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# Development of an RSE Interferometer Using the Third Harmonic Demodulation

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Suspended-mass **RSE**  
locked for the first time  
in the world

- using single modulation
- by Third Harmonic Demodulation

# Contents

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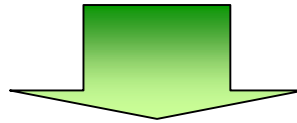
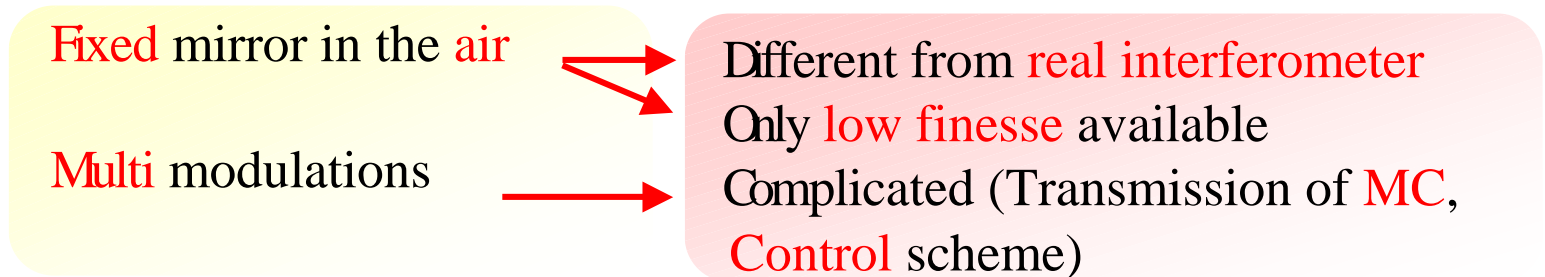
- Purpose of our experiment
- Signal sensing for SEC using Third Harmonic Demodulation
- Experiment
- Summary and next plan

# Purpose of our RSE experiment

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## Other table top experiments

### Feature



## Objectives/Scope

To establish the control scheme using single modulation

Suspended mirror

High finesse cavity in vacuum chamber

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## Most difficult point of RSE locking

the extraction of  
a Signal Extraction Cavity(SEC) signal( $\delta I_s$ ).

Mixture of  $\delta L_+$  and  $\delta L_-$  signal  
to  $\delta I_s$  signal is quite large.

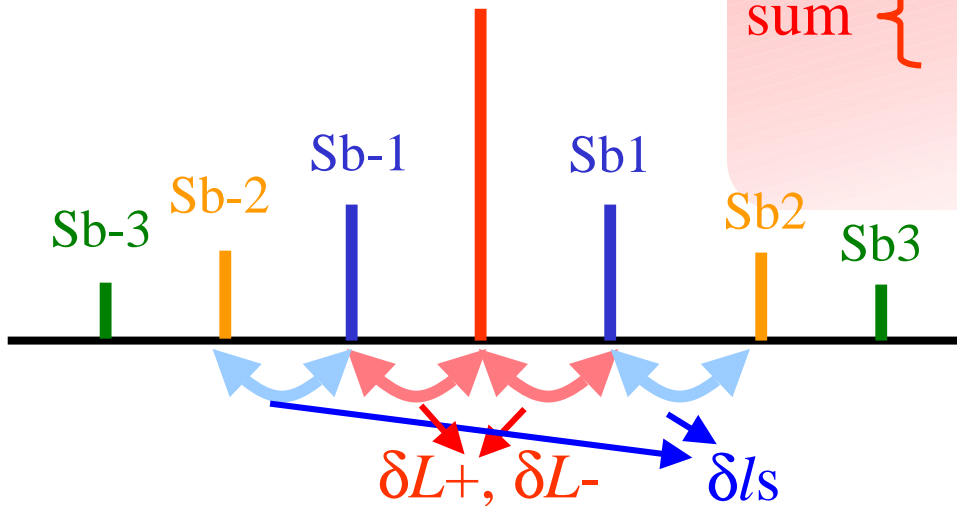


Need to improve the signal ratio of  $\delta I_s$

- multi modulation
- establish a new sensing scheme using single modulation

# Application of 3<sup>rd</sup> order harmonic demodulation

1<sup>st</sup> order demod. Ca

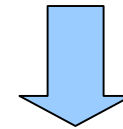


sum {

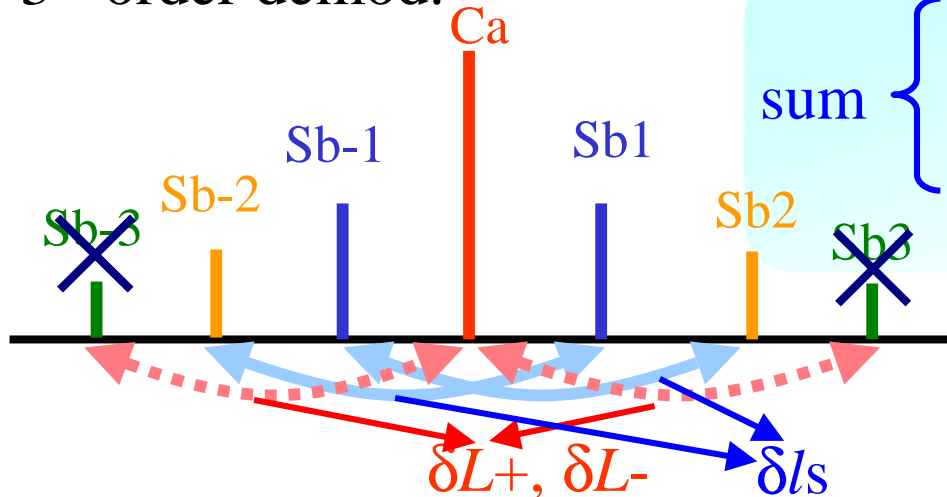
$$\delta L+, \delta L- \ominus \delta(\text{Ca}) \times (\text{Sb1}, -1)_{\text{DC}}$$

$$\delta ls \ominus \delta(\text{Sb1}, -1) \times (\text{Sb2}, -2)_{\text{DC}}$$

$$+ (\text{Sb1}, -1)_{\text{DC}} \times \delta(\text{Sb2}, -2)$$



3<sup>rd</sup> order demod.



