ADVANCED INTERFEROMETRY AT THE 40M CALTECH

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LIGO 40M, CALTECH

- houses a Prototype of the main LIGO detectors in Hanford, WA and Livingston, LA
- has the IFO arms of length 40m
- aimed at building and testing new technologies for Advanced LIGO and other future generation detectors.

IMPROVEMENT OF ALIGNMENT CONTROL OF THE INPUT MODE CLEANER

Nancy Aggarwal

CONTENTS

LIGO 40m

INTRODUCTION

HERMITE GAUSSIAN BEAMS

- Paraxial Approximation, periodic field

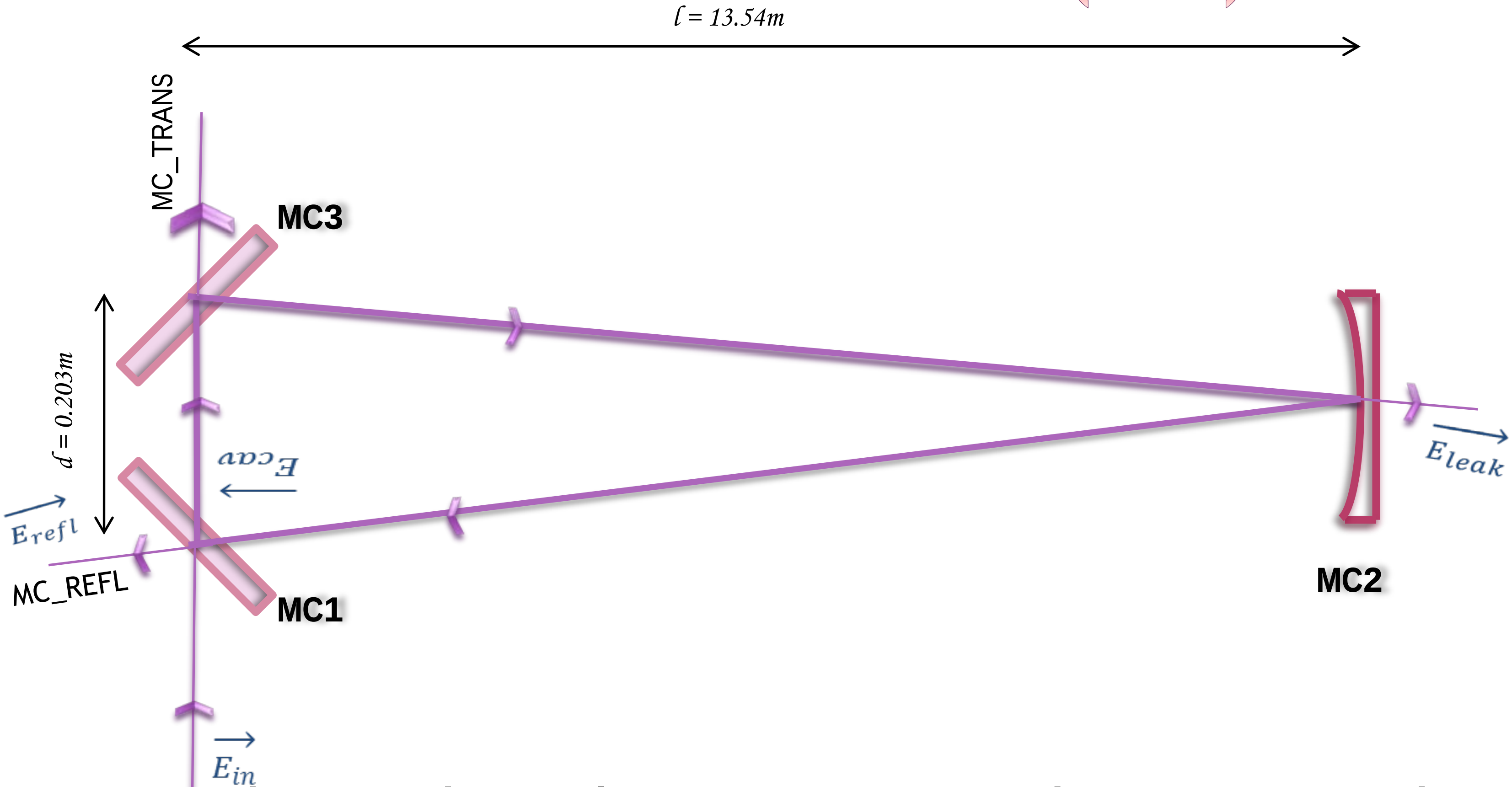
$$\overrightarrow{E} = \sum_{mn}\sum_{r}\sum_{p} a_{mnrp} exp[i(\omega_0 + r\omega)t] \times U_{mn}(x,y,z)\overrightarrow{\epsilon_p}$$

- U_{mn} : eigen-modes of optical resonator
- Hermite-Gaussian Beam :

$$U_{mn}(x,y,z) = U_m(x,z)U_n(y,z)$$

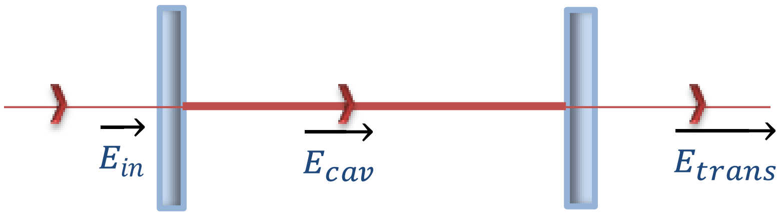
$$U_m(x,z) = \left(\frac{2}{\pi}\right)^{\frac{1}{4}}\left(\frac{1}{2^m m! w(z)}\right)^{\frac{1}{2}} H_m\left(\frac{\sqrt{2}x}{w(z)}\right) \times exp\left[-x^2\left(\frac{1}{w(z)^2}+\frac{ik_0}{2R(z)}\right)\right] \times exp\left[i\left(m+\frac{1}{2}\right)\eta(z)\right]$$

INPUT MODE CLEANER (MC)



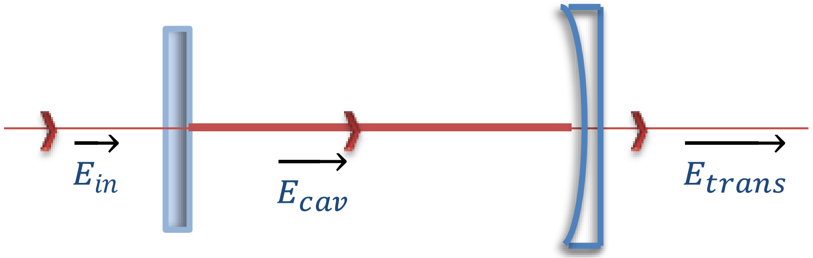
- 3 mirror triangular resonant cavity – 1 curved and 2 plane mirrors

