Preface

The ability to directly detect gravitational waves will open a completely new branch of astronomy to view the Universe, one that is inaccessible to electromagnetic-based astronomy. First-generation ground-based interferometric gravitational-wave detectors have achieved strain sensitivities of order 10^{-21}, at 100 Hz detection frequency. A new generation of detectors is under construction, designed to improve on the sensitivity of the first-generation detectors by a factor of 10.

The quantum nature of light will broadly limit the sensitivity of these new instruments. This quantum noise will originate from the quantum vacuum fluctuations that enter the unused port of the interferometer. One of the most promising options for reducing the quantum noise impact and further increasing the sensitivity is applying quantum squeezed vacuum states. These squeezed states have lower noise in one quadrature than the vacuum state. By replacing the quantum vacuum fluctuations entering the interferometer with squeezed vacuum states, the quantum noise impact is reduced.

This thesis is an account of research in the field of squeezed states for enhancing interferometric gravitational-wave detectors, undertaken between February 2008 and March 2013, administered by the Department of Quantum Science, Research School of Physics and Engineering, The Australian National University, Canberra, Australia. This Springer Theses Edition 2015 is a slightly revised version of the original thesis of April 2013.

Following the introduction and thesis overview of Chap. 1, the thesis is divided into three parts. Part I provides the background theory for the research presented, with material on the characteristics of gravitational waves and their detection (Chap. 2), quantum optics (Chap. 3), quantum noise limits of interferometric gravitational-wave detectors (Chap. 4) and squeezed-light sources (Chap. 5).

In Part II, Chap. 6 presents a doubly-resonant, travelling-wave bow-tie cavity squeezed light source and development work leading to the first measurement of 11.6 ± 0.4 dB of quantum noise suppression from 200 Hz and above. The properties affecting squeezing magnitude and low-frequency squeezing measurement are discussed. In addition, a modified squeezing-ellipse-phase control technique for squeezed vacuum states is presented. This squeezing cavity design also has benefits with intrinsic isolation to backscattered light. Chapter 7 presents the measurement of the immunity of the travelling-wave Optical Parametric Oscillator to backscattered light. The immunity value, measured using the balanced homodyne detector, is compared to a squeezing-noise coupling spectrum measurement.

Part III presents the methodologies and results from the H1 Squeezed Light Injection Experiment, performed at the Laser Interferometer Gravitational-Wave Observatory (LIGO). Chapter 8 introduces the project background, interferometer hardware modifications made for the squeezing injection, and squeezed light source, based on the Optical Parametric Oscillator from Part II of this thesis. Chapter 9 presents the main results of the LIGO H1 Squeezed Light Experiment, particularly the 2.15 ± 0.05 dB squeezing enhancement of the 4 km Enhanced LIGO interferometer above 250 Hz. An unknown area was whether the addition of a squeezer would introduce noise couplings that degrade the crucial low frequency sensitivity. Chapter 10 presents the measurements made to investigate the impact of backscattered light from an installed squeezer on LIGO. Inferred levels of backscatter noise on the interferometer readout, made from vibration excitations and optical path length modulations, are presented.

The knowledge and processes gained, from both the squeezed light source development work and the LIGO Squeezed Light Injection Experiment, will inform the design, planning and implementation of squeezed states in future gravitational-wave detectors. Chapter 11 concludes the thesis, with a summary of the work presented and the discussion of extensions to this research.

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