LIGO

Designing a frequency offset locking loop for the 40m prototype Arm Length Stabilization System

Sai Akhil Reddy

Indian Institute of Technology , Patna

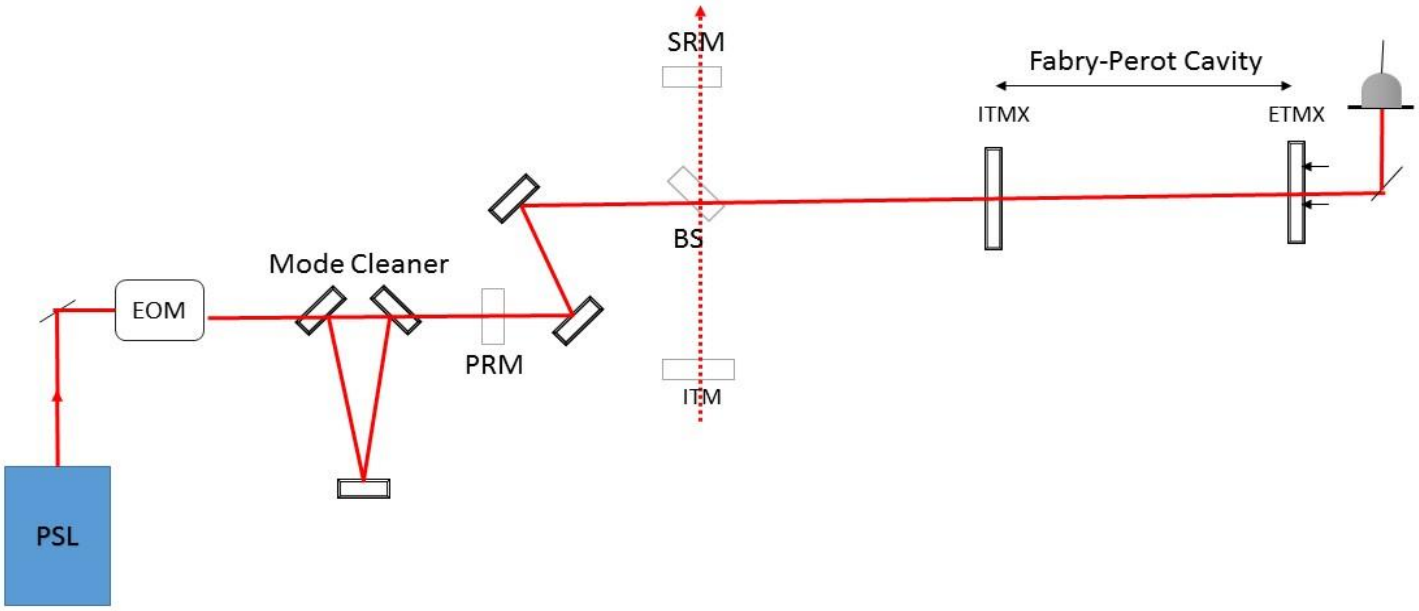
Mentors: Manasa T., Eric Quintero, Koji Arai

LIGO

Outline of the Talk

- What is Arm Length Stabilization (ALS)?
- Issues in the ALS system.
- Solving the issue: Frequency Offset Locking (FOL) Loop.
- Building the FOL control loop.
- Challenges faced.
- Testing and Commissioning

Advanced LIGO Optical Configuration



LIGO

Arm Length Stabilization (ALS)

- Precise length measurements ⇔ Lock acquisition of the interferometer.

LIGO

Arm Length Stabilization (ALS)

- Precise length measurements ⇔ Lock acquisition of the interferometer.
- Problems: Higher degrees of freedom due to coupling of cavities, non-linearities in length measurement and noise.

LIGO

Arm Length Stabilization (ALS)

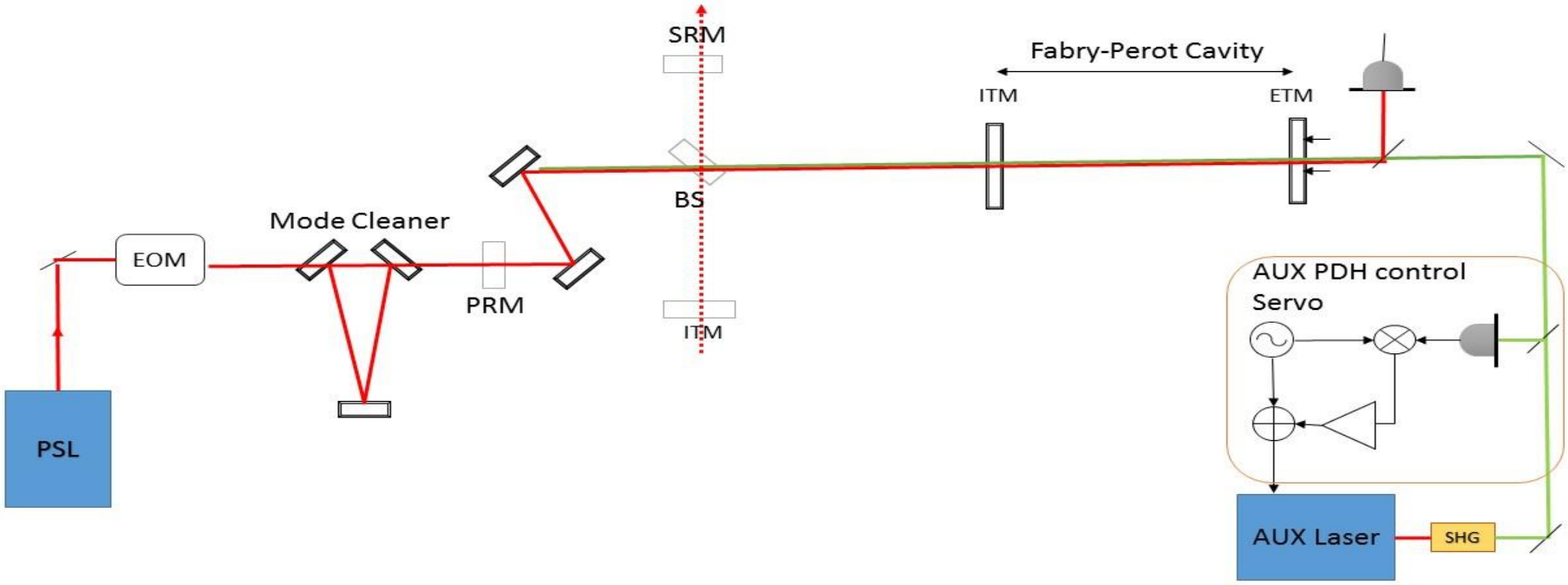
- Precise length measurements ⇔ Lock acquisition of the interferometer.
- Problems: Higher degrees of freedom due to coupling of cavities, non-linearities in length measurement and noise.
- Multicolour laser interferometry technique

