Squeezing at 1064nm
...towards a GEO-Squeezer Mk2

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Squeezing performance

- Squeezing at GEO since 2010
- Stable operation with high duty cycle
- Slow but steady improvements

- High power and ultra-low-noise photodetector for squeezed-light enhanced gravitational wave detectors, Hartmut Grote et al. LIGO DCC: P1500203)
Recent squeezing

![Graph showing strain vs. frequency with and without squeezing. The graph includes a vertical arrow indicating a 4.2 dB difference.](image-url)

- **Frequency (Hz)**: 200, 500, 1000, 2000, 5000
- **Strain (Hz\(^{-1/2}\))**: 
  - without squeezing
  - with squeezing

4.2 dB
GEO-Squeezer

**LASER PREPARATION STAGE**

- **Main Laser**
  - λ's
  - SHG
  - EOM 1
  - Main Laser
  - DBS
  - Pump beam
  - 2ω
  - EOM 2
  - Mode cleaner, MC532
  - PD_{MC532}
  - PD_{PumpBeam}
  - Pump field
- **Aux1 Laser**
  - λ's
  - EOM 1
  - Squeezing ellipse & phase control beam
  - p-pol
  - EOM 3
  - p-pol
  - PBS
  - PBS
  - Squeezed Light Source
  - Squeezed field
- **Aux2 Laser**
  - λ's
  - EOM 1
  - Squeezing ellipse & phase control beam
  - s-pol
  - PBS
  - PBS
  - PD_{greenPhase}
  - PD_{SLS, cavity}
  - PD_{LO, trans}
  - Orientation

**Diagnostic Homodyne Detector**

- LO beam
- 50/50
- to GEO
- Rotator
- GEO-Squeezer
GEO-Squeezer

- dimensions: 1.15m x 1.35m
- weight: 120kg
- build in 2009 / sign of wear
GEO-Squeezer upkeep

- SHG was replaced
- MC532 was replaced
- Broken OPA crystal
- Auxiliary lasers show occasional excess noise

broken OPA crystal
Doubly resonant OPA

- Linear cavity design
- Finesse of 240 at 532nm
- Low loss OPA (Finesse of 47 at 1064nm)
- Simultaneous resonance tuned via crystal temperature
Mechanical OPA design

- Compact design
- High mechanical stability
- Sealed air gap
- Easy to assemble
- In air design
- Can be made vacuum compatible
Experimental setup

- 500um custom made photo diodes (made in 2009 by Laser components) installed for homodyne detection
- measured 0.3% PD-AR reflection
- Homodyne quantum yield enhanced using retro reflectors
15dB squeezing

- Vacuum noise
- Squeezed vacuum noise
- Electronic dark noise

- 15dB squeezing directly measured w/o dark noise correction
- only 16mW OPA pump power required

LIGO Document P1600153-v2
Squeezing vs pump power

- 15.3dB squeezing if dark noise corrected
- only 7mW pump required for 10dB squeezing with only 11.5dB anti-squeezing
- High purity!
- only 2.5% total optical loss
- ultra low 1.7mrad phase noise

Quantum noise normalized to vacuum (dB)

Frequency (MHz)

P=16mW
P=7mW
P=1.6mW

DCC: P1600153-v2
Loss budget

2.5% total optical loss

\[ \eta_{\text{homodyne}} = 99.2^{+0.1}_{-0.1} \% \]
\[ \eta_{\text{propagation}} = 99.8^{+0.01}_{-0.01} \% \]
\[ \eta_{\text{escape}} = 99.05^{+0.4}_{-0.45} \% \]

accounts for \( 2.0^{+0.5}_{-0.6} \% \) loss

Photo diode quantum efficiency of \( \eta_{PD} = 99.5^{+0.5}_{-0.5} \% \)

DCC: P1600153-v2
Added coherent control scheme

Double resonant squeezed light source

Required for audio-band squeezing

1064nm Laser

Second Harmonic Generation (SHG)

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High purity squeezing at kHz

Preliminary!

11.9 dB anti-squeezing

vacuum noise

10.4 dB squeezing

<10mW pump

$\frac{P}{P_{\text{thr}}} = 34\%$
GEO-Squeezer Mk2

- Based on doubly resonant linear OPA cavity design
- Stand-alone squeezer
- Only 1m² size
- 2 units in preparation
- Fully automated as the current GEO Squeezer
- Free choice of coherent control frequency
15dB vacuum squeezing demonstrated in a doubly resonant linear OPA cavity design
Operated in air with only 1.7 mrad phase noise
10dB squeezing with only 11dB anti-squeezing with low pump power
Calibration of PD quantum efficiency to 99.5 +/- 0.5%
Doubly resonant linear OPA design transferable to the GEO-Squeezer layout