Developing Methods of Gravitational Wave Detector Characterization

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Overview

- **MEDM tab on summary pages**
  - Introduction to 40m and summary pages
  - What is MEDM?
  - Incorporating MEDM into summary pages
- **Measuring the coupling of acoustic noise to interferometer**
  - Requirements and design
  - Microphone layout
  - Results
- **Conclusion and Future Work**

Part 1: Incorporating MEDM Screens into Summary Pages

Caltech 40m: Small Scale Controls Prototype

- 100x smaller than actual sites
- Convenient to make changes at the interferometer
- Less expensive and catastrophic when something goes wrong at a small-scale prototype
- Easier to handle a 100x smaller instrument
- Helpful to confirm that something works here before trying it out at the actual sites
- Only full aLIGO-style prototype interferometer in the world
- Several aLIGO control systems were developed at the 40m

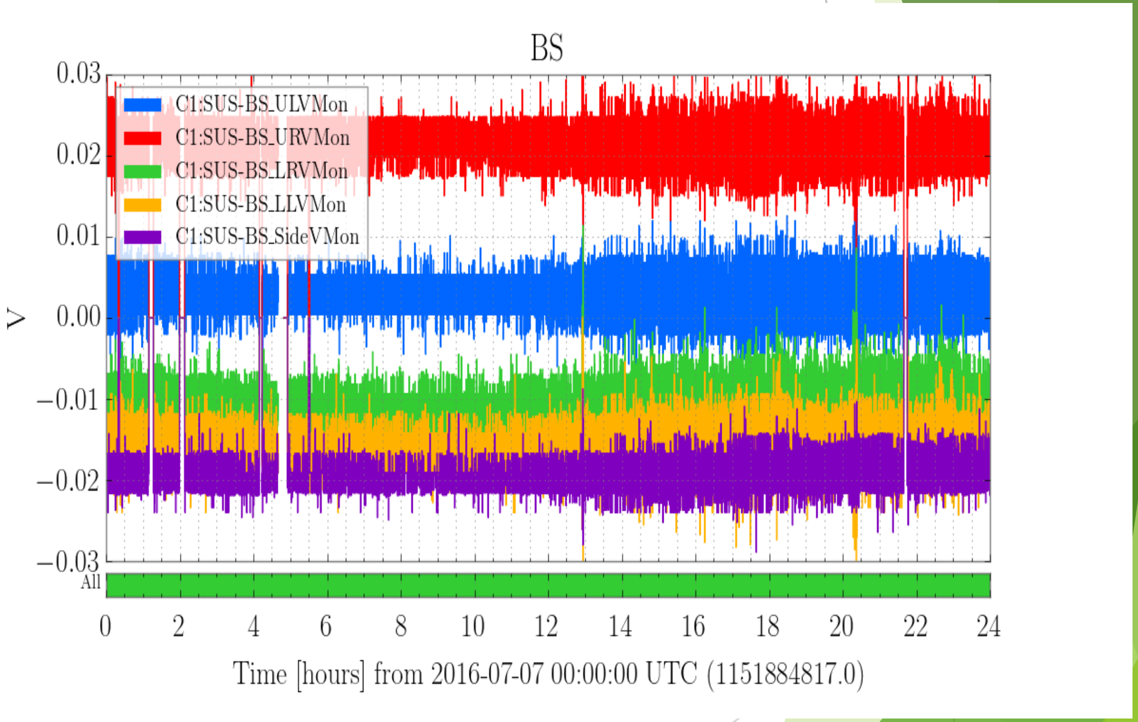
Caltech 40m Prototype Interferometer

Detector Characterization

- Detector characterization: understanding state of the interferometer in its environment
- Detecting gravitational waves is possible because of the work to study and identify noise sources
- Must be able to distinguish noise from signal to make any detections
- Understanding noise sources improves detection ability
- Learning how to isolate and remove noise from the signal