LIGO

Arm Length Stabilization (ALS)

- Precise length measurements ⇔ Lock acquisition of the interferometer.
- Problems: Higher degrees of freedom due to coupling of cavities, non-linearities in length measurement and noise.
- Multicolour laser interferometry technique.
- Length information from Pound Drever Hall (PDH) scheme.

Pound Drever Hall (PDH) Scheme

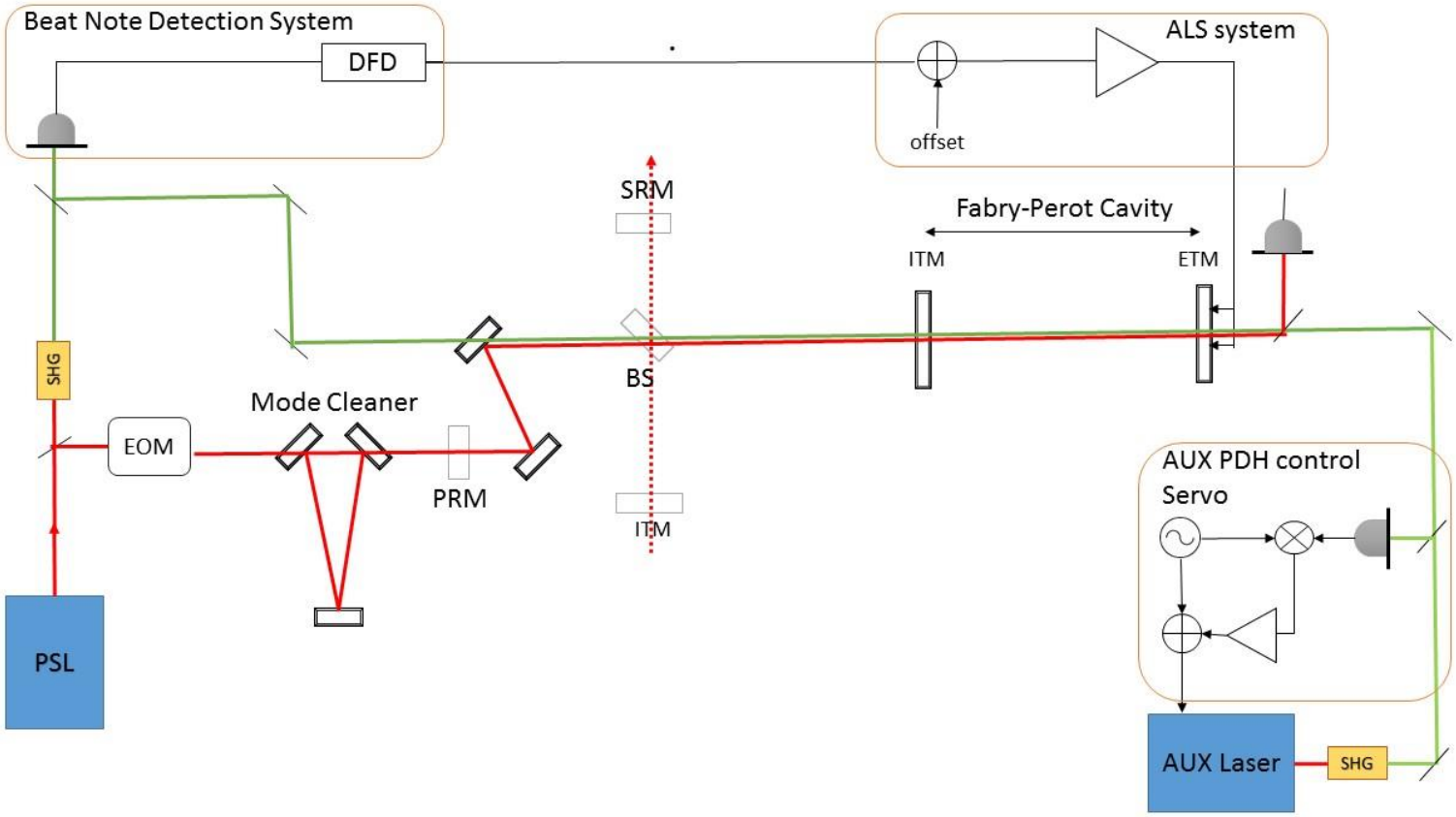


LIGO

Arm Length Stabilization (ALS)

- Precise length measurements ⇔ Lock acquisition of the interferometer.
- Problems: Higher degrees of freedom due to coupling of cavities, non-linearities in length measurement and noise.
- Multicolour laser interferometry technique
- Length information from Pound Drever Hall(PDH) scheme.
- Beat note between the Green Auxiliary(AUX) laser and the infrared Pre-Stabilised(PSL) used to stabilize the length of the cavity using a digital servo.

Arm Length Stabilization (ALS)



LIGO

Issues in the ALS system

- Frequencies of two lasers hugely different (could vary by few GHz).