SIMPLE FABRY-PEROT CAVITY



- High reflectivity mirrors
- Many round trips inside the cavity
- Amplificatin of f = nc/2L (standing waves)
- Attenuation of all other frequencies

Plane Mirror FP

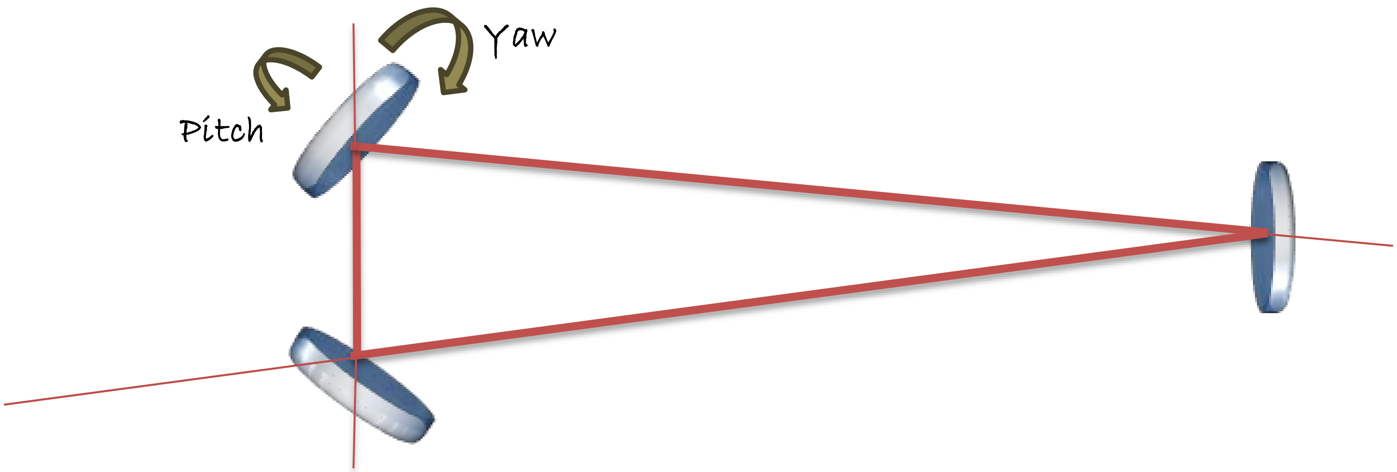


- Direction of resonant mode is perpendicular to the plane mirror, hence dependent on the plane mirror only
- Also now come in the picture the modes of light resonating in this cavity.

One mirror curved

MODE CLEANER AND ITS ALIGNMENT

INPUT MODE CLEANER (MC)



- 3 positional and 6 rotational dof (pitch and yaw for each mirror)
- Required to maintain a particular alignment wrt the input beam for desired role.

MAIN FUNCTIONS OF MC

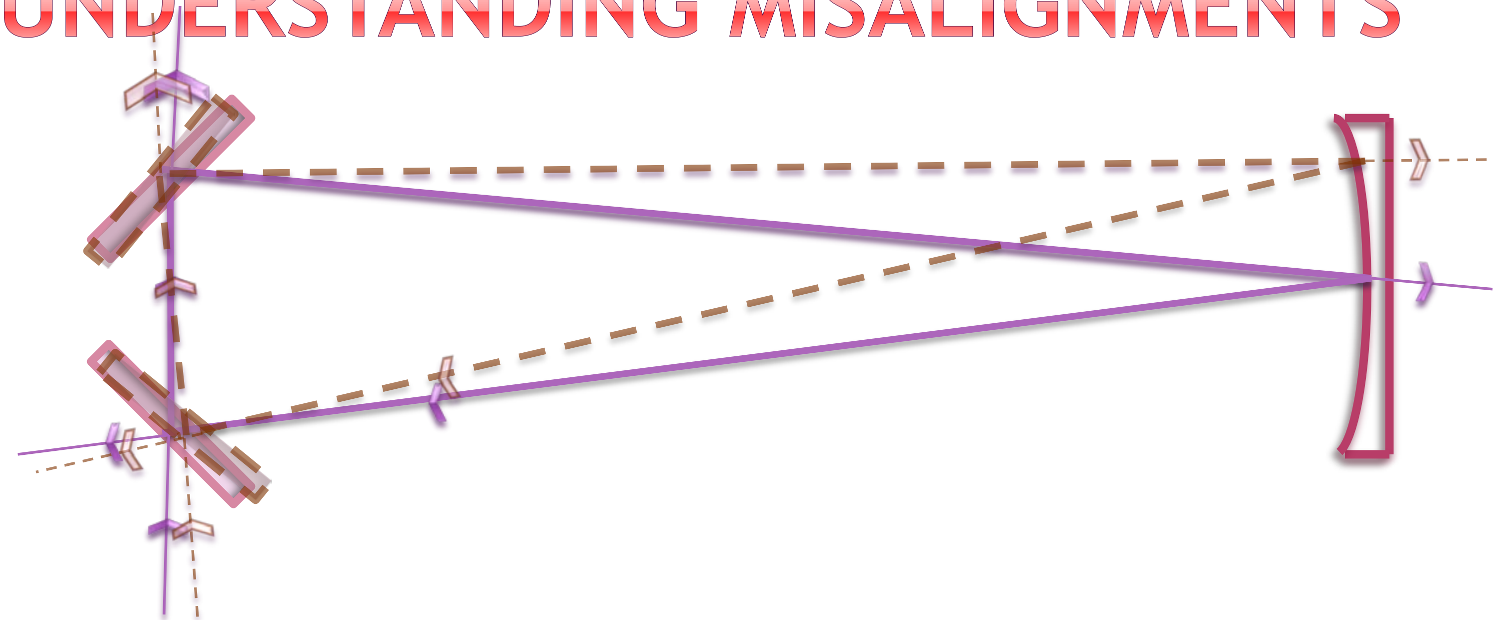
- Frequency Stabilization
  - length control of the cavity, only f=nc/2L is allowed to resonate inside it.
- Mode Selection
  - Hence the name Mode Cleaner.
  - The cavity is designed such that it allows some particular combinations of frequency and mode of the light to resonate. We choose it such that it is **TEM00** at the PSL frequency.
- Angular Reference
- Polarization Selection

NEED FOR ALIGNMENT

- Stabilize the intensity of the beam going to the main IFO
- Stabilize the direction and shift of the beam (or the path taken by the beam) going to the main IFO

