Homodyne readout of an interferometer with Signal Recycling

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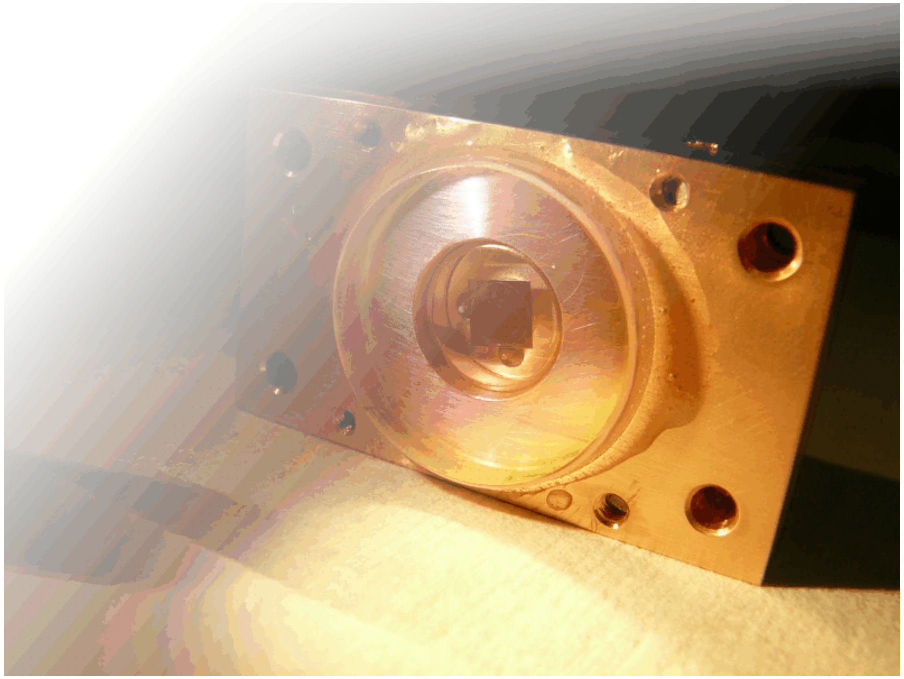
for the GEO600 team



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LSC-Virgo meeting Hannover

LIGO-G070746-00-Z

Motivation for DC-readout (1)

Disadvantages

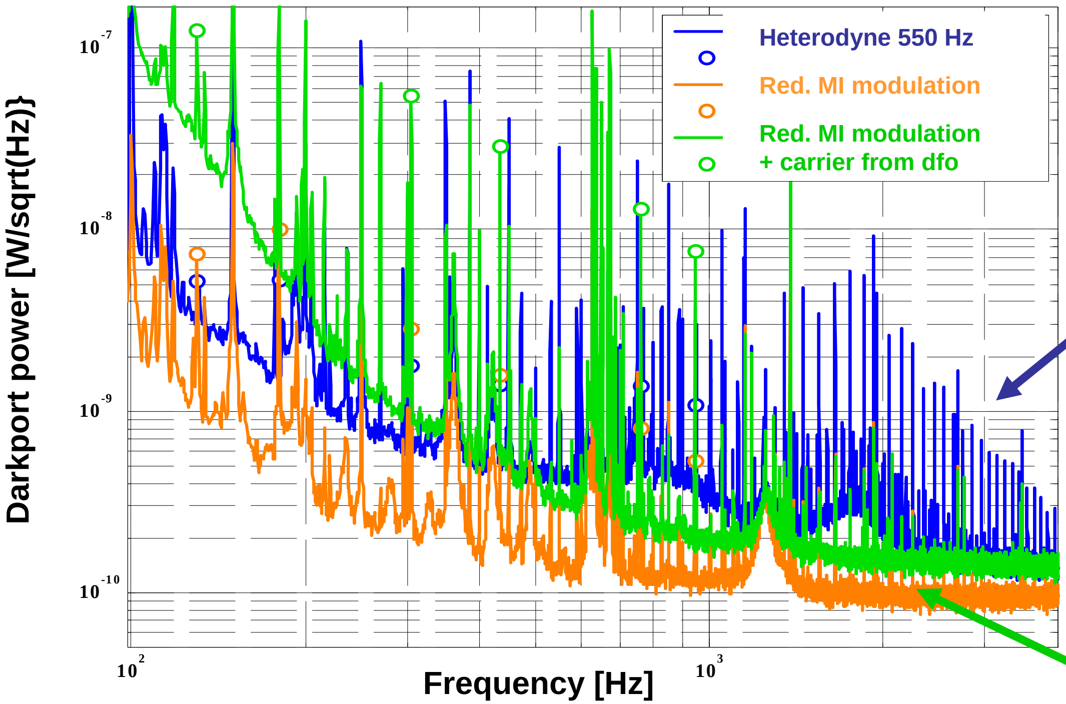
- Increased coupling of laser power noise.
- Usually an output mode cleaner (OMC) is required.
- Very sensitive to imbalances of the interferometer arms.

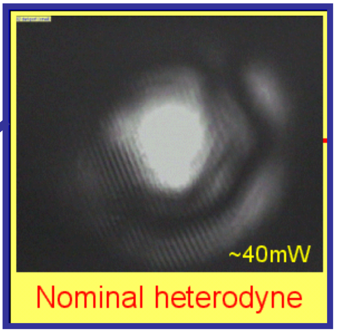
Motivation for DC-readout (2)

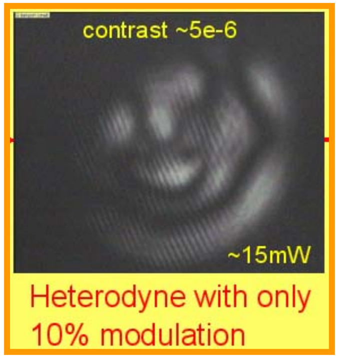
Advantages

- **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.

