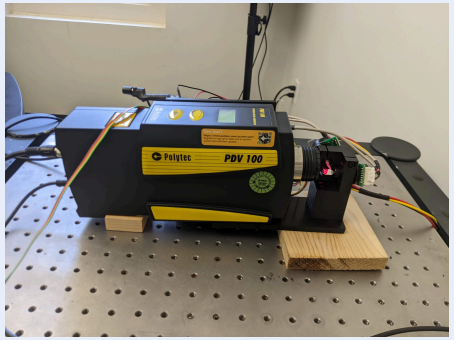
3aMU3: Augmenting a Single-Point Laser Doppler Vibrometer to Perform Scanning Measurements



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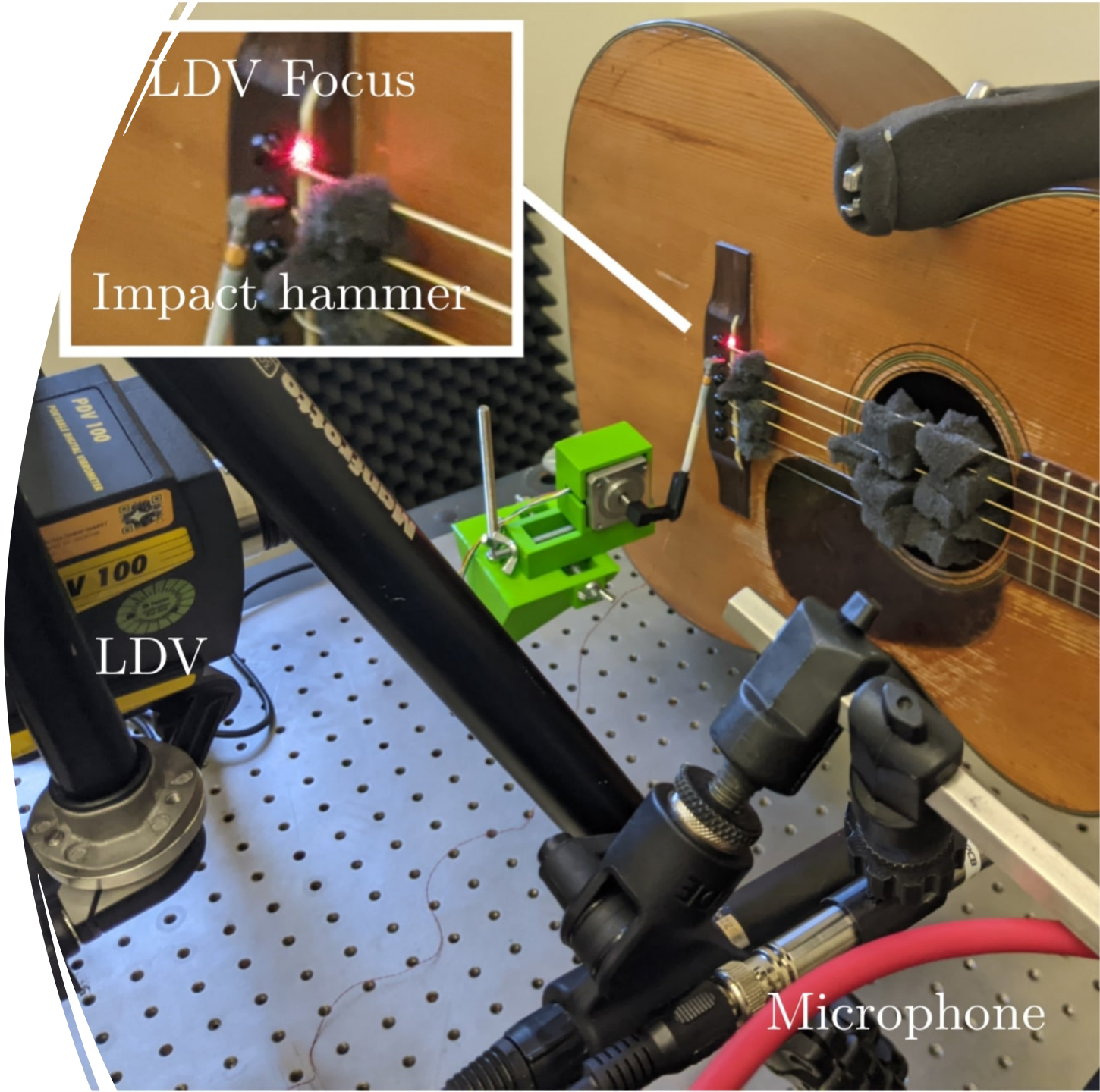
182nd Meeting, May 23, 2022

Denver, Colorado

Vibration Measurements

- Measure vibration of stringed instruments at the driving location (typically bridge)
- Laser vibrometer (or accelerometer) to measure surface velocity
- Force sensing impact hammer for excitation