WAVEFRONT SENSING

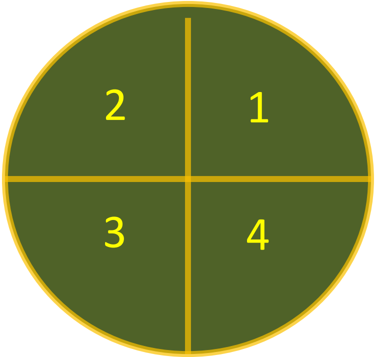
UNDERSTANDING MISALIGNMENTS

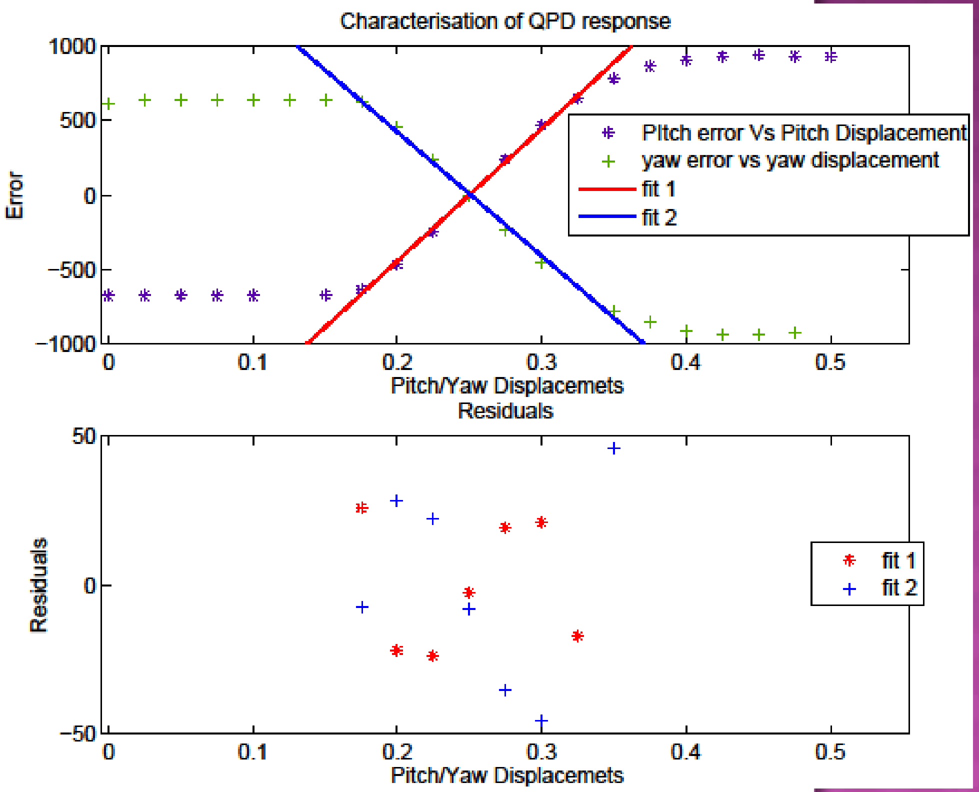


- Change in spot position on MC2
- Change in cavity axis – angle and displacement wrt nominal cavity axis
  - Equivalent to Change in line of path of reflected beam.
  - 2 WFSs used to measure these tips and tilts in the cavity axis.

QUADRANT PHOTODIODE

- PD containing 4 segments
- Spot Position :
  - Pitch - 1+2-3-4
  - Yaw - 1-2-3+4
- Total Intensity : 1+2+3+4
- Linear response b/w Voltage Output and deviation from center of QPD



