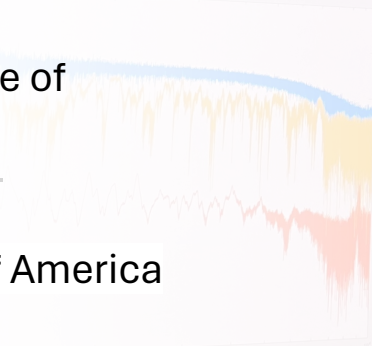


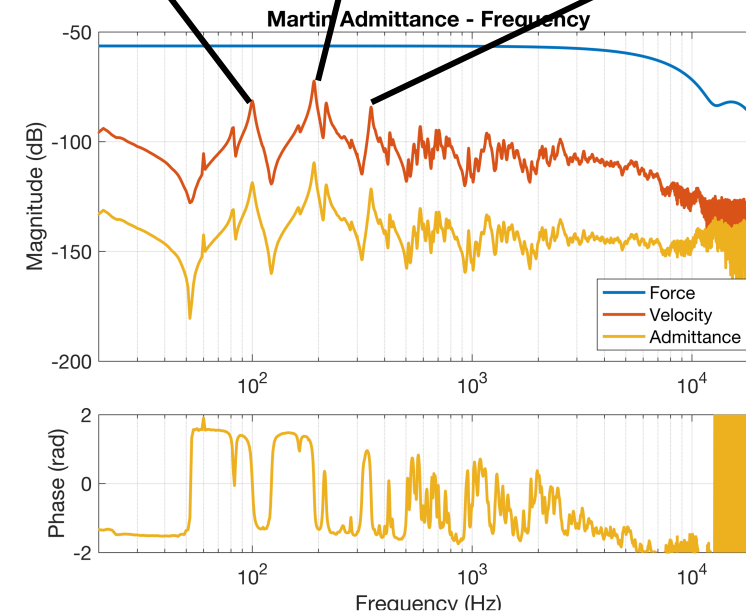
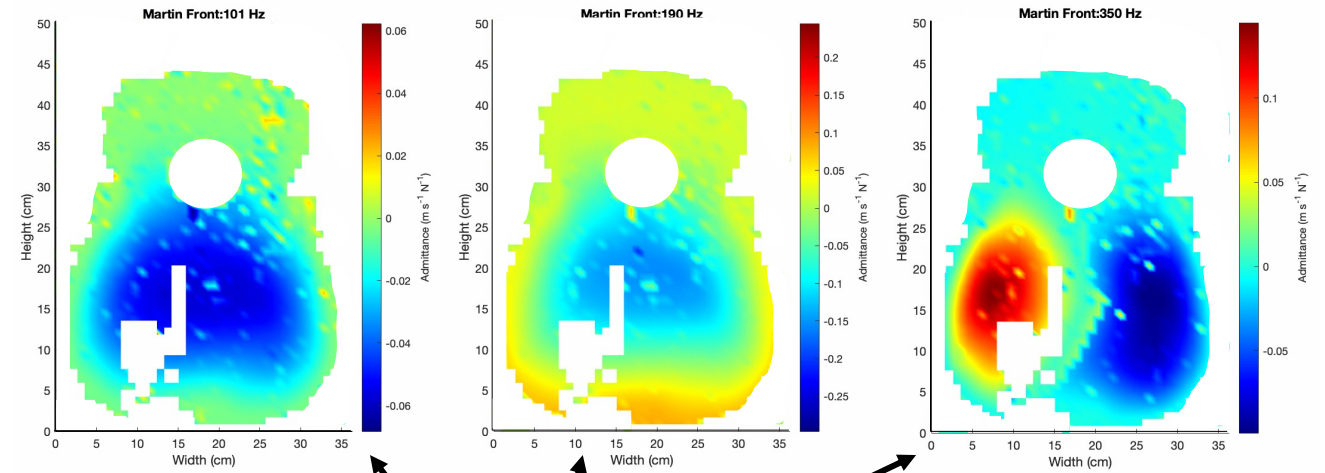
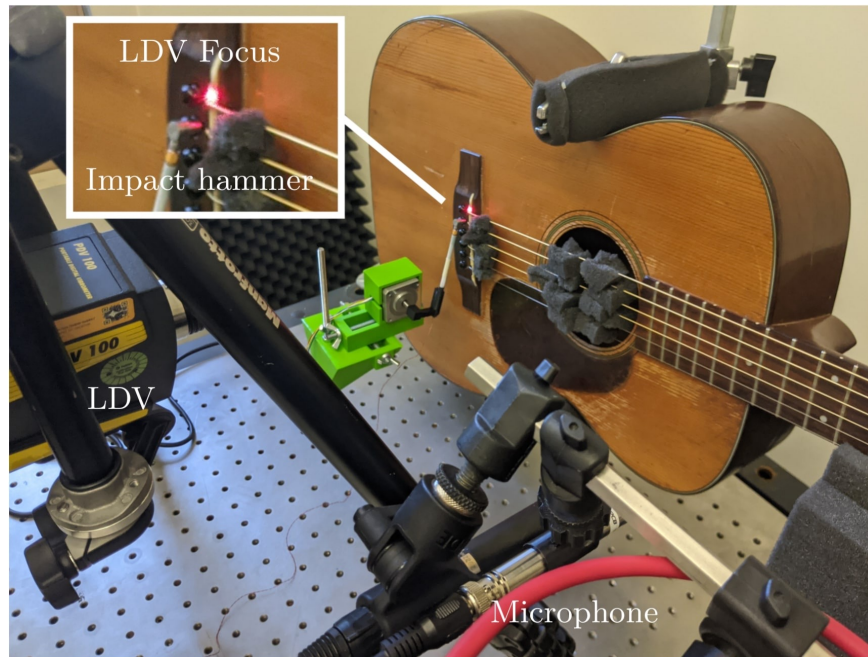
# Measuring Body Vibrations of Stringed Instruments

- Mark Rau
  - mrau@mit.edu
  - Computational Acoustic Modeling Laboratory, McGill University
  - Music Technology, Massachusetts Institute of Technology
- 
- 187th Meeting of the Acoustical Society of America
  - November 21, 2024, 3aMU





