Scaling of Berry's phase close to the Dicke quantum phase transition

(2006) *Europhysics Letters*, 76 (2), pp. 182-188. Cited 32 times.
doi: 10.1209/epl/i2006-10270-x

View at Publisher

45 Larson, J.
Jahn-Teller systems from a cavity QED perspective

(2008) *Physical Review A - Atomic, Molecular, and Optical Physics*, 78 (3), art. no. 033833. Cited 33 times.
http://oai.aps.org/oai?verb=GetRecord&Identifier=oai:aps.org:PhysRevA.78.033833&metadataPrefix=oai_apsmeta_2
doi: 10.1103/PhysRevA.78.033833

View at Publisher

46 Larson, J.
Absence of vacuum induced Berry phases without the rotating wave approximation in cavity QED

(2012) *Physical Review Letters*, 108 (3), art. no. 033601. Cited 40 times.
http://oai.aps.org/filefetch?identifier=10.1103/PhysRevLett.108.033601&component=fulltext&description=markup&format=xml
doi: 10.1103/PhysRevLett.108.033601

View at Publisher

47 Moroz, A.
A hidden analytic structure of the Rabi model

(2014) *Annals of Physics*, 340, pp. 252-266. Cited 18 times.
doi: 10.1016/j.aop.2013.10.014

View at Publisher

☐ 48 Yoshihara, F., Fuse, T., Ashhab, S., Kakuyanagi, K., Saito, S., Semba, K.
Superconducting qubit-oscillator circuit beyond the ultrastrong-coupling regime

(2017) *Nature Physics*, 13 (1), pp. 44-47. Cited 70 times.
http://www.nature.com/nphys/index.html
doi: 10.1038/nphys3906

View at Publisher

☐ 49 Le Boité, A., Hwang, M.-J., Nha, H., Plenio, M.B.
Fate of photon blockade in the deep strong-coupling regime

(2016) *Physical Review A*, 94 (3), art. no. 033827. Cited 11 times.
http://harvest.aps.org/bagit/articles/10.1103/PhysRevA.94.033827/apsxml
doi: 10.1103/PhysRevA.94.033827

View at Publisher

☐ 50 Forn-Díaz, P., García-Ripoll, J.J., Peropadre, B., Orgiazzi, J.-L., Yurtalan, M.A., Belyansky, R., Wilson, C.M., (...), Lupascu, A.
Ultrastrong coupling of a single artificial atom to an electromagnetic continuum in the nonperturbative regime

(2017) *Nature Physics*, 13 (1), pp. 39-43. Cited 62 times.
http://www.nature.com/nphys/index.html
doi: 10.1038/nphys3905

View at Publisher

☐ 51 Louisell, W.H.
Quantum Statistical Properties of Radiation
(1990) , p. 205. Cited 2925 times.
Wiley Classic Library Edition New York

☐ 52 Fan, H.-Y., Li, C., Jiang, Z.-H.
Spin coherent states as energy eigenstates of two coupled oscillators

(2004) *Physics Letters, Section A: General, Atomic and Solid State Physics*, 327 (5-6), pp. 416-424. Cited 7 times.
doi: 10.1016/j.physleta.2004.05.049

View at Publisher

☐ 53 Rebón, L., Rossignoli, R.
Entanglement of two harmonic modes coupled by angular momentum

(2011) *Physical Review A - Atomic, Molecular, and Optical Physics*, 84 (5), art. no. 052320. Cited 7 times.
http://oai.aps.org/filefetch?identifier=10.1103/PhysRevA.84.052320&component=fulltext&description=markup&format=xml
doi: 10.1103/PhysRevA.84.052320

View at Publisher

☐ 54 Abdo, B., Kamal, A., Devoret, M.
Nondegenerate three-wave mixing with the Josephson ring modulator

(2013) *Physical Review B - Condensed Matter and Materials Physics*, 87 (1), art. no. 014508. Cited 34 times.
http://oai.aps.org/filefetch?identifier=10.1103/PhysRevB.87.014508&component=fulltext&description=markup&format=xml
doi: 10.1103/PhysRevB.87.014508

View at Publisher

55 Flurin, E.
The Josephson Mixer, a Swiss Army Knife for Microwave Quantum Optics (Ph.D. thesis), tel-01241123, 2014, p.33.

56 Nayfeh, A.H.
Introduction to Perturbation Techniques
(1981) . Cited 2654 times.
Wiley New York

57 Bellman, R.
Methods of Nonlinear Analysis, Vol. 1, Academic Press, New York, 1970, p. 198.

58 Bender, C.M., Orszag, S.A.
Advanced Mathematical Methods for Scientists and Engineers
(1999) , p. 546. Cited 3735 times.
McGraw Hill Book Company New York

59 Carruthers, P., Nieto, M.M.
Phase and angle variables in quantum mechanics
(1968) *Reviews of Modern Physics*, 40 (2), pp. 411-440. Cited 813 times.
doi: 10.1103/RevModPhys.40.411
View at Publisher

60 Loudon, R.
The Quantum Theory of Light
(2000) . Cited 4012 times.
3rd Ed. Oxford University Press Oxford

61 Loudon, R., Knight, P.L.
Squeezed light
(1987) *Journal of Modern Optics*, 34 (6-7), pp. 709-759. Cited 1487 times.
doi: 10.1080/09500348714550721
View at Publisher

62 Walls, D.F.
Evidence for the quantum nature of light
(1979) *Nature*, 280 (5722), pp. 451-454. Cited 128 times.
doi: 10.1038/280451a0
View at Publisher

Mandal, S.; Department of Physics, Visva-Bharati, Santiniketan, India; email:swapanvb@rediffmail.com