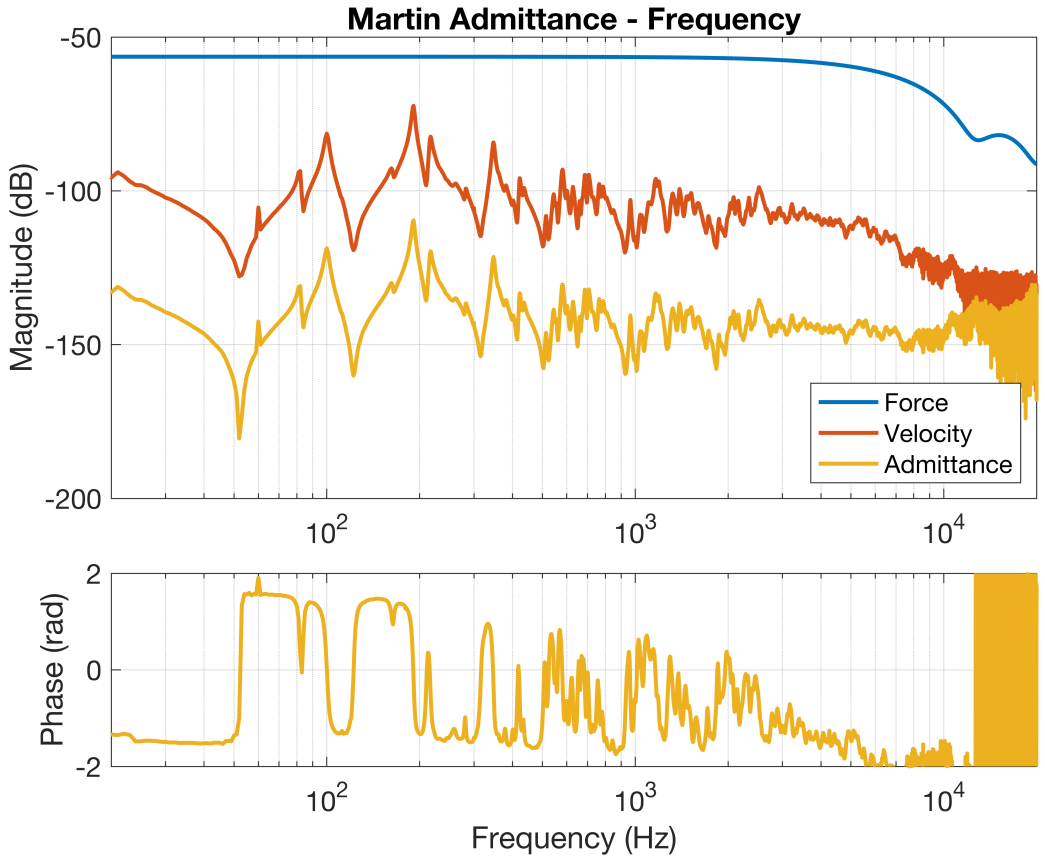


Admittance

- In musical acoustics, we typically work with the admittance or impedance

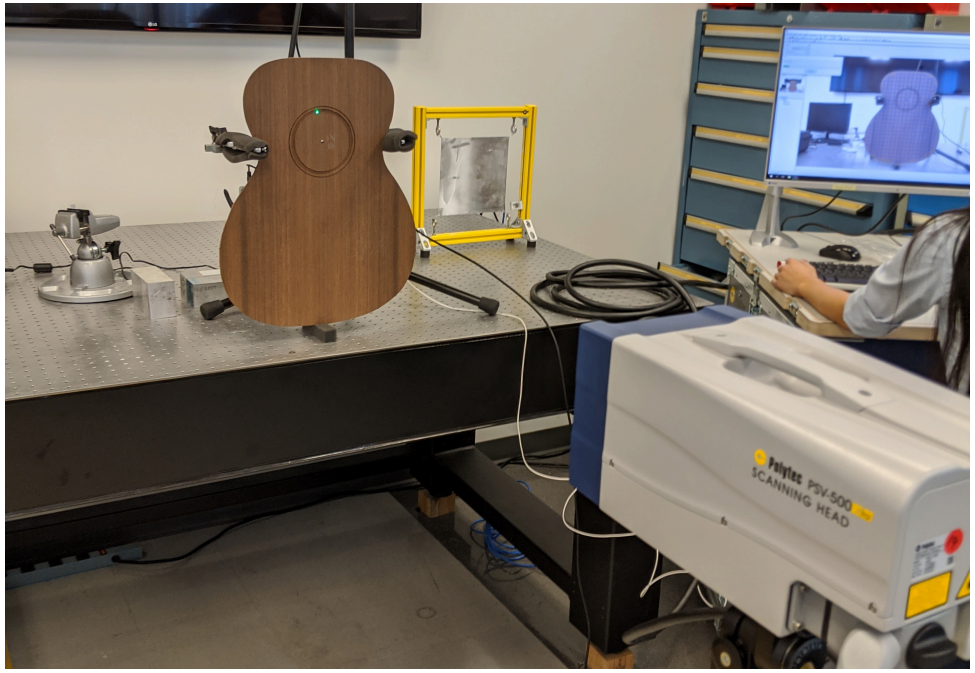
$$\Gamma(z) = \frac{V(z)}{F(z)}$$

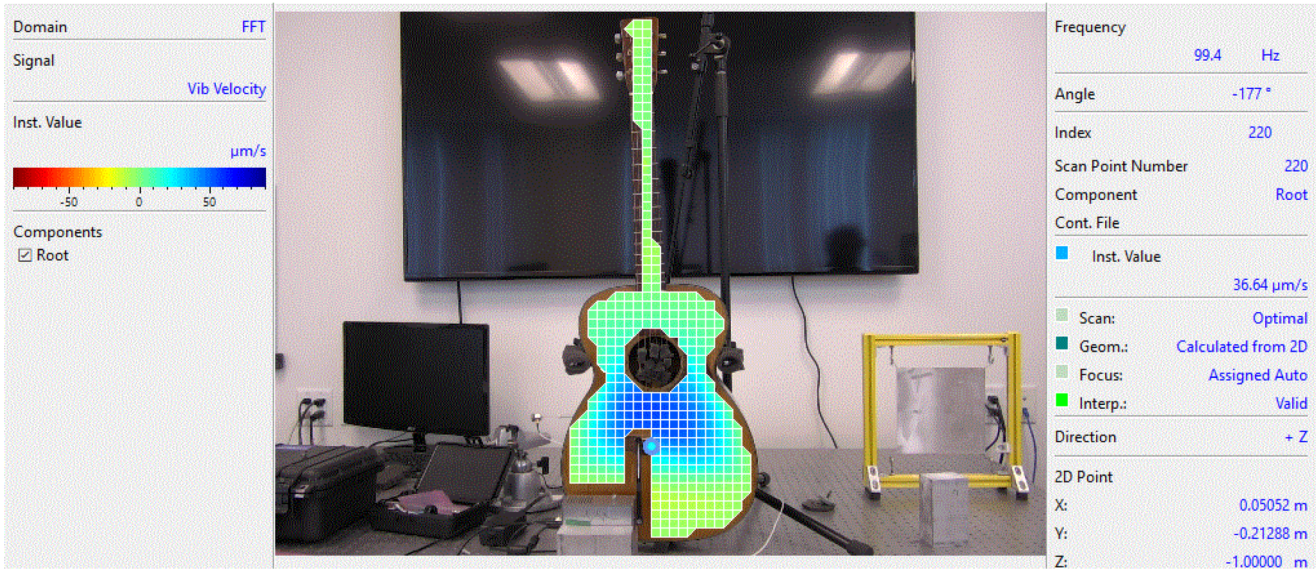
$$\Gamma(z) \rightarrow admittance$$
$$V(z) \rightarrow velocity$$
$$F(z) \rightarrow force$$