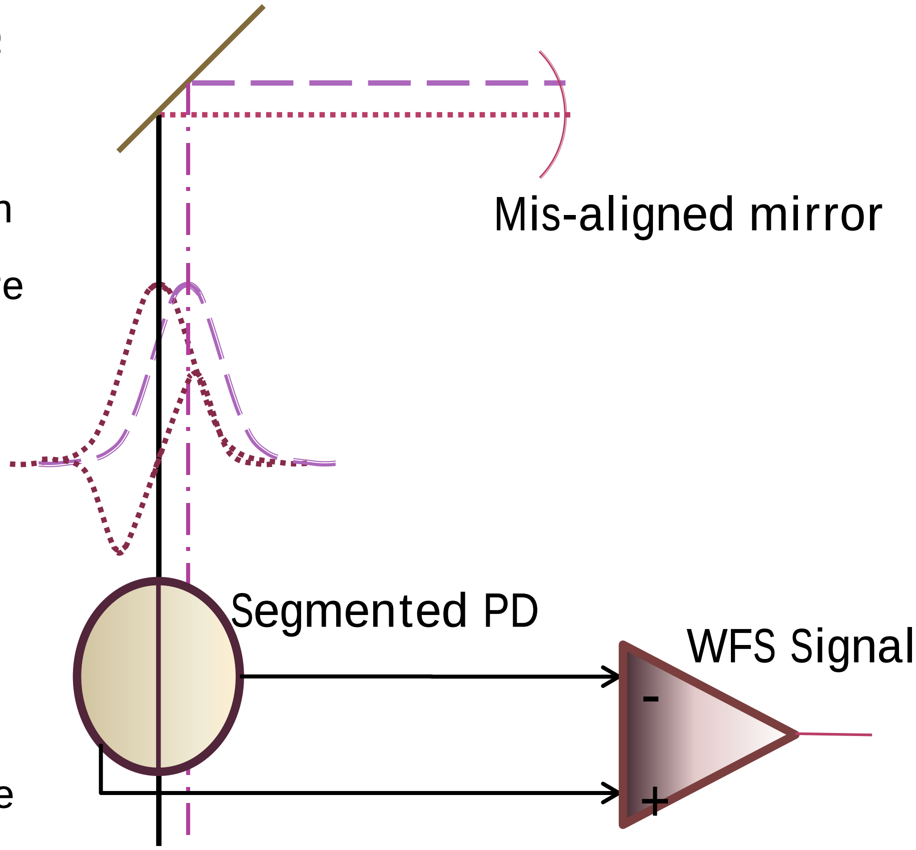


WAVEFRONT SENSORS

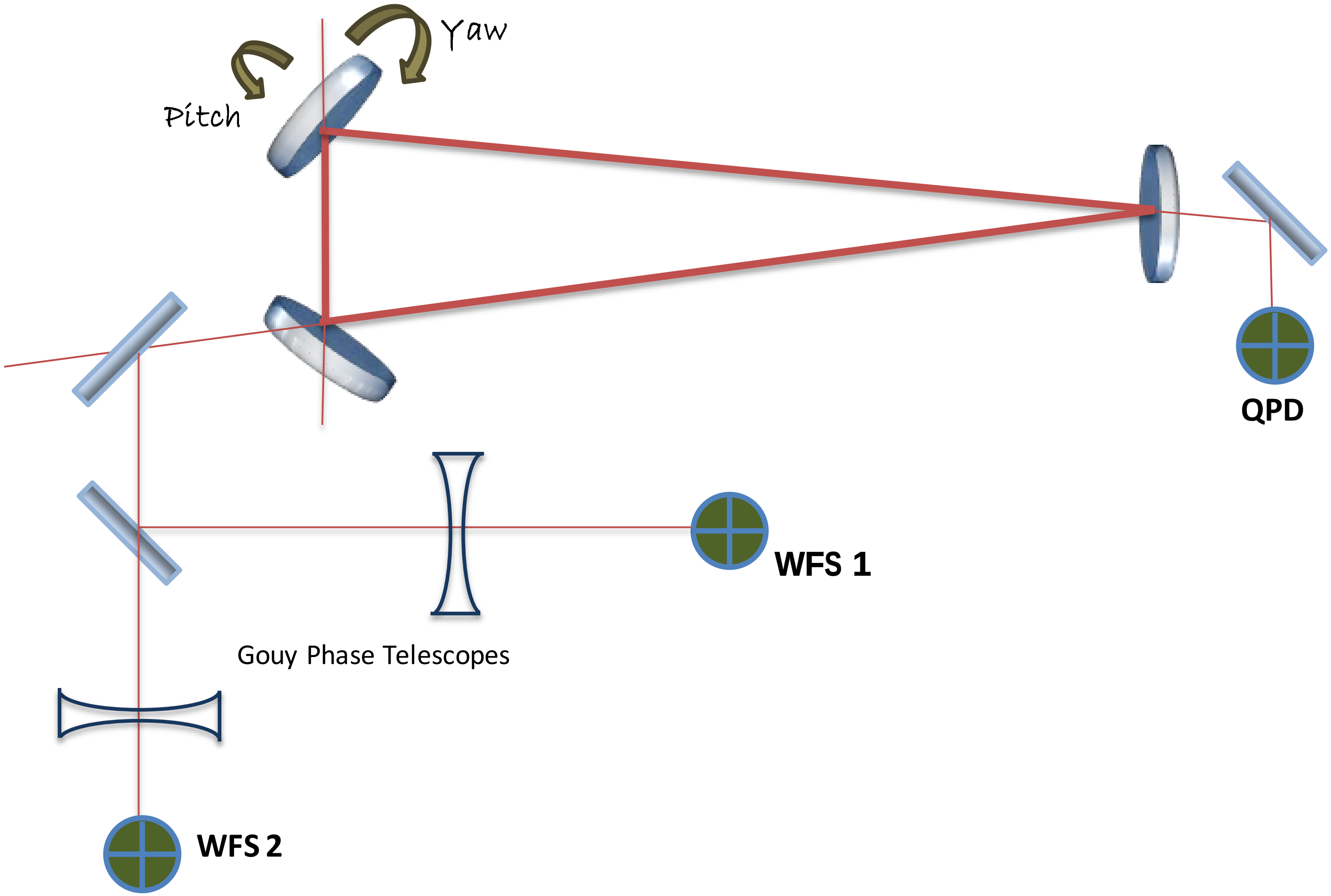
- Are yet another type of QPDs, but good for RF regime too.
- Differentially Measure the overlap between the even mode of one and odd mode of another frequency light, the difference between them lying in the RF region.
- Cancels out the even – even overlap, and hence information about length is discarded.

WFS IN OUR APPARATUS

- Look at the RF sidebands (say at Ω) in the promptly reflected beam, and the carrier frequency in the beam coming from the cavity.
- The carrier frequency acquires non TEM00 modes because of misalignments in the cavity (we are concerned about TEM01 and TEM10).
- These 2 signals interfere and produce a beat signal at Ω, which can be seen by the WFS – Asymmetric Overlap.
- The signal is then demodulated at Ω to get the I and Q phase components.
- Two WFS put at different Gouy Phase, because different modes acquire different Gouy phase while travelling



ALIGNMENT CONTROL



- 2 Signals from WFS, and one from QPD in each plane.
- Hence total 6 signals to control 6 dof

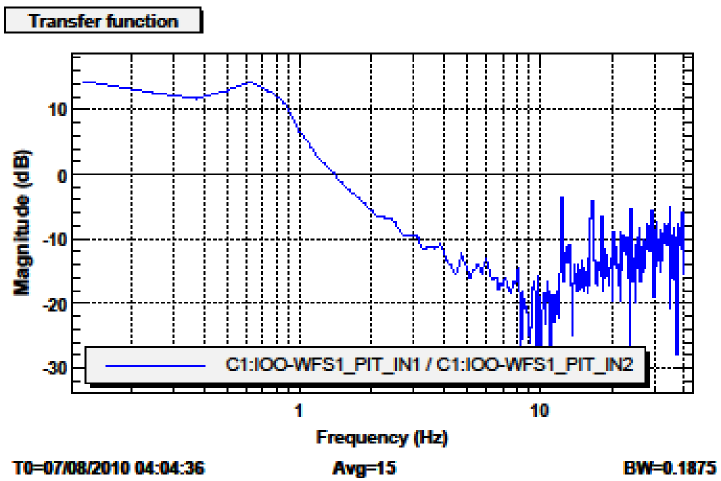
ALIGNMENT SENSING MATRIX

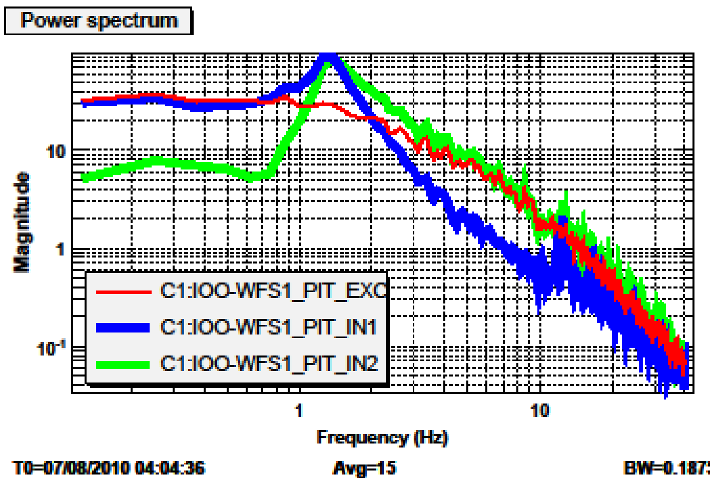
- A 6×6 Alignment Sensing Matrix
  - Transforms from the basis of mirror mis-alignments to the new tip/tilt and MC2 spot position basis
  - Inverse gives the mirror mis-alignments from measured signals
- Reduction :
  - Pitch and Yaw fairly independent, hence reduces to two 3×3 matrices
  - Since the control is dyanamic, not required to use information of all 3 mirrors in all 3 signals
  - Hence decided to use WFS for MC1 and 3, and QPD for MC2