# Why?







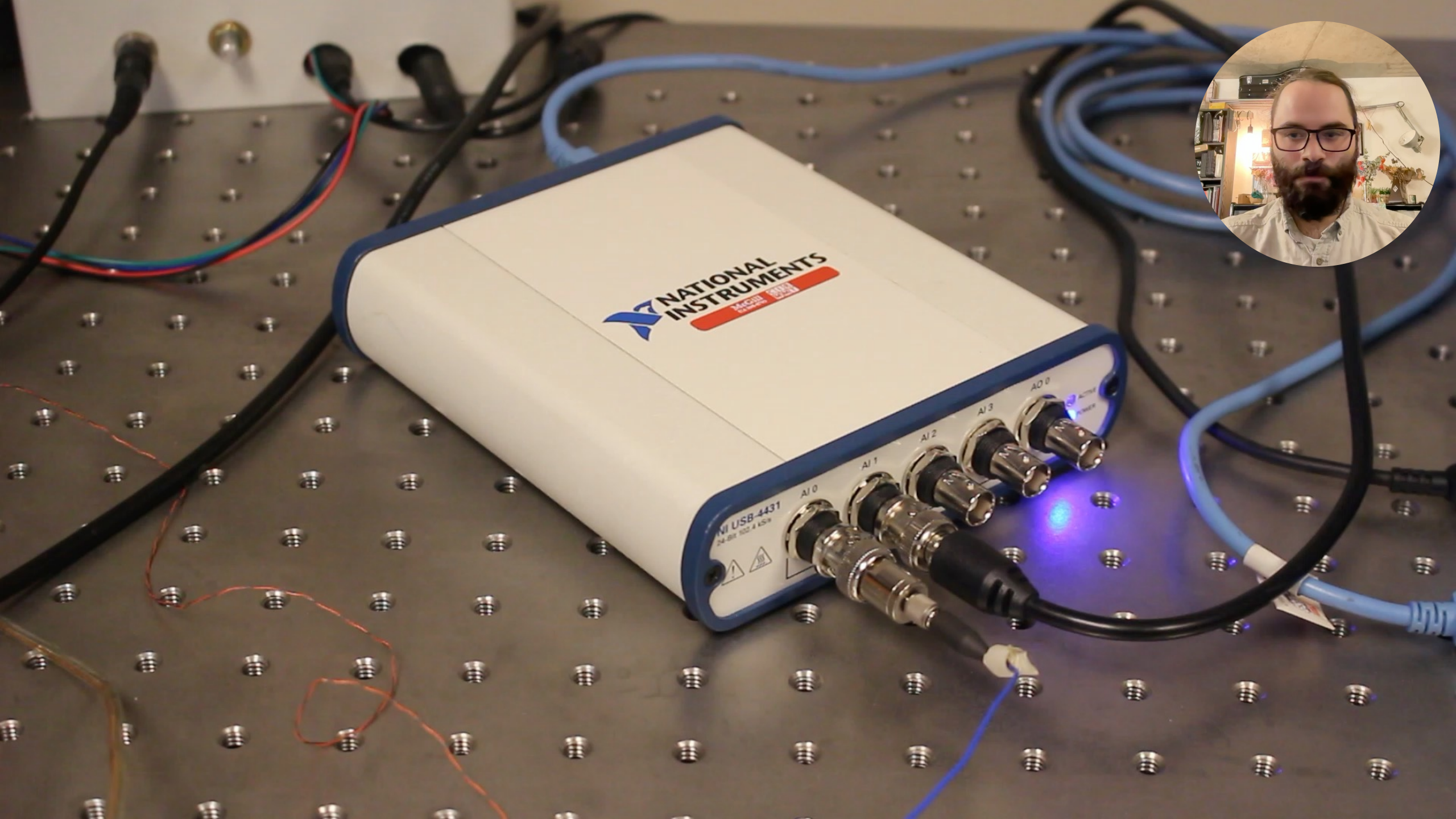




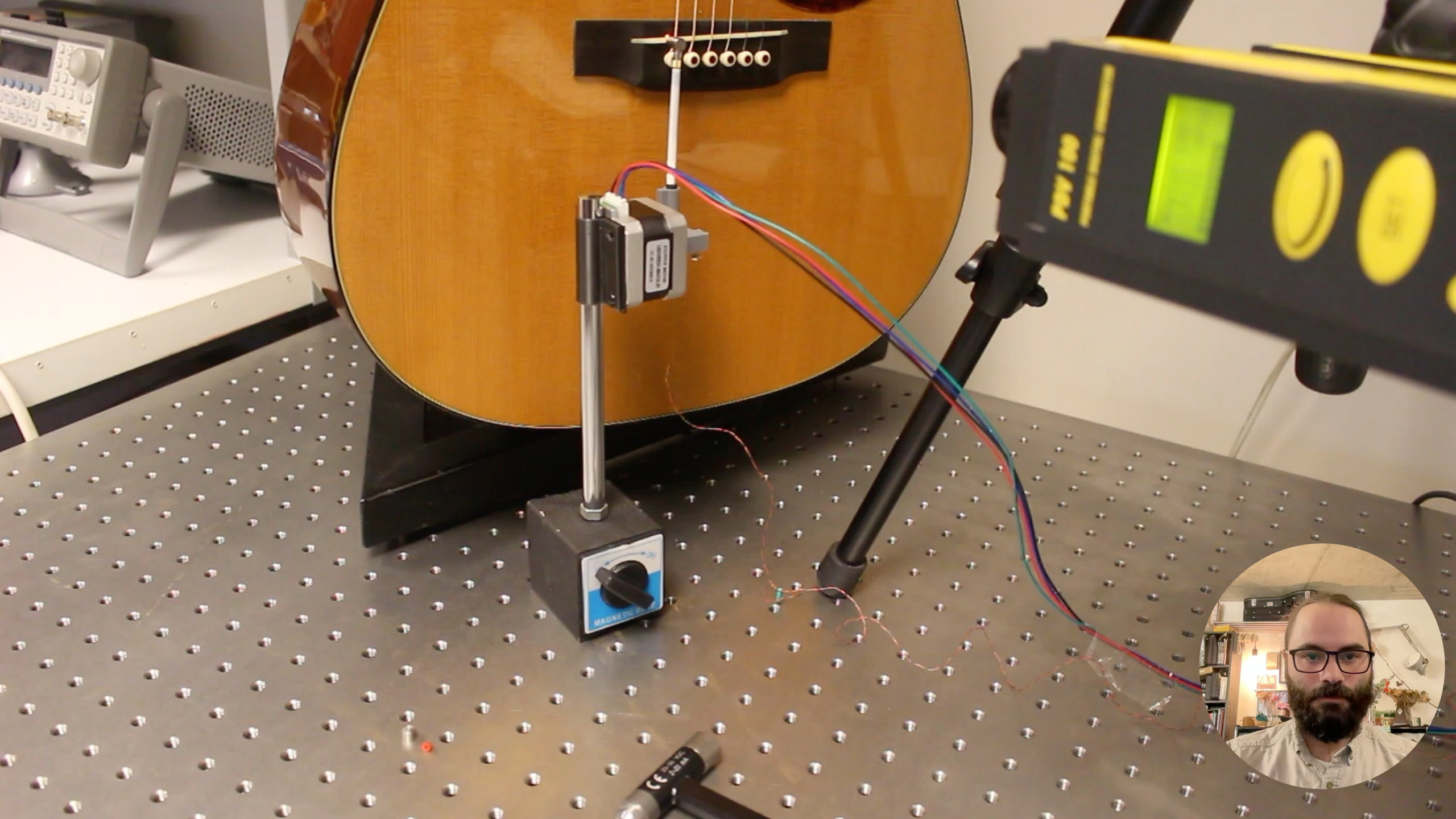




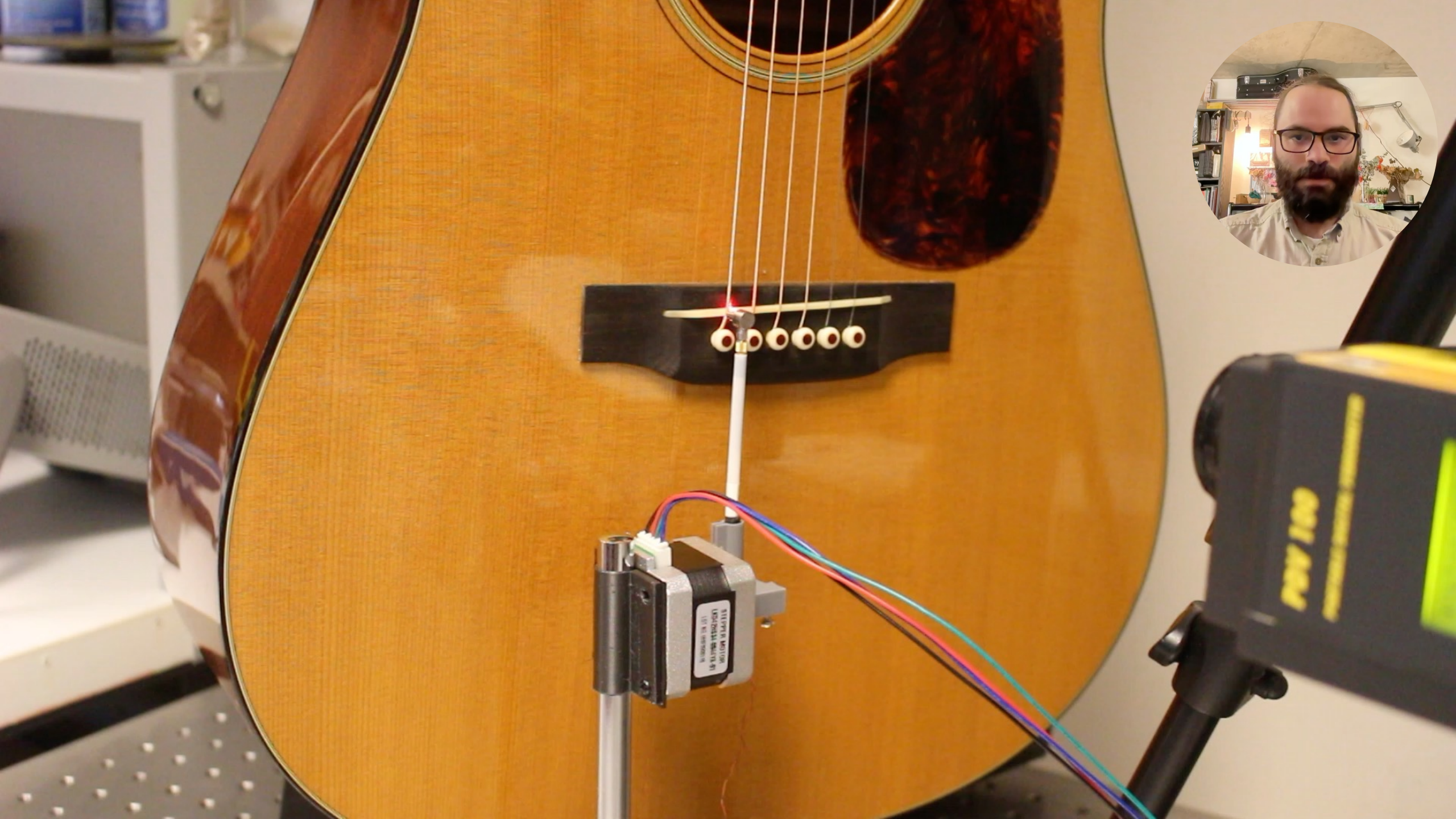








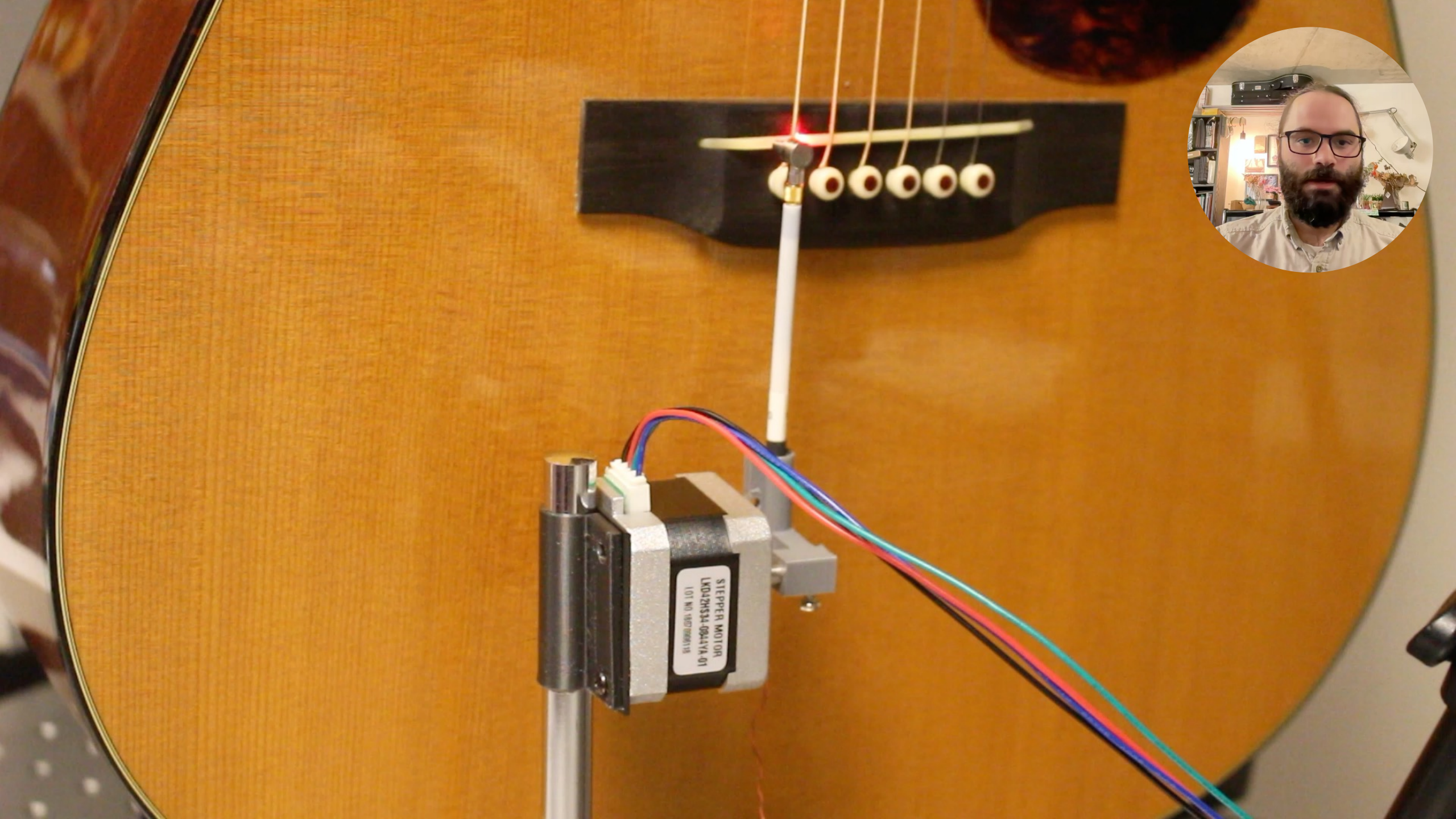








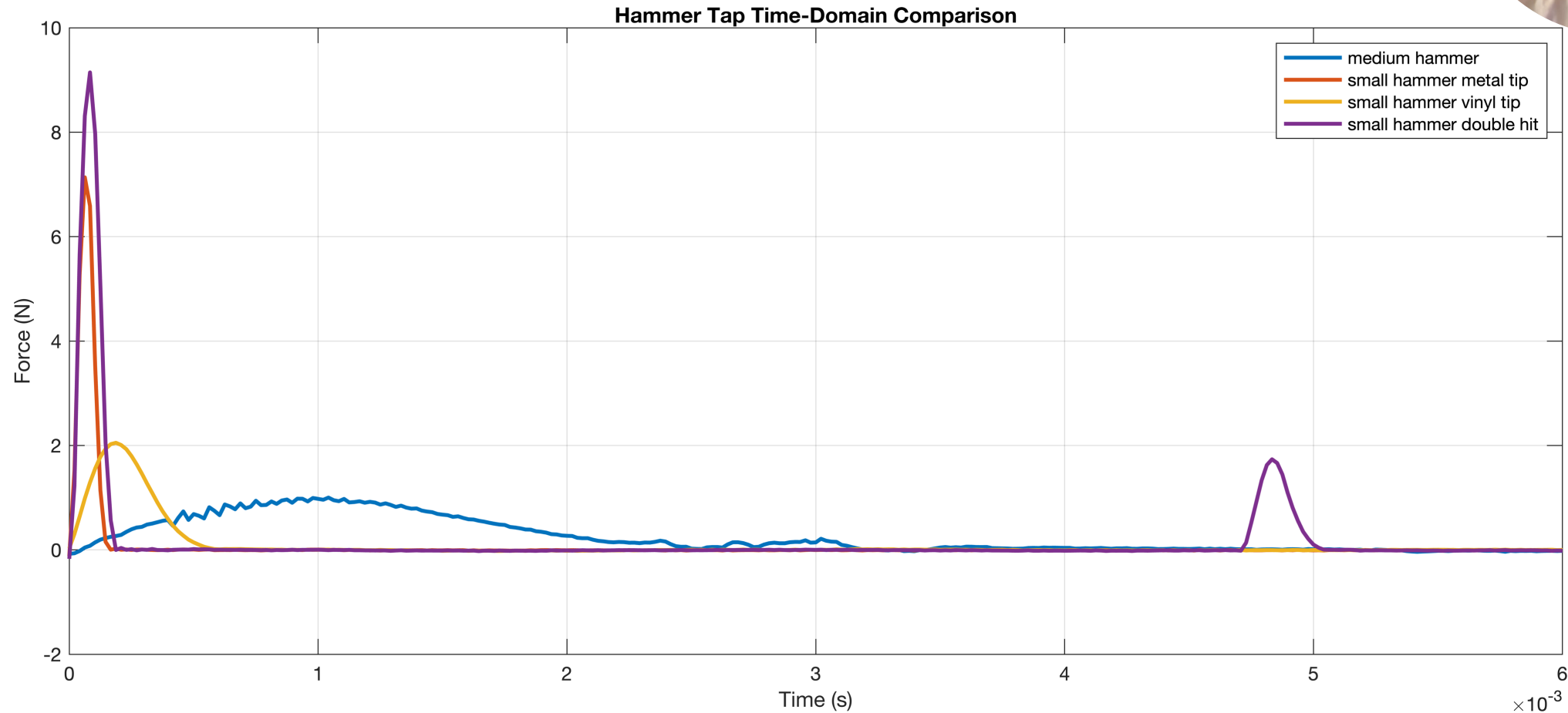




STEPPER MOTOR  
LM042H514-0044YA-01  