sum {

~~$$\delta L+, \delta L- \ominus \delta(\text{Ca}) \times (\text{Sb3}, -3)_{\text{DC}}$$~~

**→ zero**

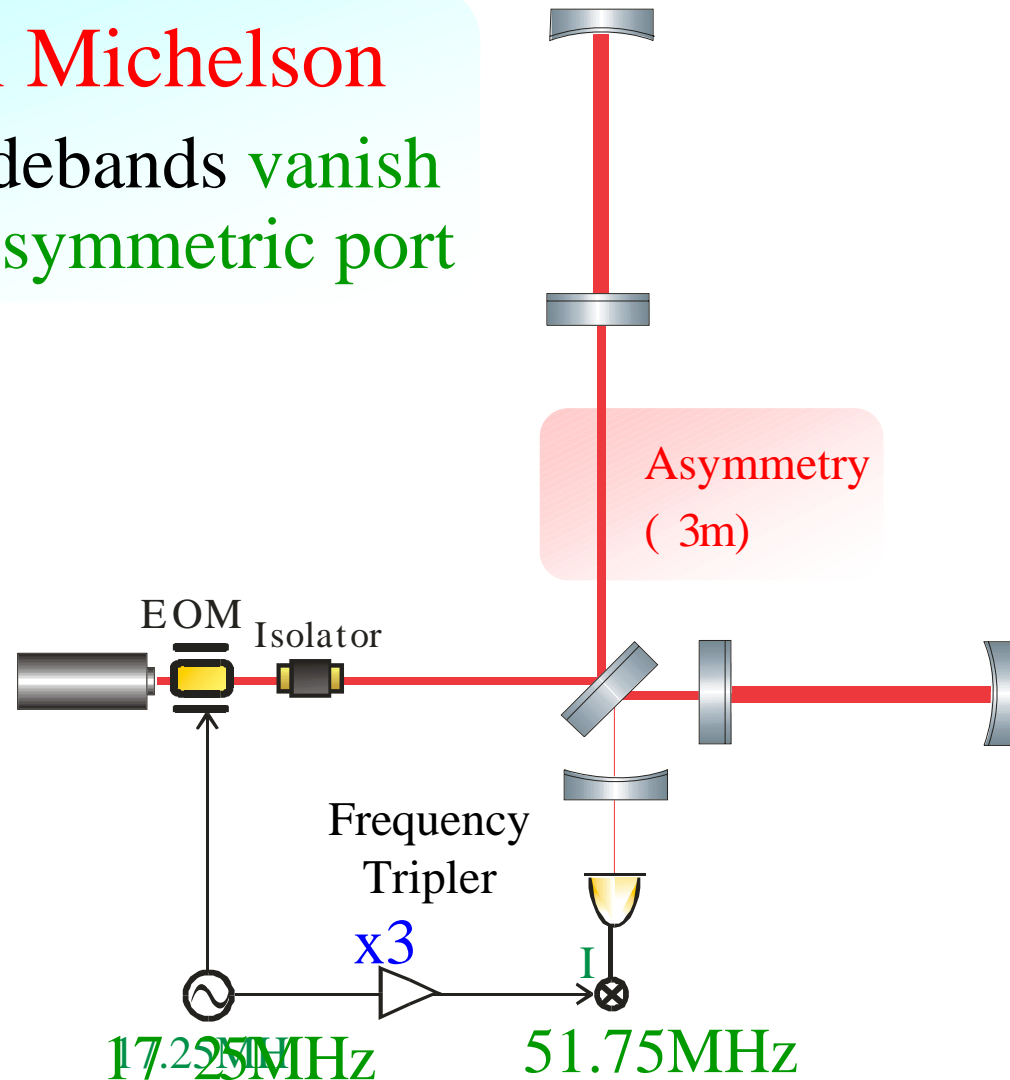
$$\delta ls \ominus \delta(\text{Sb1}, -1) \times (\text{Sb}, -2, 2)_{\text{DC}}$$

$$+ (\text{Sb}, -1, -)_{\text{DC}} \times \delta(\text{Sb2}, -2)$$

# Dark condition of 3<sup>rd</sup> order sideband

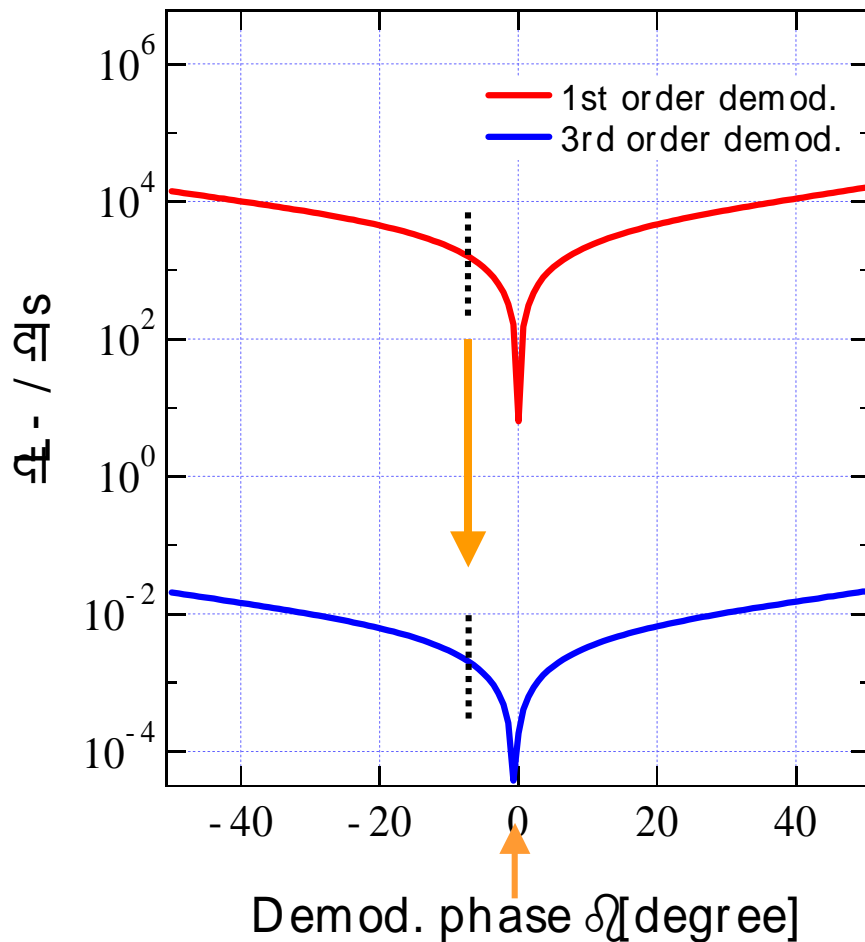
## Asymmetry in Michelson

3rd order sidebands **vanish**  
at the **anti symmetric** port



# Signal ratio

Signal ratio of  $\delta L$ - and  $\delta ls$   
with 1<sup>st</sup> and 3<sup>rd</sup> order demodulation