Scanning Vibrometer

- Can make vibration scans to visualize and study mode shapes





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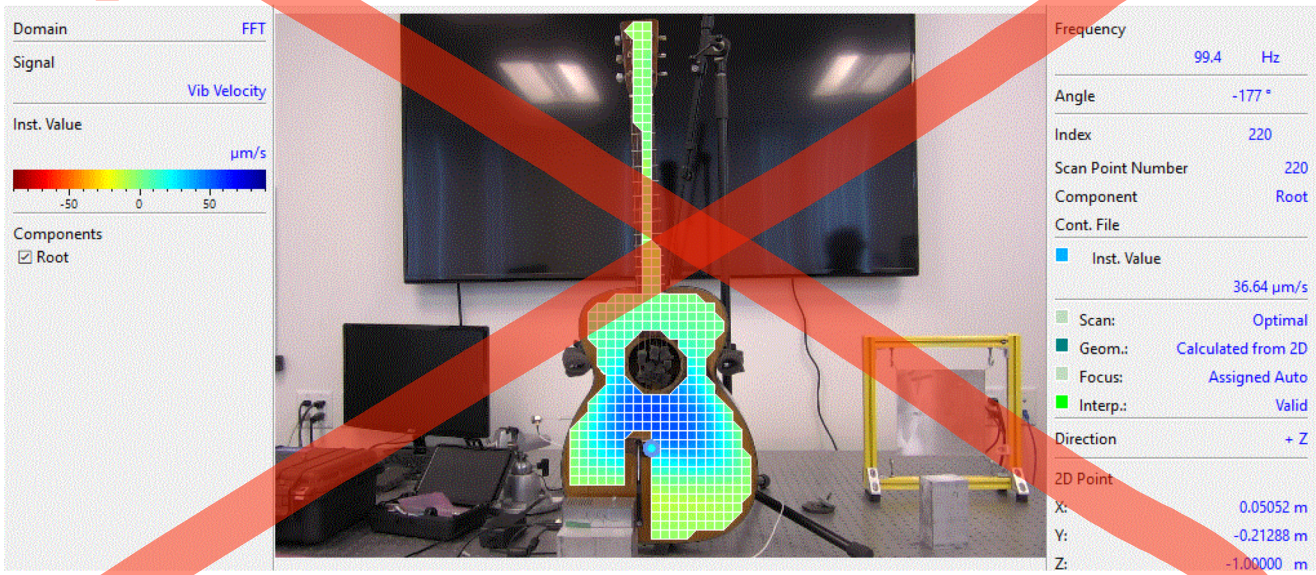
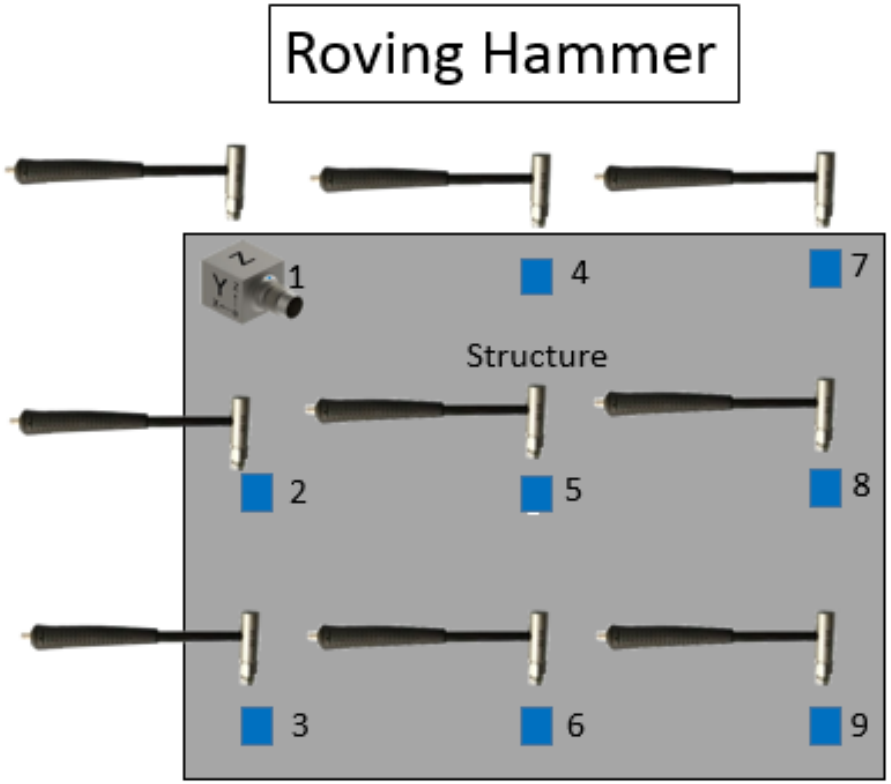


What's the Problem?

- Scanning vibrometers are very expensive
- Generally over $100000 to my knowledge
- I can't afford one

Alternatives?

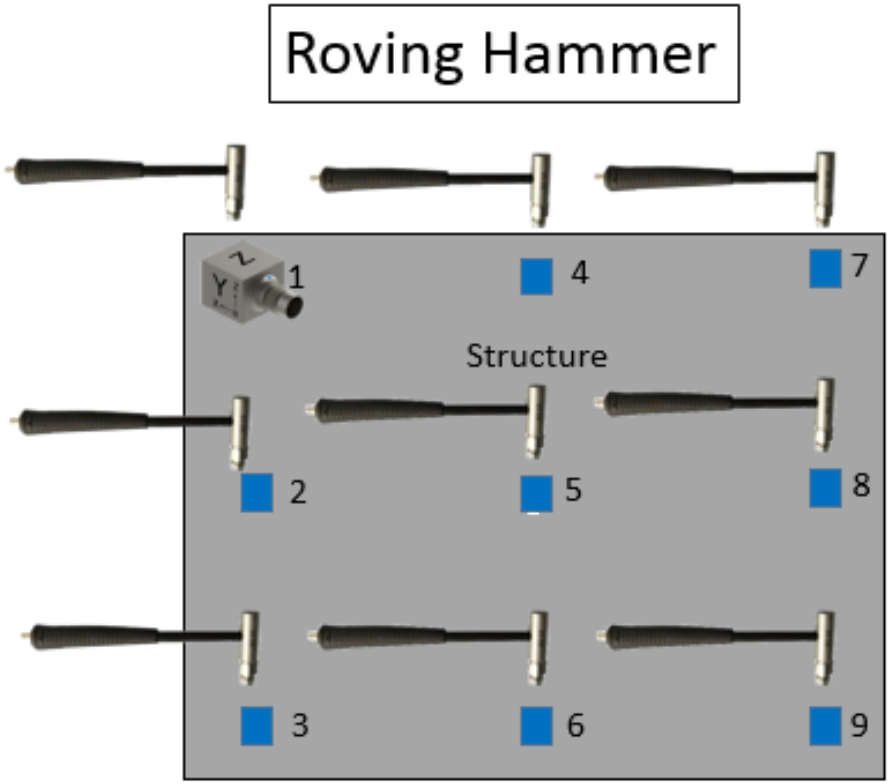
- Roving hammer/vibrometer method
- Manually make measurements over a pre-marked grid



(image from Siemens)

Alternatives?

- Very time consuming
- Imprecise
- Physically taxing



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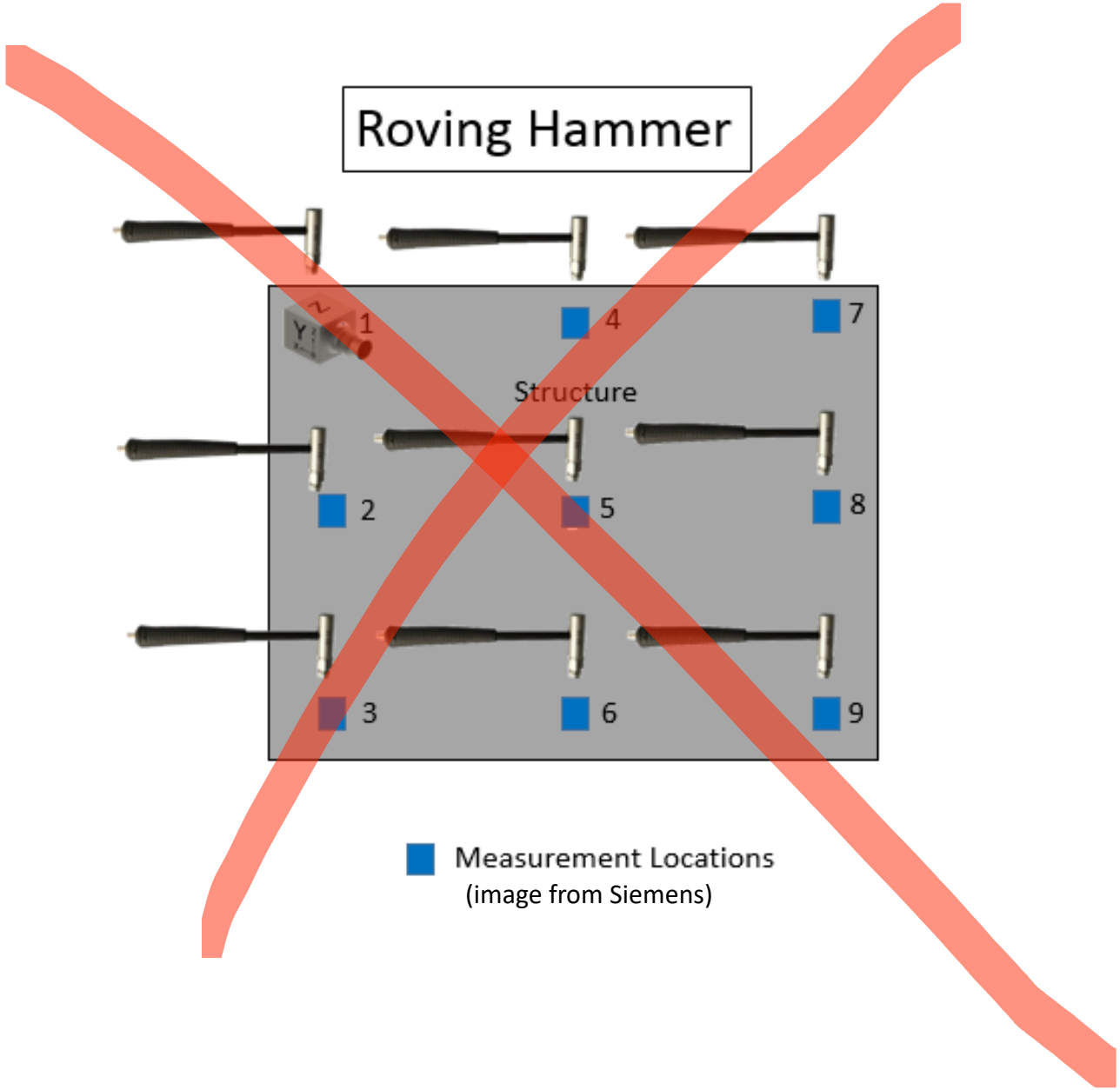