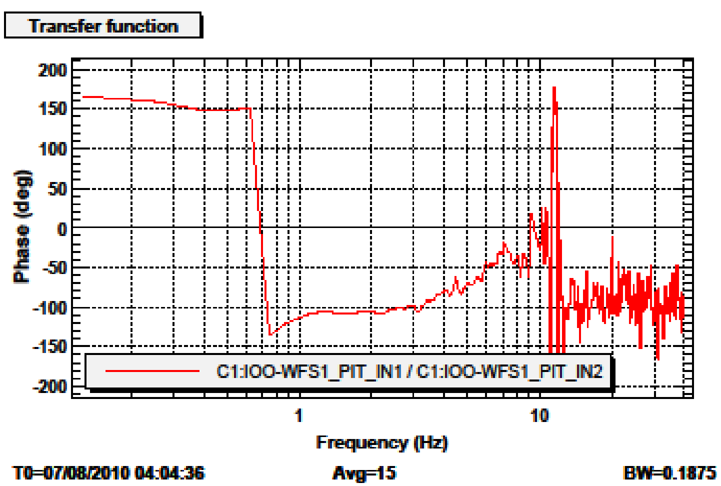
	P1	P2	P3	Y1	Y2	Y3
W1P						
W2P						
QP						
W1Y						
W2Y						
QY						

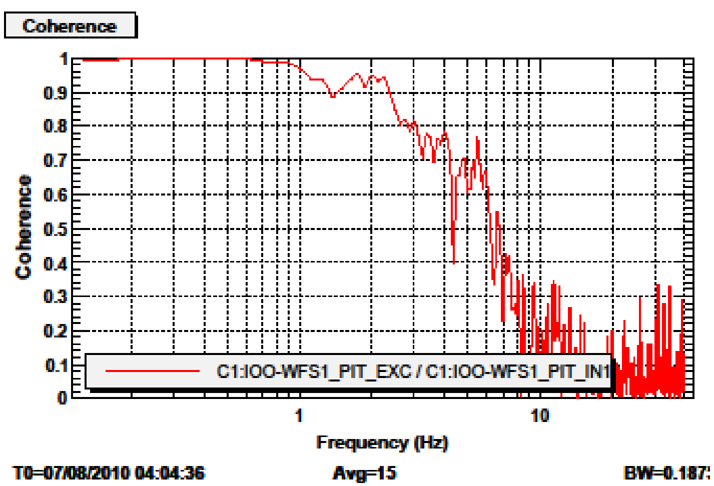
	W1P	W2P	QP	W1Y	W2Y	QY
P1						
P3						
P2						
Y1						
Y3						
Y2						