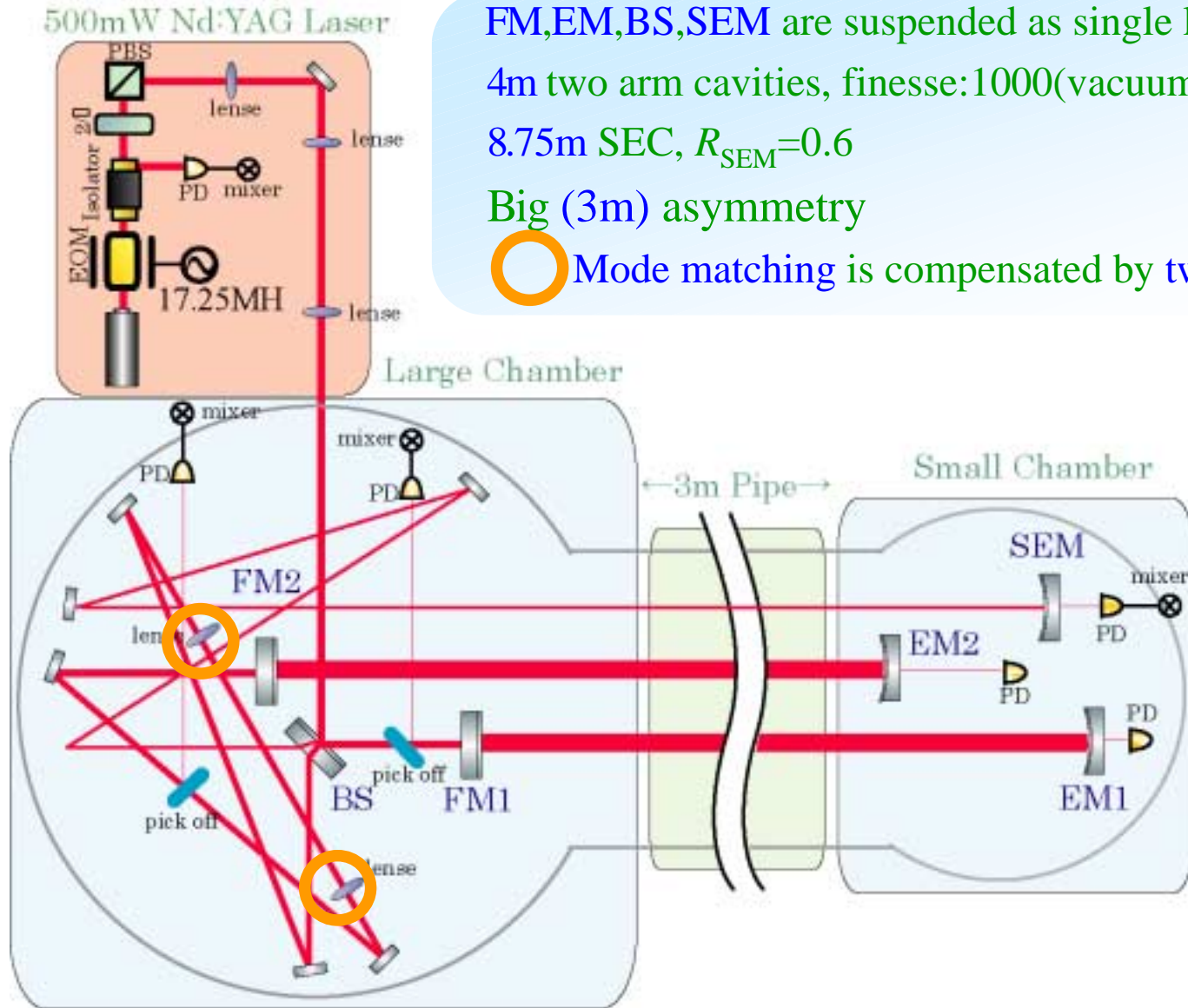


If the demodulation phase is exactly zero,  $\delta L$ - is zero in both 1<sup>st</sup> and 3<sup>rd</sup> demodulation case, but in non zero demodulation phase case, 3<sup>rd</sup> demodulation has good signal ratio.

The depth of improvement is depend on the asymmetry length. We can adjust the modulation frequency instead of asymmetry length to satisfy the condition.



# RSE experimental setup



FM, EM, BS, SEM are suspended as single loop pendulum.