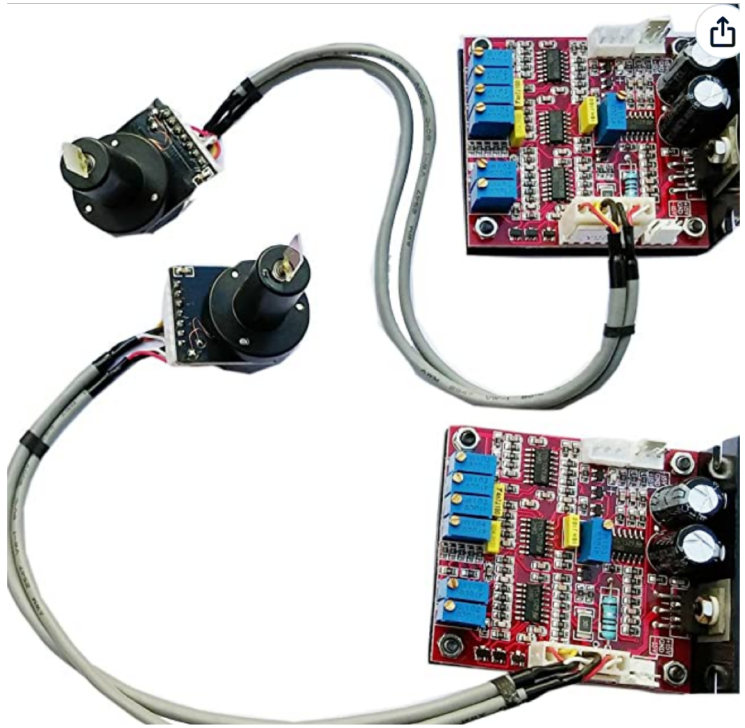
I’m too Lazy!

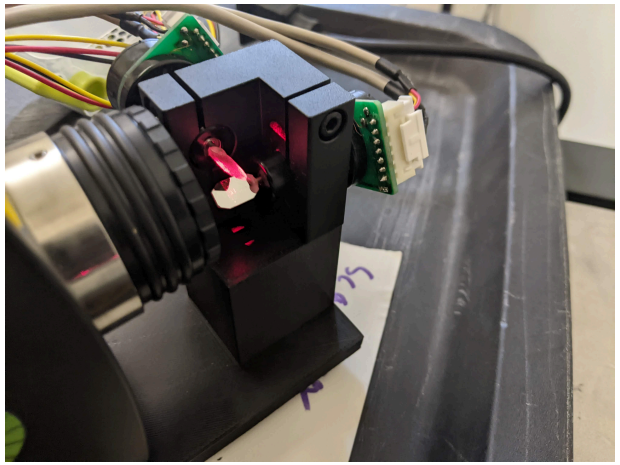
Alternatives?

- Let’s try to hack a scanning vibrometer
- My lab has a single-point vibrometer (PSV-100) as do many other labs
  - Less expensive (~ $15-40000?)

Mirror Galvo

- Redirect laser beam with a mirror galvanometer
- Current controlled electromagnet with mirrors that turn when the magnetic field is varied
- Purchasing options
  - Scientific supplier: ~ $3000
  - Inexpensive galvo meant for light shows: $ 137





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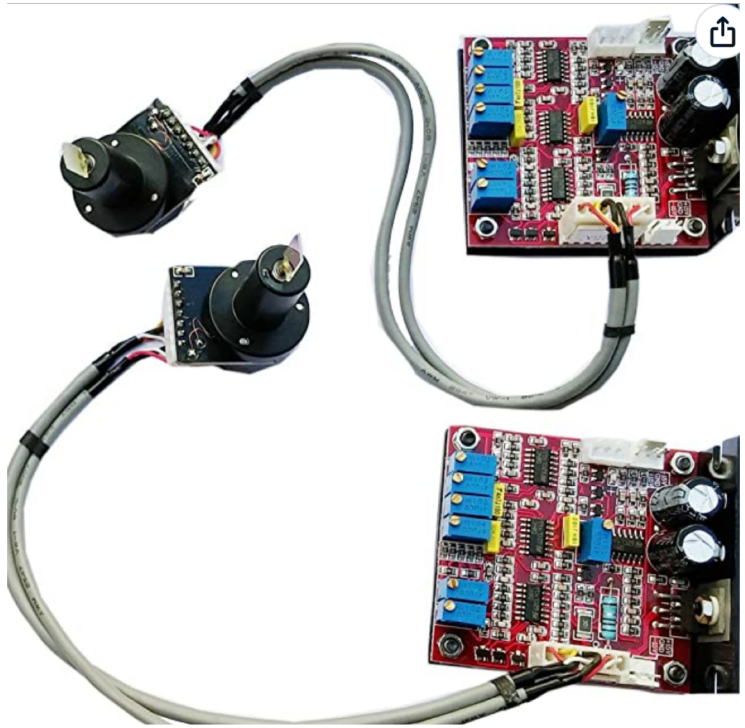

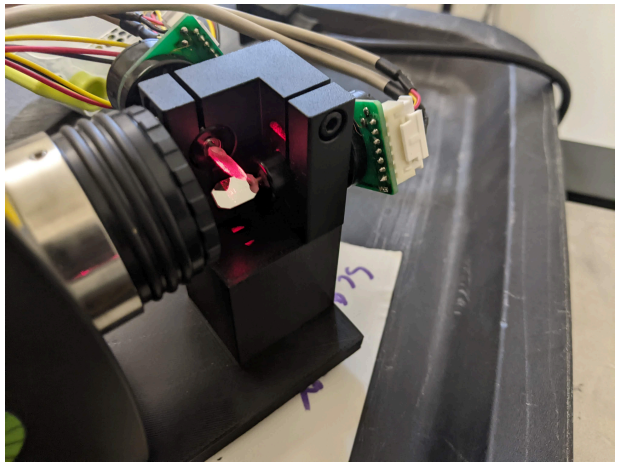

Galvo Control

- Controlled by microprocessor (Teensy 3.6)
- Takes voltage between ± 10 V
  - 3.3 V output from Teensy
  - Op-amp amplifiers for proper voltage scaling
- 12-bit DAC for mirror control
  - 4096 vertical and horizontal positions