LOT NO. 18070006118

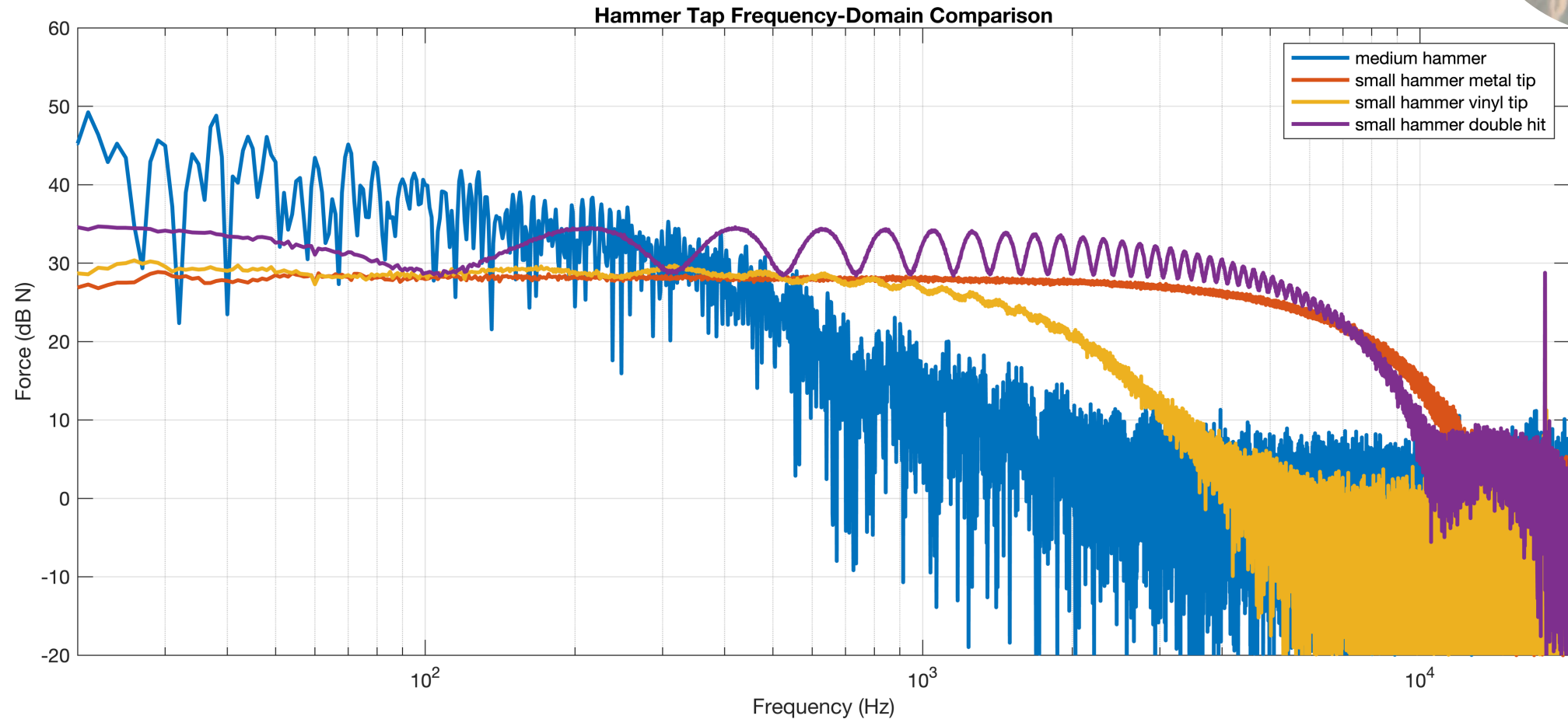


# Impact Hammer



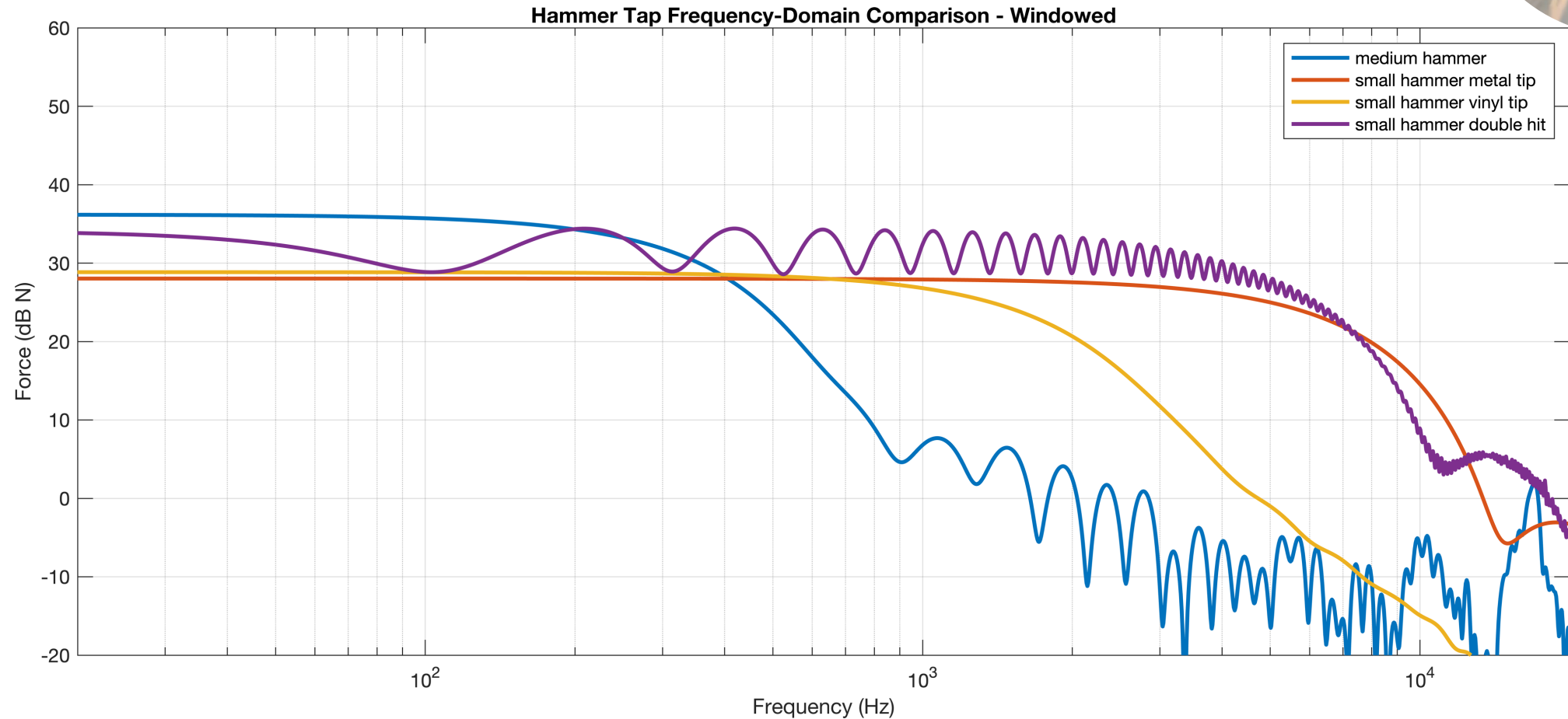


# Impact Hammer





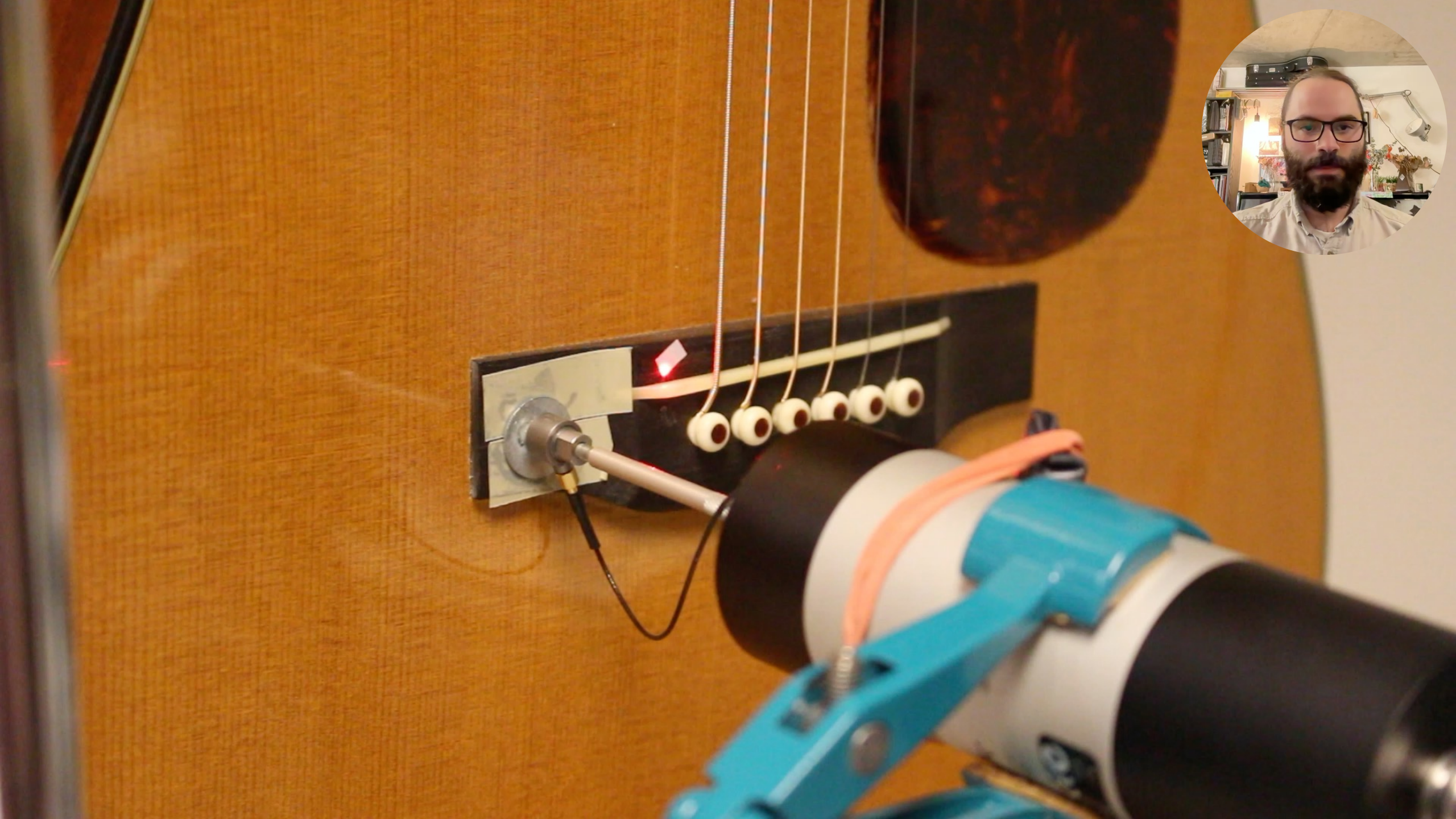
# Impact Hammer





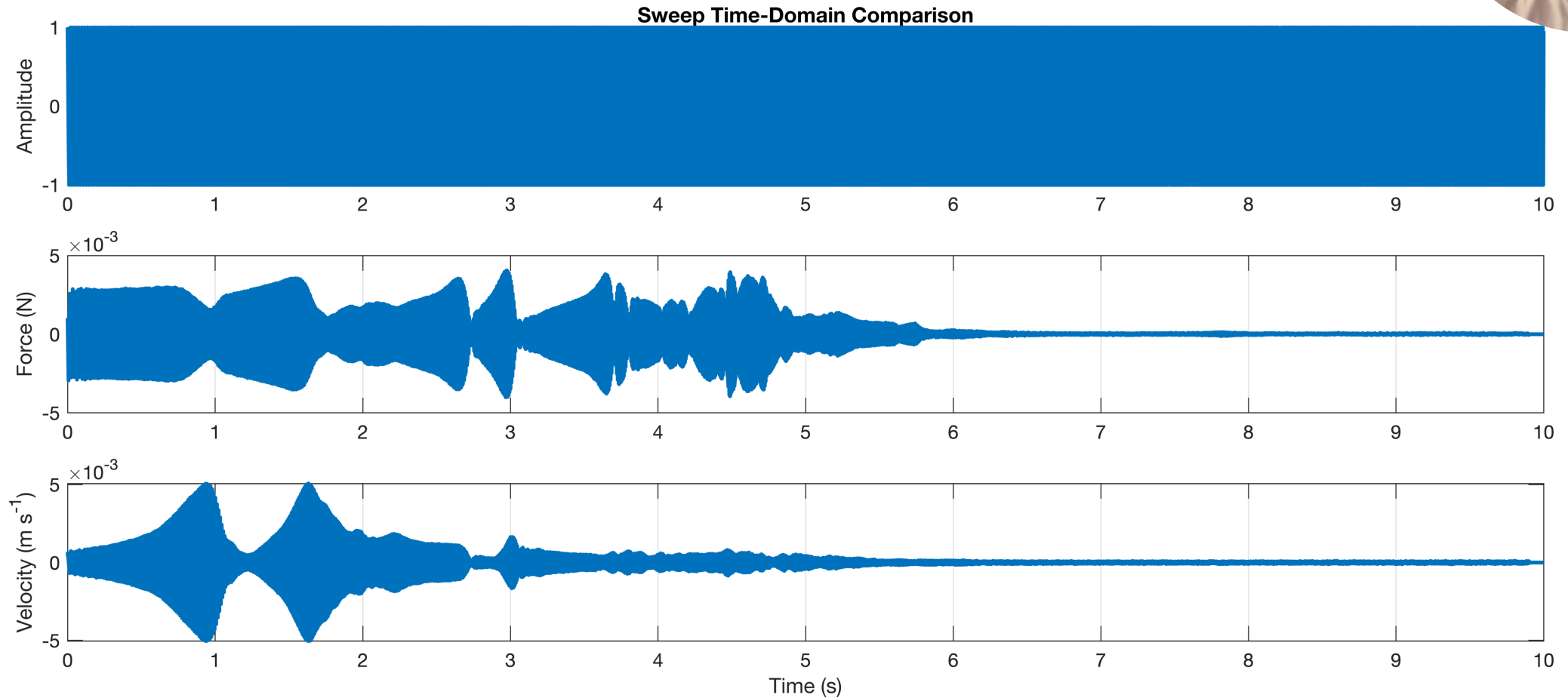






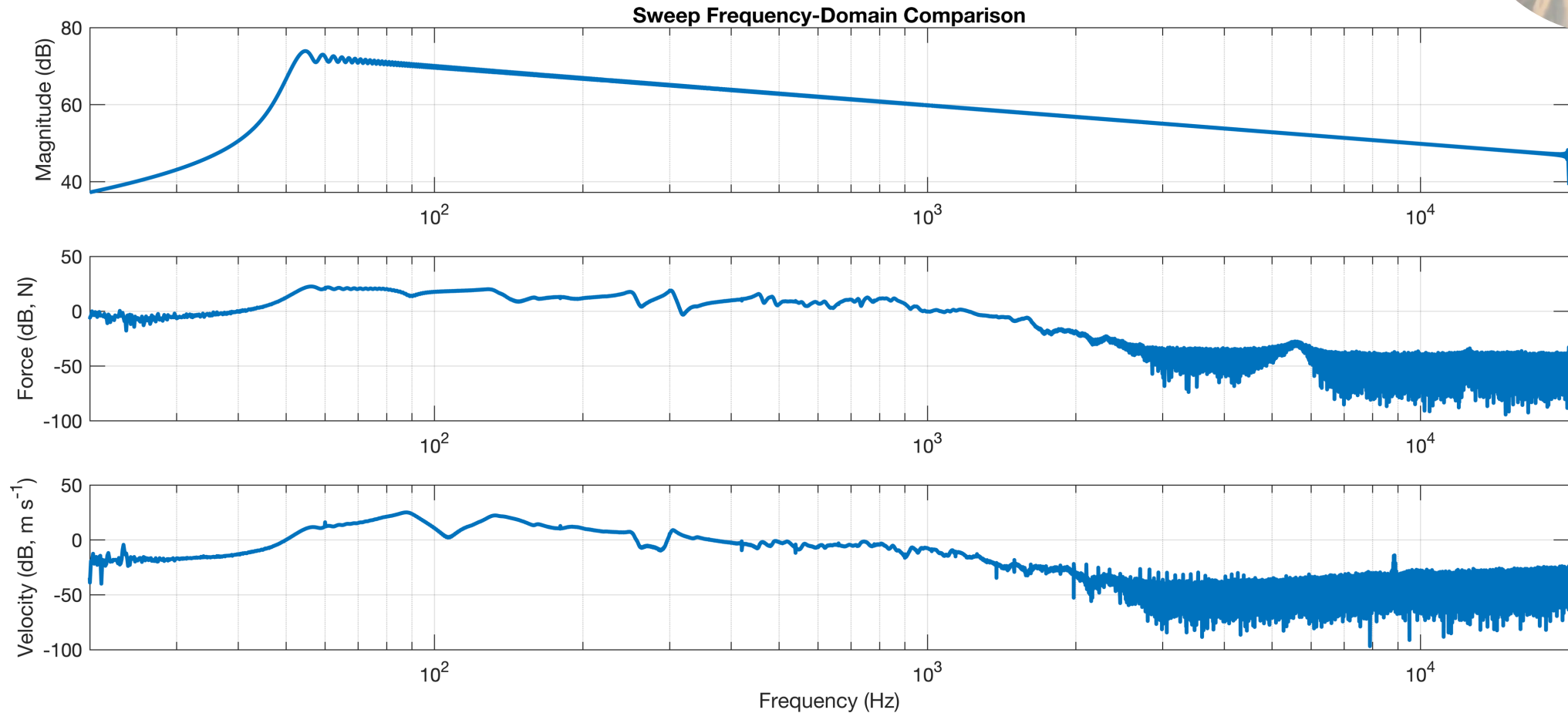