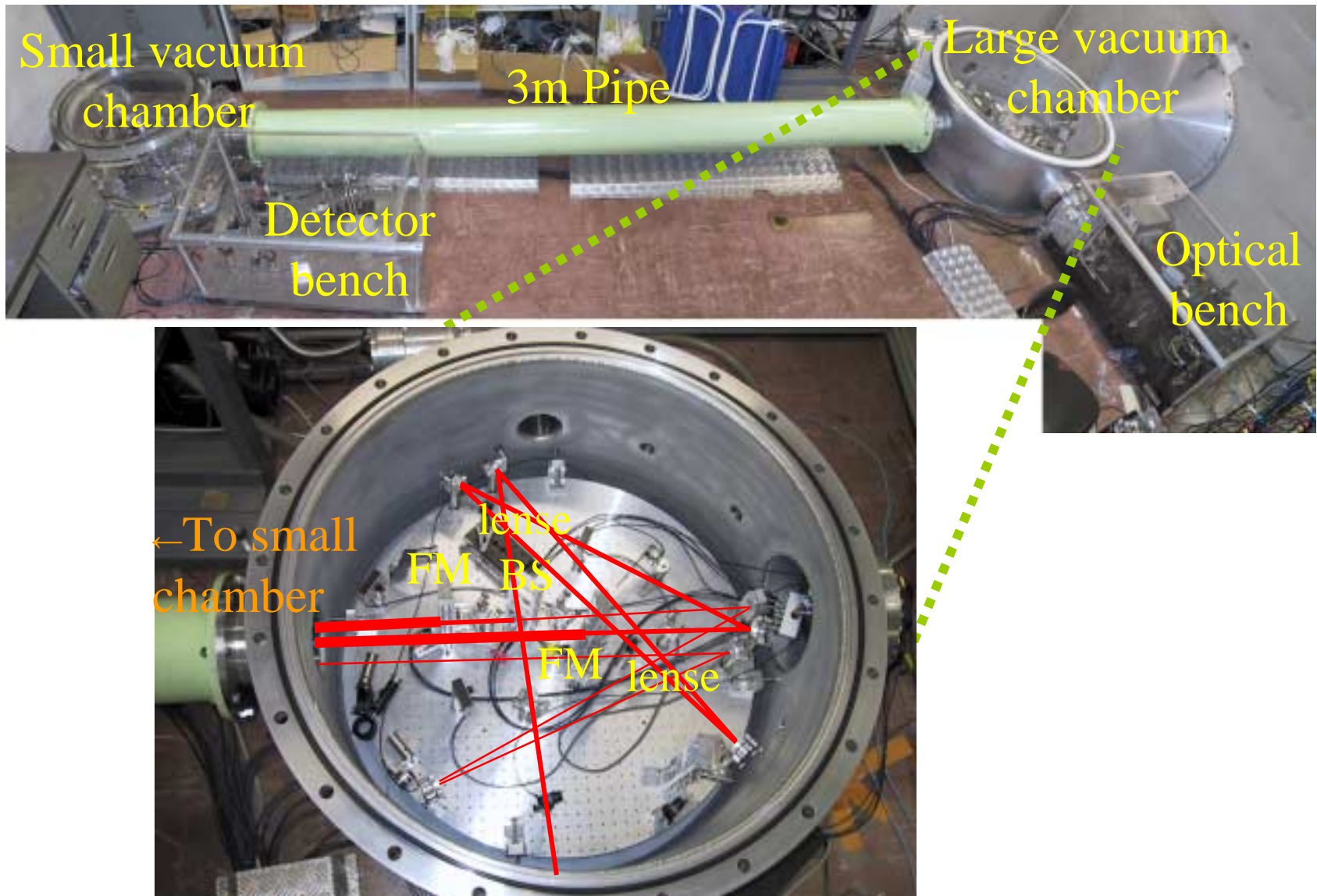
4m two arm cavities, finesse: 1000 (vacuum) or 300 (air)

8.75m SEC,  $R_{SEM} = 0.6$

Big (3m) asymmetry

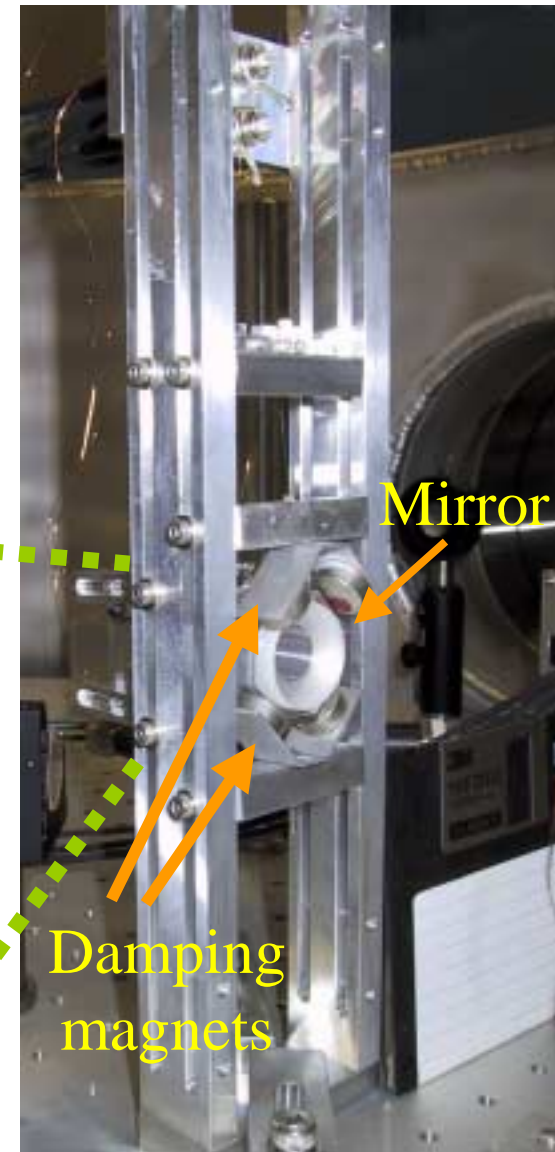
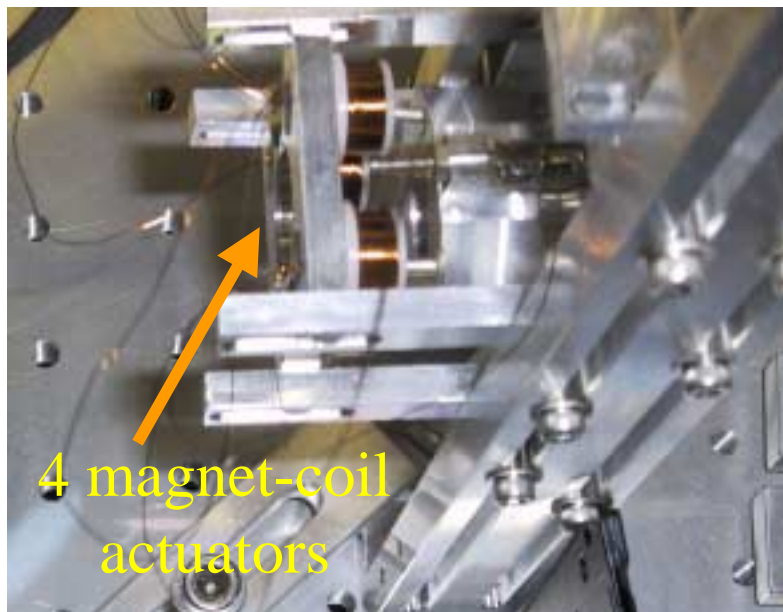
○ Mode matching is compensated by two lenses.

