Current Status of the 40m Detuned RSE Prototype

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2004 Aspen Winter Conference on Gravitational Waves
Gravitational Wave Advanced Detector Workshops

Feb. 15 - 21, 2004

40m Team:
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Objectives

- Develop **lock acquisition procedure** of detuned Resonant Sideband Extraction (RSE),
- Characterize noise mechanism,
- Verify optical spring effect,
- Develop DC readout scheme,
- etc.

for **Advanced LIGO, LCGT, and other future GW detectors**
Target Sensitivity of Advanced LIGO and 40m

Advanced LIGO Strain Sensitivity

40 Meter Strain Sensitivity

$\eta f_0 / H^2$ vs. $f$/Hz

Residual Gas

Total noise

Quantum
Important Achievement (1)
Installation of FP Michelson

**September, 2003**

- Four TMs and BS: installed
Important Achievement (2)
Modification of PSL

October 2003

- Stabilize frequency of light with Reference Cavity (RF) after Pre-Mode Cleaner (PMC) instead of before PMC
- Noise sources associated with PMC and steering optics after PMC should be suppressed!

[S. Kawamura, “Configuration Study of Pre-Mode Cleaner and Reference Cavity in the 40m PSL System, LIGO-T030149-00-R (2003)]
Important Achievement (3)
Improvement of PSL Noise

October 2003
- PSL noise improved above 1 kHz
- New Calibration Method (AOM as a reference) used

[S.Kawamura and O. Miyakawa, “Convenient and Reliable Method for Measuring Frequency Noise of the Pre-Stabilized Laser”, LIGO-T030239-00-R (2003)]
November 2003

- FP Michelson locked
- Method similar to the one used for TAMA
- Interesting phenomena observed

[S. Kawamura and O. Miyakawa, “Polarity of Michelson Length Signal Obtained at the Symmetric Port In a Fabry-Perot Michelson Interferometer”, LIGO-T030295-00-R (2004)]
Important Achievement (5)
Spectrum of FP Michelson

December 2003

- Displacement spectrum obtained
- With all the whitening/de-whitening filters ON
- Convenient calibration method (Michelson mid-fringe locking) used

February 2004

- Power Recycling Mirror (PRM) and Signal Extraction Mirror (SEM) installed
Signal Extraction Method

Carrier

PRM

BS

ITMy

ETMy

SEC

PRC

SEM

ITMx

ETMx

\[ f_1:33\text{MHz} \]

\[ f_2:166\text{MHz} \]

Phase: flipped

Off-Resonant

Detuned

Anti-Resonant

Aspen 2004
Signal Extraction Matrix

\[ L_+ = \frac{L_x + L_y}{2} \]
\[ L_- = L_x - L_y \]
\[ l_+ = \frac{l_x + l_y}{2} \]
\[ l_- = l_x - l_y \]
\[ l_s = \frac{l_{sx} + l_{sy}}{2} \]

<table>
<thead>
<tr>
<th>Port</th>
<th>Dem. Freq.</th>
<th>Dem. Phase</th>
<th>( L_+ )</th>
<th>( L_- )</th>
<th>( l_+ )</th>
<th>( l_- )</th>
<th>( l_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>( f_1 )</td>
<td>10</td>
<td>1</td>
<td>-3.8E-9</td>
<td>-1.2E-3</td>
<td>-1.3E-6</td>
<td>-2.3E-6</td>
</tr>
<tr>
<td>AP</td>
<td>( f_2 )</td>
<td>271</td>
<td>-4.8E-9</td>
<td>1</td>
<td>1.2E-8</td>
<td>1.3E-3</td>
<td>-1.7E-8</td>
</tr>
<tr>
<td>SP</td>
<td>( f_1 \times f_2 )</td>
<td>189,32</td>
<td>-1.7E-3</td>
<td>3.0E-4</td>
<td>1</td>
<td>-3.2E-2</td>
<td>-1.0E-1</td>
</tr>
<tr>
<td>AP</td>
<td>( f_1 \times f_2 )</td>
<td>4,81</td>
<td>-6.2E-4</td>
<td>1.5E-3</td>
<td>7.5E-1</td>
<td>1</td>
<td>7.1E-2</td>
</tr>
<tr>
<td>PO</td>
<td>( f_1 \times f_2 )</td>
<td>164,12</td>
<td>3.6E-3</td>
<td>2.7E-3</td>
<td>4.6E-1</td>
<td>-2.3E-2</td>
<td>1</td>
</tr>
</tbody>
</table>

Calculated by FINESSE

(A. Freise: http://www.rzg.mpg.de/~adf/)

PO: light from BS to ITMy
Double Demodulation

- Double Demodulation used for $I_+$, $I_-$, and $I_s$
- Demodulation phases optimized to suppress DC and to maximize desired signal

[S. Kawamura, “Signal Extraction Matrix of the 40m Detuned RSE Prototype”, LIGO-T040010-00-R (2004)]
Length Tolerances

- Acceptable cavity length deviations from the ideal points:
  - 6 cm for \( l^- \)
  - 3 mm for \( l^+ \)
  - 3 mm for \( l_s \)