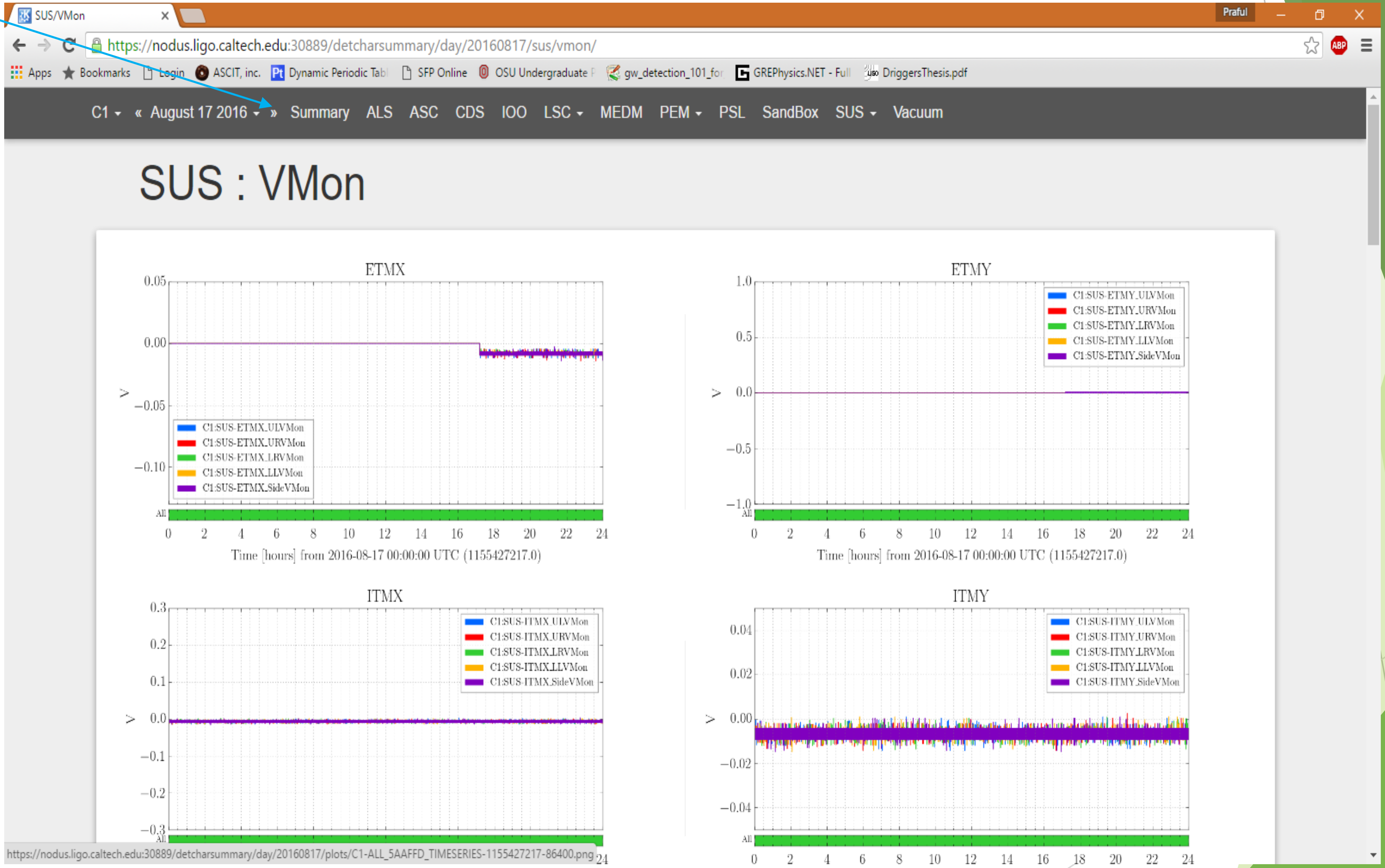
Summary Pages

- Data channel- raw timeseries data from different detector subsystems
- Display plots of various data channels, updated every 30 minutes
- Exist for the actual detectors (not available to the public), 40m (open to public)
- Helpful for quickly diagnosing issues and debugging
- Main goal: can be used to monitor the state of the interferometer
- One major benefit: visual archive of channel data



Code created by Duncan Macleod

Different tabs organized by detector subsystem



MEDM Screens

- MEDM: a human-machine interface
- Can read and change interferometer parameters conveniently
- Display information about physical status of interferometer
- Main point: useful for interacting with the interferometer

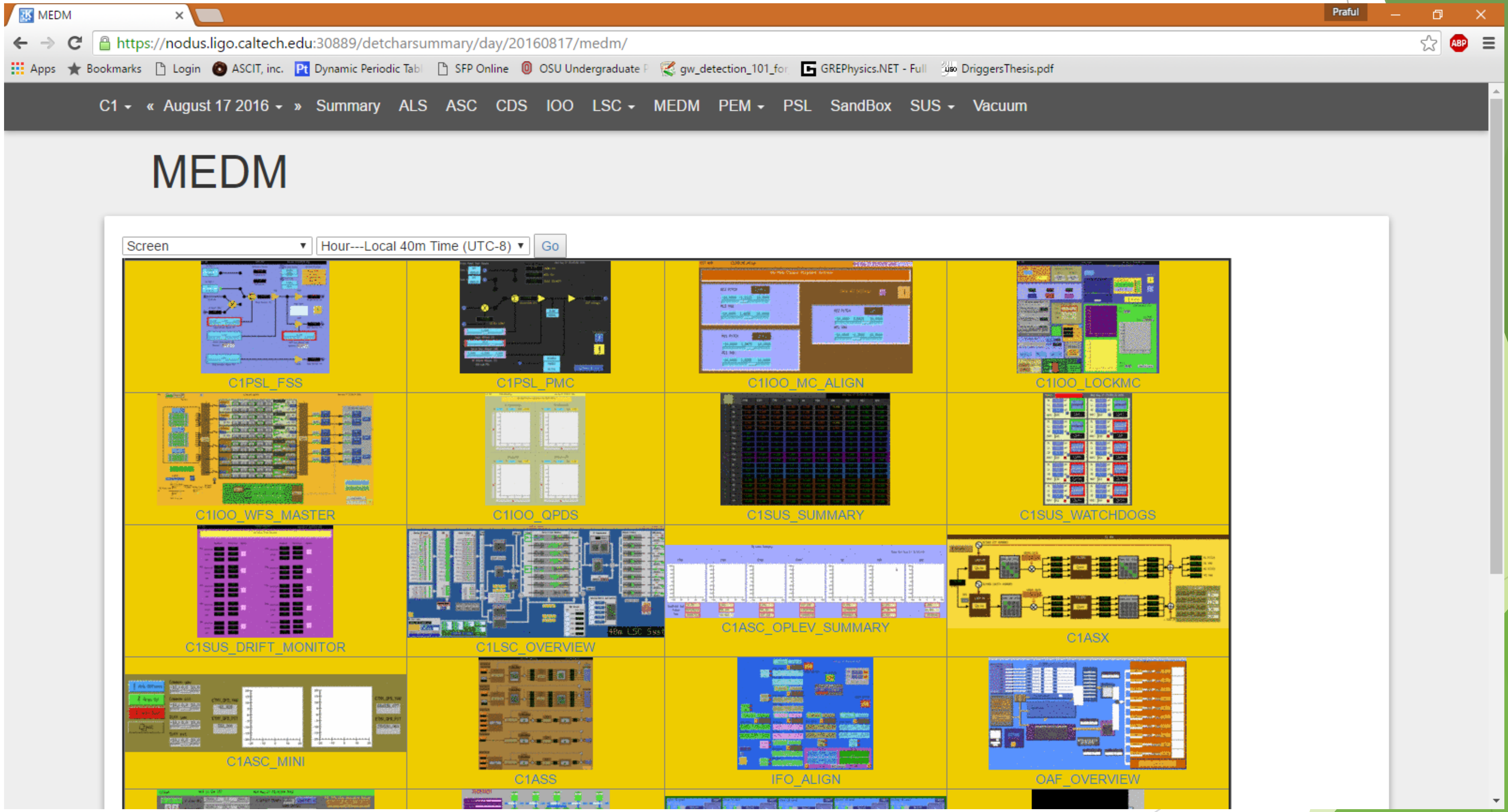
Each column represents a frontend machine

Each row in a column represents a core responsible for running a specific model (suspension, arm length stabilization, etc.)