# Shaker



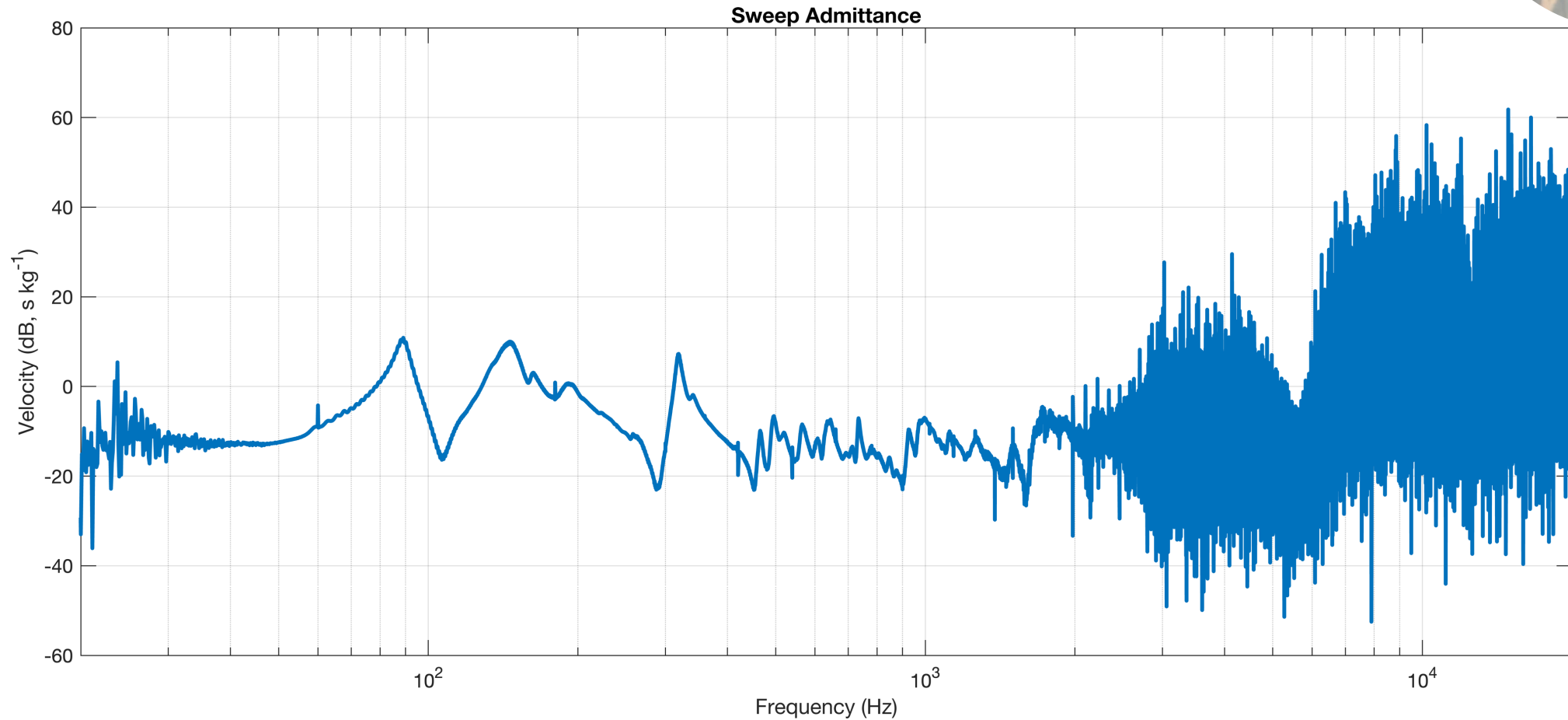


# Shaker

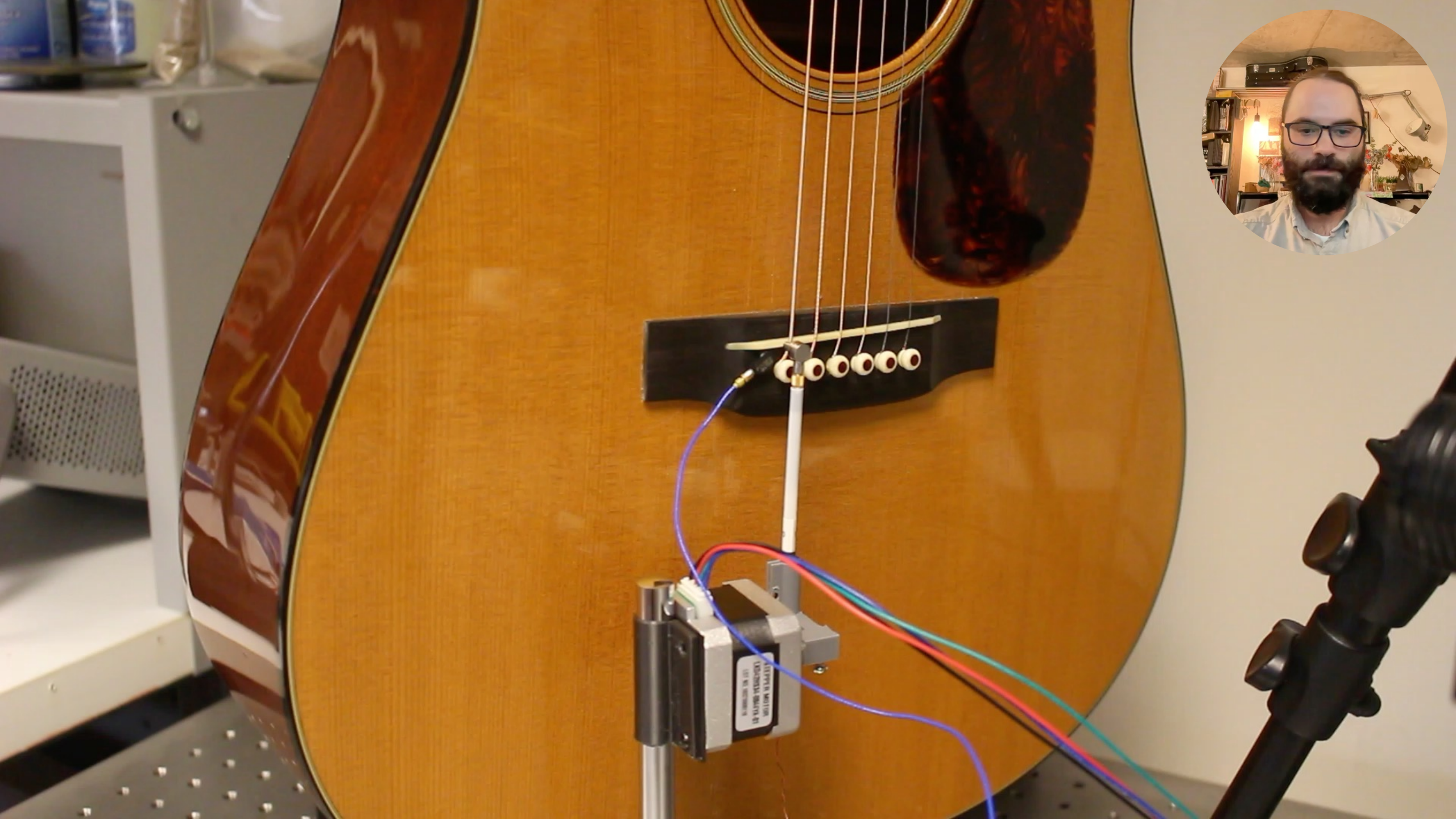




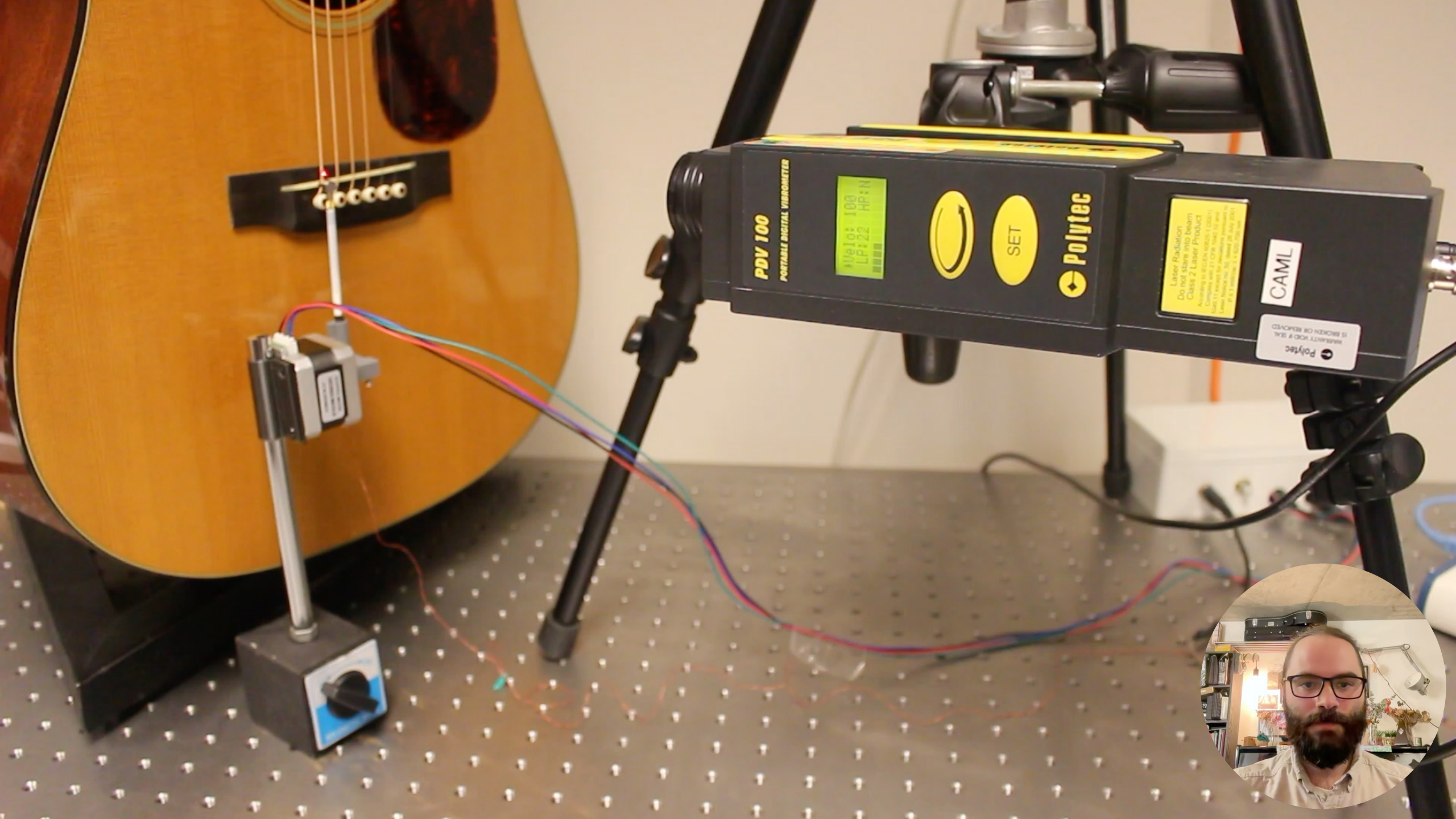
# Shaker





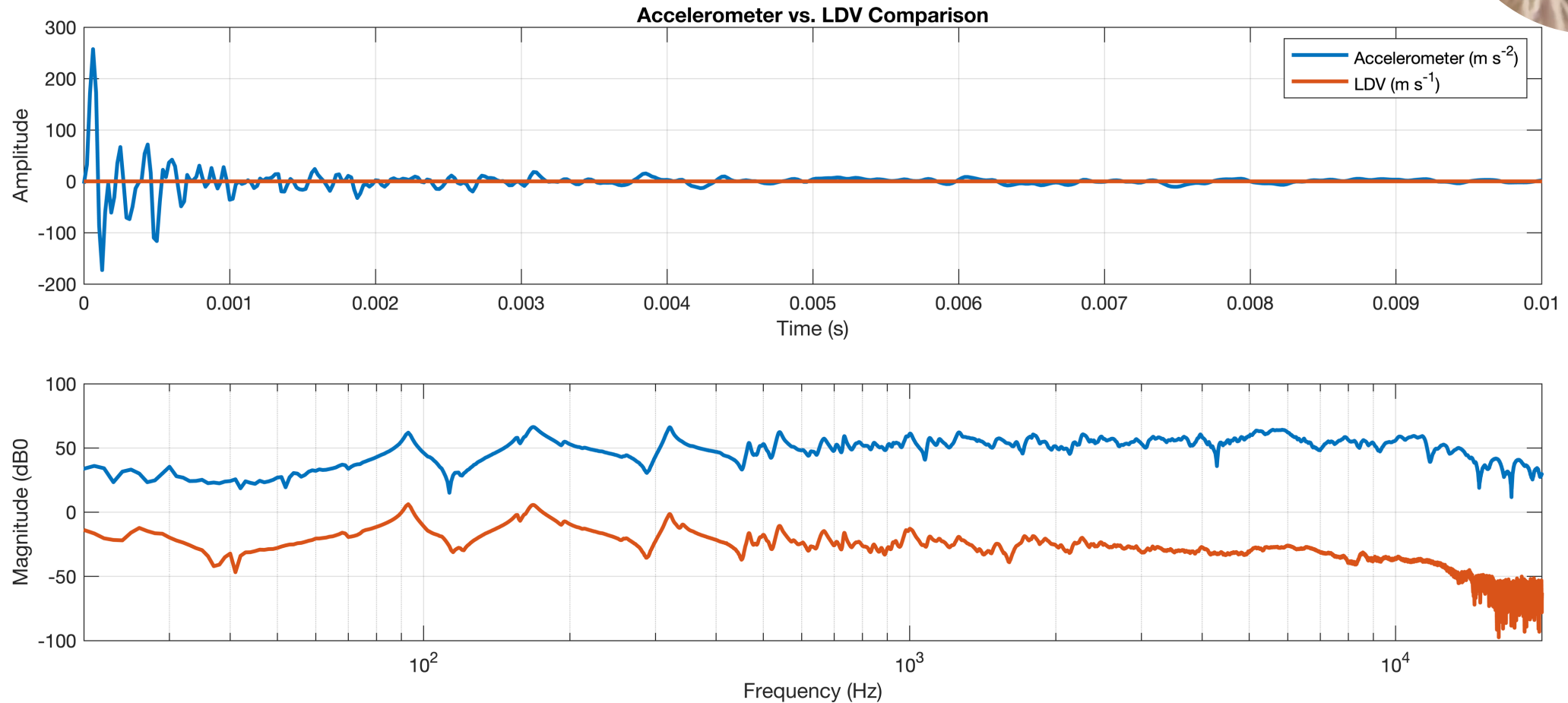




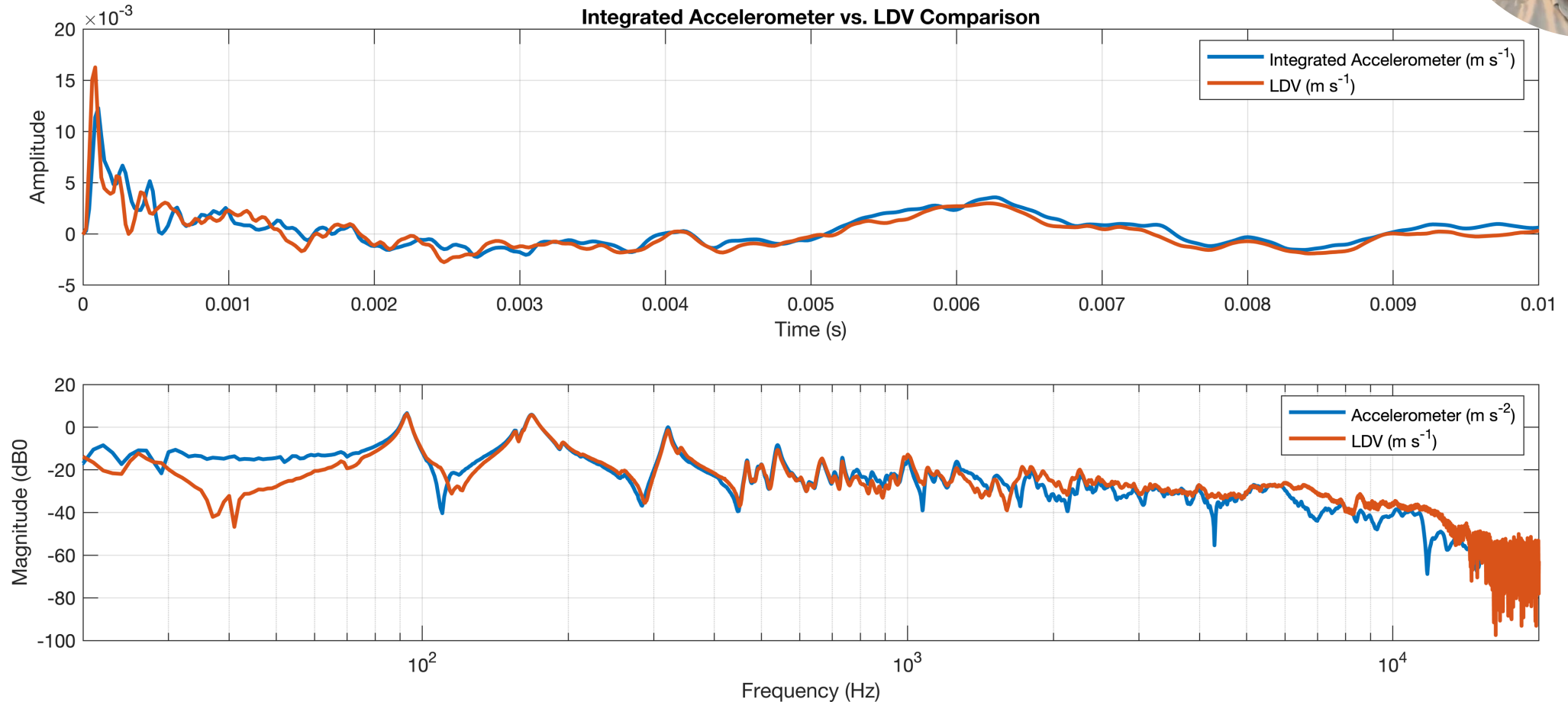