# Experimental setup of RSE



# Small Suspension System (SSS)

- 1 inch mirror is suspended by **single-loop wire**.
- Mirror **position** and **orientations** are controlled by **4 coil-magnet actuators**.
- Motion of the mirror at resonant frequency is efficiently damped by the **eddy-current damping**.



# RSE control topology using THD

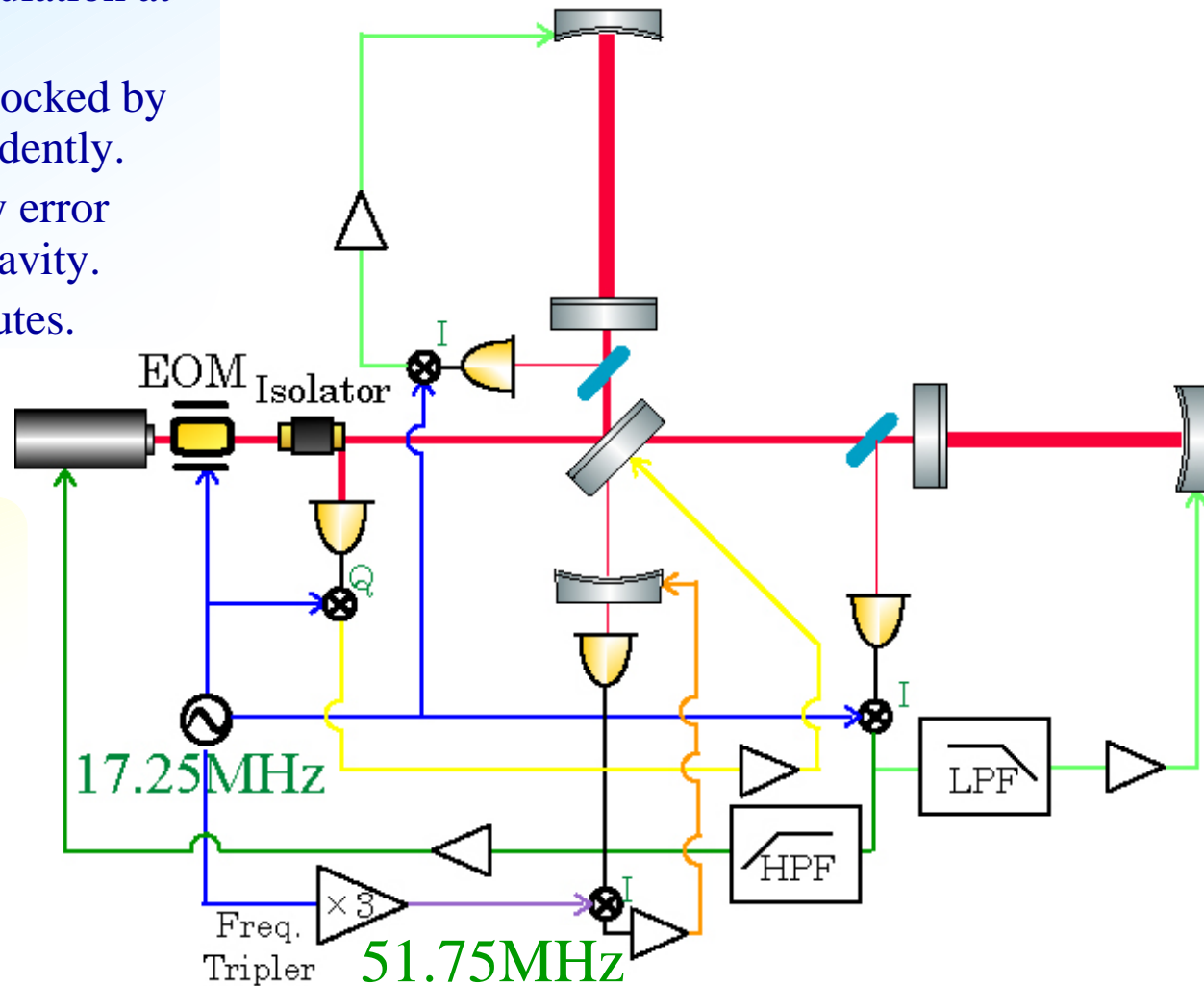
SEC error signal is extracted by Third Harmonic Demodulation at Anti Symmetric port.

Two FP arm cavities are locked by picked-off light independently.