LIGO

Issues in the ALS system

- Frequencies of two lasers hugely different (could vary by few GHz).
- The PDH control loop of the AUX laser allows its frequency to follow the motion of the cavity length.

LIGO

Issues in the ALS system

- Frequencies of two lasers hugely different (could vary by few GHz).
- The PDH control loop of the AUX laser allows its frequency to follow the motion of the cavity length.
- The laser cavity Piezoelectric(PZT) actuator has a control range of a few hundred MHz and an actuator response of around 5 MHz/V.

LIGO

Issues in the ALS system

- Frequencies of two lasers hugely different (could vary by few GHz).
- The PDH control loop of the AUX laser allows its frequency to follow the motion of the cavity length.
- The laser cavity Piezoelectric(PZT) actuator has a control range of a few hundred MHz and an actuator response of around 5 MHz/V.
- The PZT control becomes ineffective when the beat note between the lasers crosses the actuator range mainly due to green PD range.

Motivation of FOL Loop

- Slow control: Temperature Actuation -- larger response (1 GHz/K).

LIGO

Motivation of FOL Loop

- Slow control: Temperature Actuation -- larger response (1 GHz/K).
- Tracks the infrared (PSL) beat note frequency and pushes it within the efficient working range of ALS (<100 MHz).

LIGO

Motivation of FOL Loop

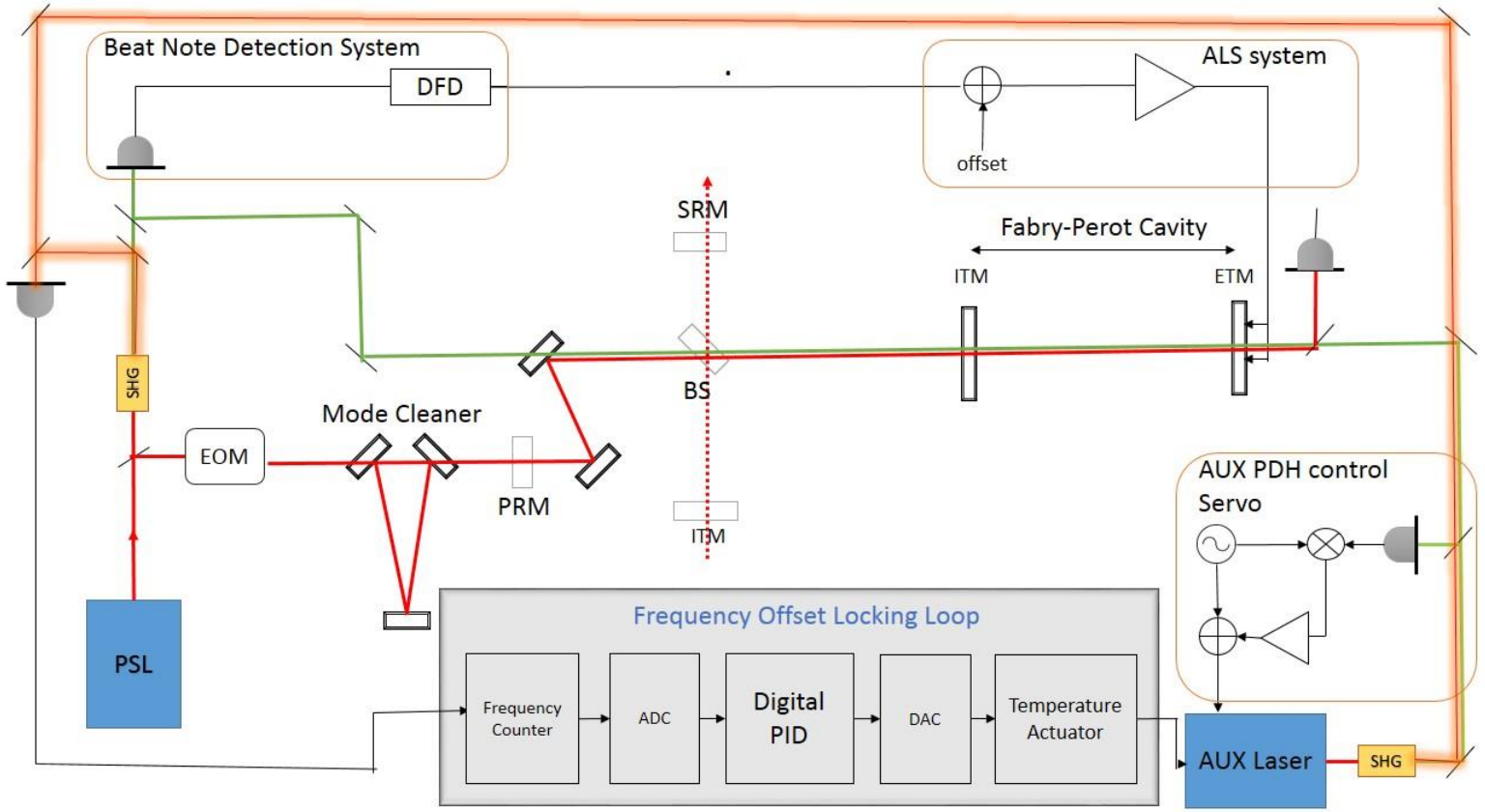
- Slow control: Temperature Actuation -- larger response (1 GHz/K).
- Tracks the infrared (PSL) beat note frequency and pushes it within the efficient working range of ALS (<100 MHz).
- So we build an automated Servo using a Proportional-Integral-Derivative controller (PID).

