Topics on Commissioning of KAGRA

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Background image: (c)KAGRA Collaboration / Rey.Hori
Overview

-- The current status of IFO commissioning of KAGRA
  * X arm experiment
  * Feedback to test mass (commissioning with both arms)

-- Commissioning topics from KAGRA
  * ALS (green lock)
  * Mach-Zehnder modulator
Current Status
All of the main mirrors installed
3 TMs are now ~20K

now cooling

~20K

3 km
All of the main mirrors installed
3 TMs are now ~ 20K

X arm comm. - 2019 Jan
Our current focus: Commissioning of both arms is now on-going (feedback to test mass)

- All of the main mirrors installed
- 3 TMs are now ~ 20K

X arm comm. - 2019 Jan
X arm commissioning

-- Succeeded in locking the X arm
  * hand-over from ALS to the main laser signal
  * direct lock of the main laser freq to X arm
  * longest lock: > 1day

-- Characterized the cavity, and test mass suspension
  * cavity scan
  * ringdown
  * loss measurement
  * suspension TF measurement

=> No major issues found
Feedback to test mass

**Configuration:** use X arm (CARM) to stabilize the main laser frequency, and then feedback the green lock signal of Y arm to ETMY

- Use a cryogenic test mass as actuators of LSC for the first time
- damping of mechanical resonances
- design of the blending filter for each stage
- trial of the lock

→ Ongoing
Topics
ALS (green lock)

-- LIGO/KAGRA type lock acquisition needs ALS
  1. keep the main laser off-resonant by the ALS
  2. lock the central interferometer
  3. put the main laser frequency at resonances of both arms

-- Requirement of control by ALS
  CARM < ~ 1-10 Hz
  DARM < ~200 Hz

-- Requirement for ALS CARM
  will be more stringent in 3G
  => CARM_{3G} < ~ 0.1-1 Hz
(CARM linewidth ∝ [roundtrip loss in arm] / L, assuming efficient power recycling)
**Topics: ALS**

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**KAGRA ALS**

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**Features:**

* Green lasers injected from center area
  - don’t need km-long optical fibers,
  - no laser rooms in end stations
  - guide for the alignment

* CARM/DARM signals are obtained by the sum/diff of voltage signals
  - optical beat notes in aLIGO
KAGRA ALS: Noise characterization

- Fiber phase noise
- Doppler?
- RMS = 8.2 Hz
- Resonance width: 36 Hz

Graph showing frequency noise versus frequency with various labeled curves representing different noise sources, such as optical fiber, green lock PD, green lock servo, green lock VCO, seismic, main-laser related, PLL related, and cumulative RMS.
Found issues: Fiber noise

-- To meet the requirement, we had to carefully reduce the fiber noise.
→ fix the fibers to stable pillars
→ remove the vibration source for the fibers;
we stopped clean filter units

-- Still the fiber noise is limiting the ALS noise.

TO DO:
=> Implementation of fiber noise cancellation technique
Found issues: Doppler noise

-- The **main laser** and the **green lasers** take **different paths** before their injection to arms.

-- The motion of each suspended mirror that reflects only **IR** or **green** causes the phase noise → Doppler noise

-- Coherence found between PR2 motion and the ALS noise, in fact.

**TO DO:**

=> Careful damping of them

For 3G ALS design...

=> Pick off the main beam more down-stream or inject green from more up-stream
Found issues: IMC cavity pole

\[
\delta f_{\text{psl}} \rightarrow \delta f_{\text{arm}} \rightarrow \delta f_{\text{ifo}}
\]

\(\delta f_{\text{psl}} = \delta f_{\text{arm}}\)

\(\delta f_{\text{ifo}} = \frac{\delta f_{\text{psl}}}{1 + i f / f_{\text{imc}}}\)

\[\Rightarrow \delta f_{\text{arm}} - \delta f_{\text{ifo}} = \frac{i f / f_{\text{imc}}}{1 + i f / f_{\text{imc}}} \delta f_{\text{arm}}\]

* Let us consider the arm length fluctuation at 0.2 Hz.
* Let us assume \(\delta f_{\text{arm}} \approx 1 \text{ um/\sqrt{Hz}}\) at 0.2 Hz

Case 1: \(f_{\text{imc}} = 5 \text{ kHz (2G case)}\) => \(\delta f_{\text{arm}} - \delta f_{\text{ifo}} > 0.1 \text{ nm/\sqrt{Hz}}\) OK