DC-readout without OMC

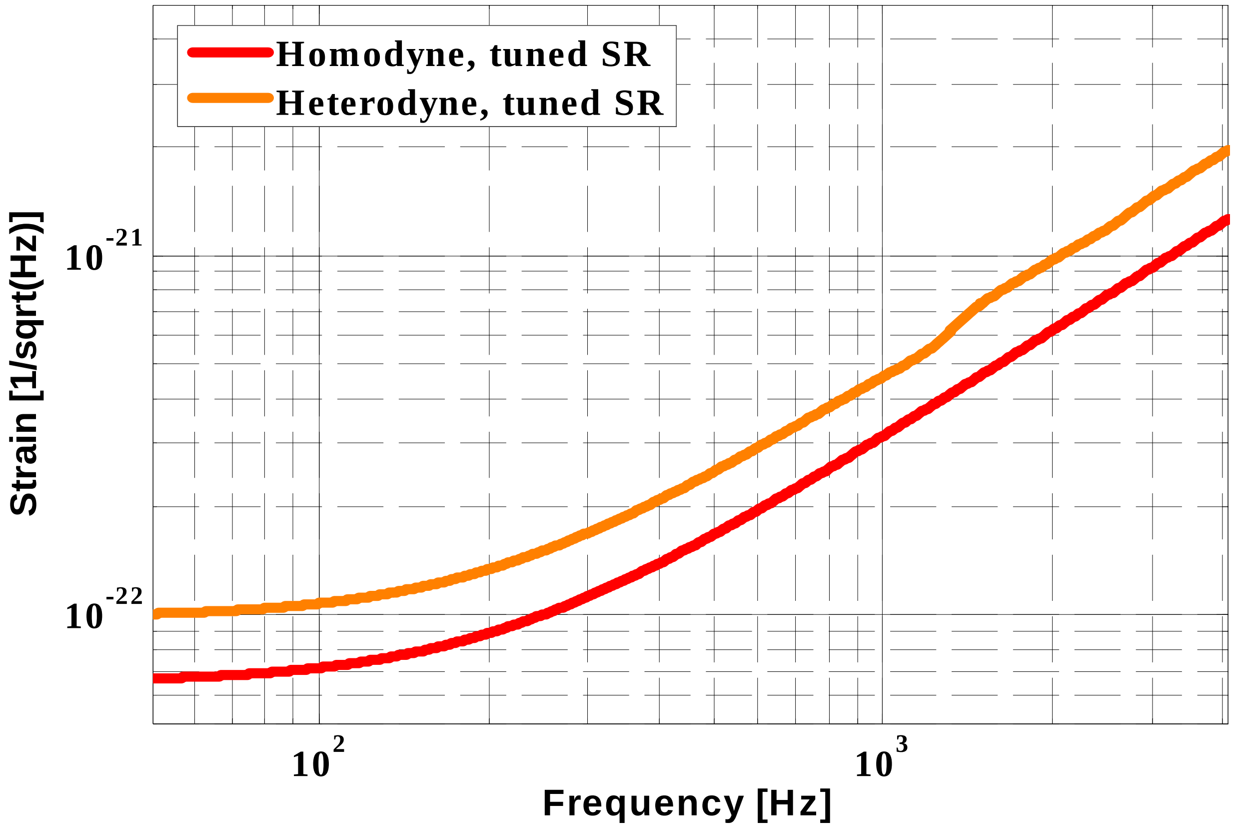






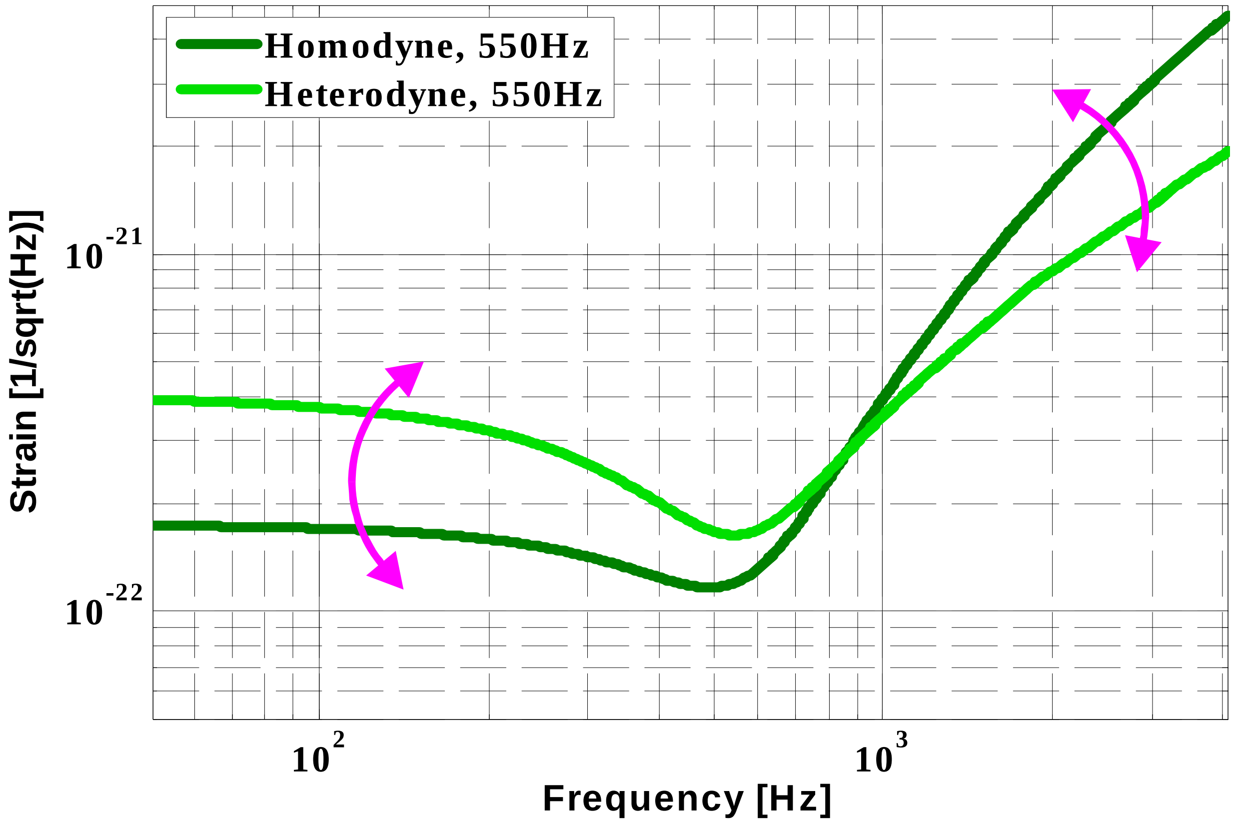
- Turning down the radio frequency modulation (stable operation is possible with 10 times lower sidebands)
- Dark port is dominated by carrier light (TEM_{00}) from a 50 pm dark fringe offset
- Disadvantage: Still some shot noise contribution from RF-sidebands.

Simulated shot noise: Homodyne vs Heterodyne detection



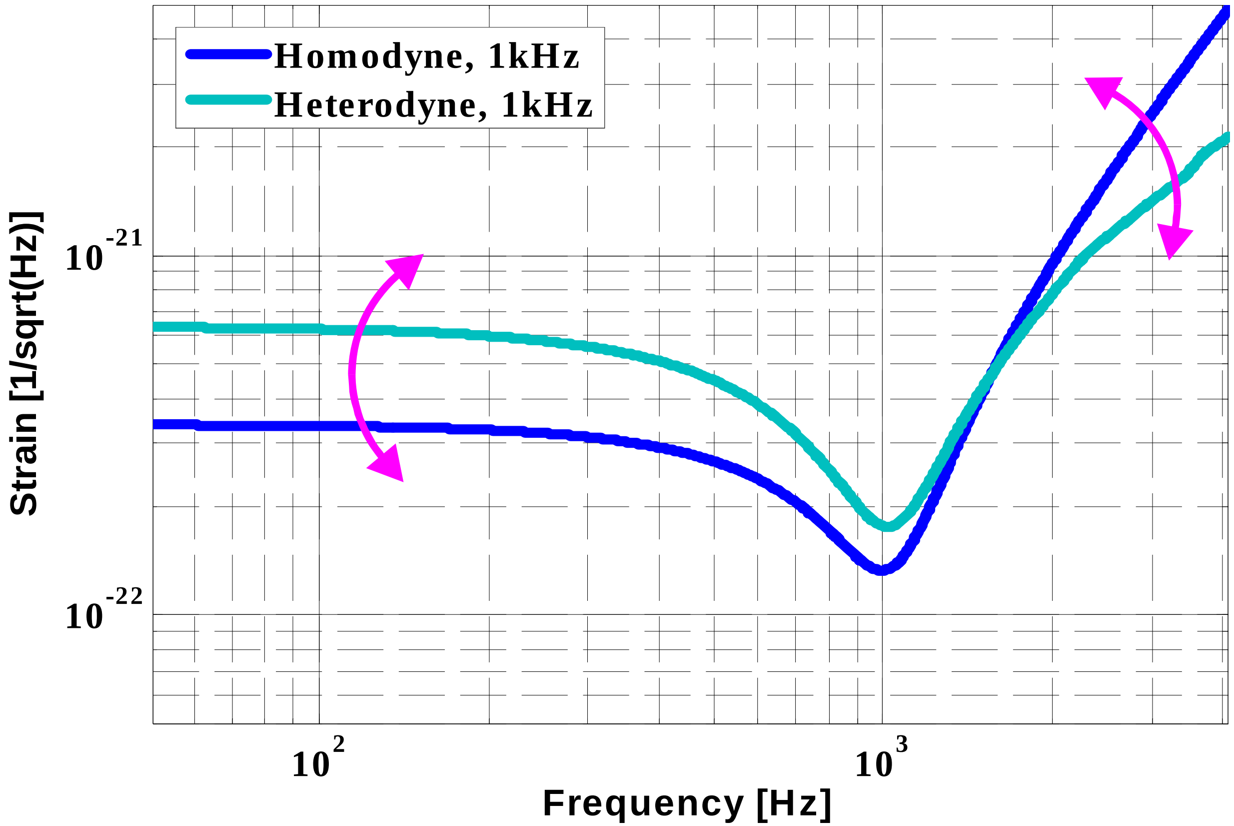
DC-readout with tuned Signal-Recycling:
- shape stays constant
- overall level is reduced

Simulated shot noise: Homodyne vs Heterodyne detection



DC-readout with detuned SR: - better peak sensitvity
- shape is rotated => better at low freqs, worse at high freqs.