  Moves with serial commands over USB
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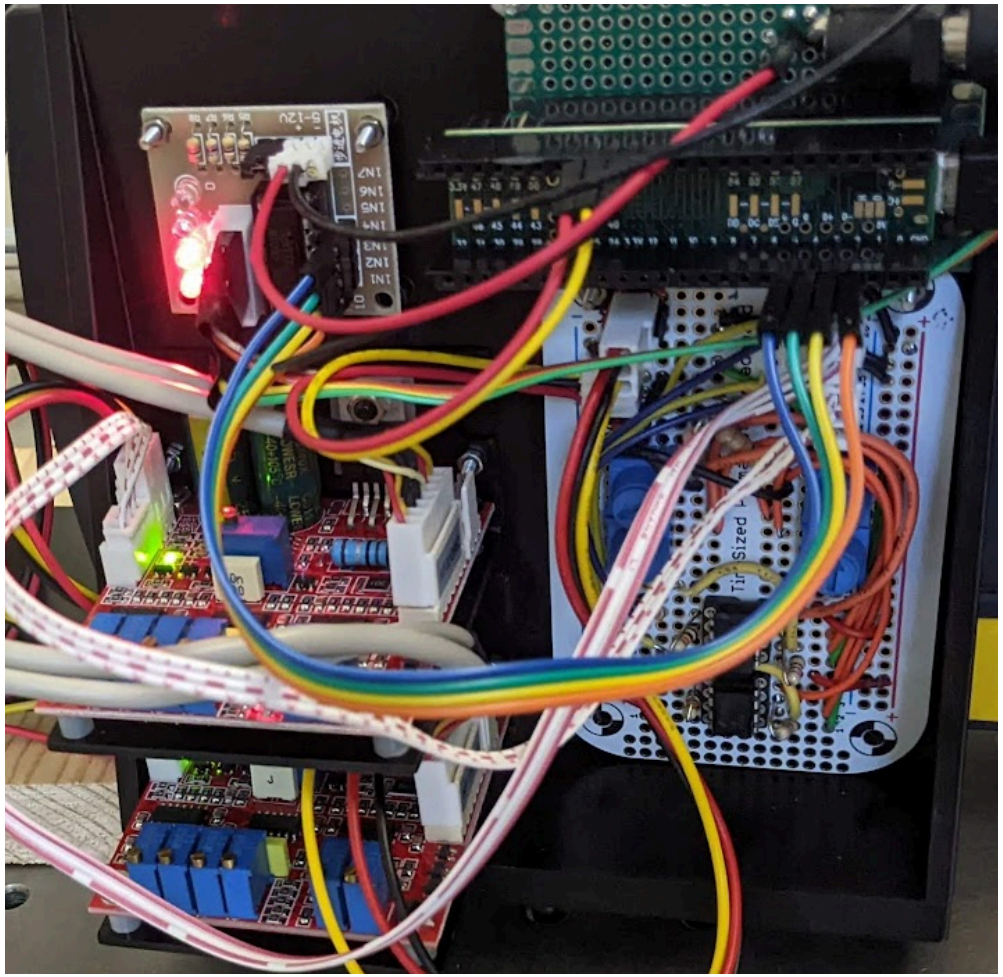
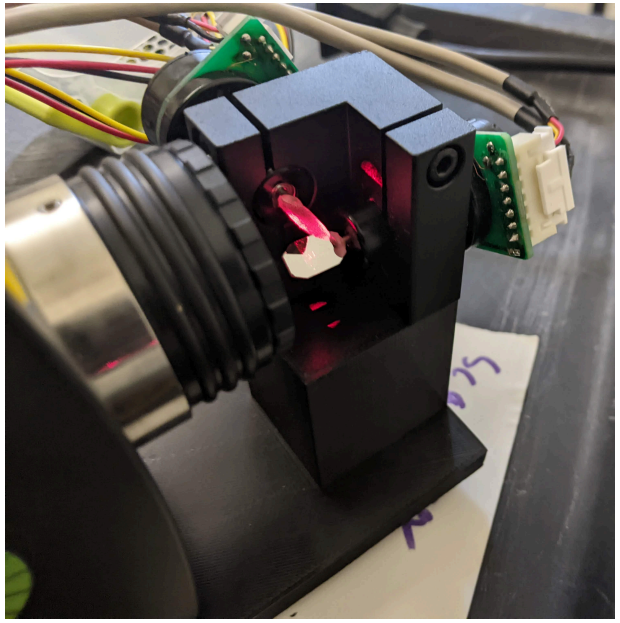
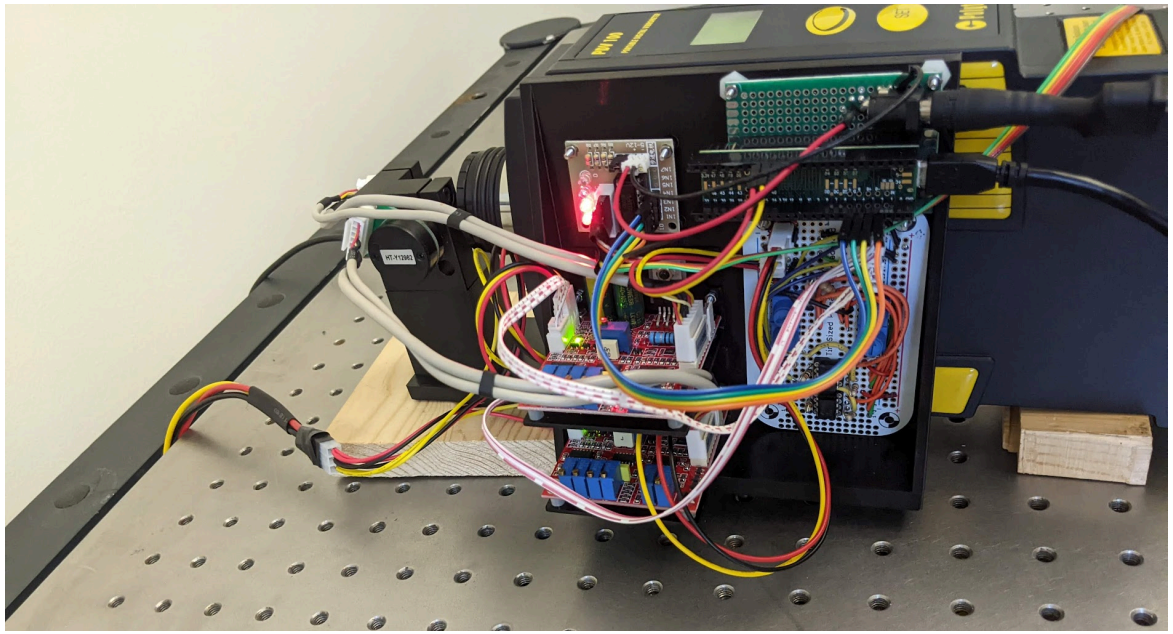


Mounting

- 3D printed base
- Attaches to the LDV
- Mounts for the circuitry
- Will make a nicer fully enclosed mount later