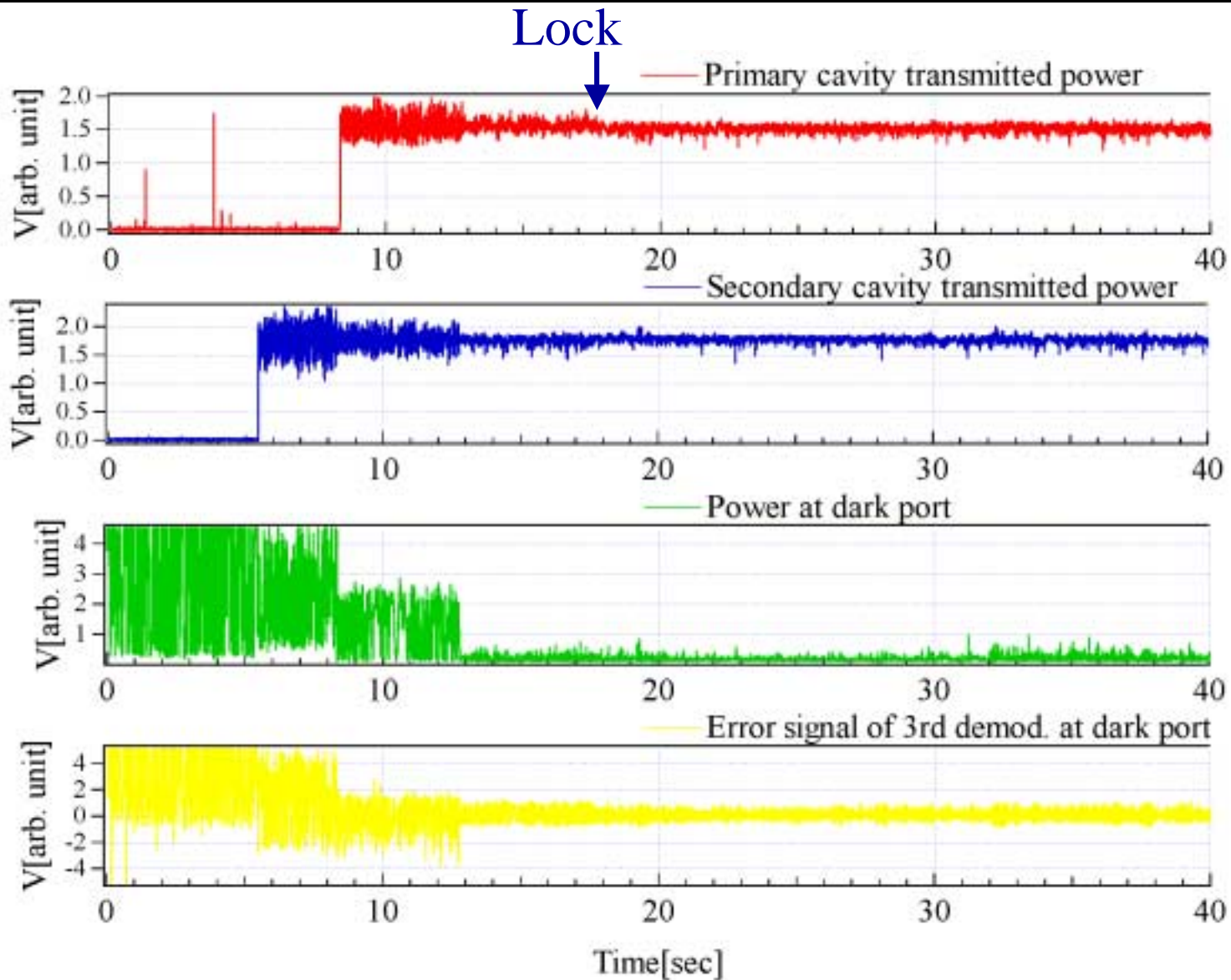
Frequency is stabilized by error signal of primary arm cavity.

Lock time is over 10 minutes.

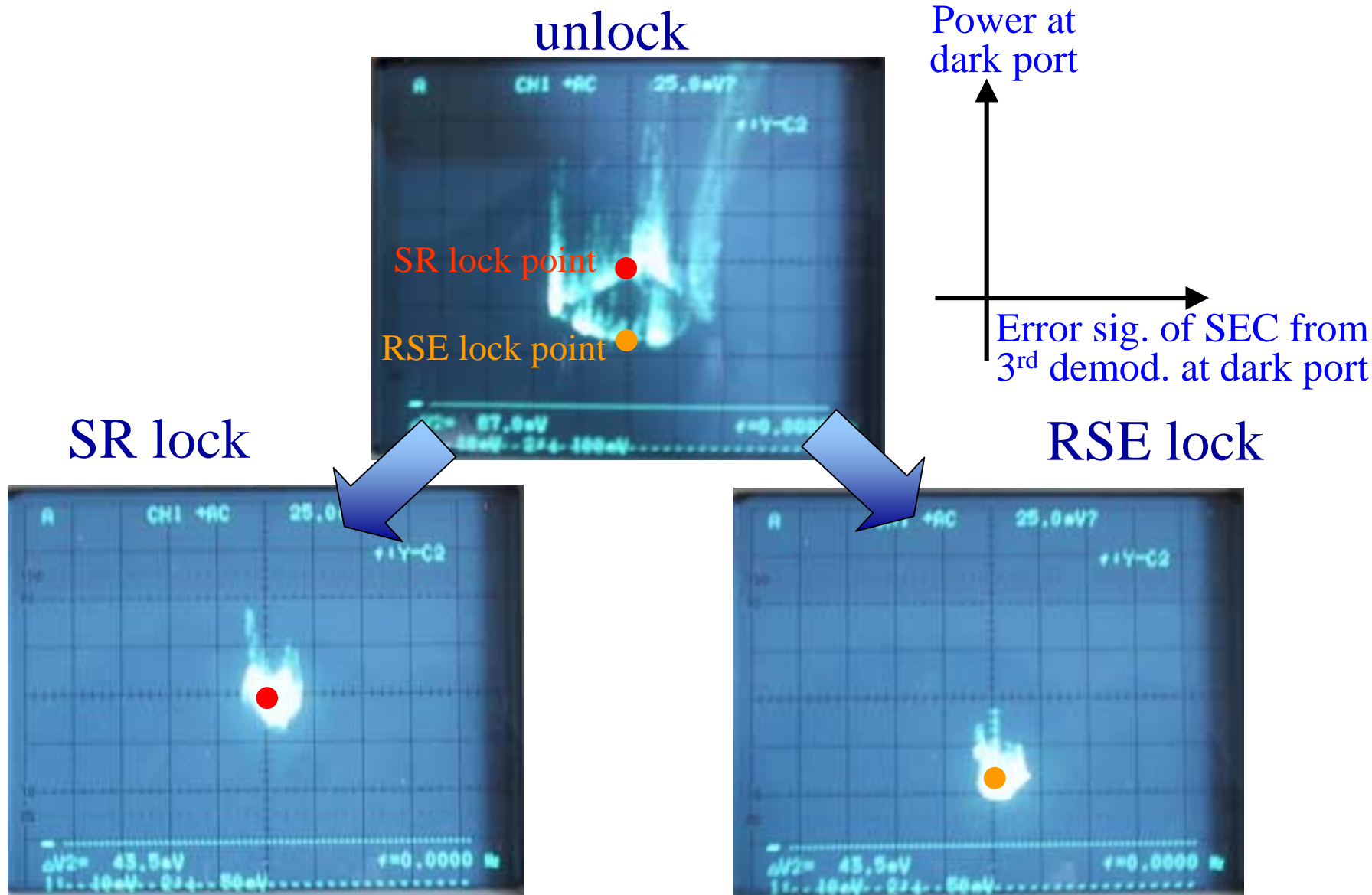
not vacuum  
without Power Recycling  
not detuned