Simulated shot noise: Homodyne vs Heterodyne detection



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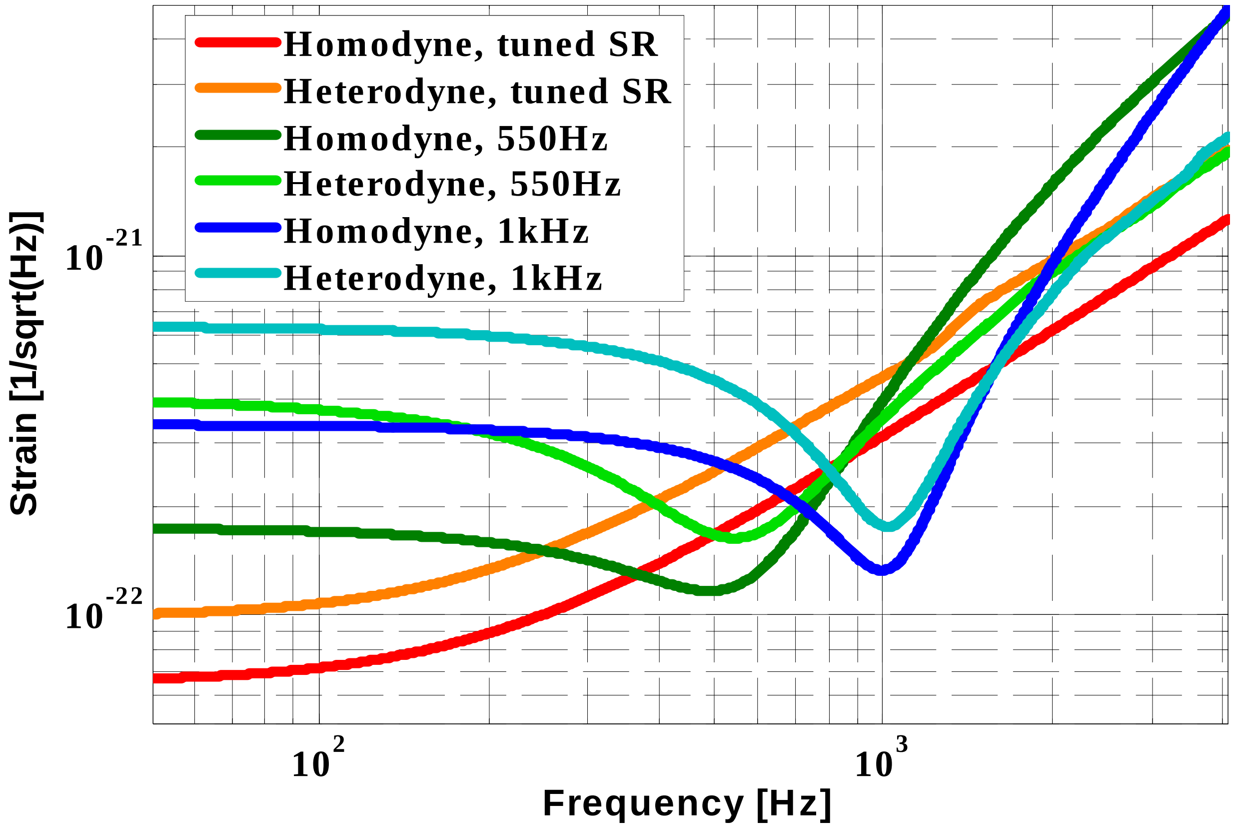
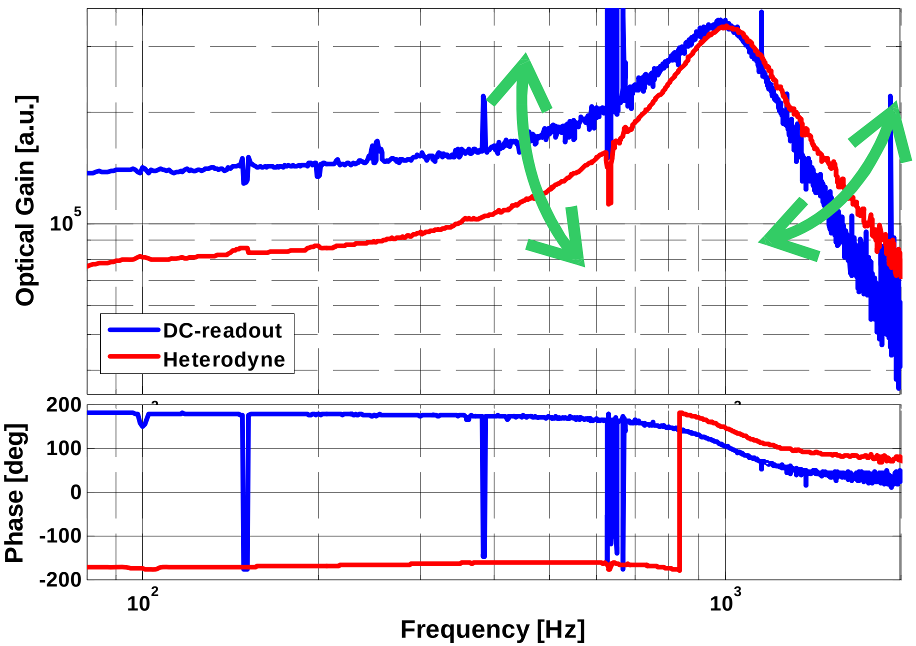
Simulated shot noise: Homodyne vs Heterodyne detection

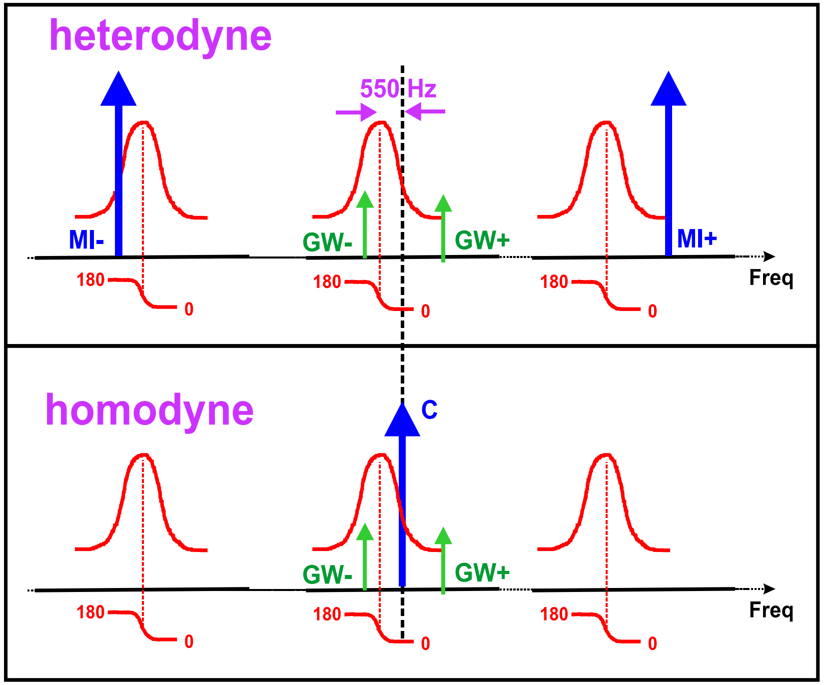


1st Question: Can we confirm the rotation of the shape in our measurements?

‚Rotation‘ of the optical gain

Rotated shape of optical response confirmed by measurement:

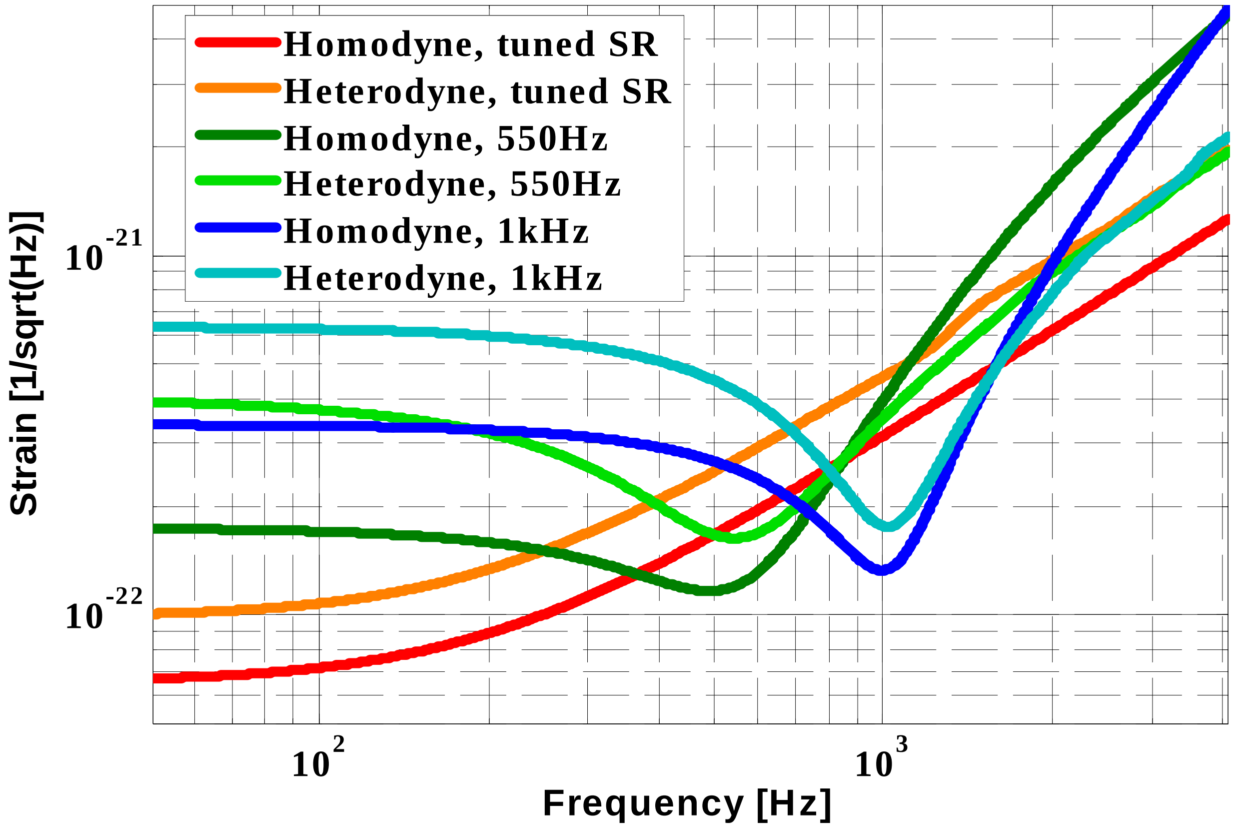




Rotated shape of optical response can be understood by looking at the phases of the contributing light fields. => change of the optical demodulation phase.

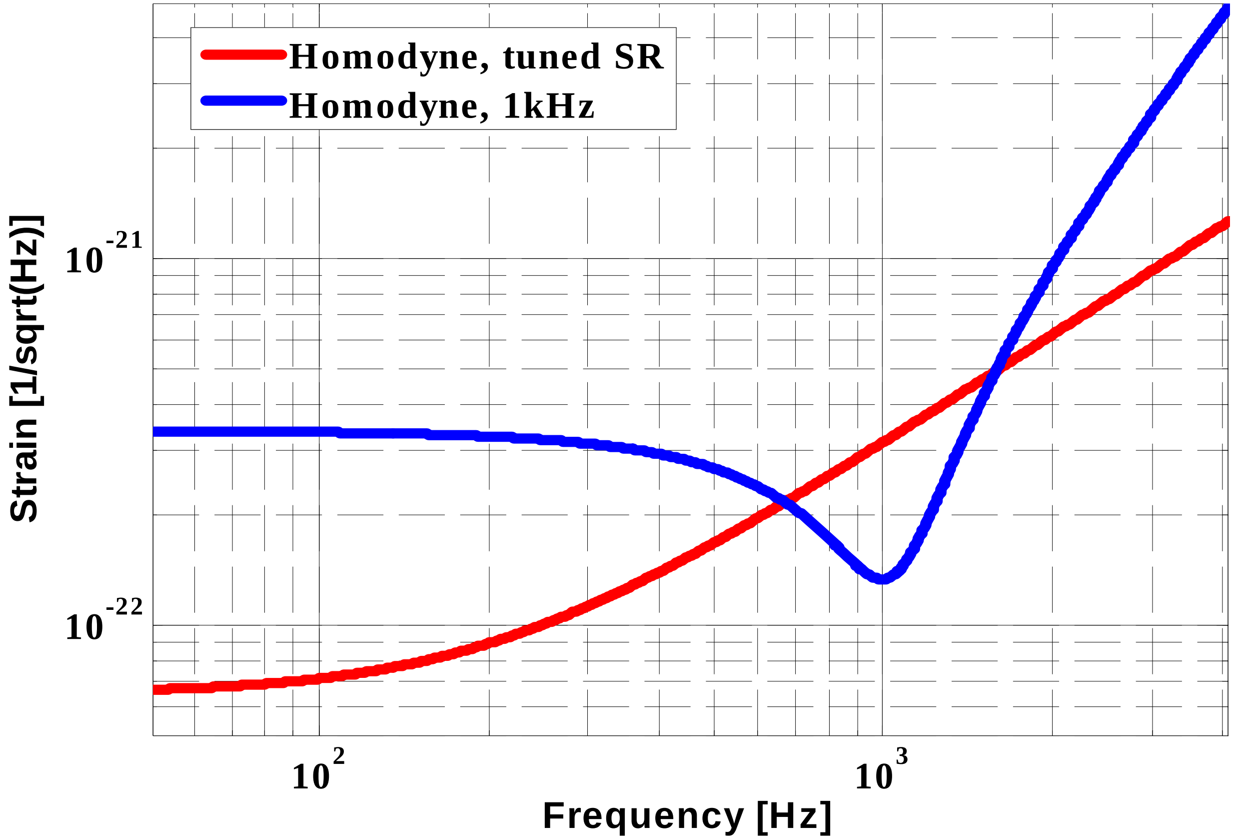
	C	GW+	GW-	MI+	MI-
f<< 550 Hz	0	0	0	0	180
f>>550 Hz	0	0	180	0	180

Simulated shot noise: Homodyne vs Heterodyne detection



2nd Question: Can we confirm the change of the relative shape of tuned and detuned SR with DC-readout ?

Simulated shot noise: Homodyne vs Heterodyne detection



2nd Question: Can we confirm the change of the relative shape of tuned and detuned SR with DC-readout ?