FEEDBACK LOOP

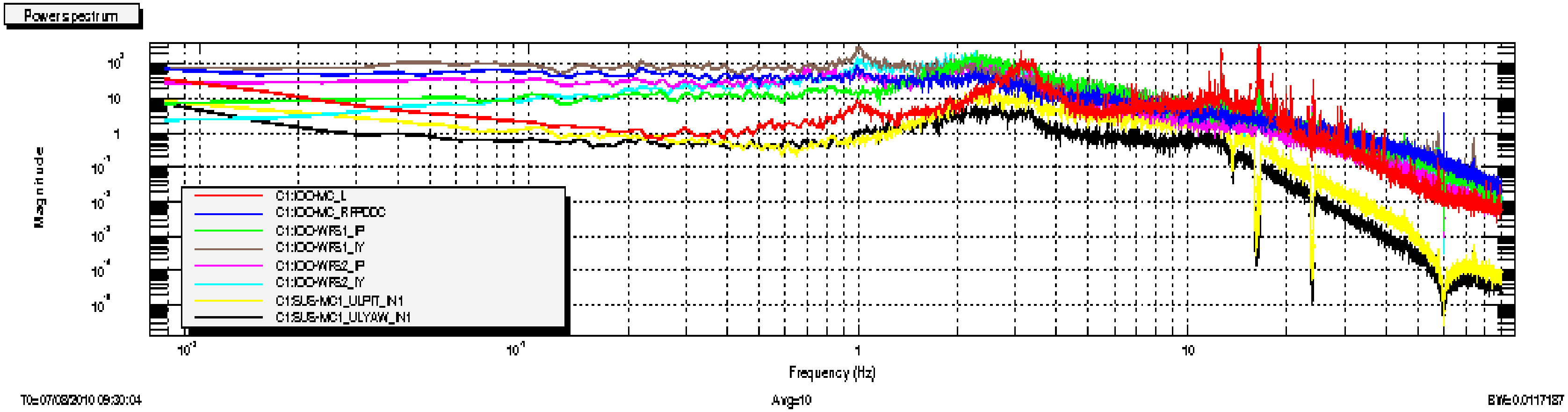


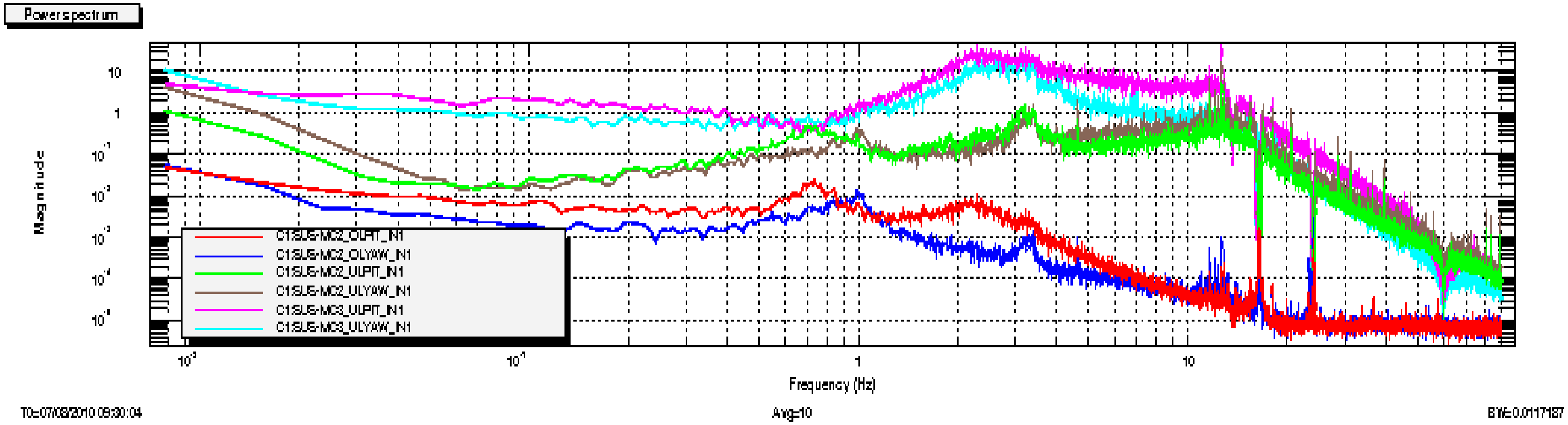




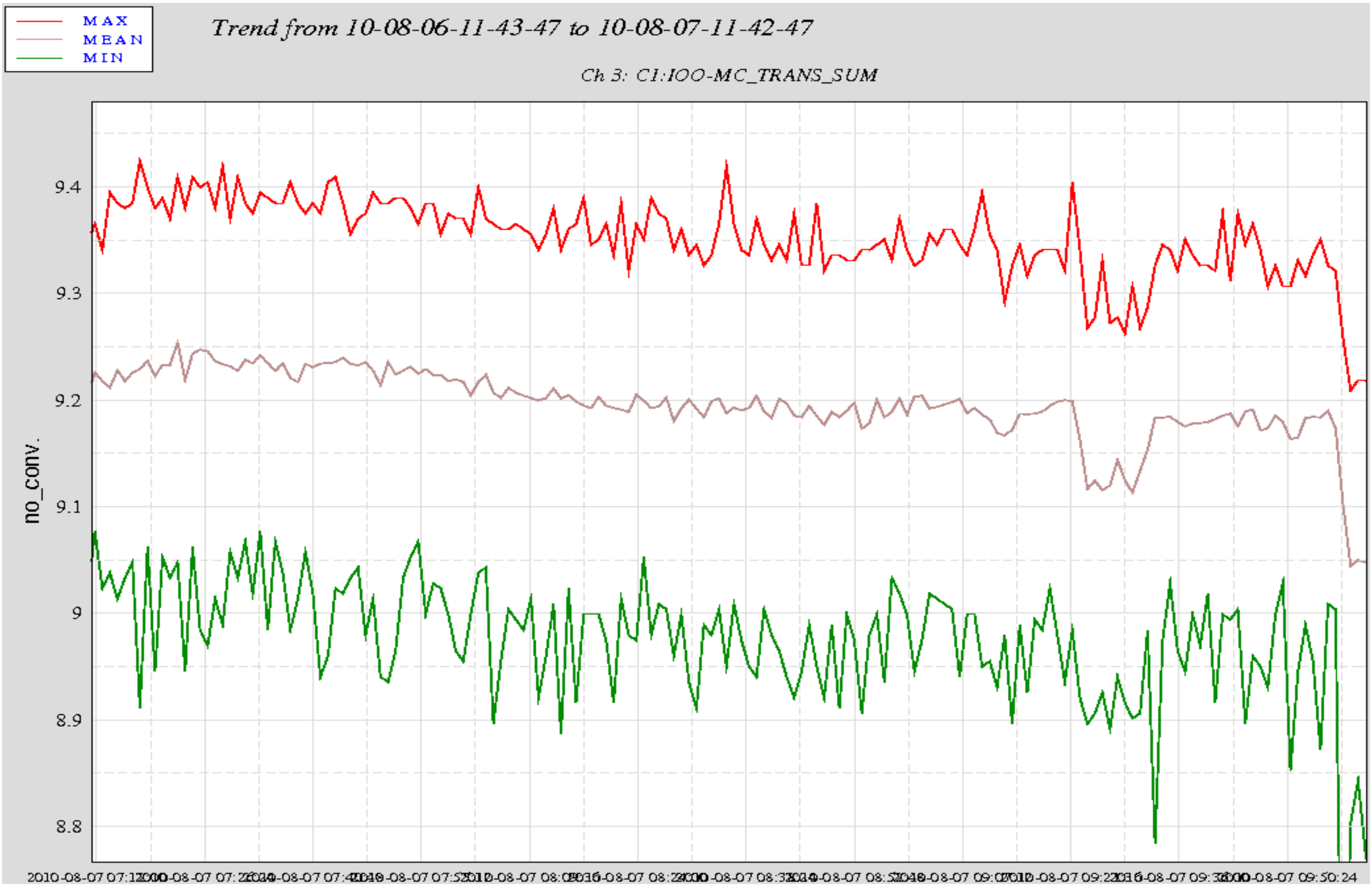


ERROR SIGNALS





GOOD START TOWARDS THE GOAL



Time Series Plot of the Transmitted Intensity

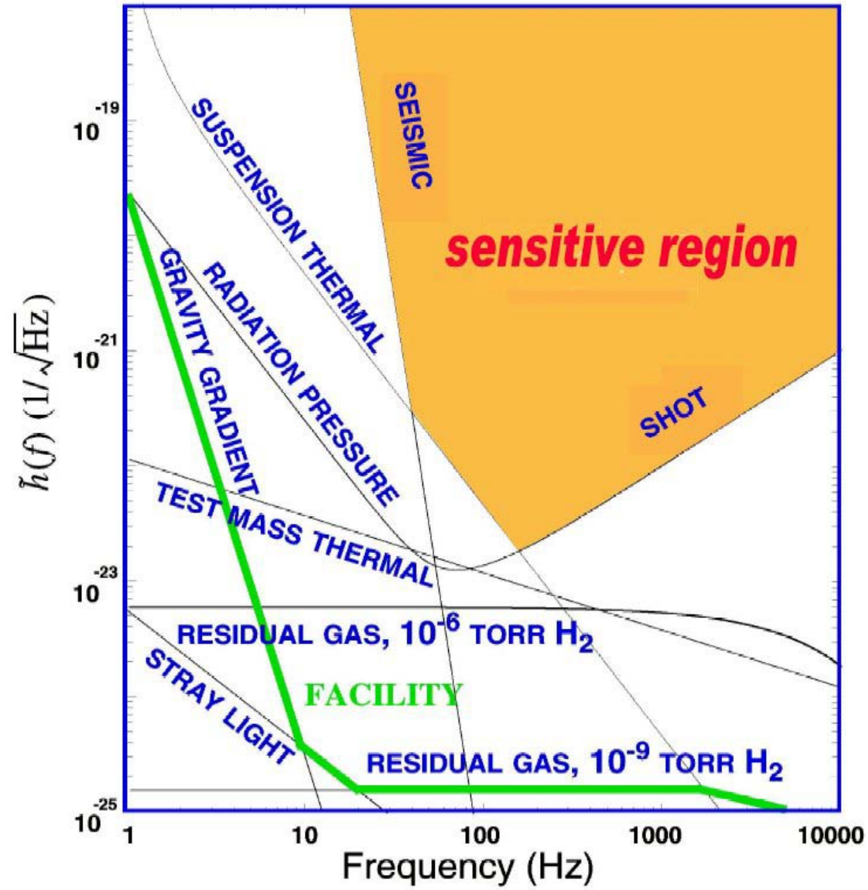
CONCLUSION

- Achieved a stable control of the system
- Optimizations of the gains on the grounds of noise considerations still remains to be done
- This scheme is theoretically more sound than the original scheme because of accessing all 6 dof without any redundancy.