MEDM Tab on Summary Pages

- Goal: integrate MEDM screens into summary pages
- Began with some scripts that took screenshots of MEDM screens
- Incorporated into summary pages as an independent system
- Archive lookup function
- Useful for people at the 40m- can look up previous MEDM screens for diagnostics
- May be transferrable to actual sites

Demonstration



Part 2: Measuring Coupling of Acoustic Noise to Interferometer

Objectives and Requirements

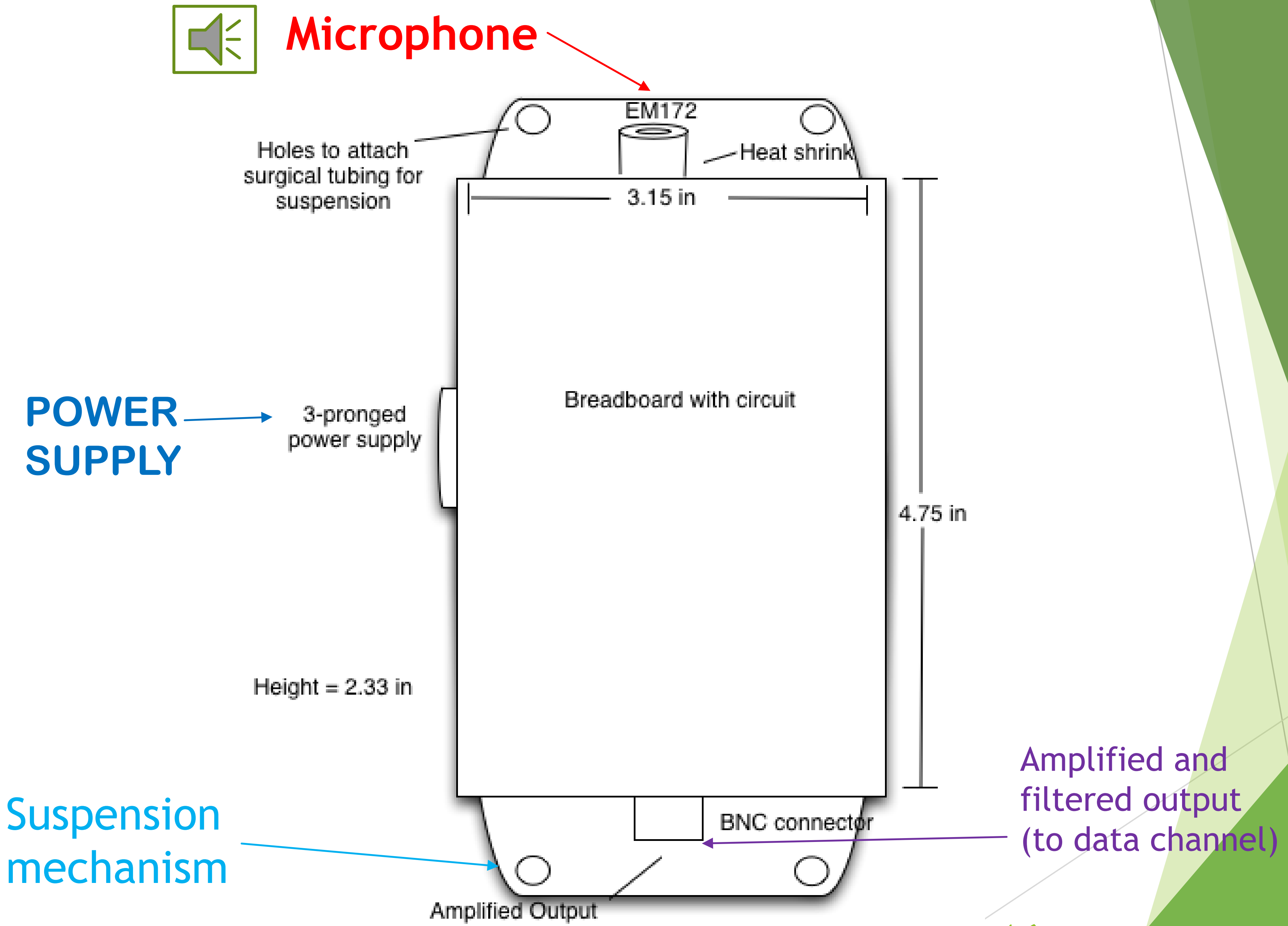
- Acoustic noise: a different frequency range than seismic noise
- Need a system to cancel acoustic noise to prevent possible coupling to the interferometer
- **Requirements**: create a circuit with an amplifier and bandpass filter, create box design, optimize microphone locations
  - Amplification: acoustic signal may be too small to see without amplifying first
  - Bandpass filter: microphones have a dynamic frequency range determined by mechanical properties
  - Microphone box: need something to hold microphones in place and attach them to amplifier circuit
  - Microphone layout: have to find optimal locations to observe coupling

Objectives and Requirements (cont.)