LIGO

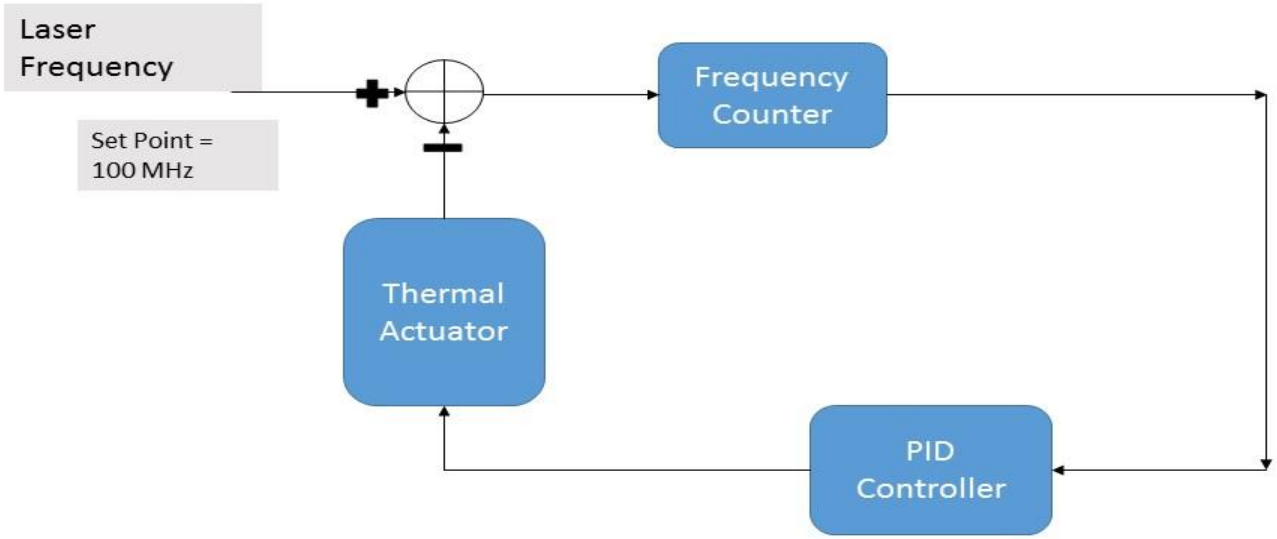
Motivation of FOL Loop

- Slow control: Temperature Actuation -- larger response (1 GHz/K).
- Tracks the infrared (PSL) beat note frequency and pushes it within the efficient working range of ALS (<100 MHz).
- So we build an automated Servo using a Proportional-Integral-Derivative controller (PID).
- FOL Works even when the green arm is not locked unlike the already existing temperature loop.

FOL Loop

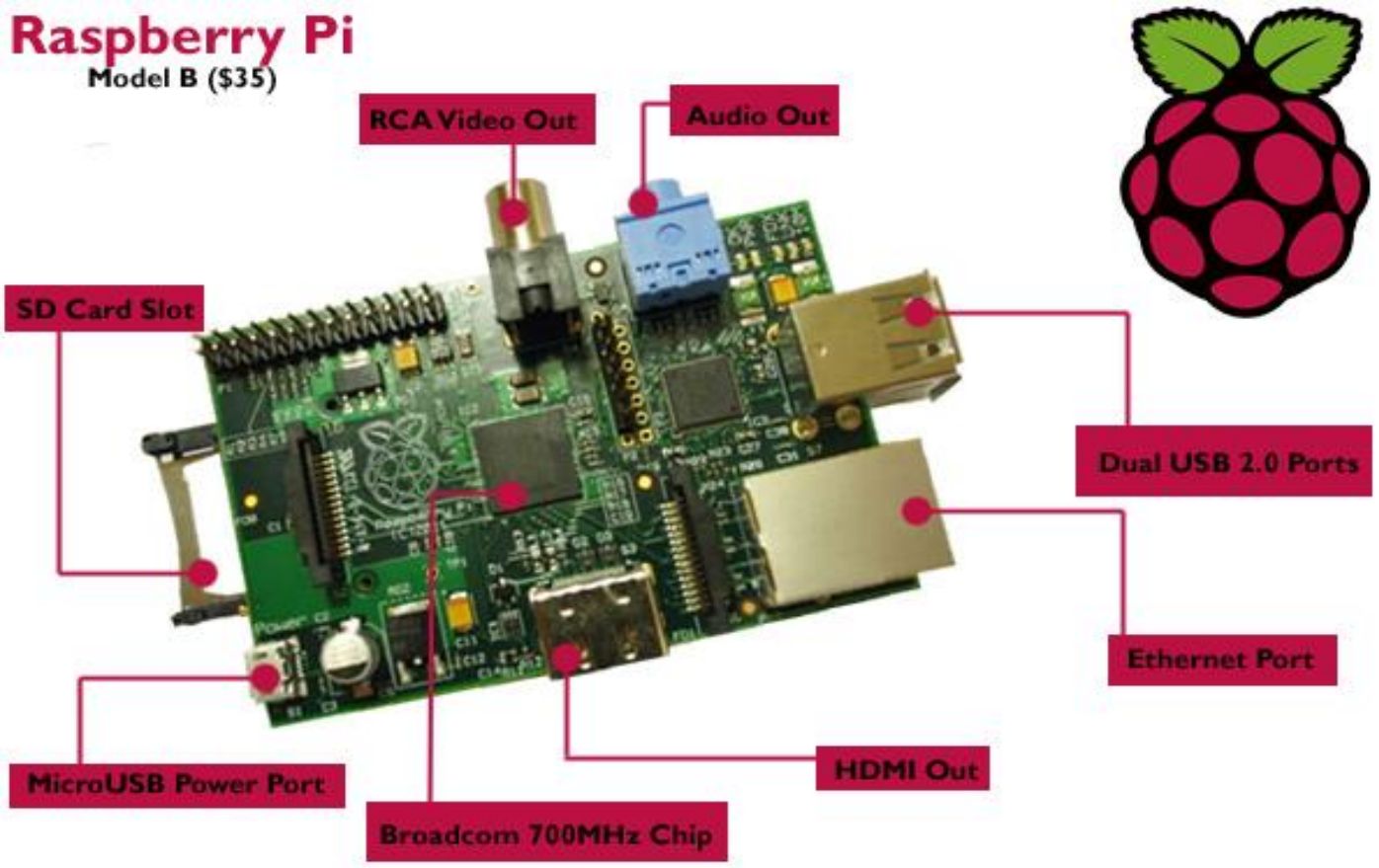

Beat Note Detection System
DFD
ALS system
offset
SRM
Fabry-Perot Cavity
ITM
ETM
SHG
BS
Mode Cleaner
EOM
PRM
ITM
AUX PDH control
Servo
PSL
Frequency Offset Locking Loop
Frequency Counter
ADC
Digital PID
DAC
Temperature Actuator
AUX Laser
SHG