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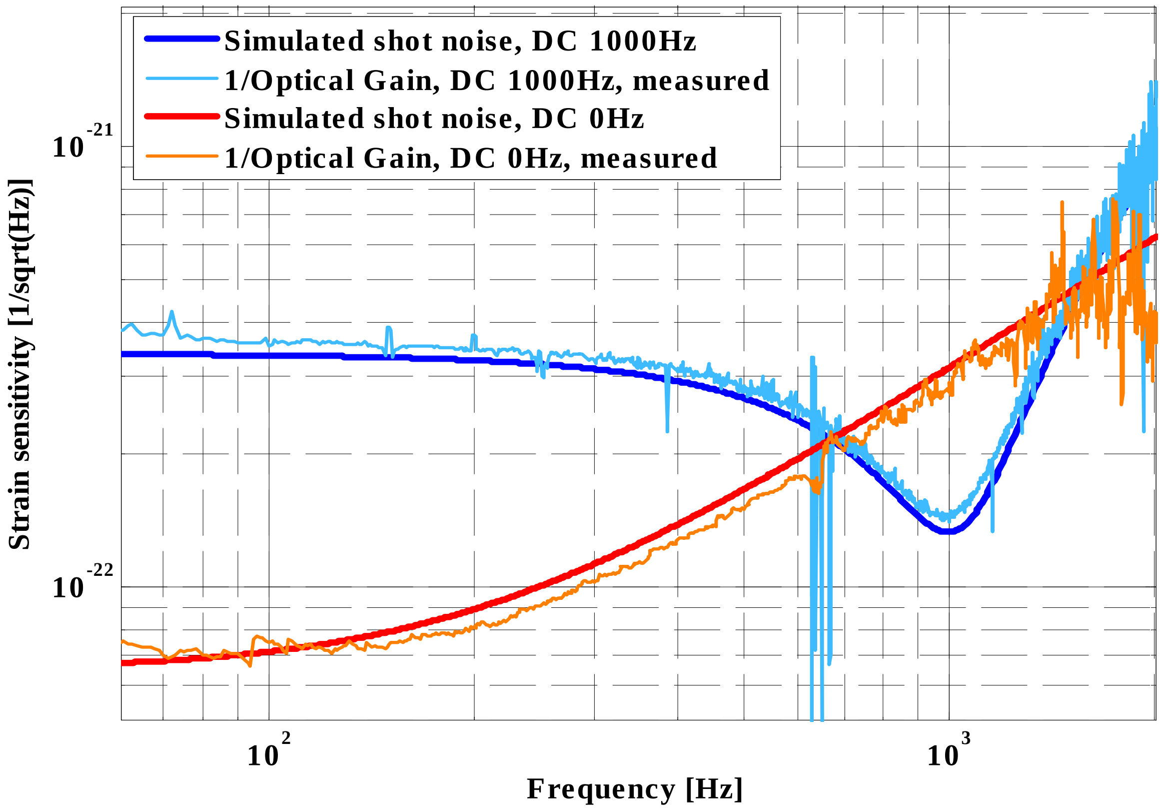
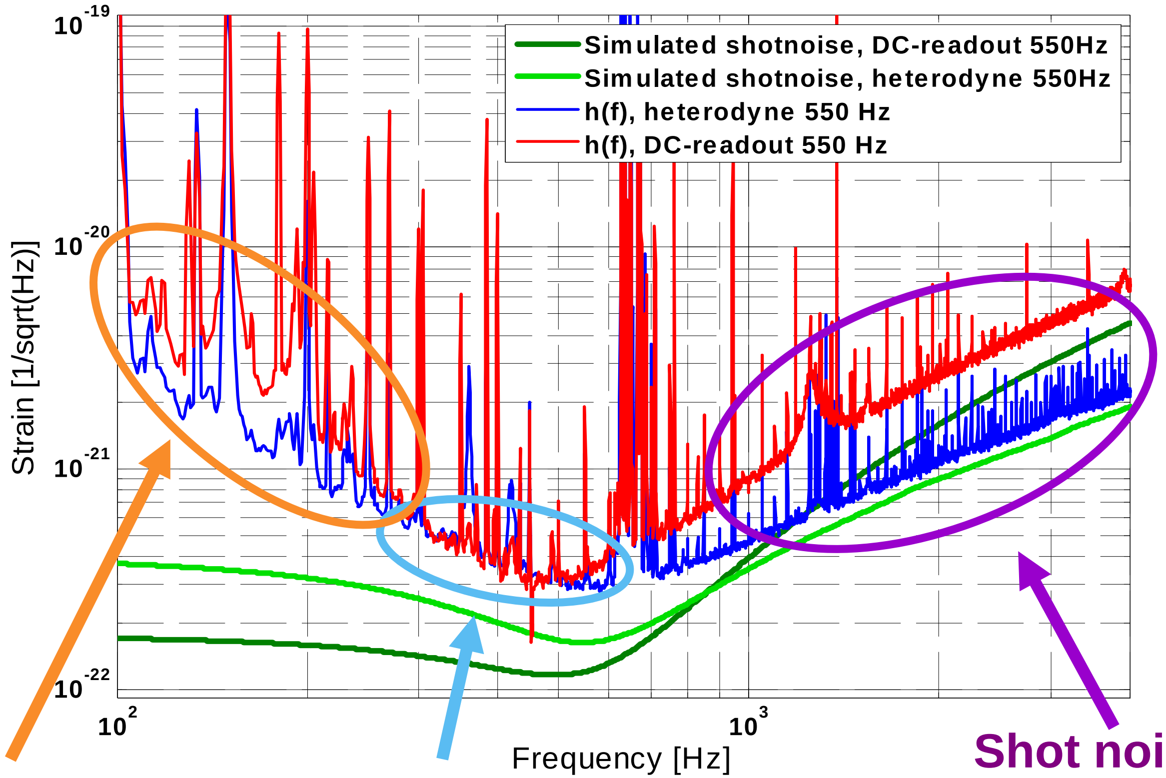
Comparison of measured and simulated optical transfer function for DC-readout



The simulated optical transfer function for tuned and detuned SR wit DC-readout is reproduced by our measurements.

Best sensitivity so far with DC-readout and a SR detuning of 550 Hz



Increased technical noise

Peak sensitivity roughly same as with heterodyne **(2e-19m/sqrt(Hz))**

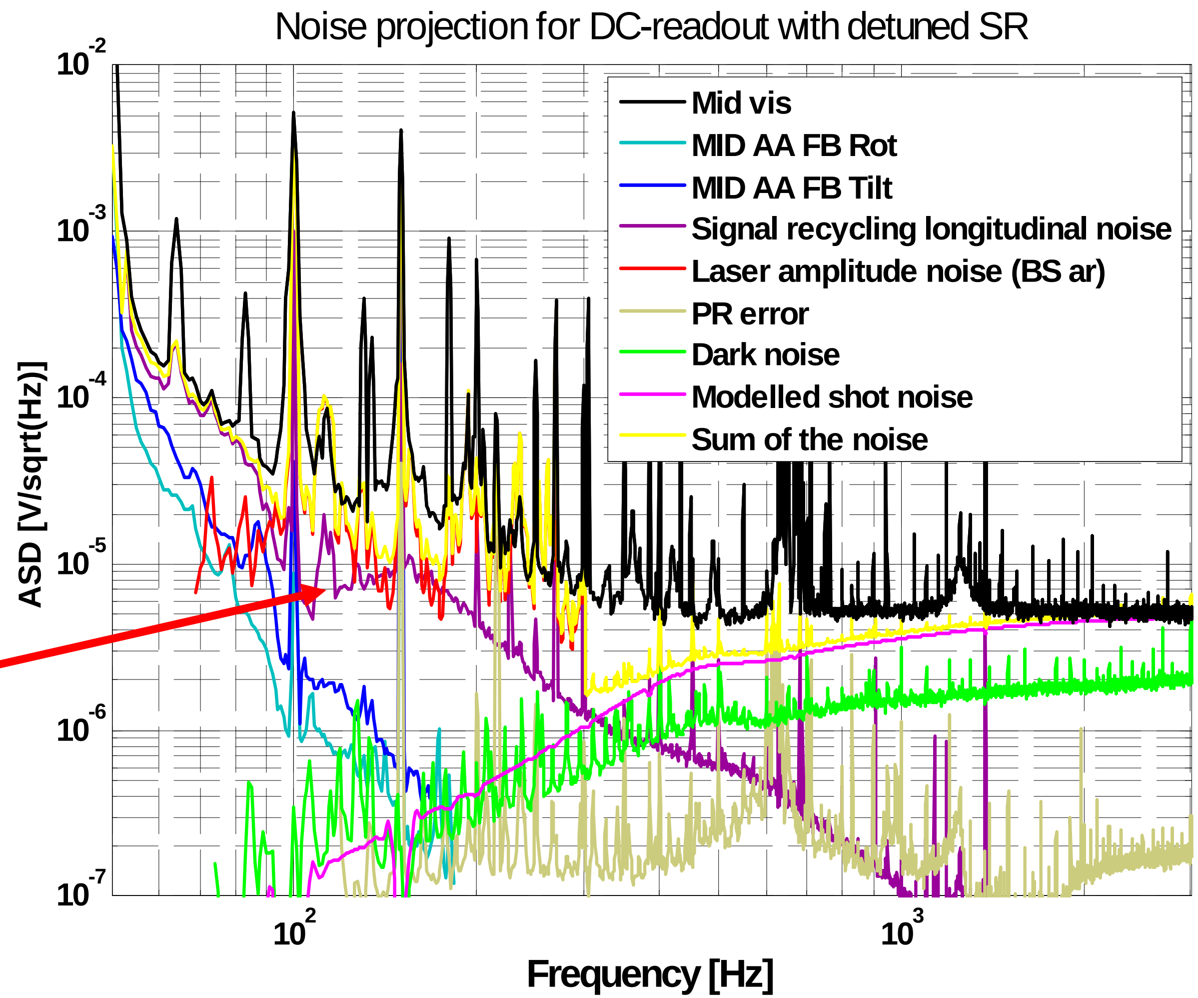
Shot noise
⇒ Increased at high freqs in DC-readout (with detuned SR)

Noise budget for DC-readout (detuned SR)

Laser power noise (LPN):