- **Known noise sources**
  - Electronics racks
  - Air conditioning units
- **Overall goal:** subtract acoustic signal out from differential arm length (DARM) readout to improve signal to noise ratio
  - DARM is the gravitational wave channel- where we expect to see a signal (not at 40m)
- System being developed simultaneously at actual sites

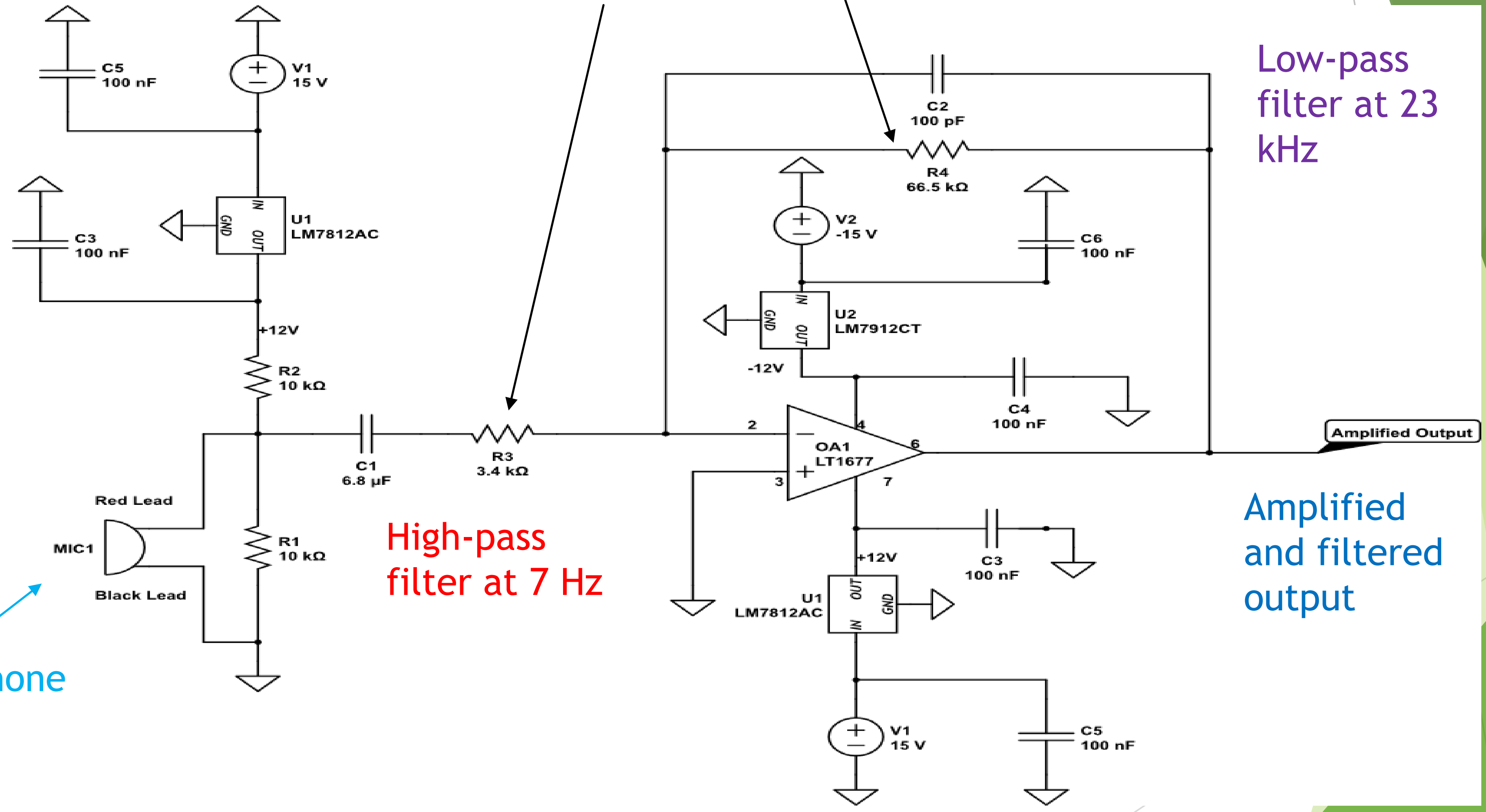
Box Design

- Needs to be isolated from ground motion as well as wind from AC, fans, etc. in order to pick up only acoustic signal
- Suspension: if the box has enough weight, it will not oscillate much above the natural frequency determined by the spring constant of the suspension material and the mass of the box
- By setting the mass appropriately and picking a good suspension material, the box can be isolated from ground motion
- Surgical tubing chosen as suspension material due to rigidity
- A heavier box also prevents movement due to wind from AC


Microphone
EM172
Holes to attach surgical tubing for suspension
Heat shrink
3.15 in
POWER SUPPLY
3-pronged power supply
Breadboard with circuit
4.75 in
Height = 2.33 in
Suspension mechanism
BNC connector
Amplified and filtered output (to data channel)
Amplified Output