BUILDING A MAGNETIC SUSPENSION SYSTEM AT THE LIGO 40M LAB

G.G.Sharmila

SENSITIVITY OF ILIGO

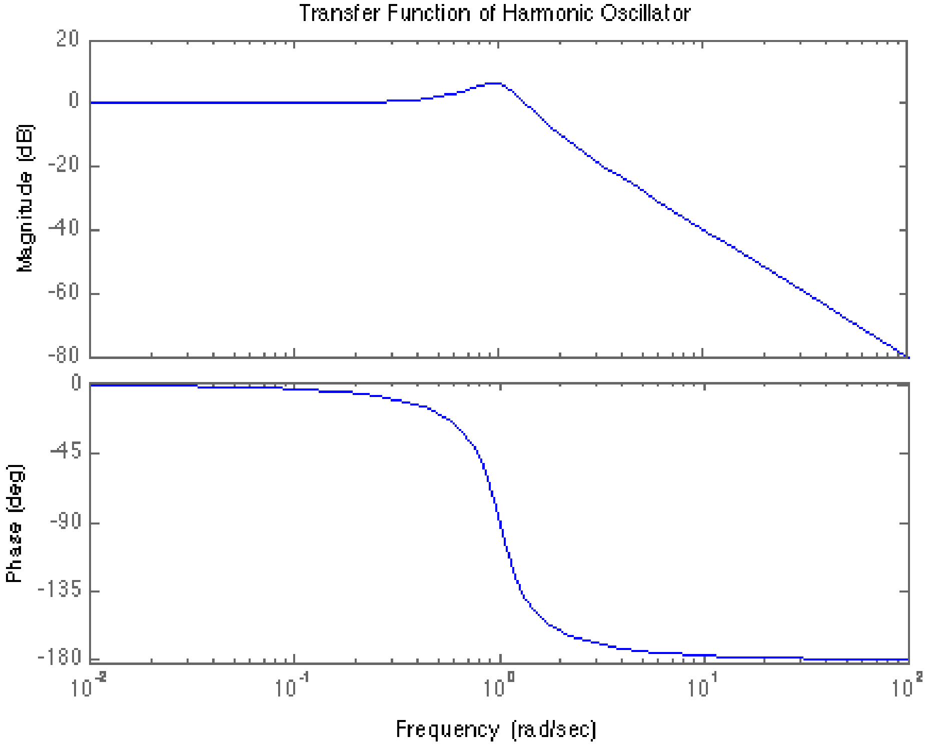


SEISMIC NOISE

- **Success in gravitational wave detection critically depends on its sensitivity**
- **aLIGO sensitivity goal is 10^{-19} m at 10 Hz**
- **At low frequencies, seismic noise is a dominant noise source**

MECHANICAL ISOLATOR

$$F(x) = m\ddot{x} + \gamma\dot{x} + Kx$$



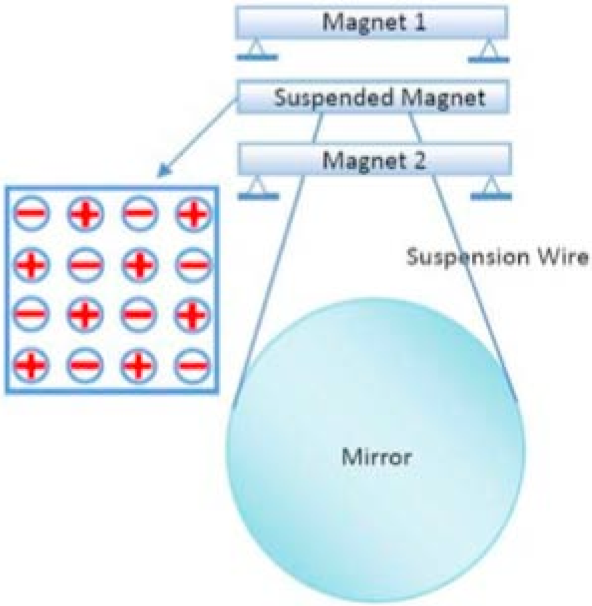
LIGO VIBRATION ISOLATION

- Initial LIGO uses single stage pendulum suspension.

- ALIGO uses Quadruple pendulum
  - Designed after triple pendulum used in the GEO600 detector
  - 4 pendulum stages provide isolation for the stage below, each reducing noise by $1/f^2$ for a total reduction of $1/f^8$

MAGNETIC SUSPENSION

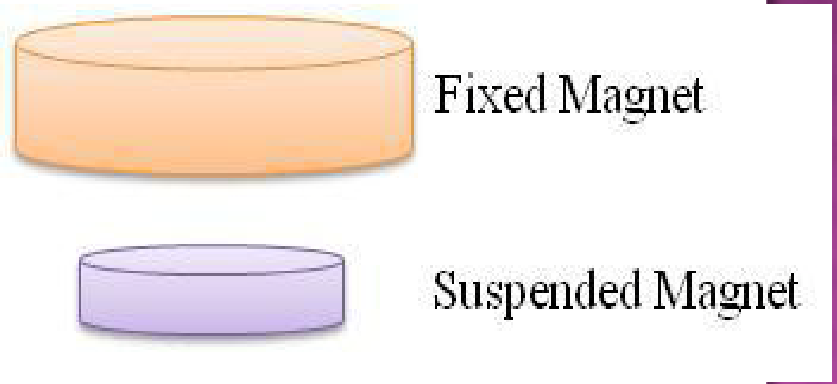
- Goal: reduce bounce mode resonant frequency to <10Hz, make test mass soft in all degrees of freedom
- Replace penultimate mass with magnetic suspension system
- Use an array of magnets to levitate another array of magnets
  - Magnetic poles aligned so that magnetic force can balance gravitational force
  - Only high-order magnetic moments exist in the far field



