Why an interferometer

- Independent sensor for test mass separation.
- It’s optical, does not interfere with test masses.
- Accelerometer sensor noise of $\sim 1 \text{ nm/}\sqrt{\text{Hz}}$ allows to measure $\sim 3 \times 10^{-14} \text{ m/s}^2/\sqrt{\text{Hz}} @ 1 \text{ mHz}$.
- Interferometer noise/non-linearity of $10 \text{ pm/}\sqrt{\text{Hz}}$ allows to measure that accelerometer performance up to $10 \text{ mHz}$. 
Heterodyne Interferometer
Heterodyne Interferometer Non-linearity
Basic Heterodyne Interferometer for DRS

Collimator/isolator assembly

S-polarized output
Test Mass Alignment sensors

Collimator/isolator assembly

S-polarized output
Frequency Stabilization Reference Cavity

Collimator (mode matching)/isolator assembly

S-polarized output
BASELINE DESIGN

To Scale
Beam dia. ~ 1 mm
Mirrors ~ 6 x 8 x 8 mm³
BS cubes ~ 8 x 8 x 8 mm³
PBS’s ~ 8 x 8 x 8 mm³
Some numbers...

- Measurement and reference optical paths are equal within 1 mm,
  \[ \Phi = \frac{2\pi}{\lambda} \times \text{OPD} = 2\pi \times \frac{\nu}{c} \times \text{OPD} \]
  \[ d\Phi = 2\pi \times d\nu/c \times \text{OPD}, \text{ e.g. } d\nu = 10 \text{ GHz and OPD} = 1 \text{ mm} \Rightarrow d\Phi \sim 3.3 \times 10^{-2} \times 2\pi \]
  \[ \Rightarrow d\Phi \sim 7 \times 10^{-2} \times \pi. \]
  We need to suppress frequency noise to $<1 \text{ MHz}/\sqrt{\text{Hz}}$ @ 1 mHz to achieve $7 \times 10^{-6}$ of a fringe = 5 pm/\sqrt{Hz}. (NOTE: $dL/L = d\nu/\nu \Rightarrow dL = d\nu/\nu \times L < 1 \text{ MHz}/\sqrt{\text{Hz}} / 227.5 \text{ THz} \times 1 \text{ mm} < 5 \text{ pm}/\sqrt{\text{Hz}}$)

- Reference cavity is also in $10^{-6} \circ{\text{K}}/\sqrt{\text{Hz}}$ @ 1 mHz environment, with ULE CTE $\sim 10^{-8}/\circ{\text{K}}$ it follows that cavity is stable to $10^{-14}/\sqrt{\text{Hz}}$, i.e. a 5 cm long cavity w/ FSR=3 GHz is stable to $\sim 1 \text{ Hz}/\sqrt{\text{Hz}}$ @ 1 mHz.
and more numbers...

- Proof mass distance stable to ~ 1 nm (~1/600 of a fringe) => let's assume we'll have ~1 nm periodic non-linearity: => max. slope of non-linearity ~ 6 nm_{pp}/330 nm => 18 pm/ nm; worst case we'll get ~20 pm non-linearity over 1 nm motion.

**Q: Over what time scale do masses drift, i.e. is non-linearity out of signal band?**
and even more...

- Measurement and reference optical paths in glass are equal within the dimensional differences of the BSs, PBSs (~100 μm), soak temperature sensitivity then is: \( \text{CTE(BK7)} \times \Delta \text{dim} \times \Delta T \sim 10^{-5} \text{°K} \times 10^{-4} \text{m} \times 10^{-6} \text{°K/√Hz} = 10^{-15} \text{ m/√Hz} \), i.e. there is room. We might use ULE for all optics since the optical bench is ULE.
Summary

- Heterodyne interferometer used as independent, non-interfering test mass separation sensor.
- Interferometer performance: ~10 pm/√Hz @ 1 mHz limited by non-linearity and pointing fluctuations (compared to 1 nm/√Hz @ 1 mHz for accelerometer noise)
The DRS Interferometer

A. Kuhnert

October 19th, 2001
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- Interferometer noise/non-linearity of 10 pm/\sqrt{Hz} allows to measure that accelerometer performance up to 10 mHz.
Heterodyne Interferometer

\[ P_{\text{IN}} \]
\[ f_0 \]
\[ S_{\text{IN}} \]
\[ f_0 + df \]
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