Amplifier Circuit

Gain of amplifier set by ratio of these two resistors



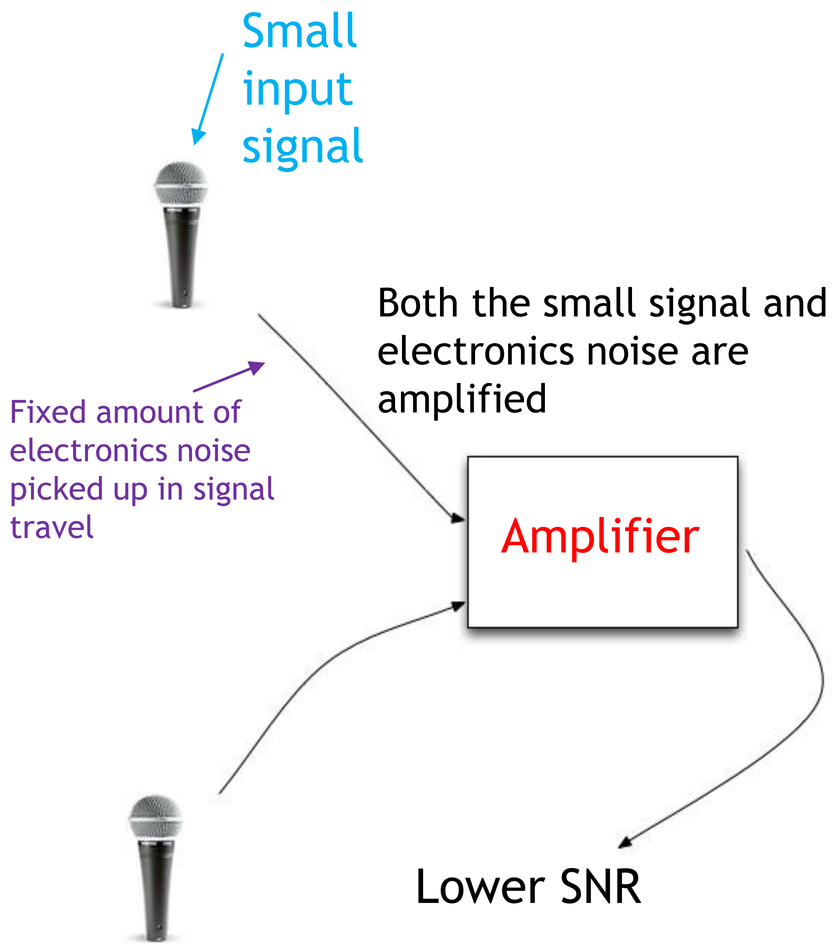
Low-pass filter at 23 kHz

High-pass filter at 7 Hz

Amplified and filtered output

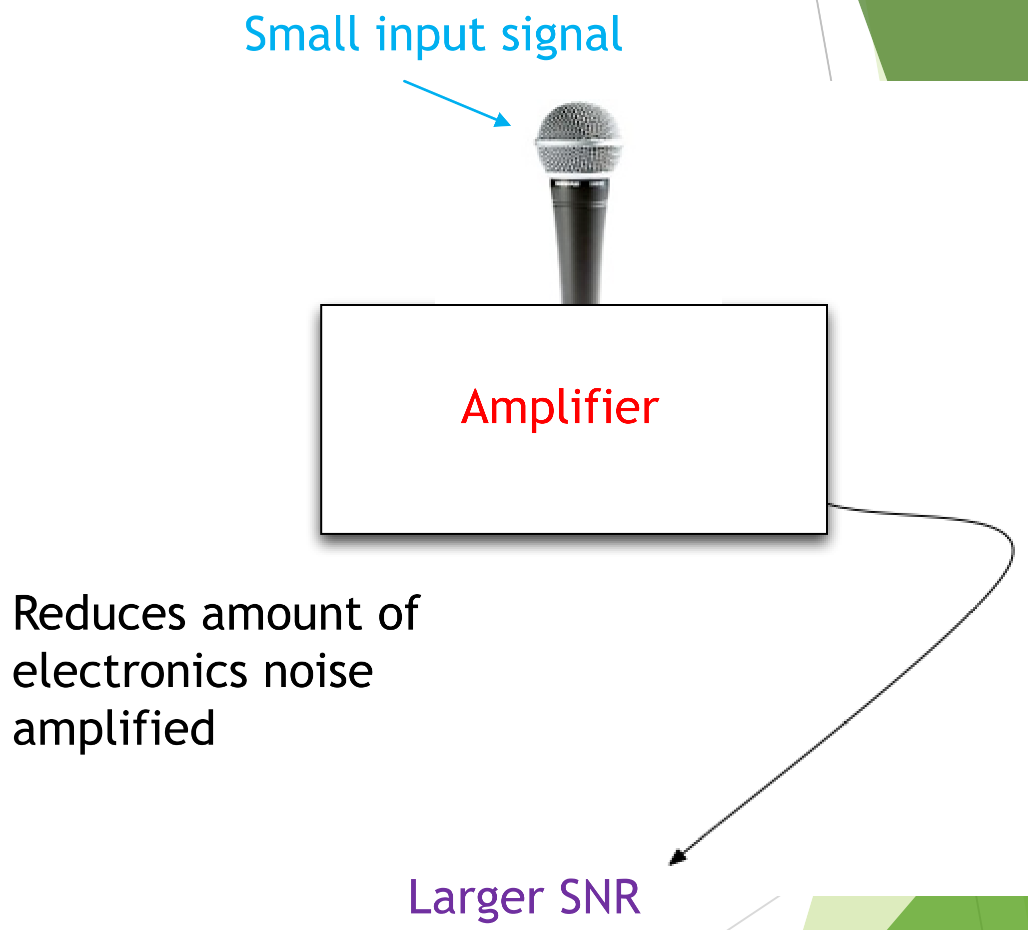
Microphone

Old System vs. New System



OLD SYSTEM

VS.