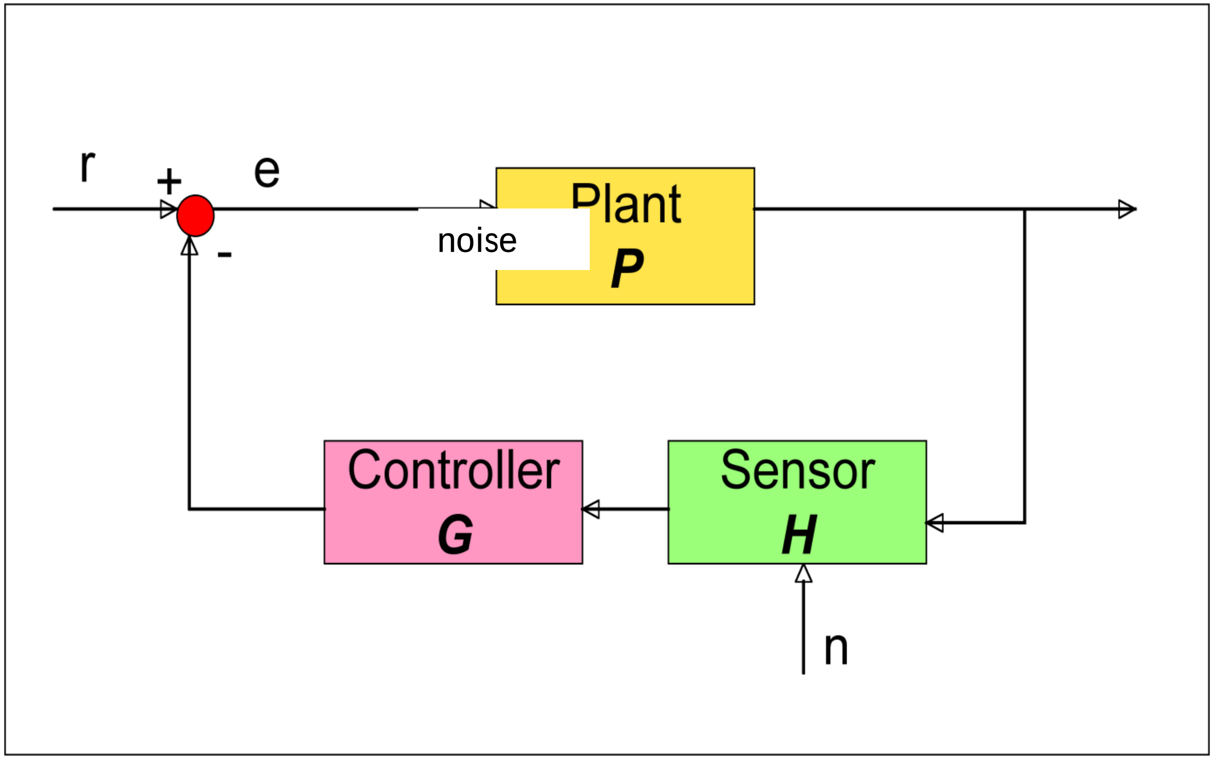
- In principle, can achieve low resonant frequency in all degrees of freedom

STABILITY AND EARNSHAW'S THEOREM

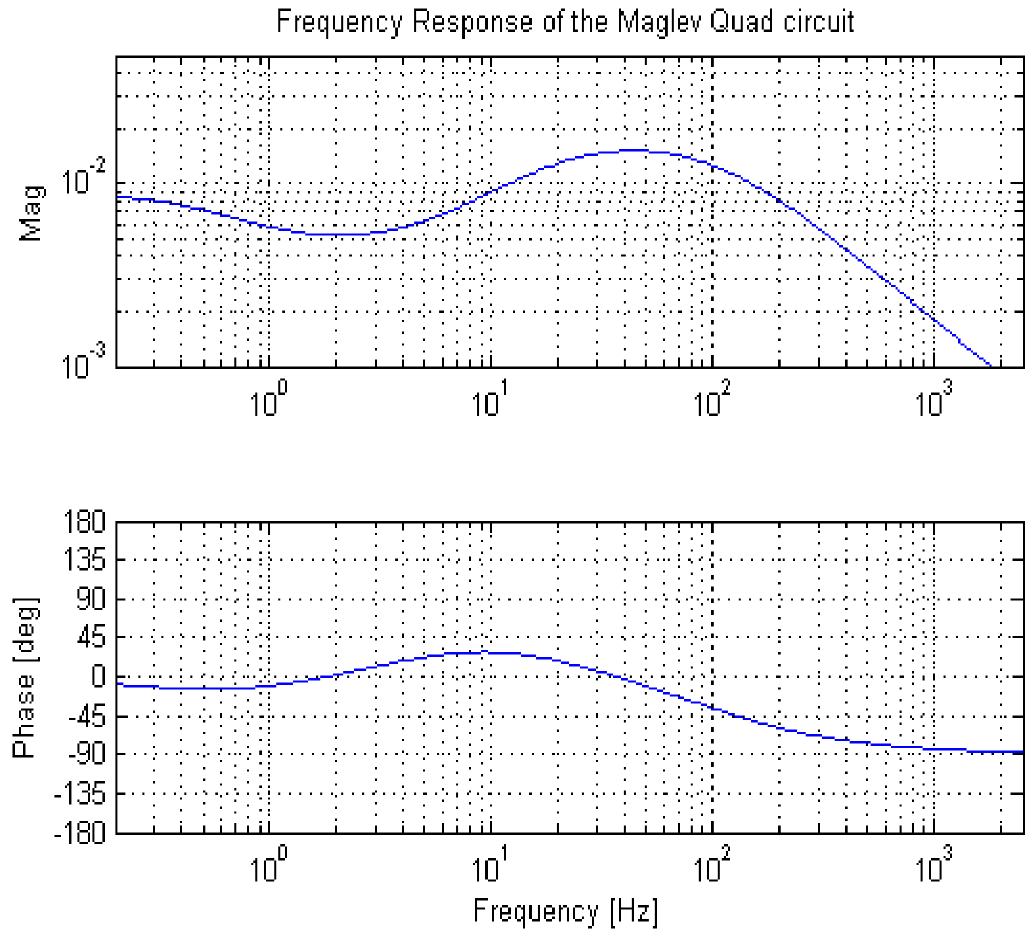
- Levitation between two permanent magnets: gravitational force balanced by magnetic force.
- Earnshaw's theorem states the condition for the stability



FEEDBACK CONTROL



FREQUENCY RESPONSE OF SYSTEM



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