Excitation

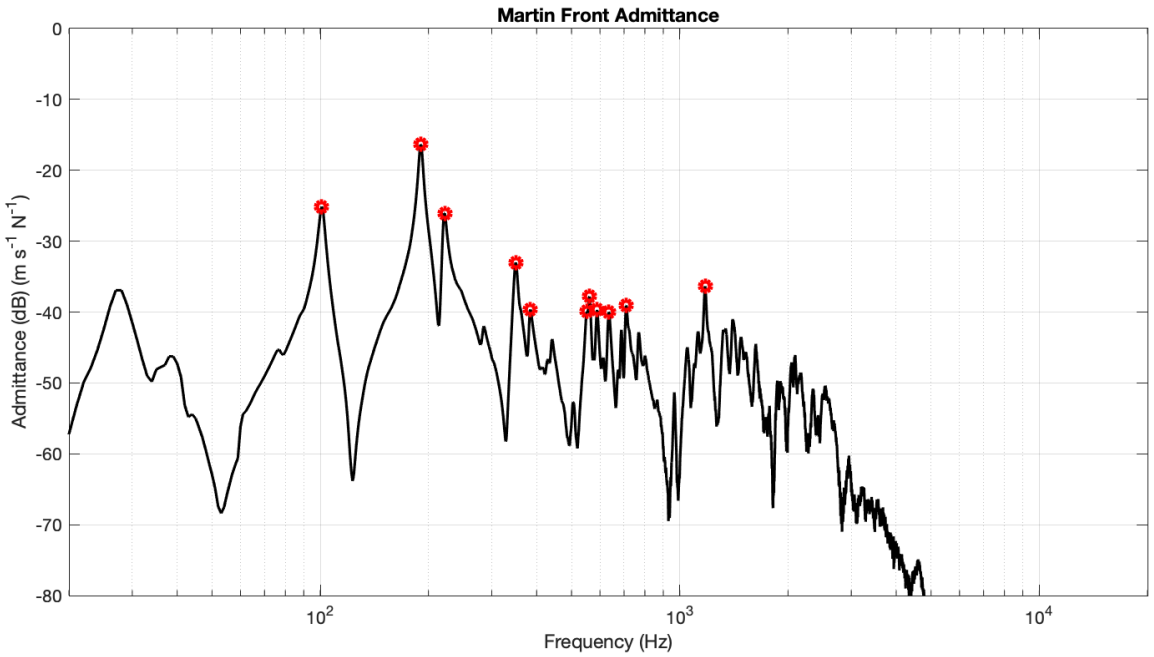
- Automated force hammer with stepper motor
- 3D printed mount
- Controlled by microprocessor and serial commands

Other Notes

- About a 16° arc of measurement
- Detect if a double hit occurred and re-take the measurement
- Pretty easy to program ands leave while measurements are being taken
- Mildly annoying to focus

Post-Processing

- Some attempt at throwing out measurements
  - Noisy
  - Hammer in the way
  - Outside perimeter of instrument
- Calculate admittance for each measurement point
  - Calibrates for differences in amplitude of hammer strikes
- Pick mode frequencies



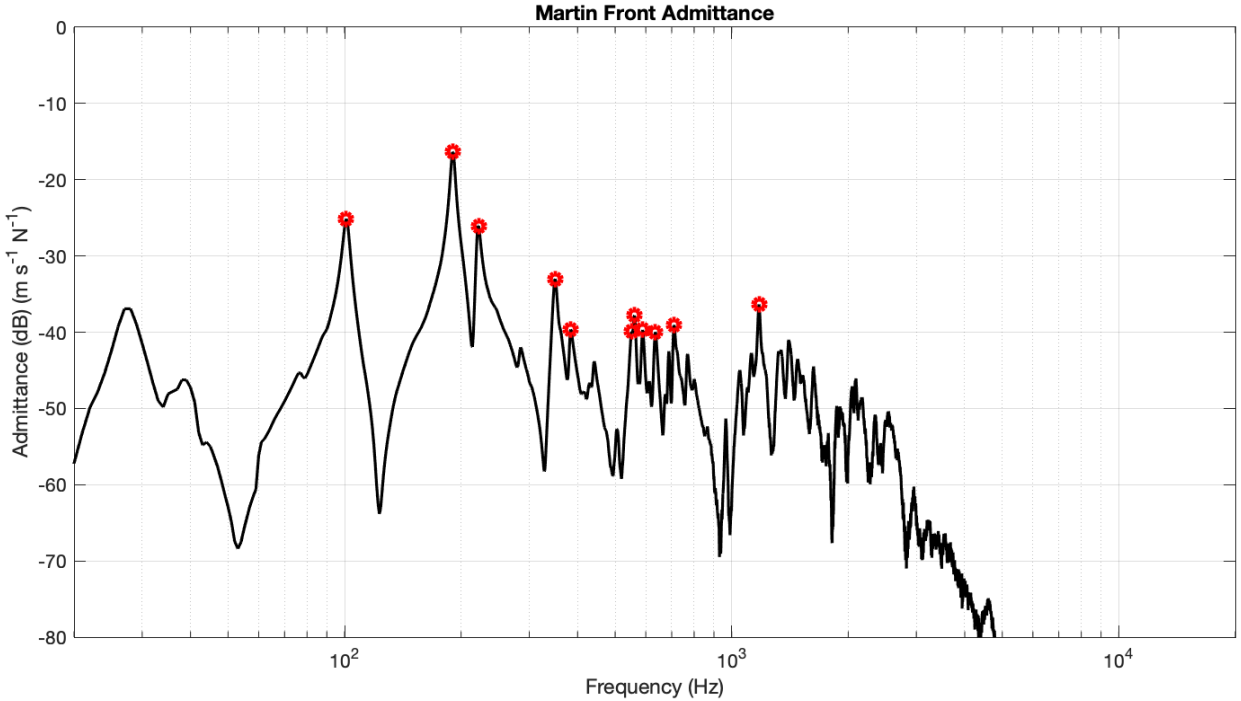
Test Case:
Does muting the back while playing affect the sound?

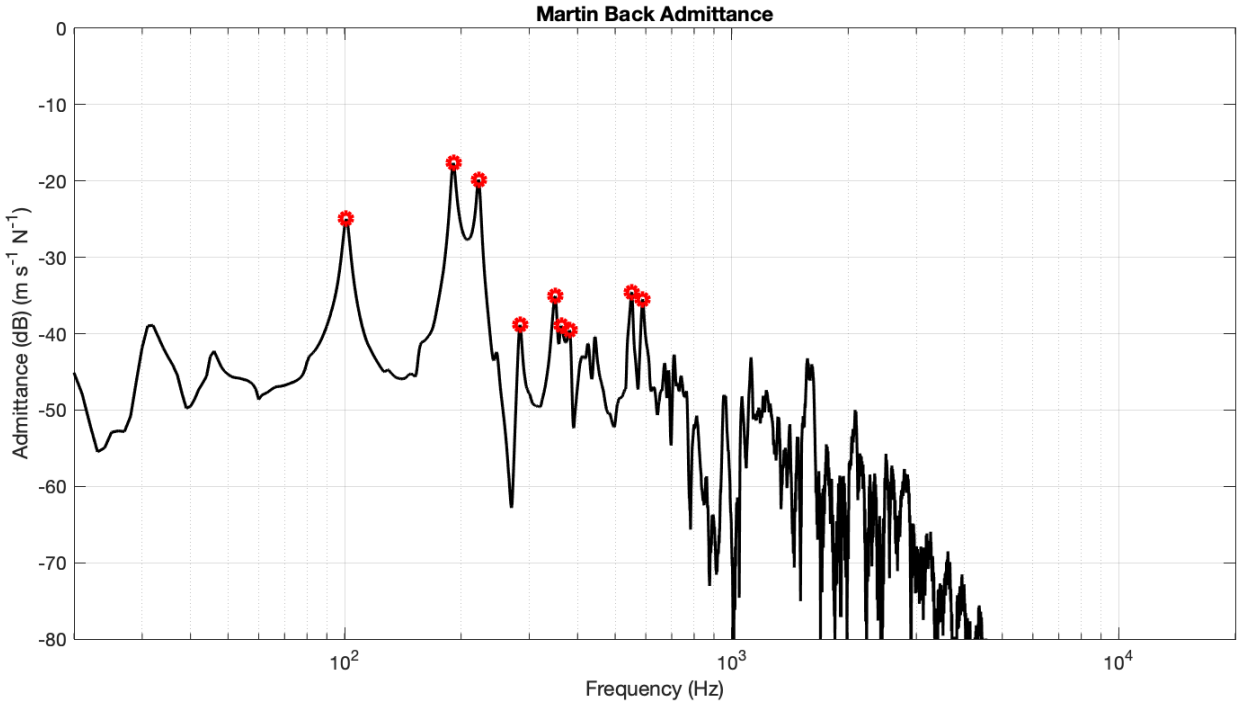
- Some guitars have “live” backs while some are not as active
- Measure my 1947 Martin 00-18 with Mahogany back and sides
- Look at LDV scans of the top and back plates

