LIGO

DC Readout for Advanced LIGO

P Fritschel

LSC meeting

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Heterodyne & homodyne readouts

Heterodyne: traditional RF modulation/demodulation

- RF phase modulation of input beam
- Lengths chosen to transmit first-order RF sideband(s) to anti-symmetric output port with high efficiency
  - Initial LIGO: RF sidebands are in principal balanced at AS port
  - AdLIGO: with detuned signal recycling, one RF sideband is stronger than the other
- RF sideband(s) serve as local oscillator to beat with GW-produced field
  - Signal: amplitude modulation of RF photocurrent

Homodyne: DC readout

- Main laser field (carrier) serves as local oscillator
  - Signal: amplitude modulation of GW-band photocurrent
- Two components of local oscillator:
  - Field arising from loss differences in the arms
  - Field from intentional offset from dark fringe

Why DC readout now?

- Requires an output mode cleaner
  - Technical amplitude noise on the total output power would be much too high
- GW-band laser power noise has to be extremely low in any case
  - Radiation pressure noise from unbalanced arms
- Anticipated technical noise difficulties with unbalanced RF sidebands
- Anticipated sensitivity advantage: lack of non-stationary noise increase

Technical noise sensitivity

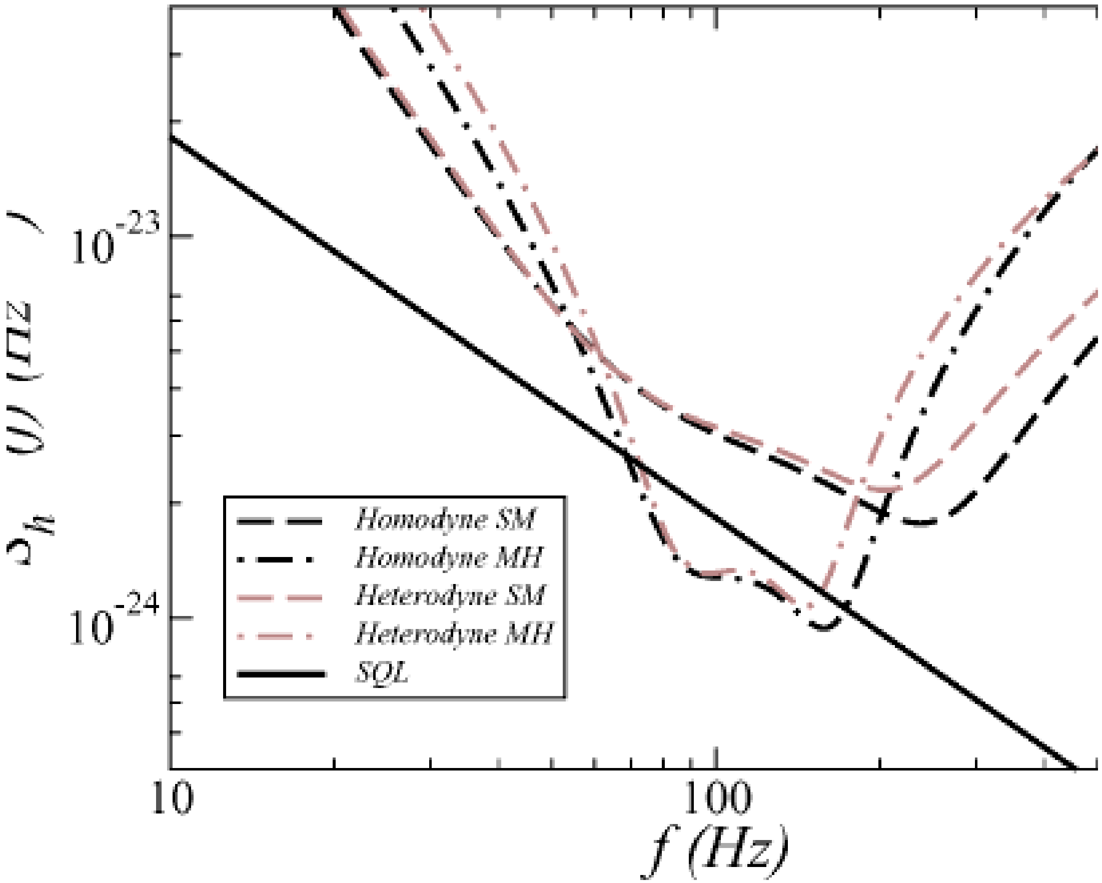
<table>
<tr><th>Noise Source</th><th>RF readout</th><th>DC readout</th></tr>
<tr><td>Laser frequency noise</td><td>~10x more sensitive</td><td>Less sensitive since carrier is filtered</td></tr>
<tr><td rowspan="2">Laser amplitude noise</td><td colspan="2">Sensitivity identical for frequencies below ~100 Hz; both driven by technical radiation pressure</td></tr>
<tr><td>10-100x more sensitive above 100Hz</td><td>Carrier is filtered</td></tr>
<tr><td>Laser pointing noise</td><td colspan="2">Sensitivity essentially the same</td></tr>
<tr><td>Oscillator phase noise</td><td>-140 dBc/rtHz at 100 Hz</td><td>NA</td></tr>
</table>

Implementation comparison

- **Output mode cleaner**
  - RF:
    - long mode cleaner, like the input MC
    - individually isolation mirrors
  - DC:
    - Short, monolithic: 0.5-1 m (similar to a pre-mode cleaner)
    - Requires a bit more beam size reduction
- **Photodetection**
  - Both
    - High quantum efficiency, low back-scatter
    - In-Vacuum
    - Low power, < 100 mW
  - RF
    - Low capacitance, 180 MHz ?

Quantum noise comparison

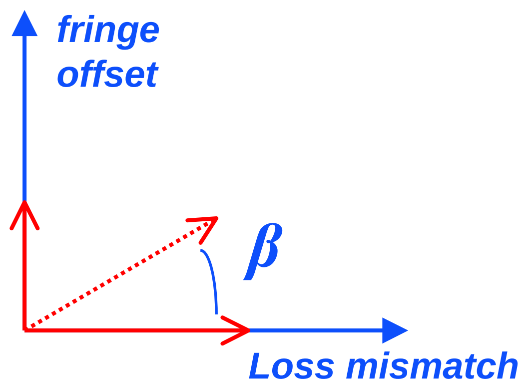
Buonanno &Chen:
Quantum noise + thermal noise



- ***parameters optimized for NS-NS binaries***
- ***single optimal demod phase chosen for RF***
- ***SNR for homodyne higher than heterodyne by***
  - ***5% for spherical mirrors***
  - ***10% for mexican hat mirrors***

Making the DC local oscillator

- Two components
  - Carrier field due to loss differences (not controllable?)
  - Carrier field due to dark fringe offset (controllable)
- Loss mismatch component
  - Average arm round trip loss: 75 ppm
  - Difference between arms: 30 ppm
  - Output power due to mismatch: 1.6 mW



- Detection angle, β
  - Tuned by adjusting fringe offset
  - Broadband (NS-NS) optmimum:
    - Fringe offset power: approx. 0.3 mW
    - Differential arm offset: approx. 1 pm
  - Can tune from 0 to 80 deg with 0-100 mW of fringe offset power

Summary

- Sensitivity of a DC readout is a 'little better' than that of an RF readout: 5-10%
- Technical noise sensitivity favors DC readout
- Technical implementation favors DC readout
- Proceeding with DC readout as baseline design
  - Output mode cleaner design:
    - Vibration isolation
    - Sensing and control: length and alignment
  - Could we switch later to RF readout? Hardest part would be changing the output mode cleaner (to pass the RF sidebands)