Building the Digital Feedback System



LIGO

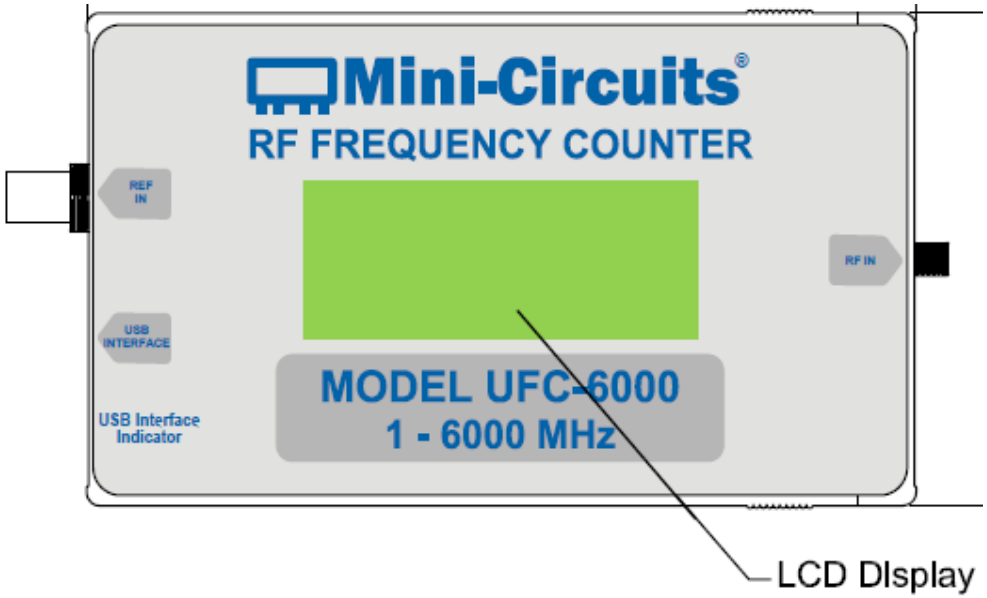
ARM Processor



Control Sensor

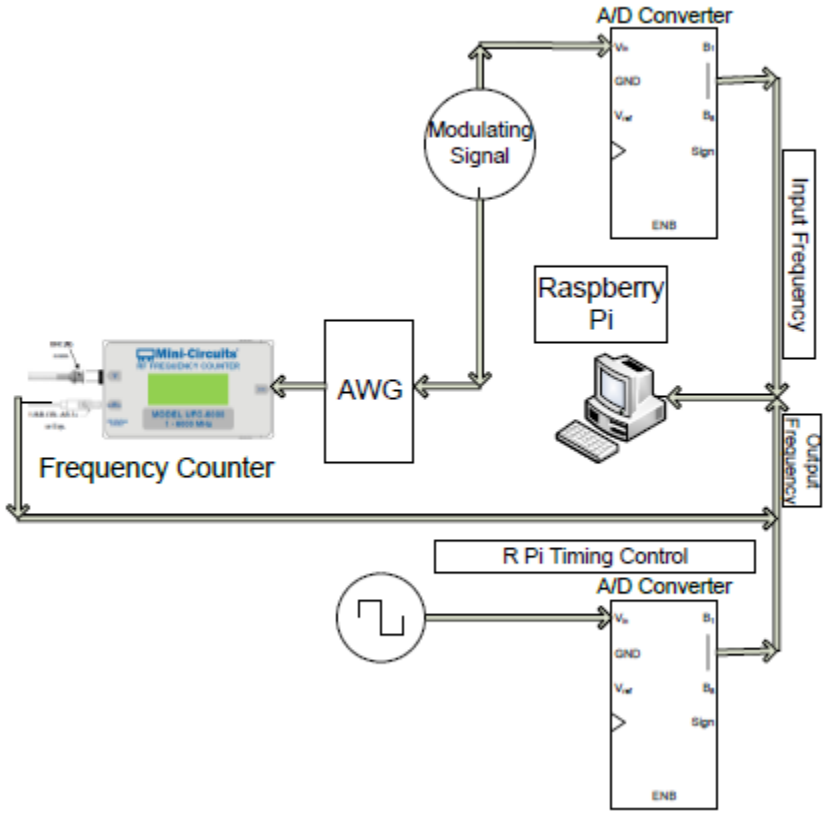
RF Frequency Counter-

- Mini-Circuits Model UFC-6000 RF Frequency Counter
- Frequency range of 1 MHz- 6000 MHz.