# Lock acquisition of RSE



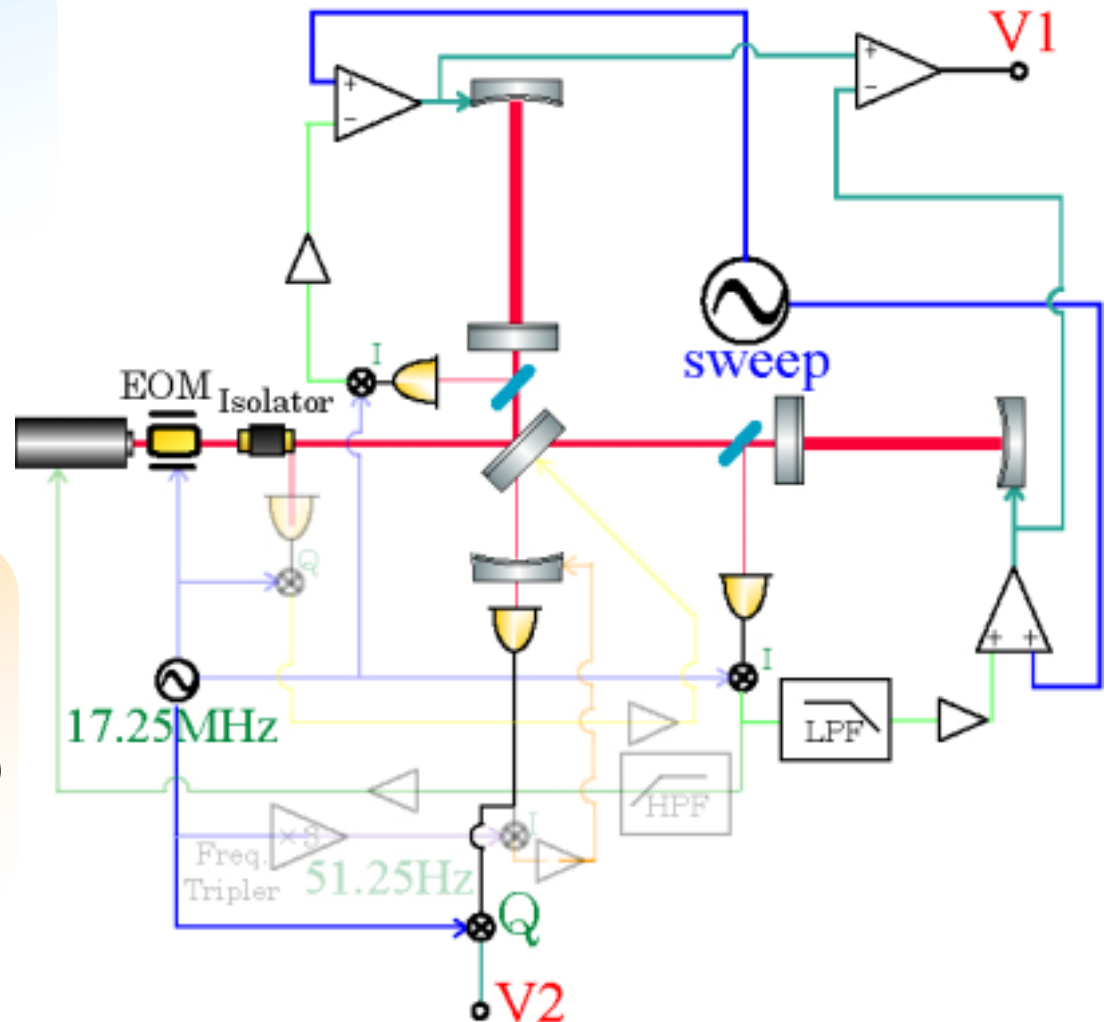
# Locking selection of SR/RSE



# Measurement of cavity Transfer Function

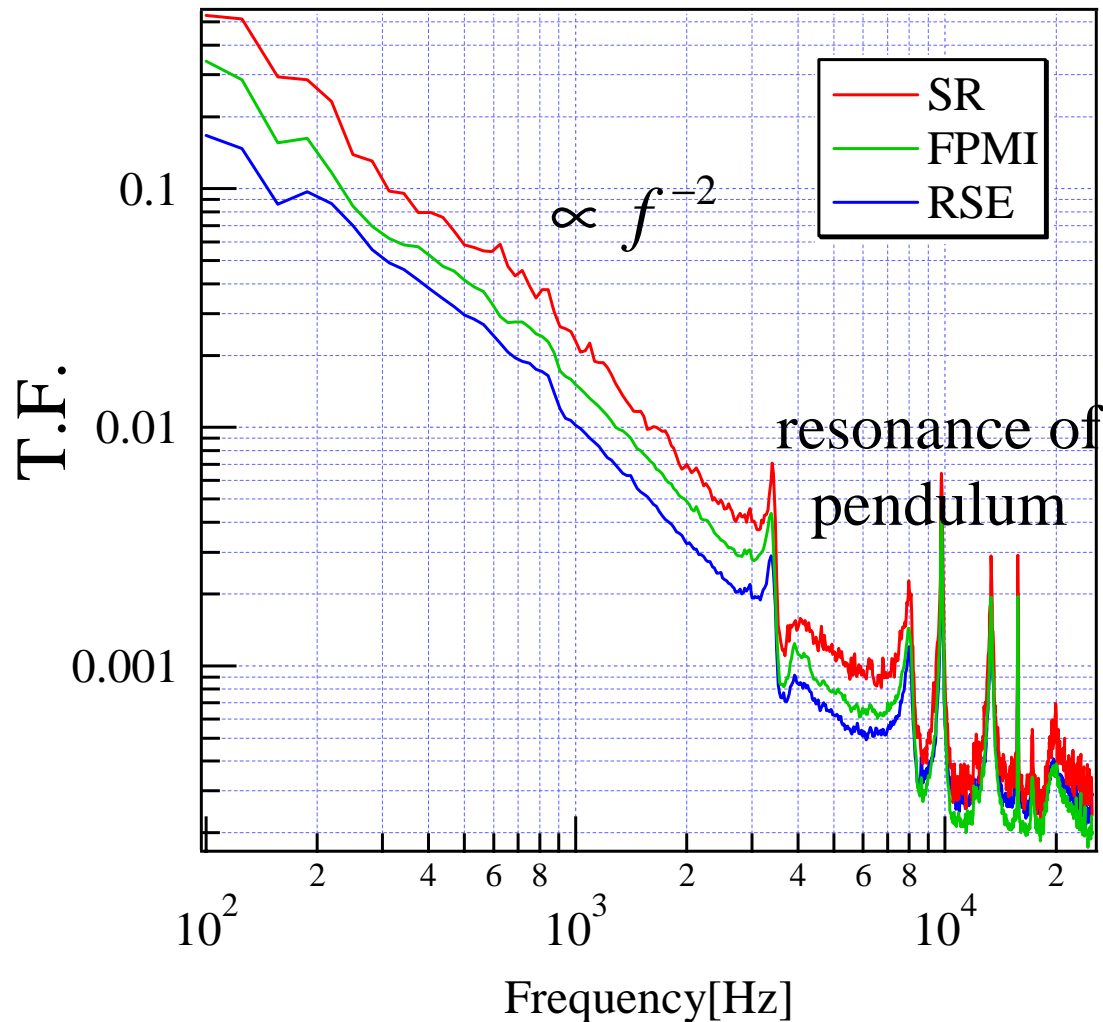
Shaking L- to see the cavity response

$$\frac{V2}{V1} = \text{Pendulum T.F.} \\ \times \text{Optical Gain}(L-) \\ (\times \text{DC})$$



# Transfer function

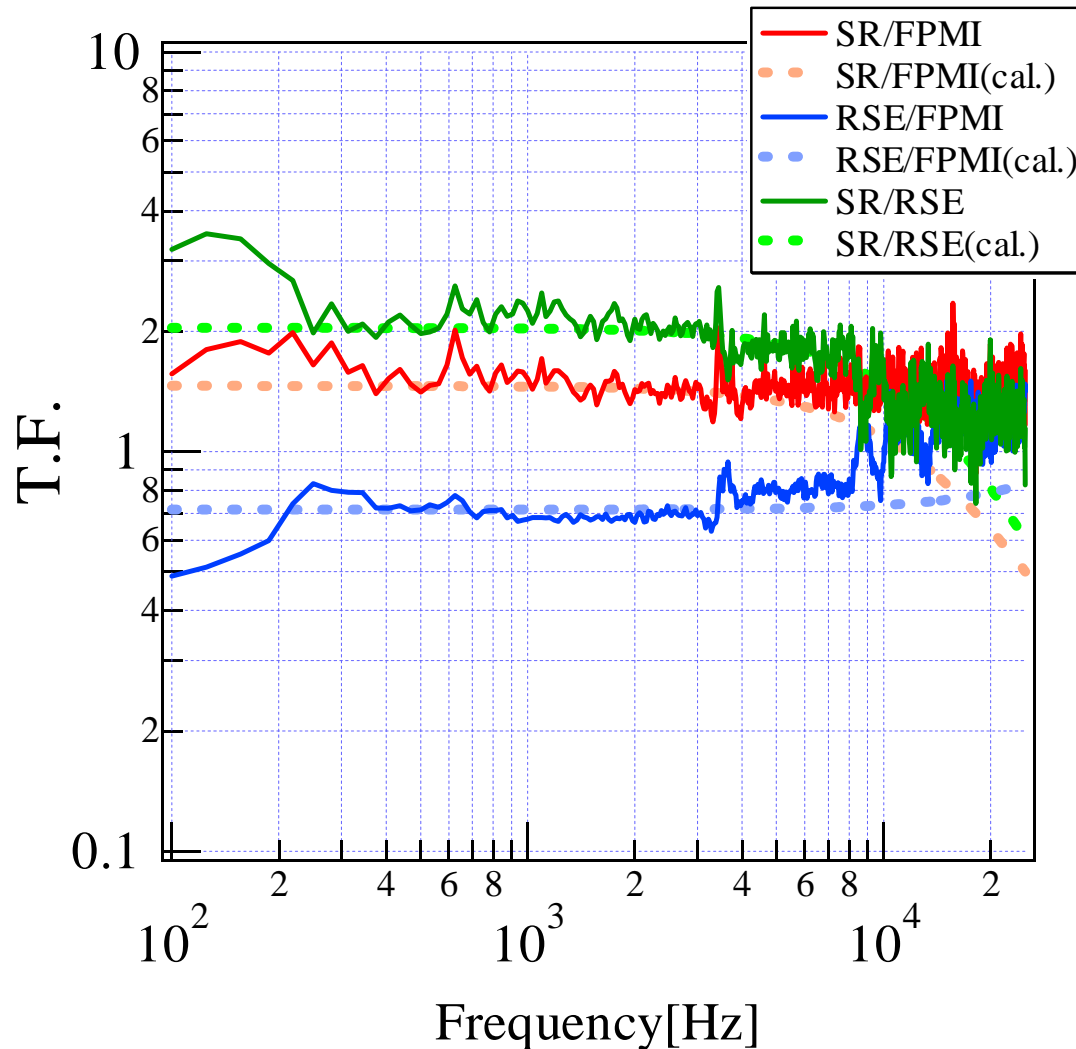
## Transfer Function of L- with Pendulum



SR : upper than FPMI  
RSE : lower than FPMI



## Relative Transfer Function



- Difference between transfer function of SR and RSE at DC is 7dB.

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## Conclusion

- We locked **suspended-mass** Resonant Sideband Extraction with **one modulation** and by **Third Harmonic Demodulation**.
- We confirmed the RSE and SR locking by comparing **the response of the interferometer** for both configurations.

## Next plan

- vacuum
- measurement of T.F. with wide band including pole
- L+ L- control
- detuned RSE
- Power Recycling