Case 2: \(f_{\text{imc}} = 500 \text{ Hz}\) => \(\delta f_{\text{arm}} - \delta f_{\text{ifo}} > 1 \text{ nm/\sqrt{Hz}}\) Problematic

* Pick off the main beam after IMC for the lock of AUX laser
  or
* Avoid using high finesse/very long IMC in 3G detectors
Toward 3G: silicon is black

2G detectors: 1064 nm, fused silica or sapphire
=> test mass is transparent for green (532nm)

In 3G detectors, we might use 1550nm/2um and silicon
=> silicon is black for 775nm or 1um
=> we can’t use “green lock”

We have to develop green-lock like technique
with, for example, Optical Frequency Comb, instead of SHG

Example:

<table>
<thead>
<tr>
<th>0</th>
<th>optical frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1550 nm</td>
<td>Main (1550 nm)</td>
</tr>
<tr>
<td>2 um</td>
<td>AUX1 (2 um)</td>
</tr>
<tr>
<td>2 um</td>
<td>AUX2 (2 um)</td>
</tr>
<tr>
<td>........................</td>
<td></td>
</tr>
</tbody>
</table>

https://en.wikipedia.org/wiki/Silicon
Mach-Zehnder modulator

-- Design of KAGRA or ET includes detuning of SRC

-- Detuning can re-shape the quantum noise spectra, but increase some noise couplings.

**Major coupling:** phase noise of the oscillator for the modulation

* RF AM can reduce such couplings

→ RF AM generation using *Mach-Zehnder modulator* is proposed and tested.
On-site test

-- MZM can create arbitrary combination of AM and PM, by changing the phase difference btw signals applied to two EOMs

-- Basic function has been demonstrated:
* modulation index vs phase diff.
* long-term stability

From a paper in preparation by Kohei Yamamoto
On-site test: Noise issue

-- Our system could not yet meet the requirement for the residual displacement noise of each MZI

TO DO:
* larger bandwidth for improved suppression
* make MZM system less sensitive to external vibrations

1st MZ interferometer

2nd MZ interferometer

From a paper in preparation by Kohei Yamamoto
Summary

-- All the mirrors installed, X arm commissioned.
-- Our current focus: To lock both arms → feedback to test mass

-- presented two topics:

**KAGRA ALS**
* basically working well
* scalable to 3G (don’t need ~10km-long fibers)
* issues to be addressed toward 3G
  - fiber noise, doppler noise, effect of IMC cavity pole

**Mach-Zehnder modulator**
* detuning may require an advanced technique on modulation
* on-site test was done, and the basic functions were confirmed
* displacement noise needs to be reduced
We haven’t discussed about after O3 schedule yet.
Measured parameters

= primary parameters =
* Roundtrip loss of X arm cavity
* Cavity finesse (IR)
* Cavity finesse (Green)
* Mode matching to the cavity (IR)
* Mode matching to the cavity (Green)
* Gouy phase separation of two QPDs (IR & Green)
* loss map on test mass surface
* CMRR for the cavity displacement
* Transverse mode spacing

= others =
* Cavity length
* Various transfer functions of the test mass suspensions
* Beam profile of the IR on TMSX table

ROOM TEMP

Good: within requirement

86(3) ppm (klog 7307)
1411(02)(30) (klog 7307)
41.0(3) (klog 6697)
91(1) % (klog 7307)
~ 70 % (klog 7335)
(klog 7575, 7502)

34.79(5) kHz (klog 7332) <-- 34.70(2) kHz from measured RoCs
does not match with the estimation from measured RoCs,
but still within requirement

2999.990(2) m (klog 7332,7301)
(klog 7502)
Current status

-- Hardware readiness:
  * All of the mirrors installed
  * 3 out of 4 test masses are now at ~20K.
    The rest will reach ~20K in one month.

-- Interferometer commissioning Status:
  * Single arm (X arm) commissioning was done (~Jan 2019)
    → ALS (green lock) was tested.
  * Our current focus: lock both arms at the same time
    → feedback to test mass actuators (hierarchical control)
Green-lock related optics

We will align green beam to X arm as well as IR beam in September.
-- On PSL table, optics for both X and Y are ready. For POP table, optics for X are ready early in September.
-- ~ 50 m long green fibers have been laid.