Un-muted	Muted

Admittance

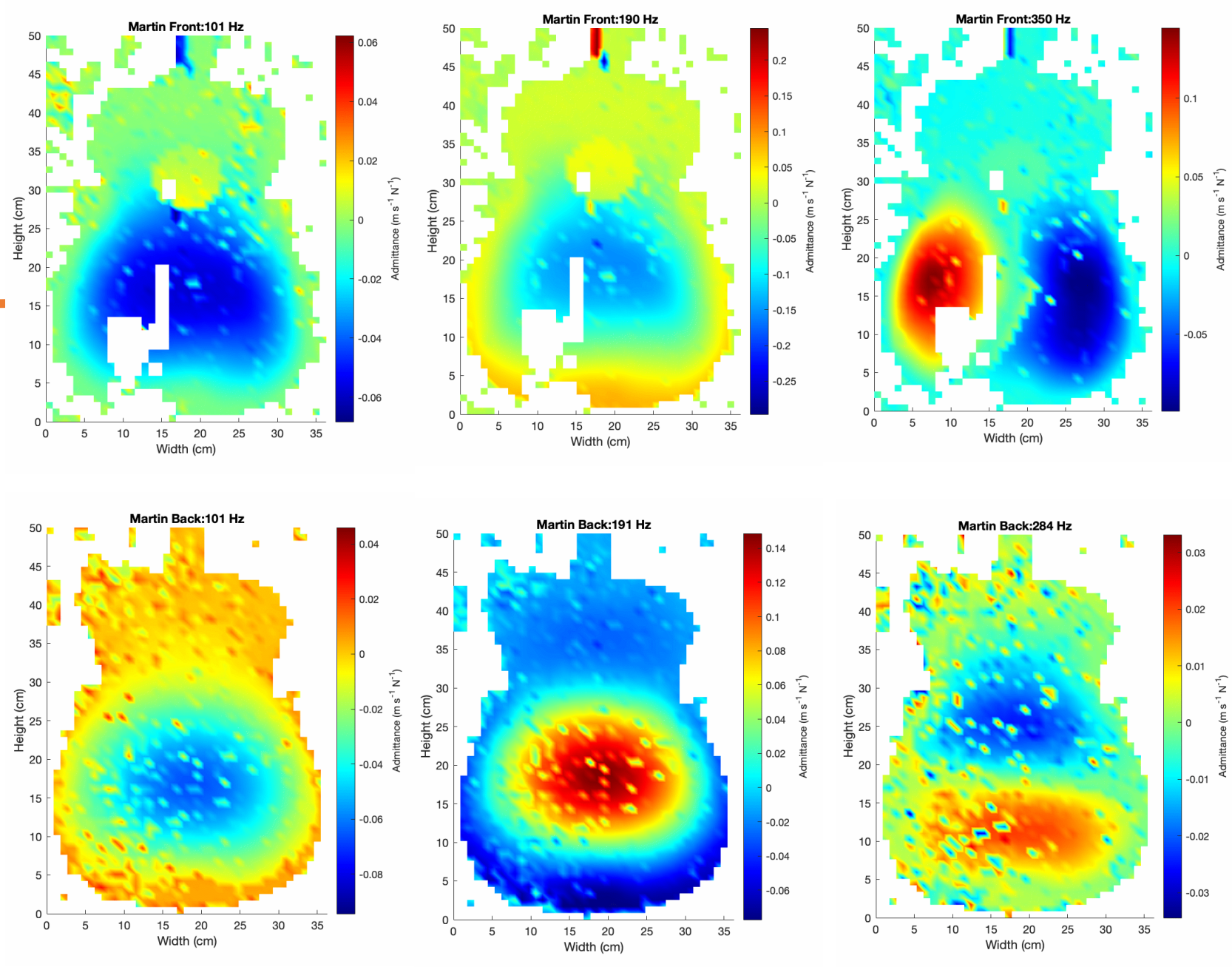
- Taken from a single scan point near the bridge location
- We see shared modes below 300 Hz as we would expect





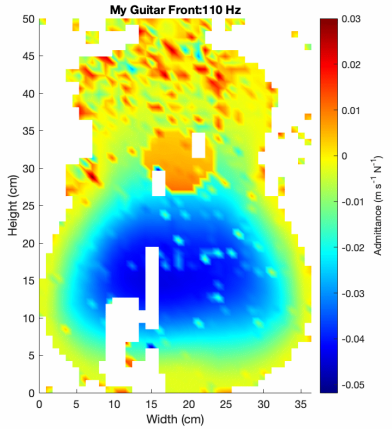
Mode Shapes

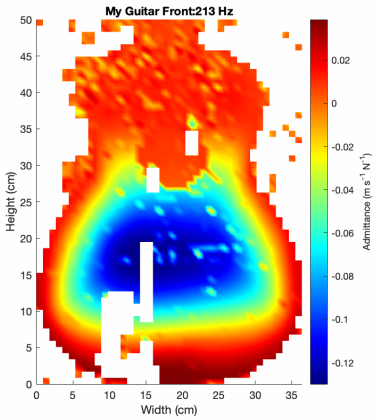
- Modes at 101 Hz and 190 Hz are the breathing modes where the top and back are in and out of phase
- Clear coupling for these low modes which can be heard
- Above ~ 300 Hz, the modes are not as strongly coupled

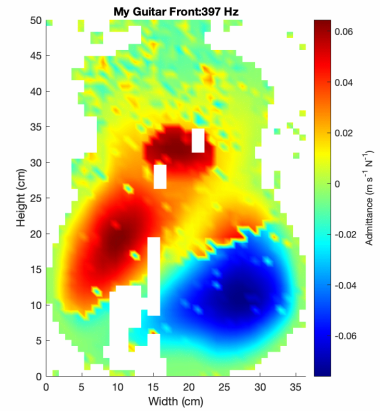


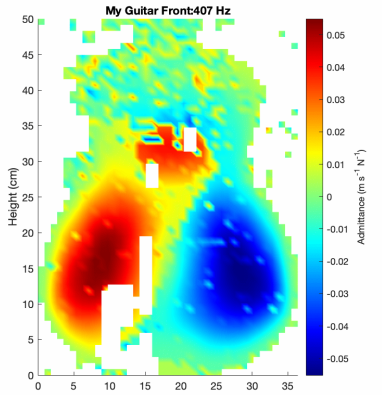
Conclusions

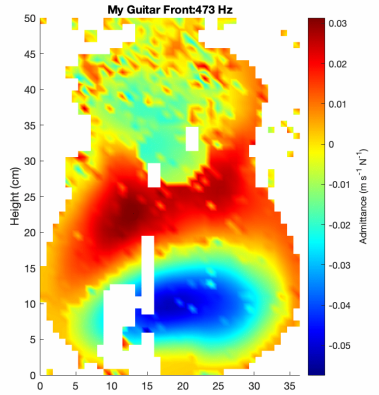
- It works reasonably well!
- Cost less than $200
- Now I can make scanning measurements without roving a hammer!