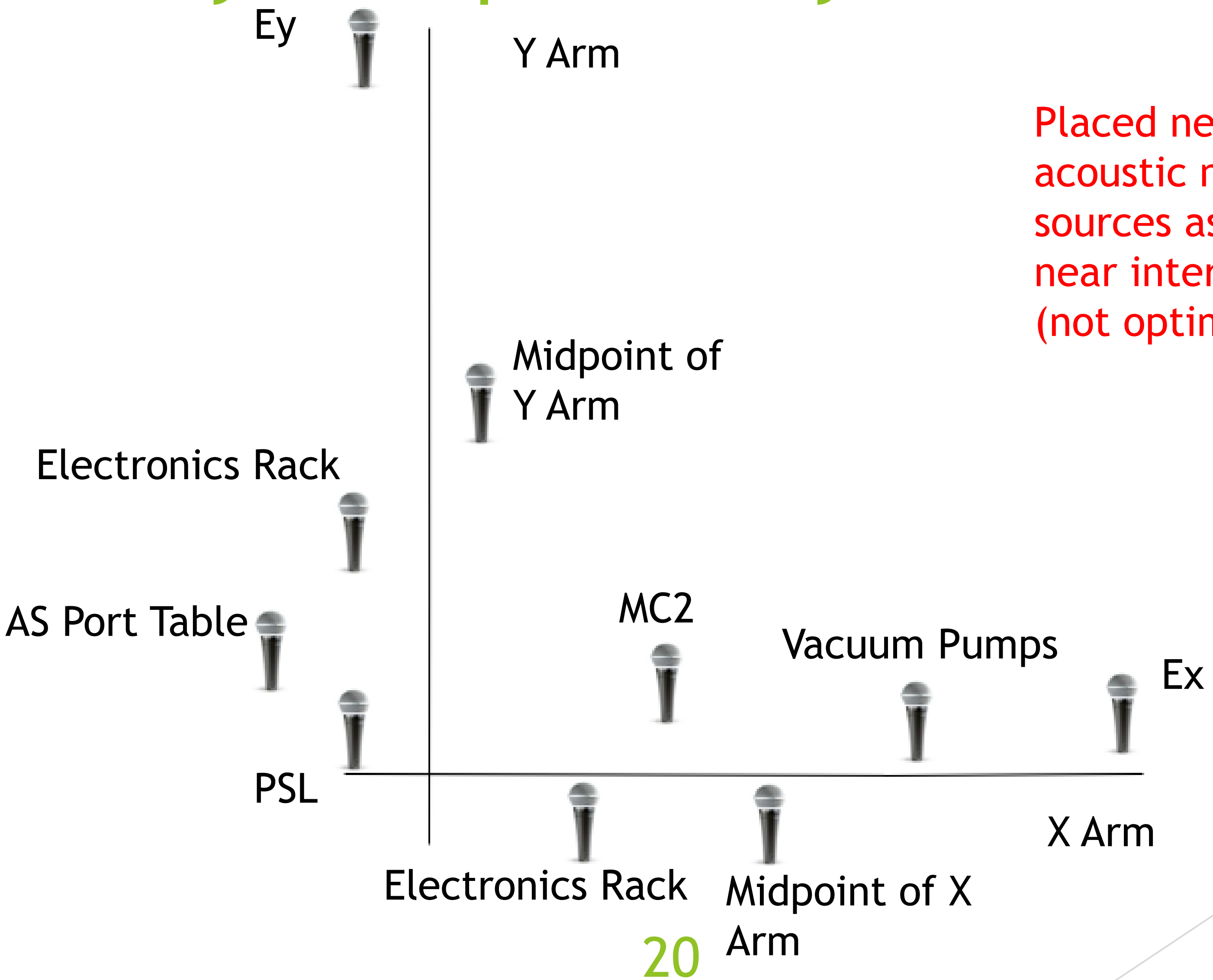


NEW SYSTEM

Optimizing Microphone Locations

- Important to have an array of sensors- can pick up things that we cannot hear and helps better distinguish between acoustic signal and self noise
- Not clear yet what locations will be best for the microphones
- A lot of trial and error in testing locations
- Tradeoff between measuring near noise sources and near the interferometer- may not be a black-and-white contrast
- Future work: use machine learning to design a system that optimizes the location to observe coupling (useful for other types of noise cancellation as well)

Preliminary Microphone Layout

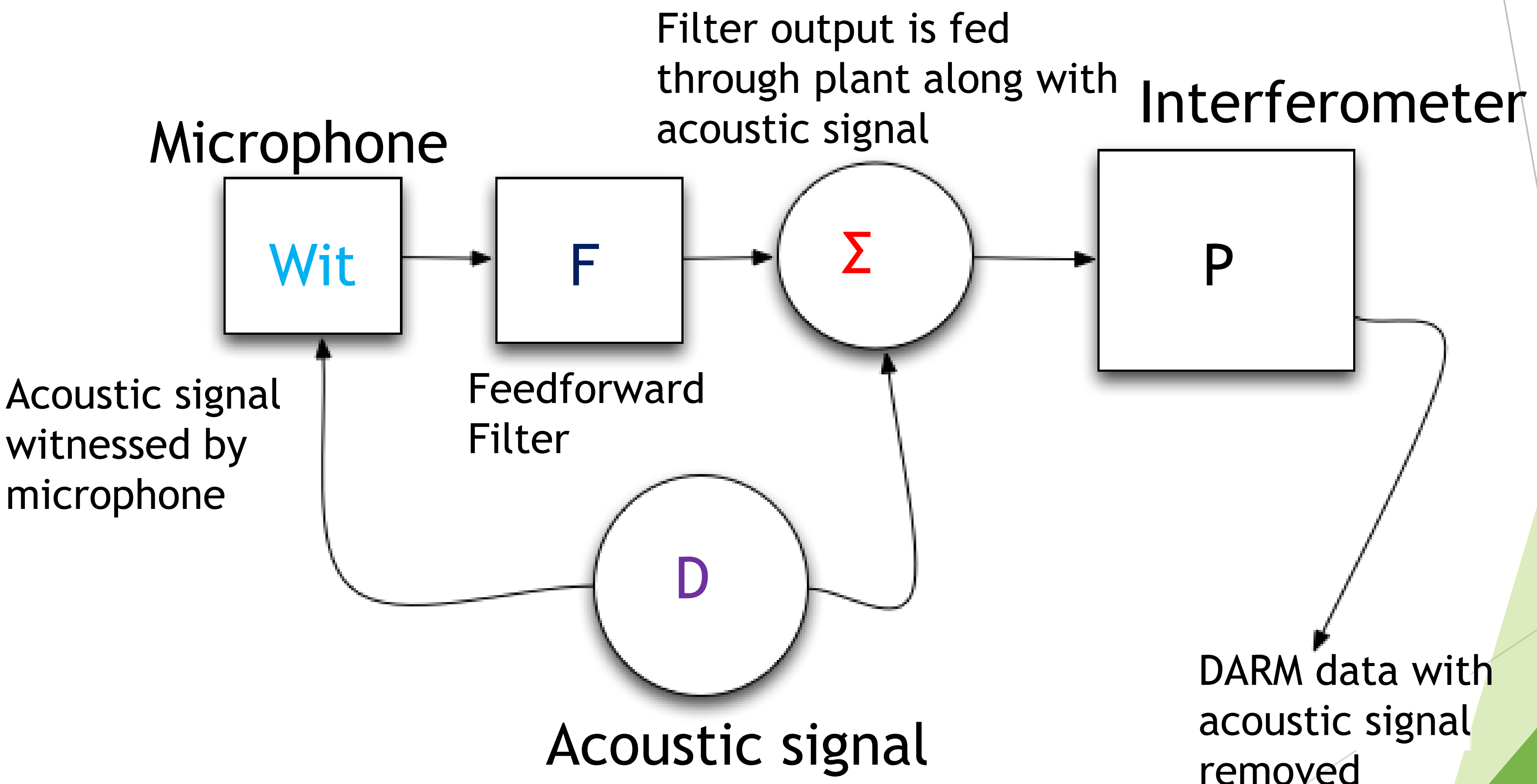


Placed near known acoustic noise sources as well as near interferometer (not optimized yet)