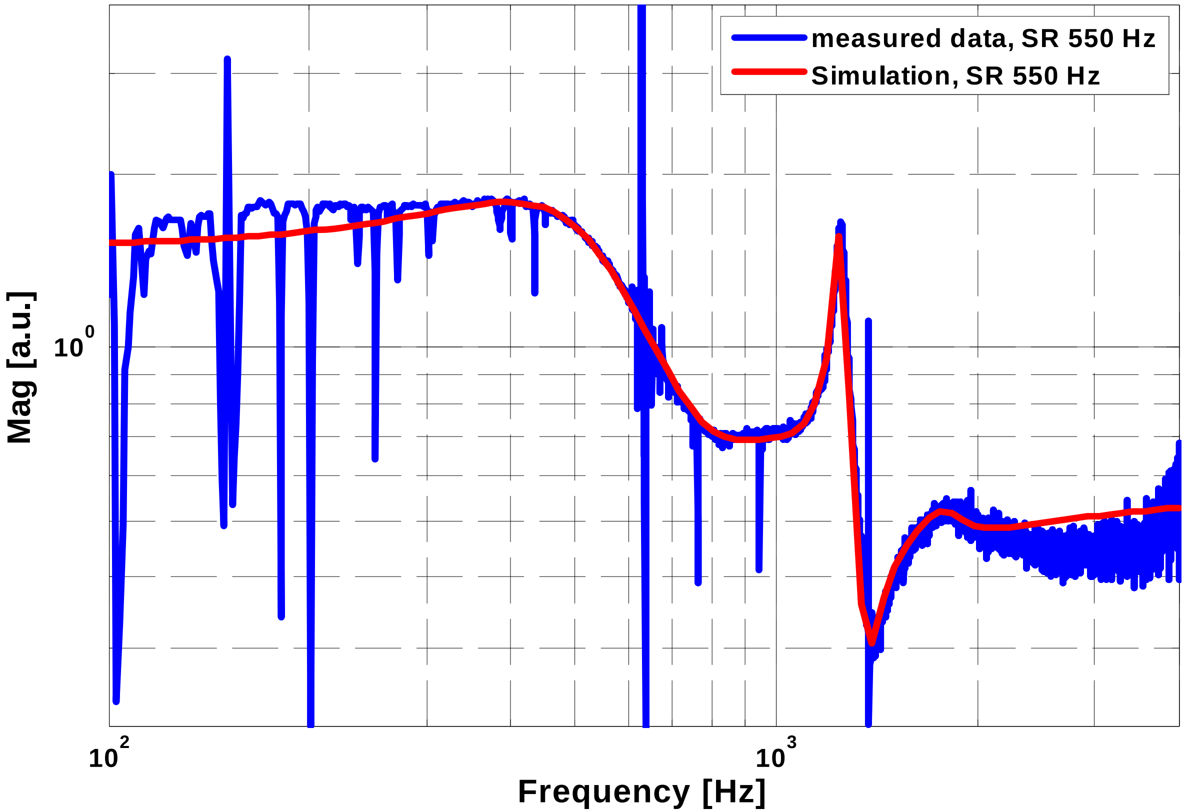
is partly limiting at low frequencies

overall seems to be less of a problem than initially expected



3rd Question: Do we understand the laser power noise coupling?

Understanding the LPN in DC-readout



Good agreement between measurement and simulation !!

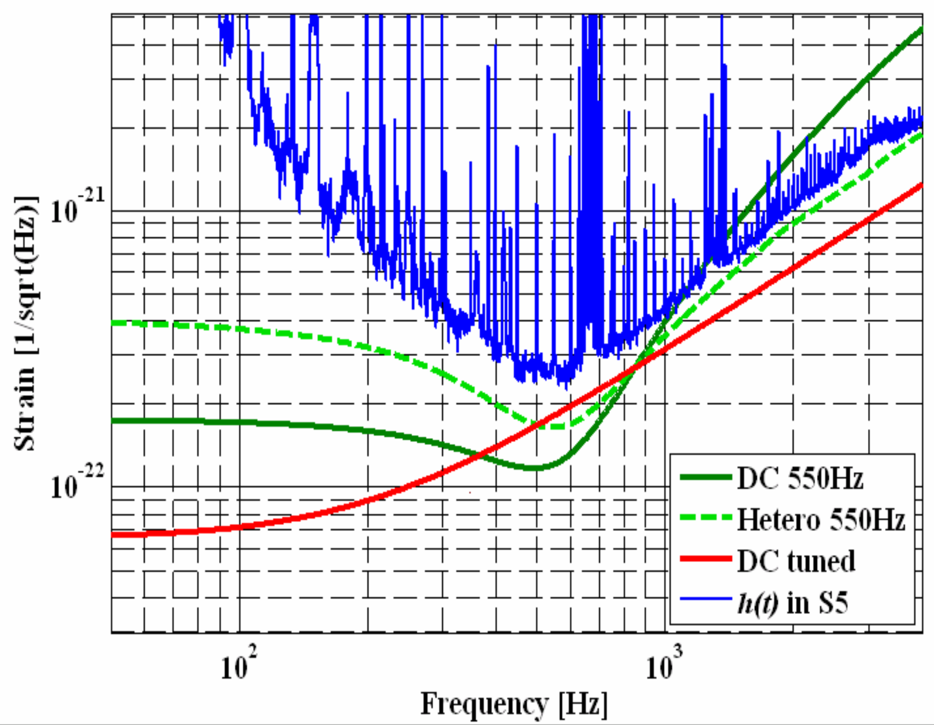
Summary

- Demonstrated DC-readout with tuned and detuned Signal-Recycling (without OMC)
- Going to DC-readout changes the optical demodulation phase (rotated shape of optical response)
- Measurements and simulations agree pretty well:
  - Optical response
  - Laser intensity noise coupling
- Achieved a displacement sensitivity of 2e-19m/sqrt(Hz) (currently worse sensitivity than in heterodyne readout)
- Laser power noise is not as bad as rumors suggest (due to filtering of PR cavity pole)

Where to go in future ??

DC-readout with tuned Signal recycling

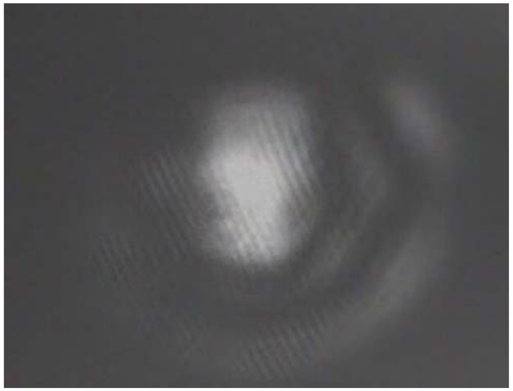
- Best shot noise at low and high frequencies.
- This combination of SR tuning and DC-readout would allow an ‚easy‘ implementation of squeezed light (no filter cavity necessary to get full benefit)



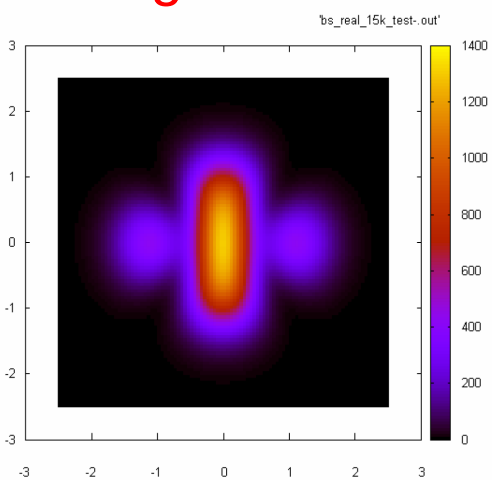
See talk by S.Chelkowski @ QND-meeting

Additional slides

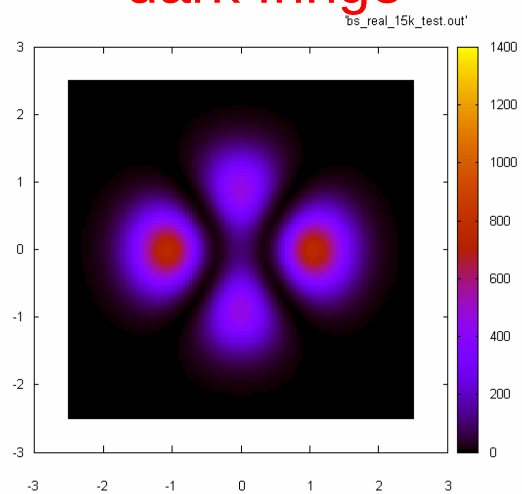
Output mode for positive and negative dfo: observation vs simulation