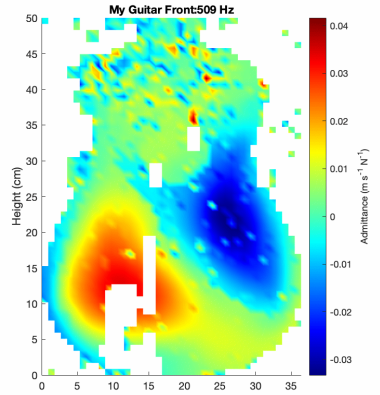


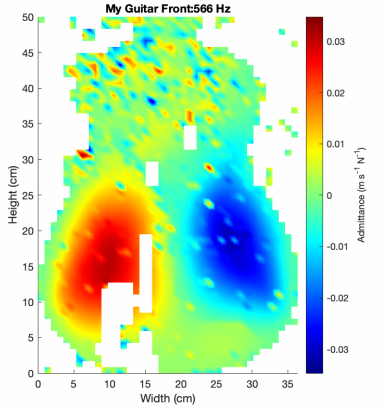


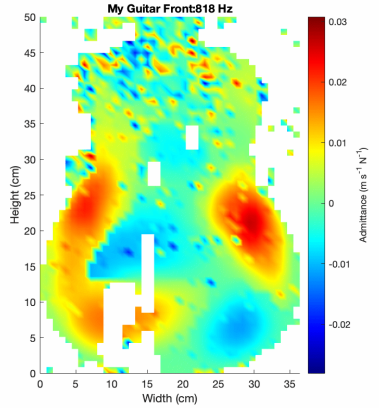


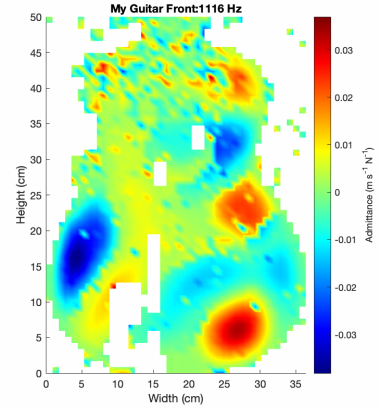


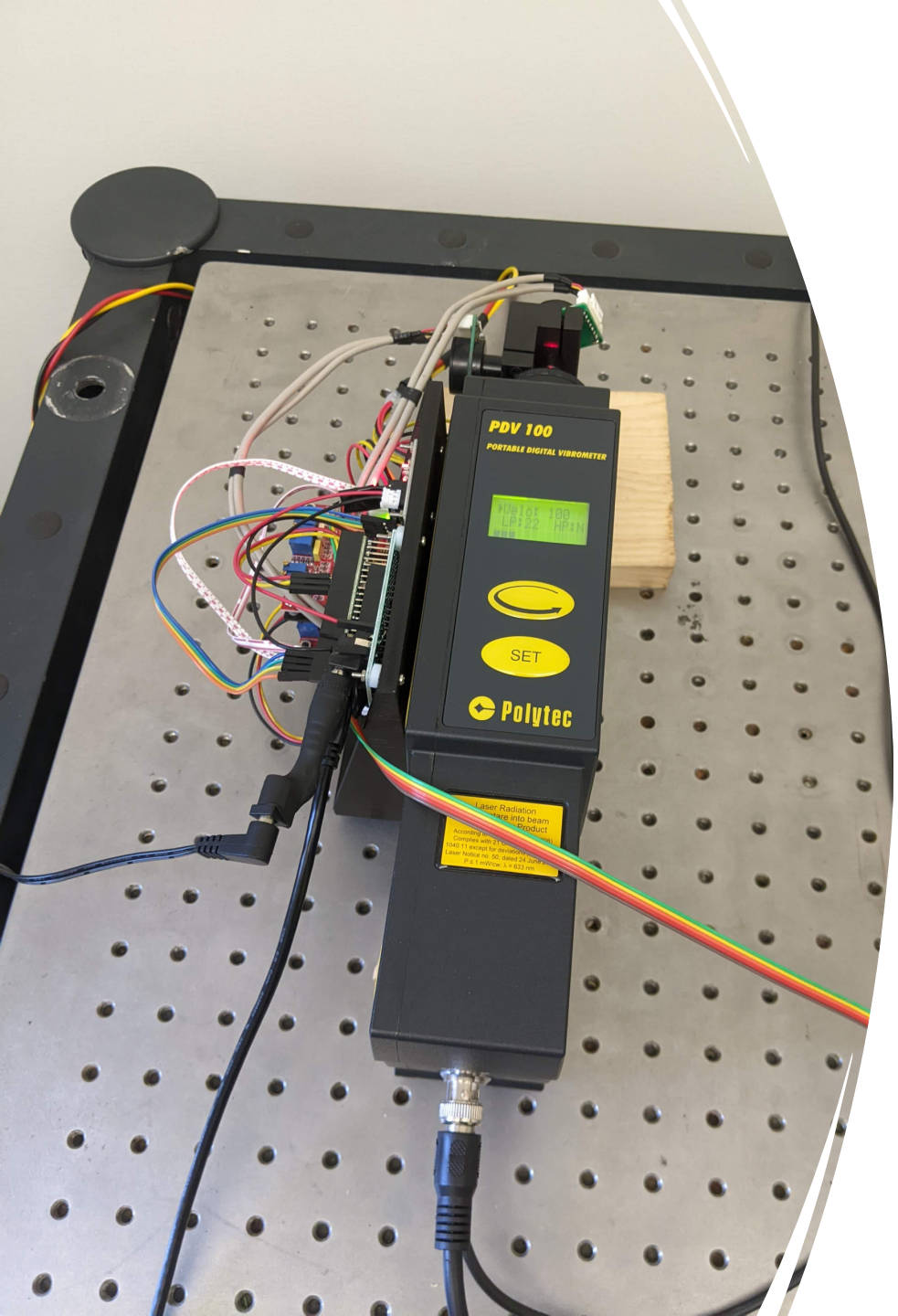












Issues + Future Improvements

- Some bad measurement points
  - Include processing during measurement to re-take measurements if noisy
- Measurement points outside instrument perimeter
  - Better processing to eliminate false positives
  - Get a camera and choose boundary for measurements beforehand
- Improve Focus
  - Make a manual auto focus
- Speed up processing
  - ~ 10 minutes for 2000 measurement points
- Clean up code, 3D modeling, and circuit info for release

Questions?

- Thanks to:
  - My Advisors: Julius Smith, Doug James
  - Ethan Buck
  - ASA

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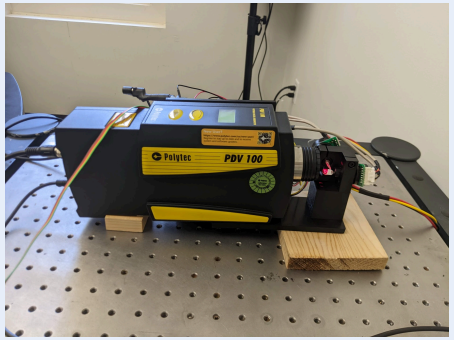

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