# Accelerometer vs. LDV



# Accelerometer vs. LDV





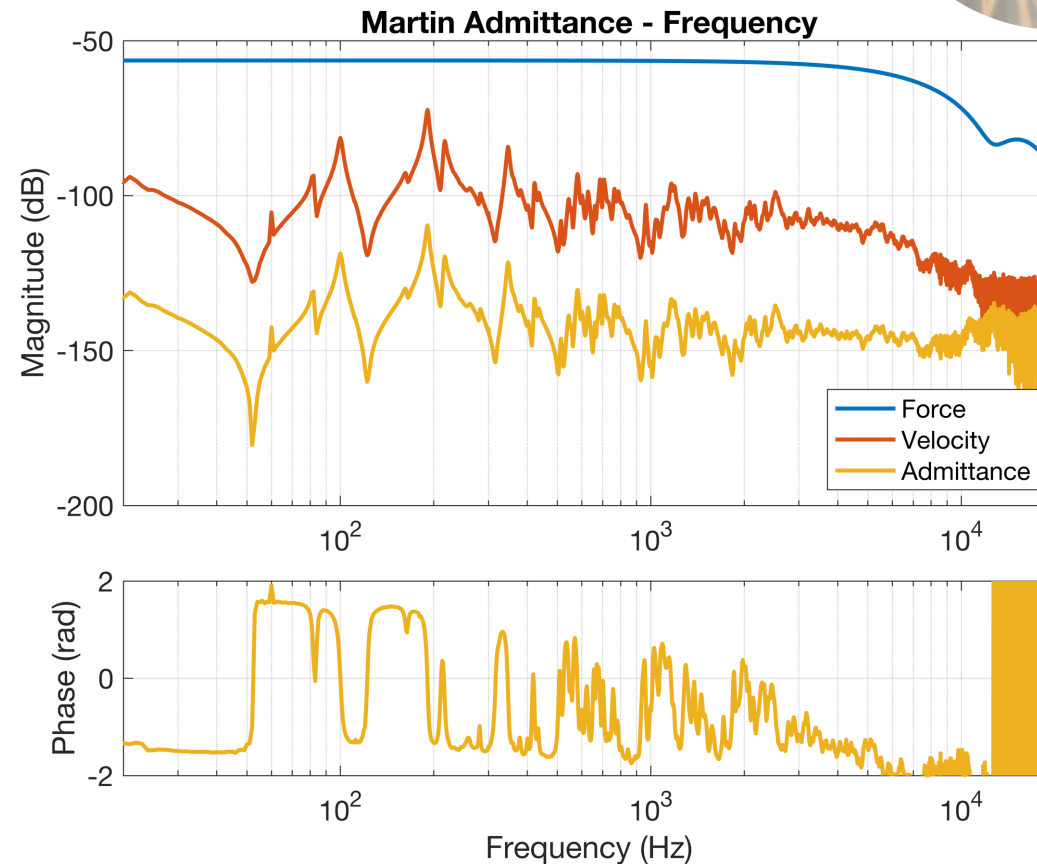
# Admittance

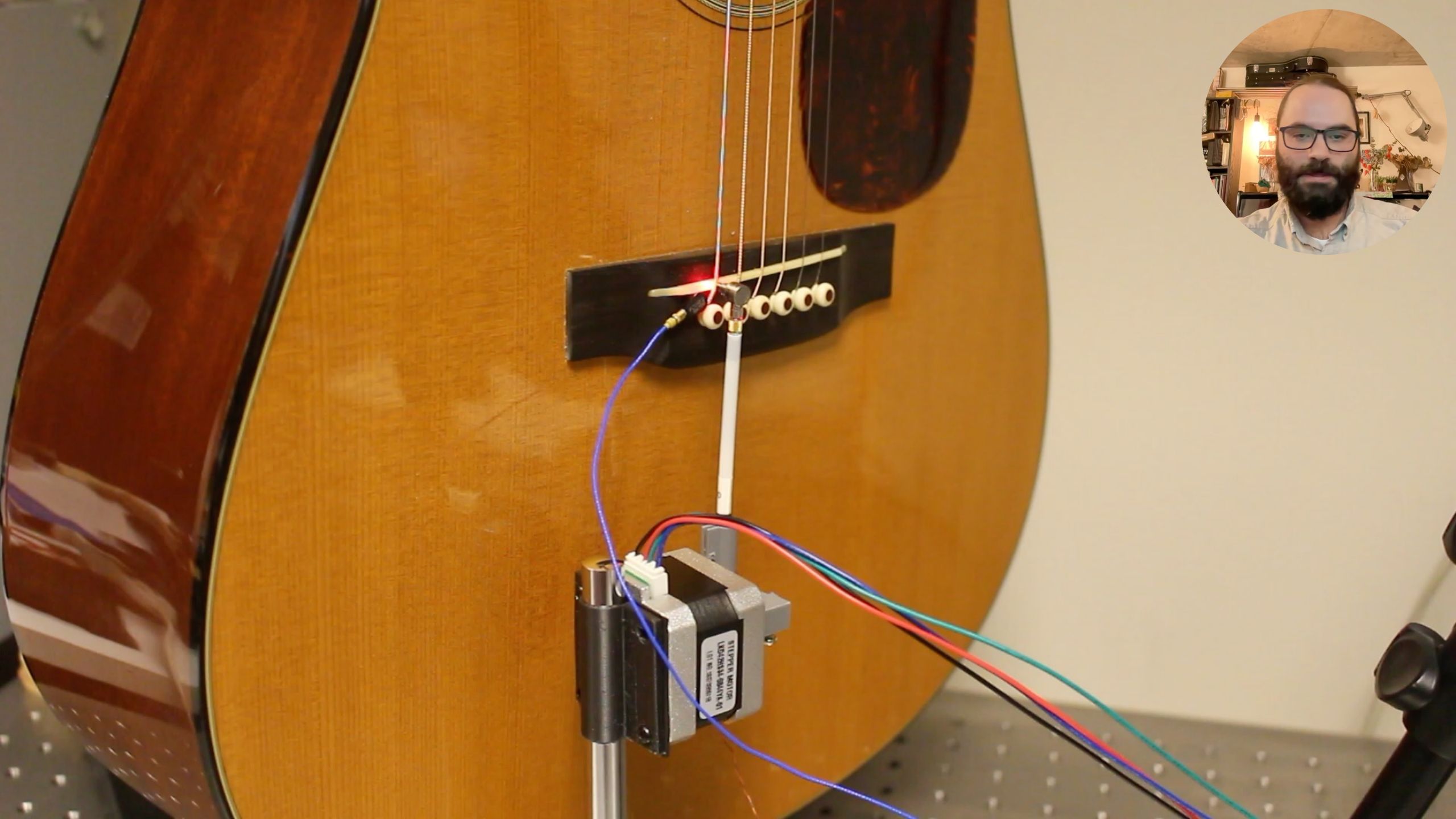
$$\Gamma(z) = \frac{V(z)}{F(z)}$$

$\Gamma(z) \rightarrow \text{admittance}$

$V(z) \rightarrow \text{velocity}$

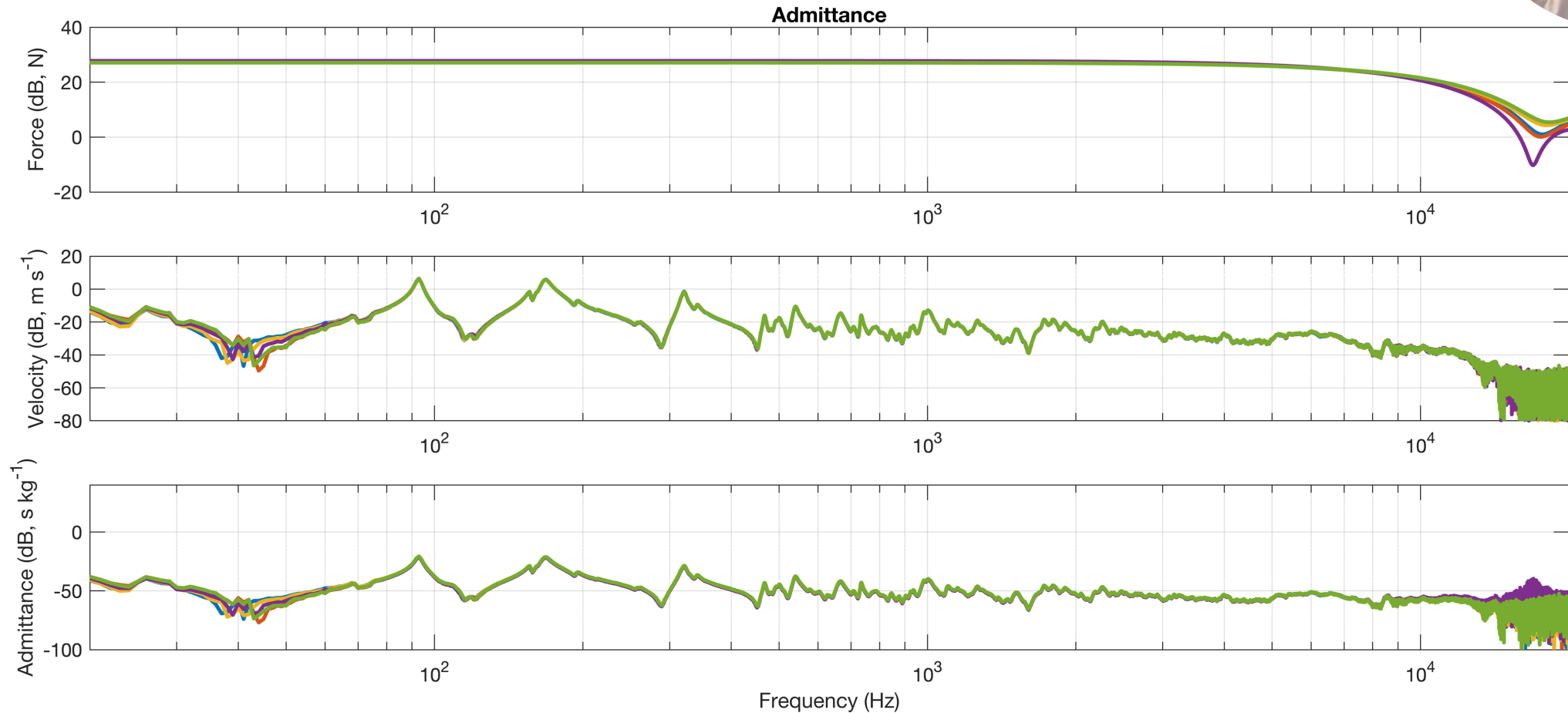