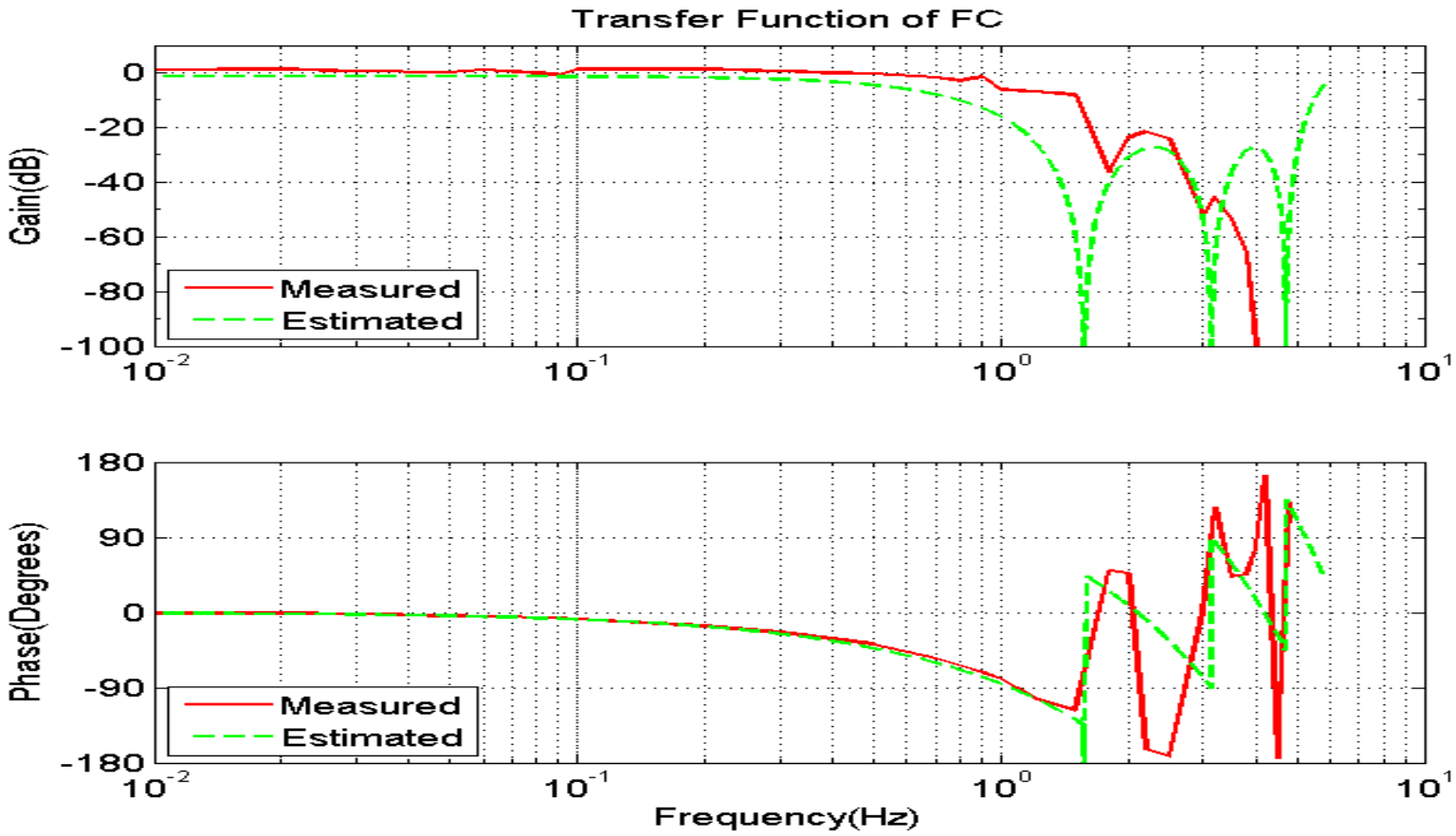


Resolving Timing Issues of R Pi and FC

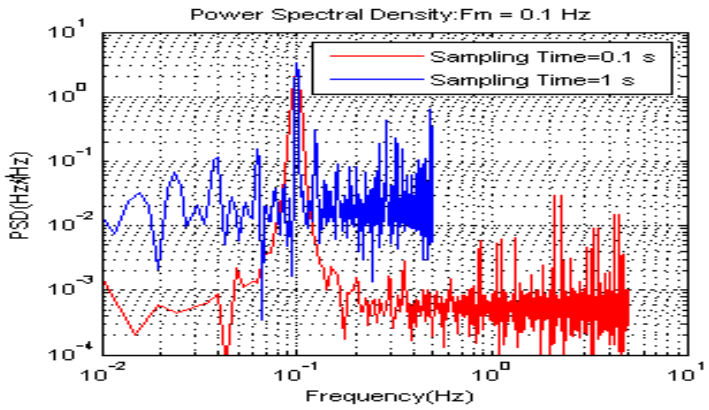
- Raspberry Pi: not an RTOS
- Issues in clock synchronization of R Pi and FC.
- Setup external clock to synchronously read data from the FC

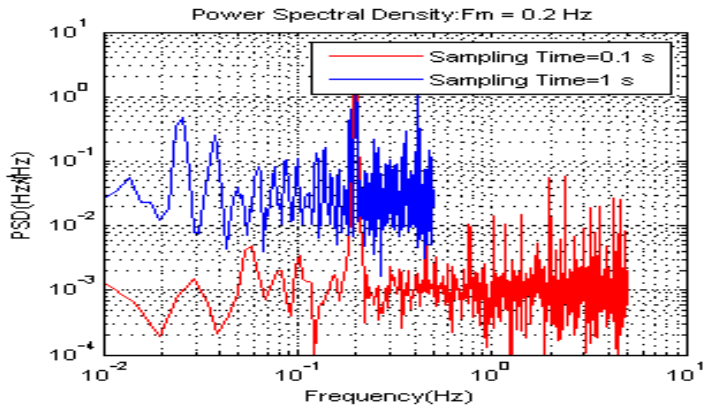


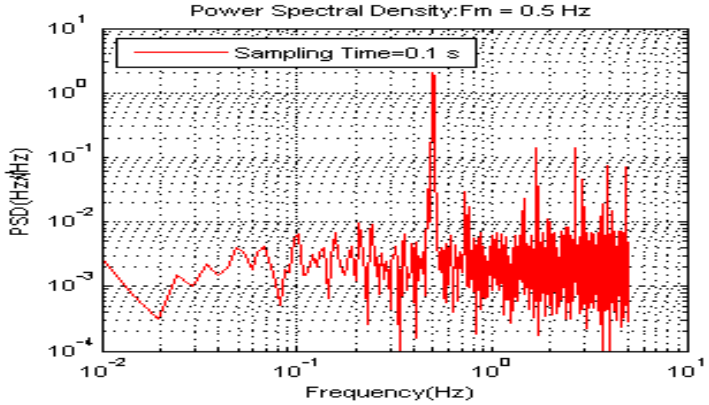
Transfer Function of the Frequency Counter