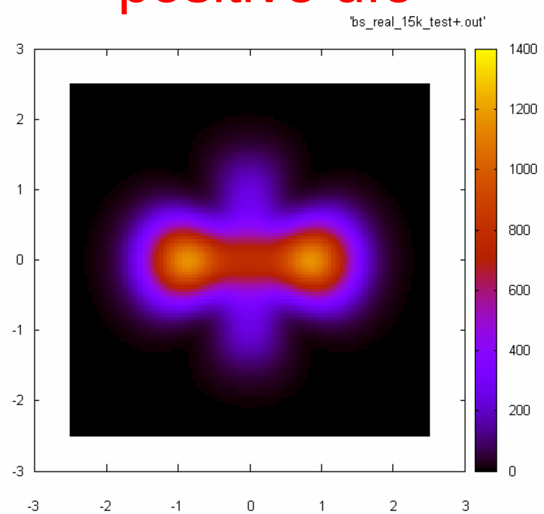
negative dfo



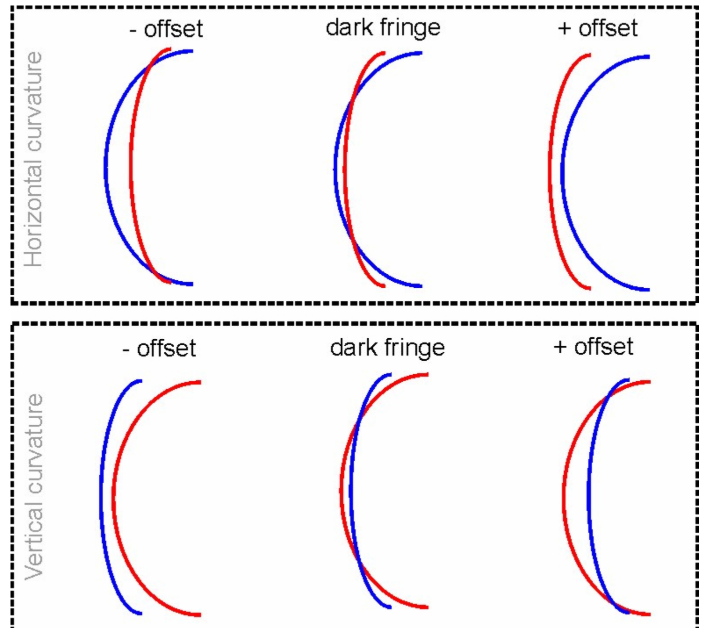
dark fringe



positive dfo



Output mode for positive and negative dark fringe offset (dfo)

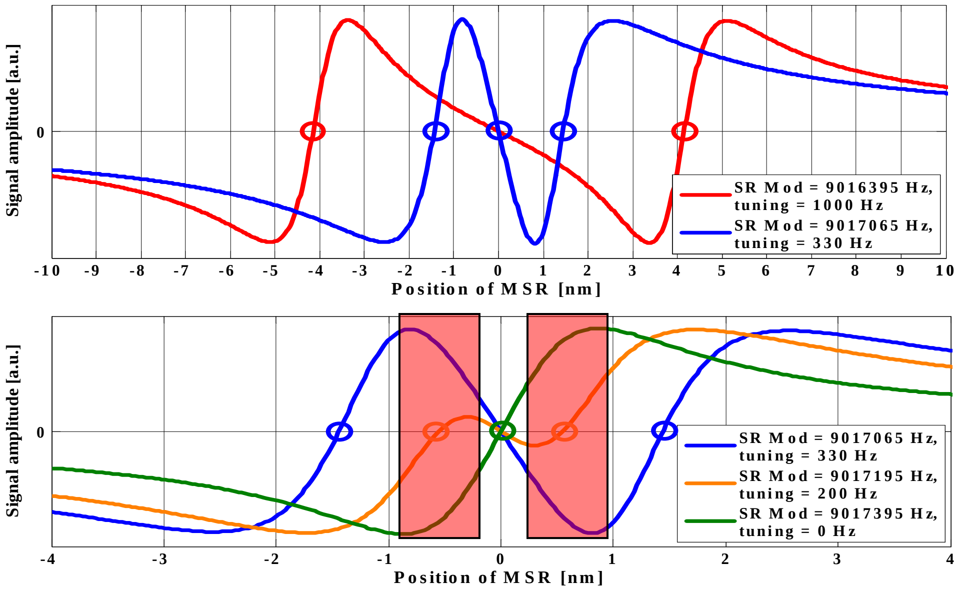


Wave front radii of returning beams @ beam splitter:

horizontal: north > east
vertical: north < east

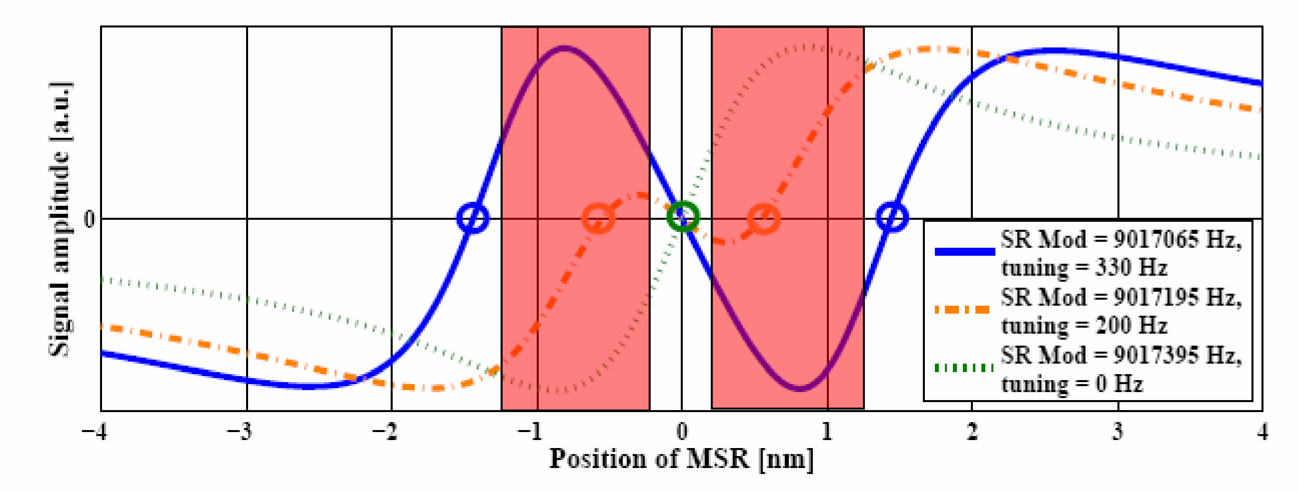
Realisation of tuned signal recycling

- For tunings < 250 Hz we cannot achieve a reasonable control signal.



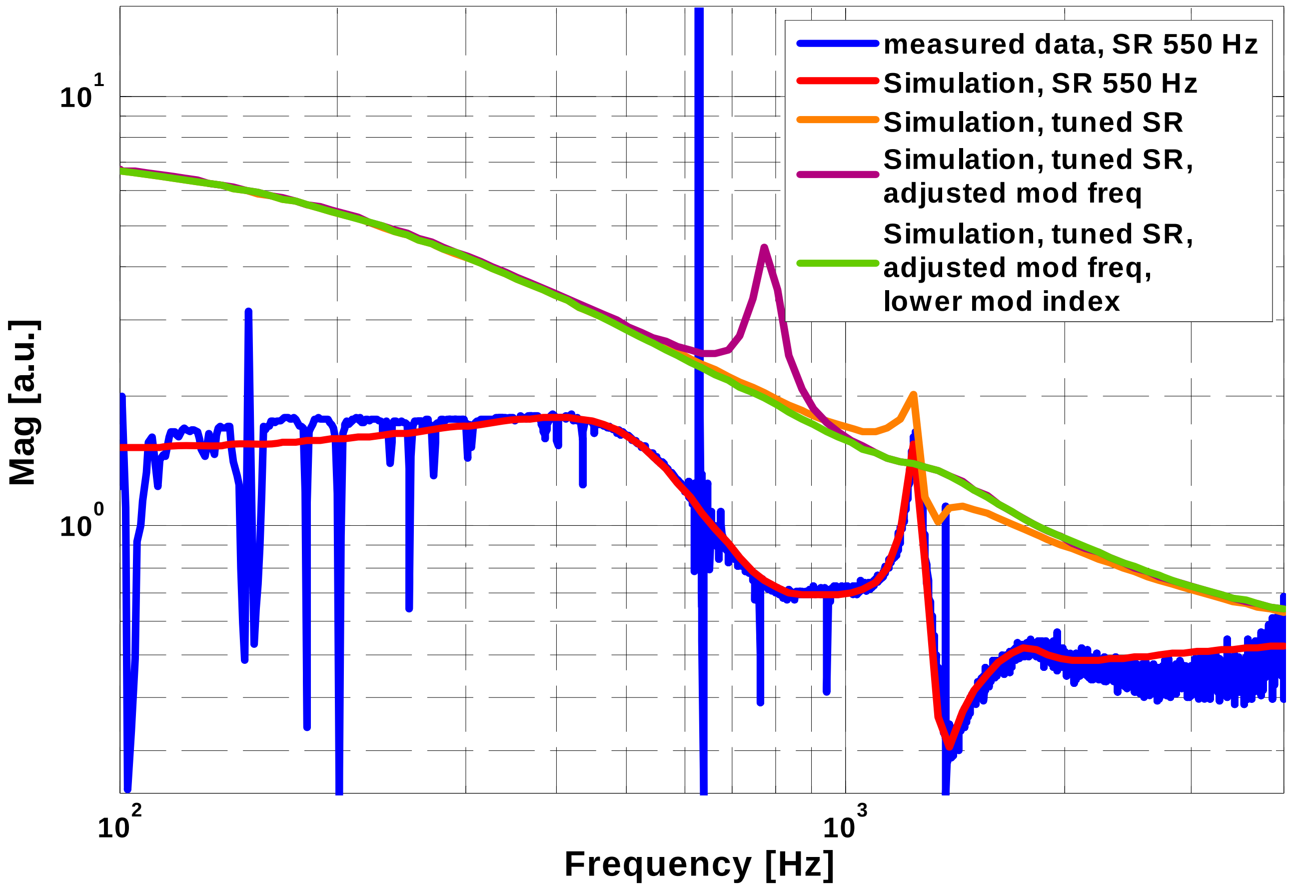
- Developed a new technique: We ‘kick‘ MSR in a controlled way to jump to tuned SR, where a reasonable control signal can be obtained again.
- MSR is caught at the tuned operating point again.