$F(z) \rightarrow \text{force}$







# Admittance Measurements



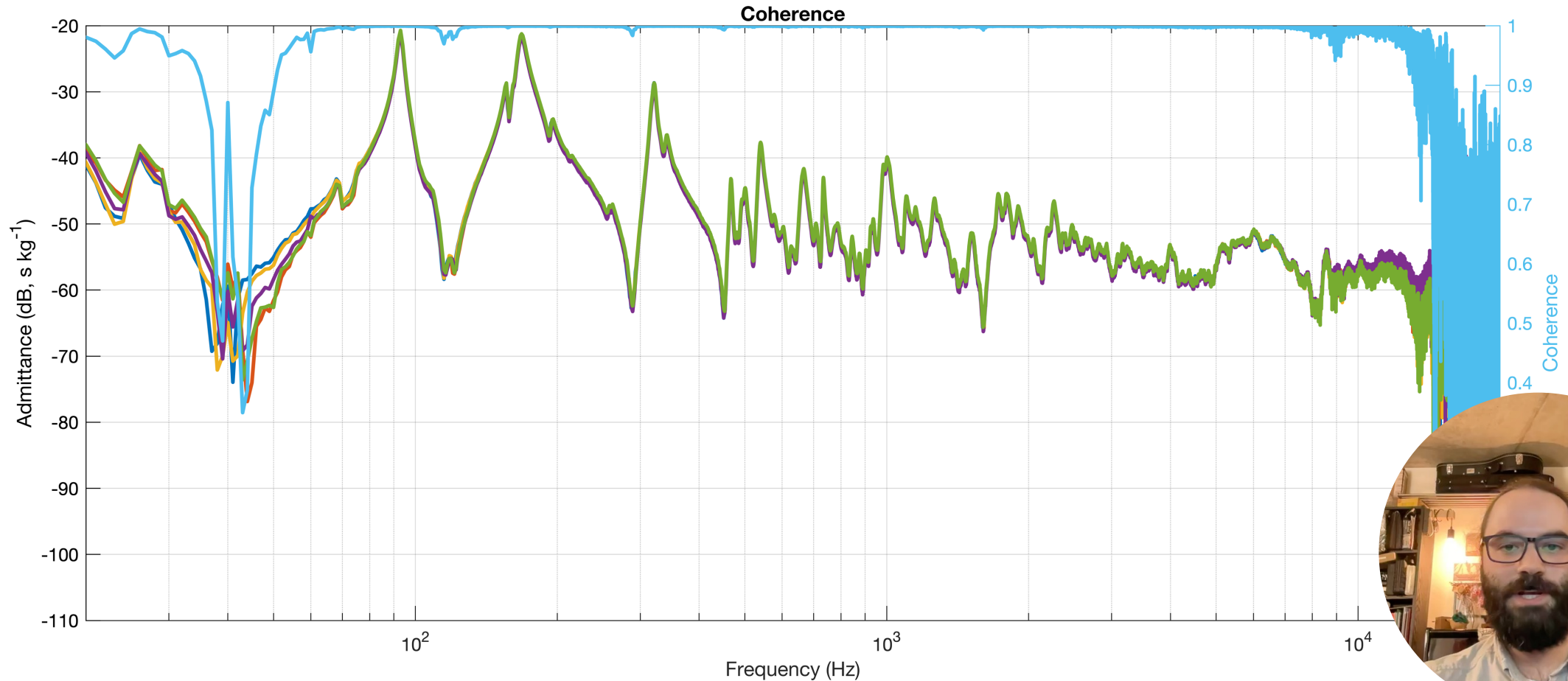
# Admittance Coherence

$$C_{xy}(\omega) = \frac{|R_{xy}(\omega)|^2}{R_{xx}(\omega)R_{yy}(\omega)}$$

$R_{xx}(\omega)$  = Power spectral density of  $x(t)$

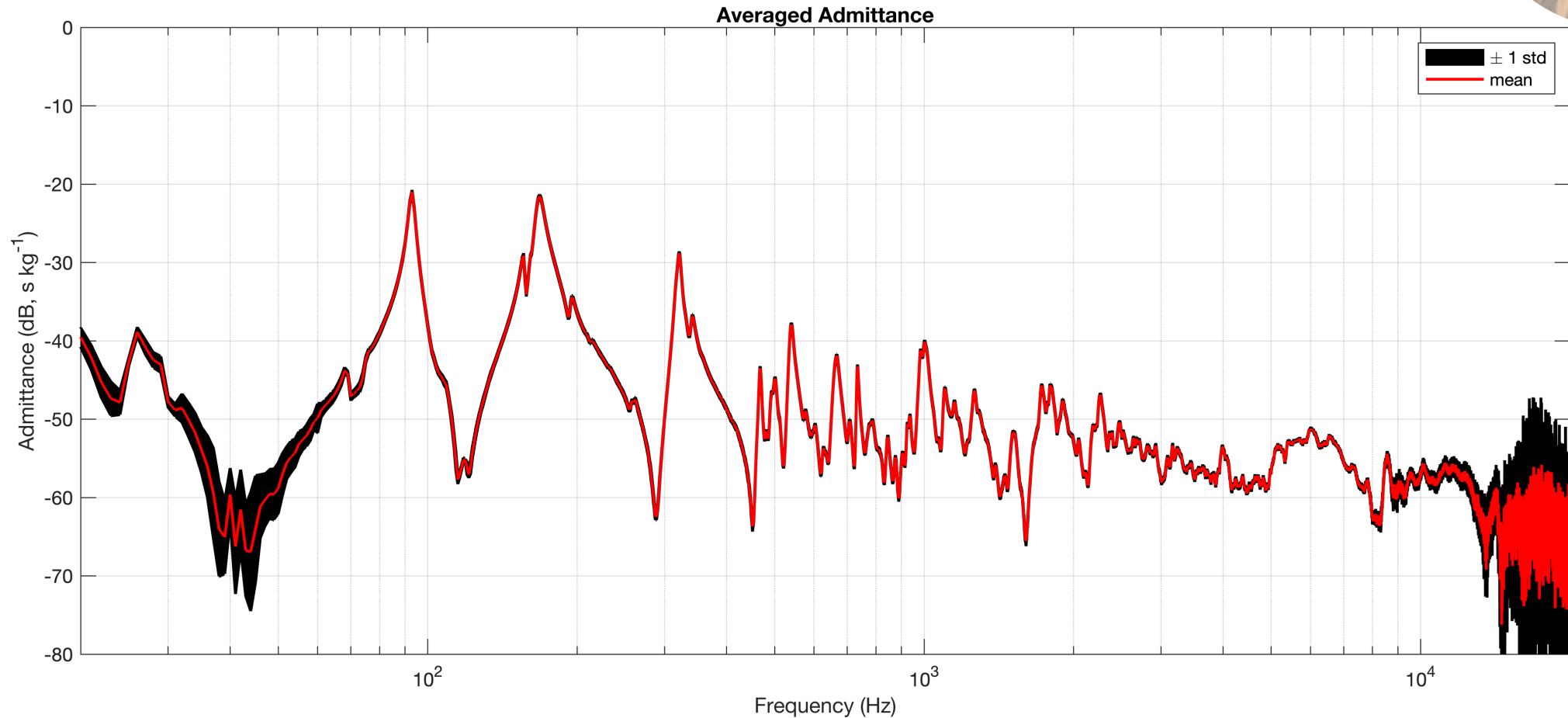