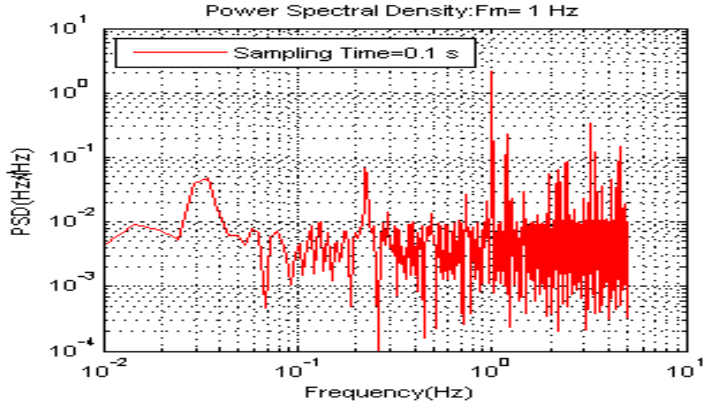


Noise Characterization in FC



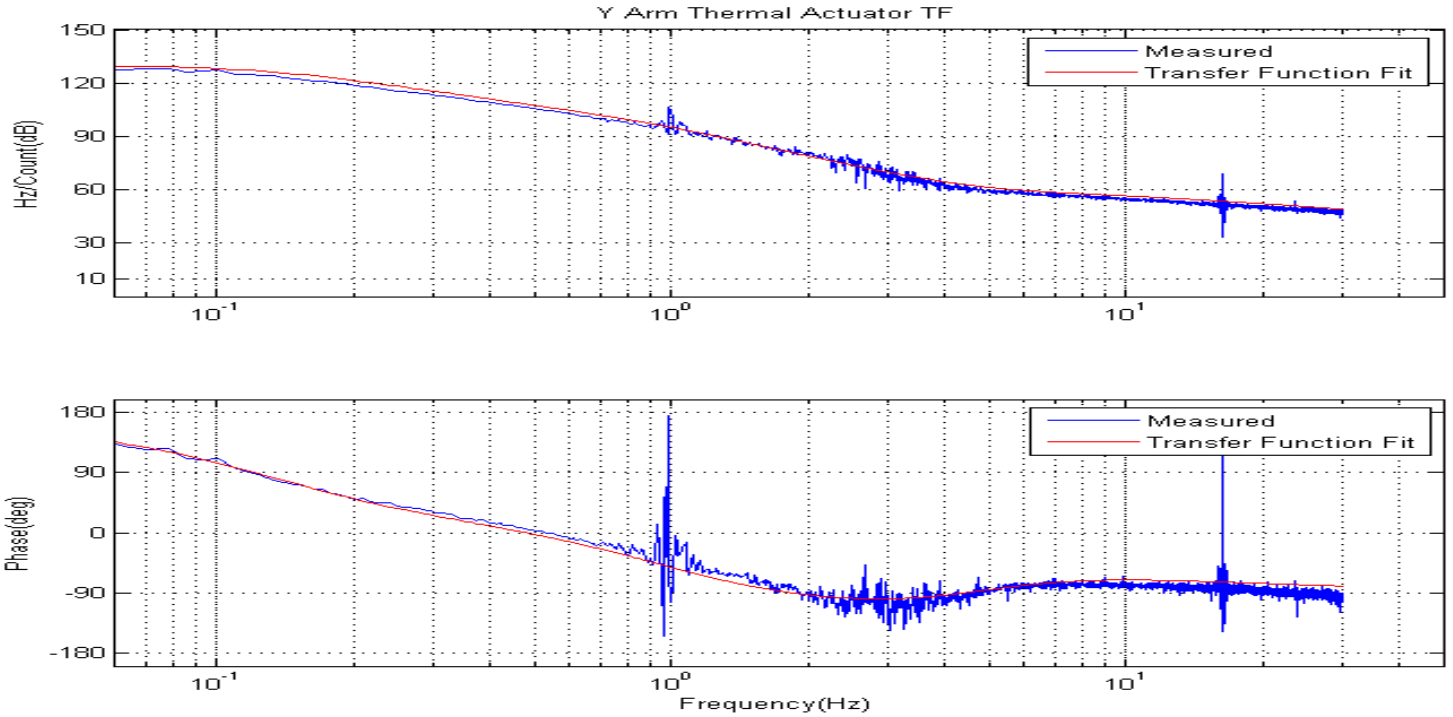






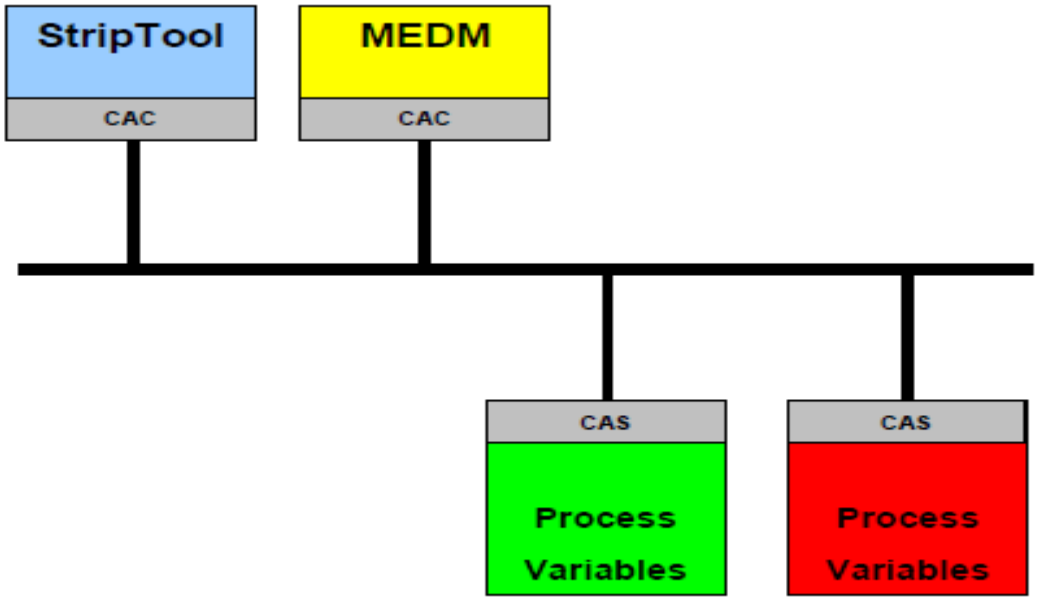
Transfer Function of the Plant: Thermal Actuator

- Thermal Actuator- Slow control actuator : Actuates on the temperature of the NPRO



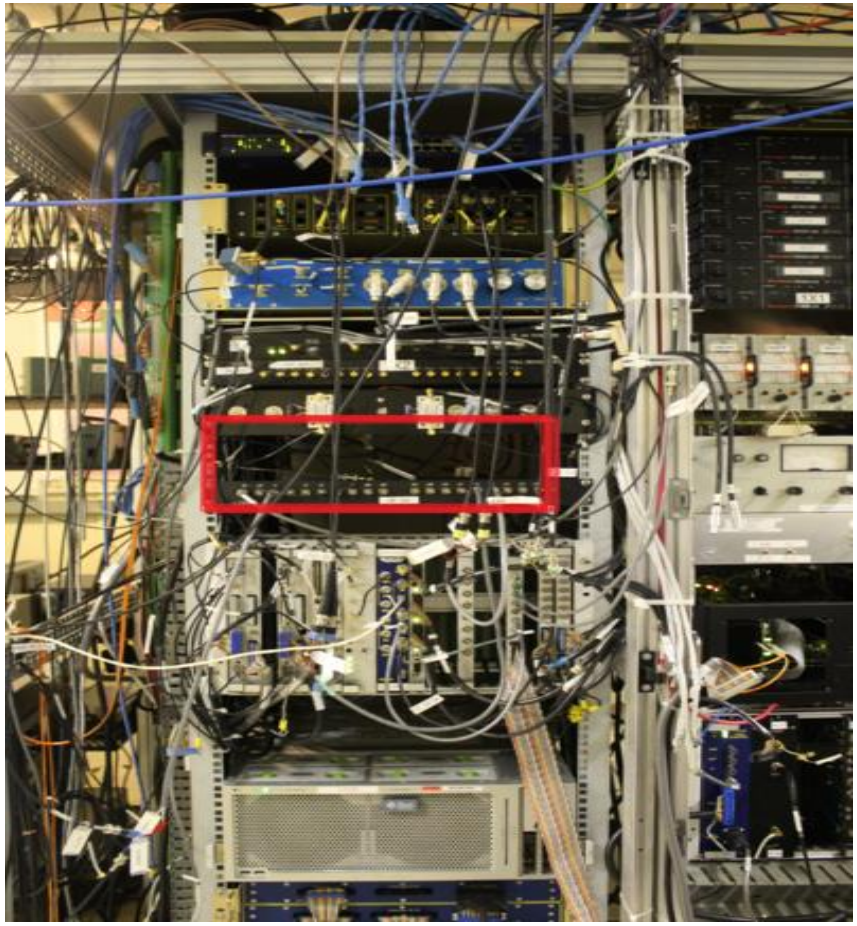
Interface with EPICS Channels

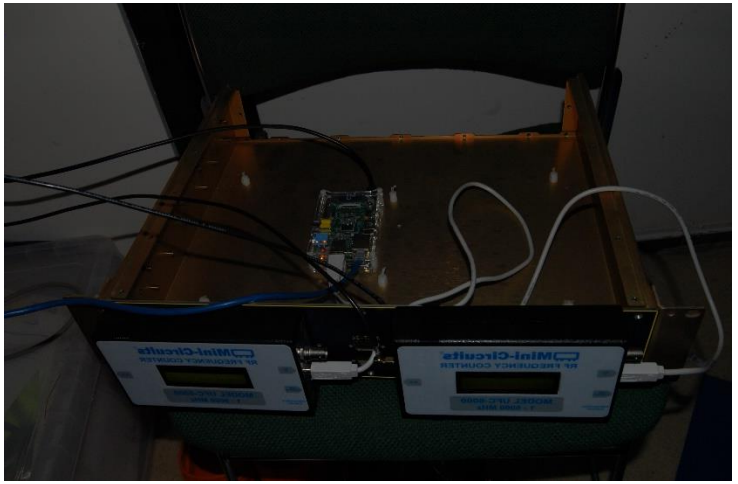
- Experimental Physics and Industrial Control System (EPICS): set of software components and tools used to create control systems.
- IOC: Input / Output Controller - Network and device interface



LIGO

Installed FOL Box





LIGO-G09xxxxx-v1

Testing and Commissioning

- Setup tested with existing green laser beat note.
- To be tested with the infrared PSL after completion of optics installation.
- The FOL box will be permanently placed inside the 40m and the software issues can be remotely debugged.

LIGO

Acknowledgements

- Mentors: Manasa T., Eric Q, Koji A.
- 40m folks: Rana A., Jamie, Jenne D., Steve V.
- Co-Interns: Harry, Nichin, Andres
- Organizations: Caltech and NSF

LIGO

Thank You