Feedforward Control- A Method of Noise Cancellation

- Method of preventing noise from appearing in output signal
- Basic idea: have a witness sensor that observes the noise, sends it to an actuator, and cancels it from the signal before the output is readout
- Application to this project: witness sensor uses multi-coherence method to isolate self noise of microphones and cancels it out from the signal so that only the acoustic signal is isolated
- Isolated acoustic signal can then be fed to an actuator to cancel the effect out from the interferometer readout (DARM)

Feedforward Control Loop



Noise-cancelling Headphones

A common example of active noise control using feedforward

Very similar to the goal of this project

Isolating the Acoustic Signal

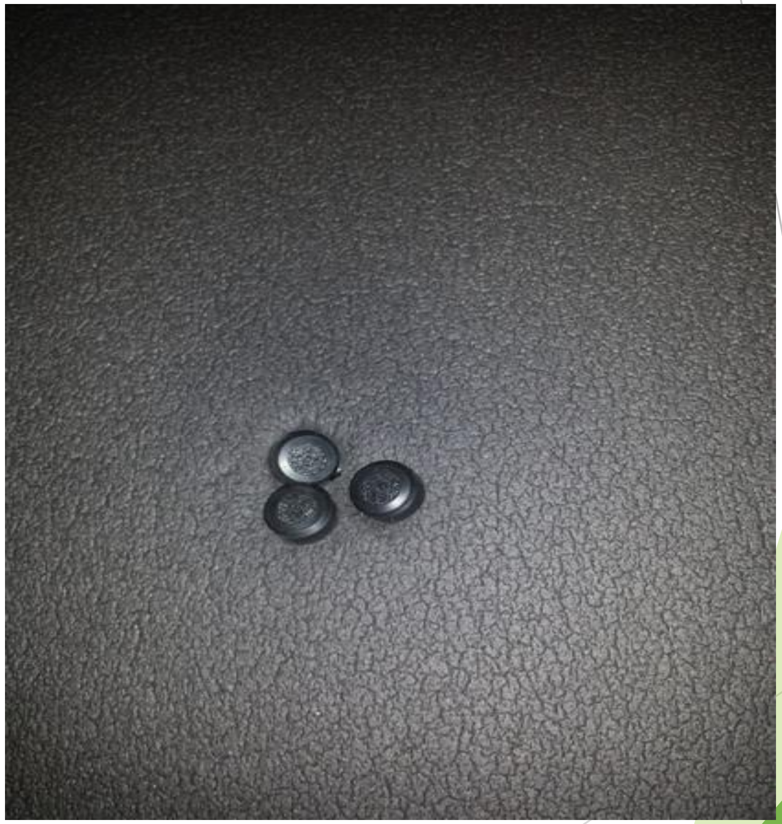
- A general microphone readout is composed of the actual acoustic signal and some instrument self noise
  - e.g. $X(t) = S(t) + N(t)$ in time domain
  - X(t) is the total readout, S(t) is the acoustic signal, and N(t) is the self noise
- The acoustic signal needs to be separated out to perform accurate feedforward noise cancellation
- **Basic idea:** multiple nearby sensors will share the same S(t) (acoustic signal) but will have N(t) (self noise) **without** any coherent phase relationship
- Need a way to isolate S(t) from N(t)

Isolating the Acoustic Signal (cont.)

- **Technique used:** frequency-dependent measurement of multi-coherence
  - Coherence in this context is the fraction of signal power (in the frequency domain)
- Need at least two sensors- target and witness(es) that receive (approximately) the same input signal
- Measures coherence of the self noise in different frequency bins
- Accounts for correlation between target and each witness as well as between witnesses

Isolating the Acoustic Signal: Experimental Setup

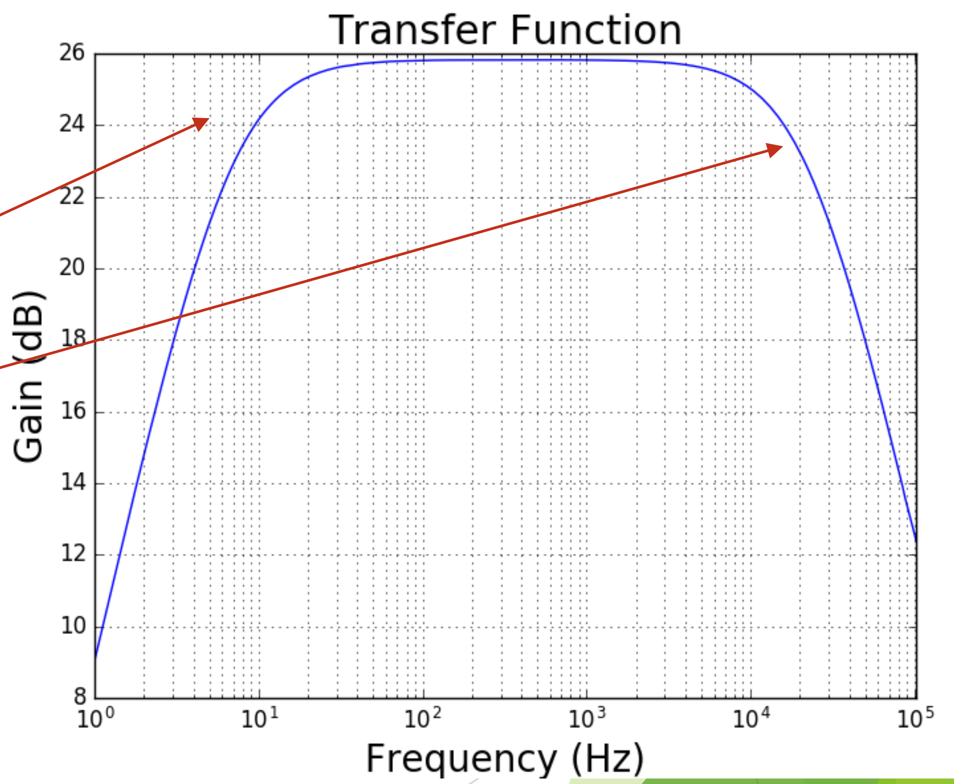
3 EM172 microphones embedded into a layer of foam to measure uncorrelated self noise