Example: Signal matrix with \( l^+ \) deviation of 1 cm

<table>
<thead>
<tr>
<th>Port</th>
<th>Dem. Freq</th>
<th>Dem. Phase</th>
<th>( L^- )</th>
<th>( L^- )</th>
<th>( l^+ )</th>
<th>( l^- )</th>
<th>( l^+_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>( f_1 )</td>
<td>334</td>
<td>1</td>
<td>-7.6E-9</td>
<td>-1.2E-3</td>
<td>-4.1E-6</td>
<td>-2.3E-6</td>
</tr>
<tr>
<td>AP</td>
<td>( f_2 )</td>
<td>230</td>
<td>-1.3E-9</td>
<td>1</td>
<td>3.0E-8</td>
<td>1.3E-3</td>
<td>-1.7E-8</td>
</tr>
<tr>
<td>SP</td>
<td>( f_1 \times f_2 )</td>
<td>162,73</td>
<td>-6.5E-4</td>
<td>3.5E-4</td>
<td>1</td>
<td>-5.6E-2</td>
<td>1.3E-1</td>
</tr>
<tr>
<td>AP</td>
<td>( f_1 \times f_2 )</td>
<td>173,218</td>
<td>1.5E-3</td>
<td>4.2E-4</td>
<td>-2.1</td>
<td>1</td>
<td>-2.4E-1</td>
</tr>
<tr>
<td>PO</td>
<td>( f_1 \times f_2 )</td>
<td>329,153</td>
<td>1.1E-3</td>
<td>2.7E-3</td>
<td>2.6</td>
<td>-1.6E-1</td>
<td>1</td>
</tr>
</tbody>
</table>

Lock Acquisition of Detuned RSE

1. lock central part using beat signal between $f_1$ and $f_2$

2. lock arm cavities

- Central part: not disturbed by lock status change of arm cavity
- Question: Not disturbed by flash of SBs or SBs of SBs in arms?
- Promising: TAMA using 3\textsuperscript{rd} harmonic demodulation in PRFPMI
Lock Acquisition of Central Part

Ideal Procedure: Lock one by one

[for example]
Step 1: Lock $l_+$ robustly
Step 2: Lock $l_-$ robustly
Step 3: Lock $l_s$

- Find primary signal not disturbed by the other two DOFs
- Find secondary signal not disturbed by the residual DOF
Quality of I+ Signal (dc=0, I+ Max)

Nb-arm detuned RSE, DDM at SP, phase1=189, phase2=33 (dc=0)
Dependence of $l+$ Signal (dc=0, $l+$:Max) on $l-$
Dependence of I+ Signal on Demodulation Phases

No-arm detuned RSE, DDM at SP, phase1=189 (dc=0), phase2: swept

- phase2=32 (dc=0)
- phase2=60
- phase2=32 (symmetric)
- phase2=88 (symmetric)
- phase2=120
- phase2=150
- phase2=180

No-arm detuned RSE, DDM at SP, phase1:Swept, phase2=32 (symmetric)

- phase1=180 (max)
- phase1=210
- phase1=240
- phase1=270
- phase1=300
- phase1=330
- phase1=360
Quality of $I^+$ Signal (Symmetric, $dc \neq 0$)

See Movie
Dependence of $I_+$ Signal (Symmetric, $dc \neq 0$) on $I_-$
Dependence of $I^+$ Signal (Symmetric, $dc\neq 0$) on $I_s$
Dependence of $I_+$ Signal (Symmetric, $dc \neq 0$) on $I_-$ and $I_s$
Beat between $f_1$ and Non-Resonant SB $f_3$ (AM)

Hint: G. Heinzel at Garching 30m
Dependence of Beat Signal between f1 and f3 on l-
Dependence of Beat Signal between f1 and f3 on ls
Quality of I- Signal

Error Signal

No arm detuned RSE, DDM at AP, phase1=4, phase2=81 (dc=0)
Dependence of I- Signal on Is
I- Signal Divided by AP signal with different Dem. Phase

Hint: H. Grote at GEO

Divided by
Dependence of Divided I- Signal on Is
Dependence of Divided l- Signal on l+
Quality of Is Signal

No arm detuned RSE, DDM at PO, phase1=164, phase2=12 (dc=0)
Dependence of $I_s$ Signal on $I^+$

![Graph showing the dependence of $I_s$ signal on $I^+$](image.png)
Looking for Good Signal …

Have tried the following, but not significant improvement…

- f1-dem, f2-dem
- For l+:
  Single sideband f2, AM f2
  NR pm, am, single sideband f3:
  (f2-f3)-dem, (f1+f3)-dem
- For l-, ls:
  Signal divided by the following:
  2×f1-dem, 2×f2-dem, DDM with different dem phases, (f2-2×f1)-dem
We Should Try More …

- Analyze error signal with one DOF locked
- Try more various signals including mechanical dither signal
- Develop quick acquisition method
- Tighten suspended optics rigidly with respect to local frame, then manually bring three DOFs near lock point to acquire lock?
Summary

- Lots of achievements; experiment on 40m going very fast and smoothly
- Almost ready to try lock acquisition
- Lock acquisition: not so easy
- Need more investigation for lock acquisition

*Hope we succeed in locking detuned RSE very soon!*