2 different possibilities for going to tuned signal recycling

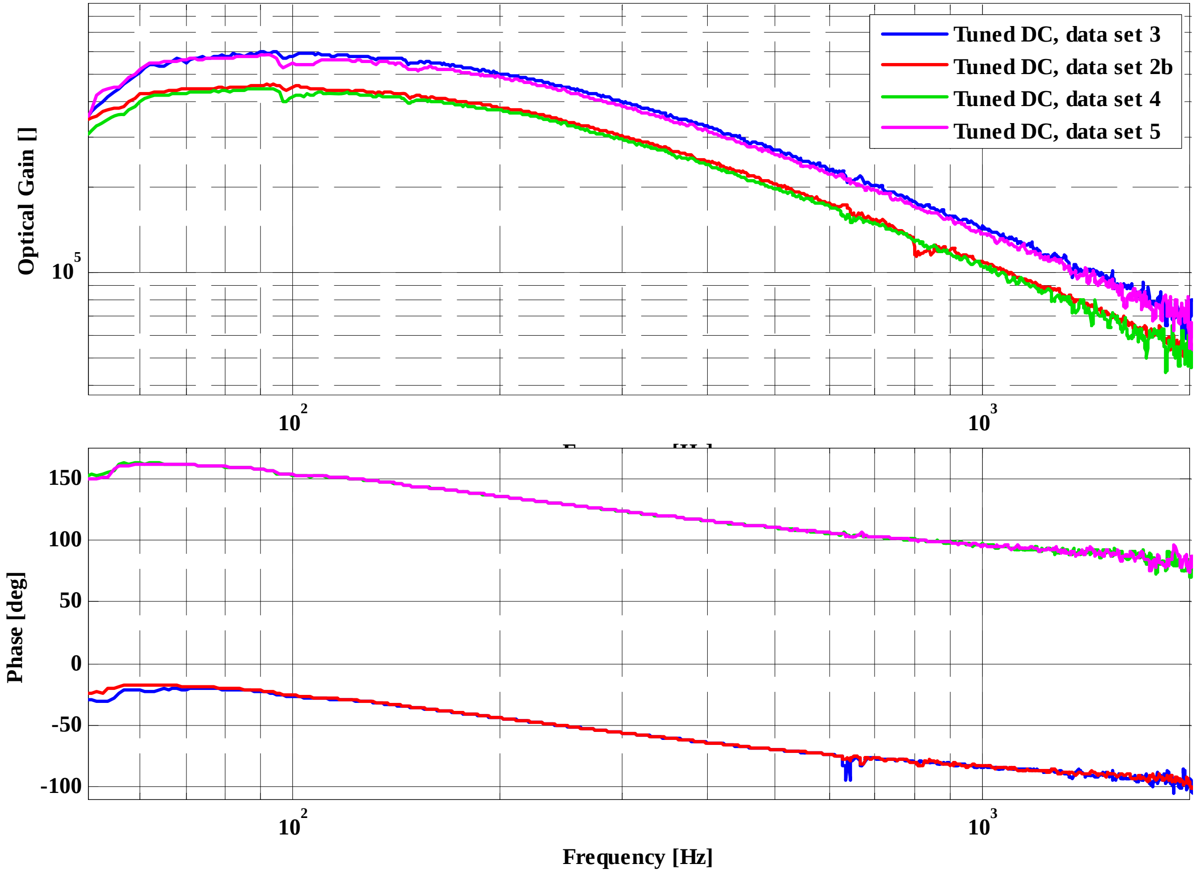


1. Keep the modulation frequency and jump to center zerocrossing.
2. Change the modulation frequency (corresponding to 0 Hz tuning) => only a single zerocrossing exists.

Laser intensity noise coupling for tuned and detuned SR



Tuned DC with various dark fringe offsets



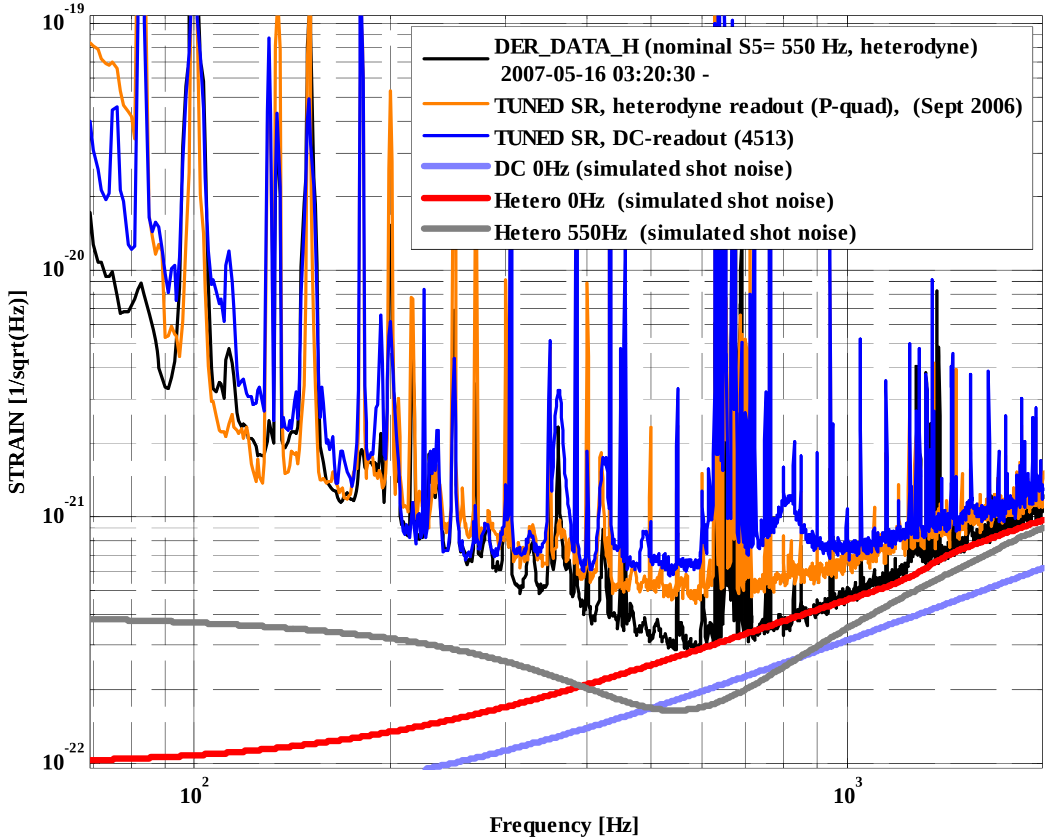
data set **2b: small –dfo**

data set **3: large –dfo**

data set **4: small +dfo**

data set **5: large +dfo**

Comparison of heterodyne 550 Hz, tuned heterodyne and tuned DC



While in the two heterodyne cases the sensitivity is close to simulated shot noise at 2 kHz,

this is not the case for tuned DC.

Combination of tuned SR and squeezing– an option for GEO HF?

- Squeezed light is available for injection

"Coherent Control of Vacuum Squeezing in the Gravitational-Wave Detection Band", Vahlbruch et al, PRL 97, 011101 (2006)

- Tuned Signal-Recycling operation was demonstrated

„Demonstration and comparison of tuned and detuned Signal-Recycling in a large scale gravitational wave detector" , S Hild et al, CQG. ***24*** *No 6, 1513-1523.*

$\Rightarrow$ No need for long filter cavity !