The microphones are placed close together to receive approximately the same acoustic signal

Results: Frequency Response

Transfer function: relationship of output signal to input signal (in this case ratio of output signal amplitude to input signal amplitude)



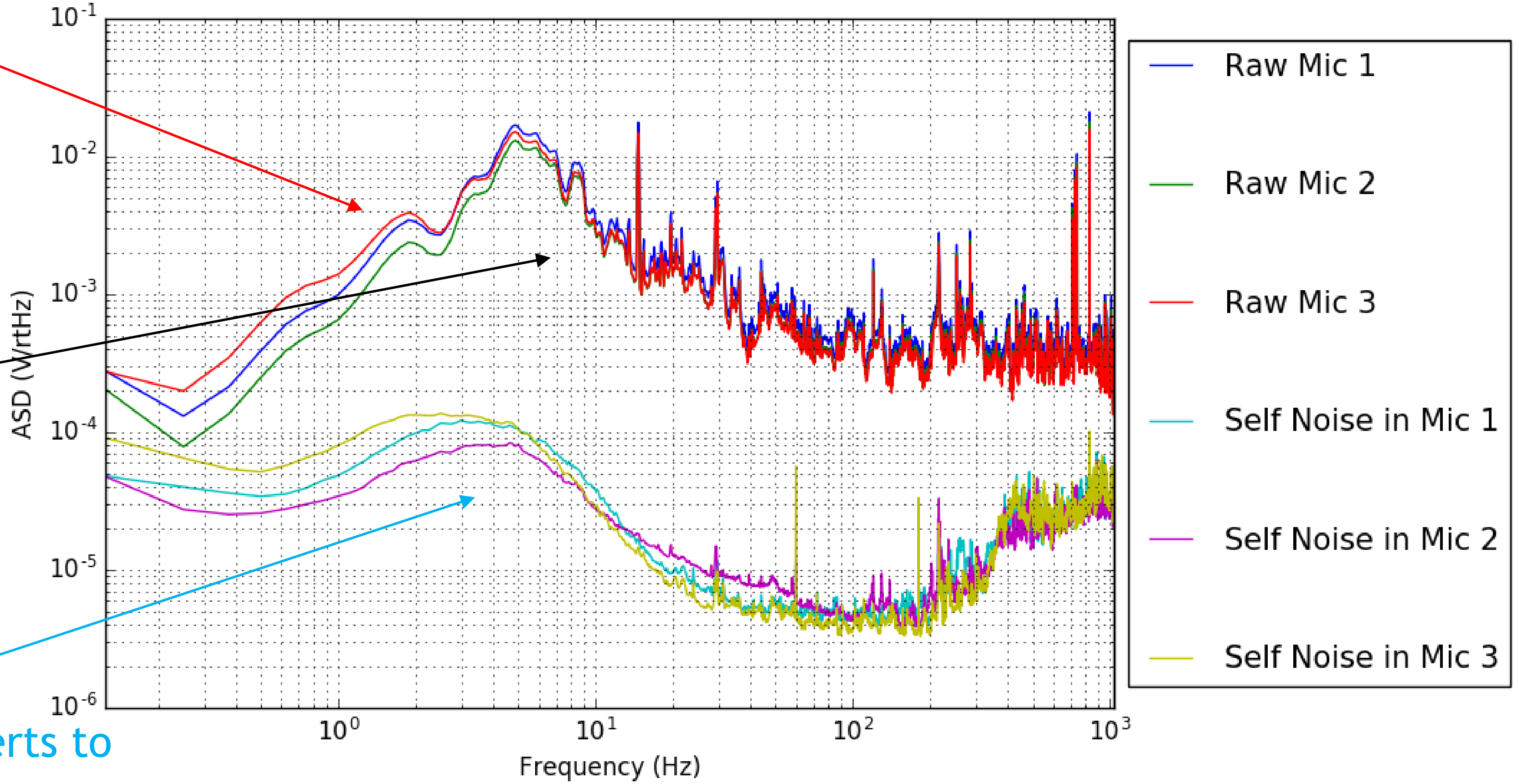
Cutoff frequencies at 7 Hz and 23 kHz

Bandpass filter attenuates frequencies outside of the cutoff range and amplifies within the passband

Results: Measuring Self Noise

All 3 microphones receive nearly the exact same signal

RMS of signal corresponds to about 45 (moderate rainfall)



RMS of self noise converts to about 15 dB (e.g. leaves rustling)

Conclusion

- Accomplished: added MEDM tab to the summary pages (includes archive function), finished preliminary design for microphone circuit and box, measured the self noise of the microphone to be used
- Still to do: create a single prototype box to ensure that everything works as planned
- Future work: send circuit design to manufacturer for easy fabrication, make a lot of boxes, suspend, optimize microphone locations

Goals for Next Week

- Make a prototype box with amplifier circuit- solder, alter a metal box to fit the requirements
- Start designing circuit for manufacturer production
- Suspend new box in the interferometer (likely near the vertex of the arms to begin with)
- Set up a data channel for the readout of this box
- Add new tab to summary pages

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