$R_{yy}(\omega)$  = Power spectral density of  $y(t)$

$R_{xy}(\omega)$  = Cross power spectral density between  $x(t)$  and  $y(t)$





# Admittance Averaging

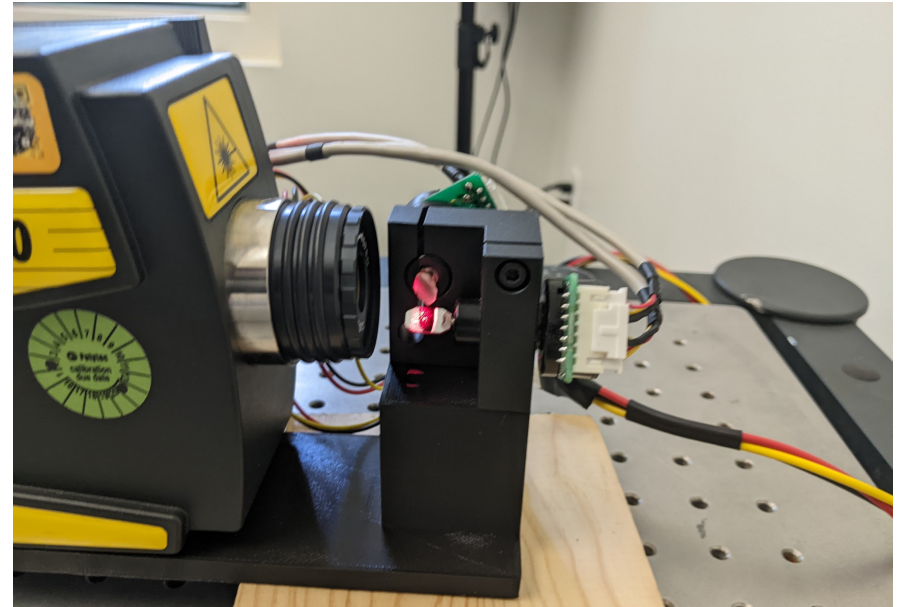


# Scanning Vibrometer



Commercial: ~ \$150-200k

