REPORT DOCUMENTATION PAGE

AD-A257 065

Form Approved
OMB No. 0704-0188

(2)

1. AGENCY USE ONLY (Lea...	10-8-92	...RT TYPE AND DATES COVERED Annual Technical 2/1/92 - 1/31/93

4. TITLE AND SUBTITLE

Interferometric Measurement with Squeezed Light

5. FUNDING NUMBERS

N00014-92-J-1302

4124133-01

6. AUTHOR(S)

Prof. Hermann A. Haus

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Research Laboratory of Electronics
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Department of the Navy
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Work by Prof. Haus and his collaborators is summarized here

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Interferometric Measurement

P.I.: Hermann A. Haus
in cooperation with Prof. Erich P. Ippen

1. Research Description:

Squeezed vacuum injected into the "unused" port of a phase measurement interferometer reduces the noise of the sensor below the shot noise level. Ever since our proposal to generate squeezed vacuum in an optical fiber ring using optical pulses for enhanced Kerr nonlinearity, while saving the pump power for local oscillator[1], we have been pursuing the goal of utilizing such radiation in a dependable way for improvements in the signal to noise ratio of optical measurements.

2. Scientific Problem:

The research calls for advances in the quantum theory of radiation. The ultimate goal is to use solitons for squeezing, because they offer a higher degree of shot-noise reduction. Thus the quantum theory of solitons needs attention. Further, the use of pulses may lead to nonlinear effects in the sensor utilizing the squeezed radiation. This calls for an investigation of such effects. Guided Acoustic Wave Brillouin Scattering (GAWBS) discovered by the IBM group can introduce sufficient "classical" noise to destroy the squeezing and thus deserves special attention. This GAWBS noise is convolved into the measurement frequency-window by the (square law) optical detector.

3. Scientific and Technical Approach

Our approach is both theoretical and experimental. The theory leads us to fundamental questions such as the "collapse" of the quantum mechanical wave function due to a measurement (paper in preparation), and to a quantum description of pulses emerging from a modelocked laser. Experimentally, we attempt to demonstrate improvement in measurement sensitivity and work on compact sources and components for the ultimate practical application of squeezed radiation.

4a. Progress:

We have made considerable progress in the past year in bringing the use of squeezed vacuum into the realm of technical utilization. The first experiment on squeezing in a fiber ring with polarization maintaining fiber produced 5dB shot-noise reduction, indicating a considerably larger degree of actual squeezing in view of the unavoidable losses and the finite (85%) quantum efficiency of the detector. The fiber had zero dispersion for the 80 ps pulses at 1.3 μ. Our numbers were questioned by Dr. Shelby of IBM (in a collegial way without undue publicity), because the IBM experiments encountered levels of GAWBS that would have prevented this amount of shot noise reduction. We investigated carefully our results. We confirmed the level of squeezing, but found that our fiber had exceptionally low level of GAWBS. A piece of the fiber given to us by IBM exhibited much higher GAWBS levels. Further theoretical and experimental studies showed that the GAWBS level is extremely sensitive to fiber geometry. Thus, if a reliable measurement technology is to evolve from our effort, means have to be found that effectively suppress GAWBS. We are working on three such schemes:

(a) If a pulse repetion rate greater than 2 GHz is used, the GAWBS spectrum which extends only to about 1 GHz does not get convolved into low frequency measurement windows. We are in the process of developing a high rep-rate modelocked source. This is the most promising scheme, because it suppresses the effect of GAWBS in any subsequent fiber sensor utilizing the squeezed radiation.

(b) A short fiber with pumping pulses of high peak power enhances the squeezing above the GAWBS production. C. Doerr, one of the students working on the project, has already demonstrated squeezing without GAWBS using this scheme. It is the basis of the paper to be presented at the next conference.

(c) π-phase modulation of the pump at 2 GHz or higher[2]. In this way the GAWBS can be subtracted upon detection. This scheme has been successfully demonstrated by K. Bergman and reported as an invited talk at the Annual Meeting of the Optical Society of America in Albuquerque, NM, Sept. 20-25, 1992. The squeezed radiation was injected into an phase measuring interferometer and a measurement noise level of 3 dB below shot-noise was realized. This is the first demonstration of measurement sensitivity improvement using our squeezing scheme.

All the above schemes could be followed by a linear phase-sensor interferometer. If the sensor is a fiber sensor, such as a fiber gyro, only scheme (a) can be utilized. Scheme (b) would lead to excessive probe intensity in the Sagnac fiber loop. If scheme (c) were be used in the Sagnac loop proper to suppress the GAWBS, it would cancel the signal as well.

In line with the objective of developing practical measurement set-ups, we are working on a modelocked fiber laser source of high rep-rate that could serve as the pumping source in an all-fiber version of the squeezing interferometer.

4b. Special Significance of Results

We believe that we have advanced the chances for the practical use of squeezed radiation. The suppression of GAWBS appears possible, irrespsetcive of the fiber employed. The re-use of the squeezing pump as the local oscillator leads to an absolute improvement of the signal to noise ratio for a fixed power budget. Other squeezing schemes employing Optical Parameteric Amplifiers sacrifice the pump power and lead to improvement of signal to noise ratio only when there is a limit on the power usable in the sensor, but no limit on the available power.

5. Extenuating Circumstances

We have been exceptionally successful (and should we say lucky) in this year's research. We can hardly expect equal succes in the coming funding period and hope that extenuating circumstances will be credited for the next reporting period.

6. Publications:

[1] H.A. Haus, "Quantization of nonlinear Schrödinger equation," Phys. Rev. A 46, 3, R1175-1176, 1 August 1992.

[2] K. Bergman, C.R. Doerr, H.A. Haus, and M. Shirasaki, "Sub-shot noise measurement with fiber-squeezed optical pulses, submitted to Optics Letters.

7. Unspent Funds

8. Other Government Support:

National Science Foundation, "Picosecond Optical Sampling Devices," 9012787-ECS. Development of all-optical switches and sampling devices.

Air Force Office of Scientific Research (with Profs. J.G. Fujimoto and E.P Ippen), "Femtosecond Photonics, Fundamental Phenomena and Device Behavior" F49620-91-C-0091. Study of subpicosecond nonlinear processes in matter; study of nonlinear pulse propagation.

Joint Services Electronics Program (with Prof Ippen), "Picosecond Optical Devices," DAAL03-92-C-0001. Development of picosecond and subpicosecond modelocked laser sources.

9. Major Equipment Purchases:

Fiber cleaver, aligner, oven: $11,246 (Amherst International). Modelocked/Driver: $10,000 (NEOS Technologies).

[1] M. Shirasaki and H.A. Haus, "Squeezing of pulses in a nonlinear interferometer," J. Opt. Soc. Am. B, 30-34 (1990).

[2] M. Shirasaki and H.A.Haus, "Reduction of guided acoustic wave Brillouin scattering noise in a squeezer," Opt. Letts. 17, 1225-1227 (1992).

Office of Naval Research

DISTRIBUTION LIST

Herschel S. Pilloff Scientific Officer Code: 1112LO Office of Naval Research 800 North Quincy Street Arlington, VA 22217	3 copies
Administrative Contracting Officer E19-628 Massachusetts Institute of Technology Cambridge, MA 02139	1 copy
Director Naval Research Laboratory Washington, DC 20375 Attn: Code 2627	1 copy
Defense Technical Information Center Bldg. 5, Cameron Station Alexandria, VA 22314	2 copies