HOMODYNE AND HETERODYNE READOUT OF A SIGNAL-RECYCLED GRAVITATIONAL WAVE DETECTOR

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LIGO-G070443-00-Z

Motivation for DC-readout

Advantages

- **Reduced shot noise (no contributing terms from 2 times the heterodyne frequency)**
- **Reduction of oscillator phase noise and oscillator amplitude noise**
- **Stronger low pass filtering of local oscillator (due to PR cavity pole)**
- **Simplify the GW detector**
  - Simpler calibration (GW-signal in a single data-stream, even for detuned SR)
  - Simpler circuits for photodiodes and readout electronics
  - Possibility to use photodiodes with larger area => reduced coupling of pointing
  - Reduced number of beating light fields at the output photodiode => simpler couplings of technical noise
- **Requires less effort for injecting squeezed light (=> useful precursor for GEO-HF)**
- LO and GW pass the same optical system (identical delay, filtering, spatial profile) => This advantage is especially important for detectors with arm cavities.

Disadvantages

- **Increased coupling of laser power noise.**
- **Usually an output mode cleaner (OMC) is required.**
- **Very sensitive to imbalances of the interferometer arms.**

Definitions

Tuning/detuning of the Signal-Recycling cavity (microscopic length)

tuned: carrier is resonant in SR-cavity

detuned: carrier is off resonance in SR-cavity (550 Hz or 1 kHz)

Optical gain

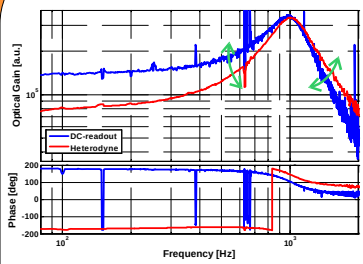
Transfer function from differential dis-placement to signal at the detection point.

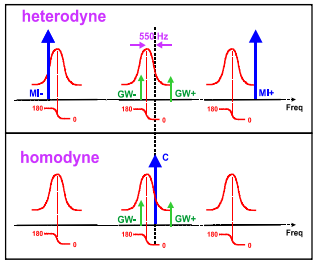
Readout system

heterodyne: LO from RF sidebands (Schnupp modulation)

DC-readout / homodyne: Carrier from dark fringe offset serves as LO

Rotation of optical response (for detuned SR)

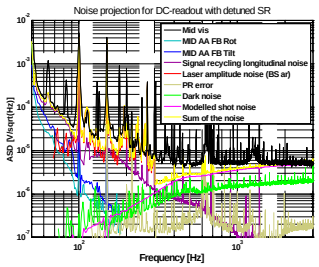


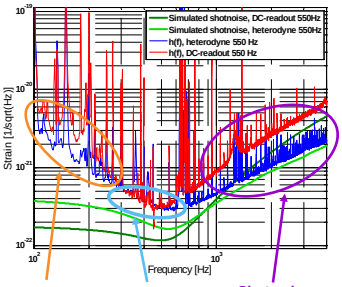


- **The predicted rotation of the detector response is confirmed by the measurements.**
- **This phenomenon can be explained by the opposite phase of the two heterodyne sidebands.**

	C	GW+	GW-	MI+	MI-
f<< 550 Hz	0	0	0	0	180
f>>550 Hz	0	0	180	0	180

Detuned Signal-Recycling (550Hz)





- Laser power noise limits the sensitivity at some frequencies below 300 Hz.
- Above 300 Hz laser power noise seems not to be a problem.

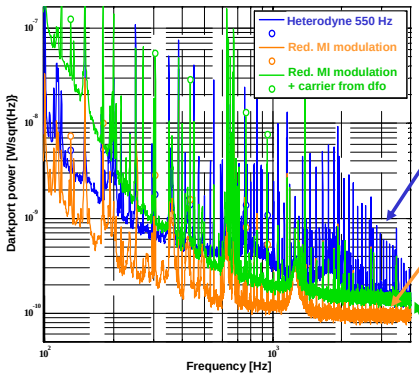
Increased technical noise

Roughly same as with heterodyne **(2e-19m/sqrt(Hz))**

Shot noise ⇒Increased in DC-readout

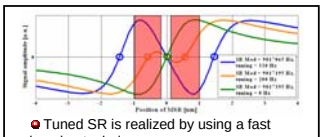
DC-readout in GEO without OMC

How to achieve DC-readout?

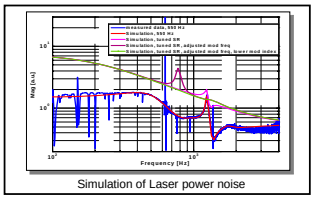


- **Turning down the radio frequency modulation (stable operation is possible with 10 lower sidebands)**
- **Dark port is dominated by carrier light (TEM_{00}) from a 50 pm dark fringe offset**

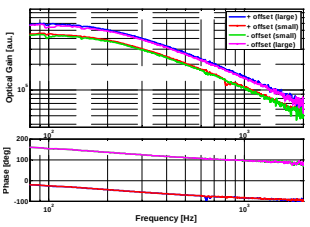
Tuned Signal-Recycling

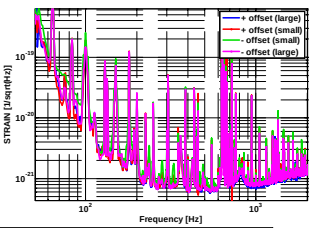


- Tuned SR is realized by using a fast jumping technique.
- Two different operation modes: resonant and non resonant RF modulation frequency.



Simulation of Laser power noise

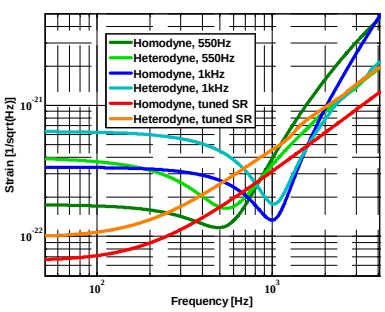




- Optical gain increases with the size of the dark fringe offset.
- Optical gain for + and – dark fringe offset have 180 degree different phase.
- Sensitivity seems to independent of sign and size of the dark fringe offset.

Simulated shot noise

- Simulations were performed with FINESSE.
- **DC-readout gives a better peak sensitivity than hetero-dyne readout**, independent of the SR tuning.
- For detuned SR: A **"rotation" of the detector response** is observed, when going from heterodyne to DC-readout



Summary

- **We demonstrated a DC-readout scheme without output mode cleaner in GEO600.**
- **DC-readout and heterodyne detection has been compared for several Signal-Recycling tunings.**
- **Using DC-readout a displacement sen-sitivity of $2 \cdot 10^{-19}$m/sqrt(Hz) is achieved.**