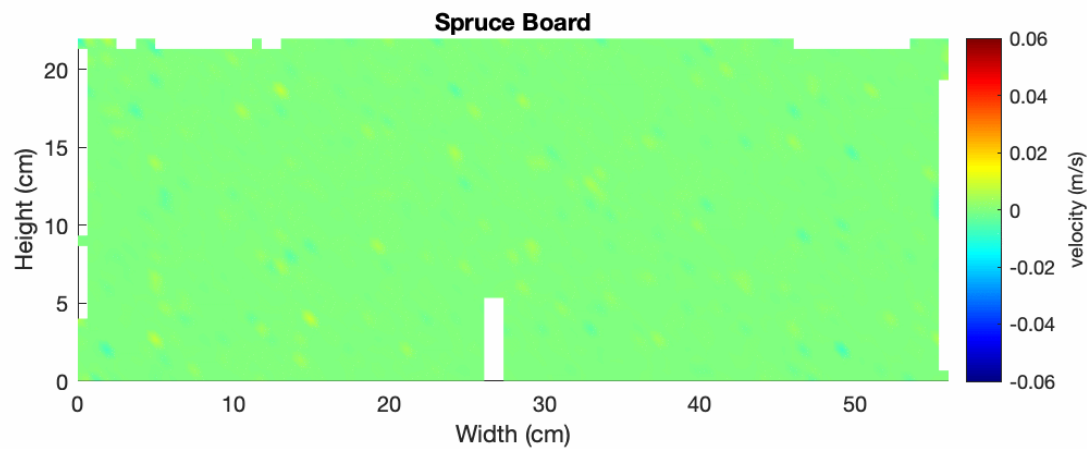
DIY: ~\$150 + single-point LDV (~\$30-50k)



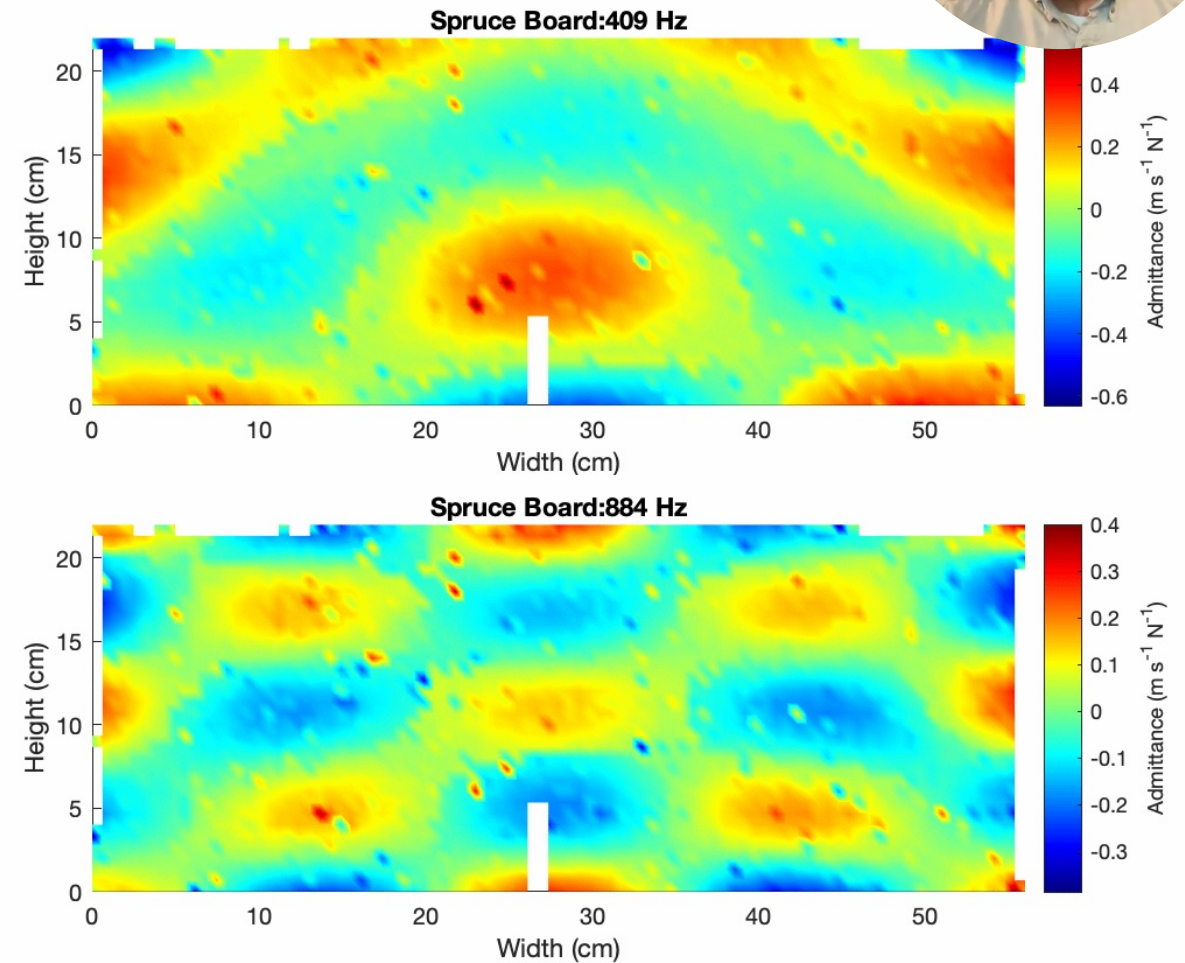


# Scanning Vibrometer

Time Domain Wave Propagation



Frequency Domain Mode Shapes



# Mode Fitting



$$y(t) = \sum_{m=1}^M \alpha_m e^{j2\pi f_m t} e^{-2\pi f_m \zeta t}$$

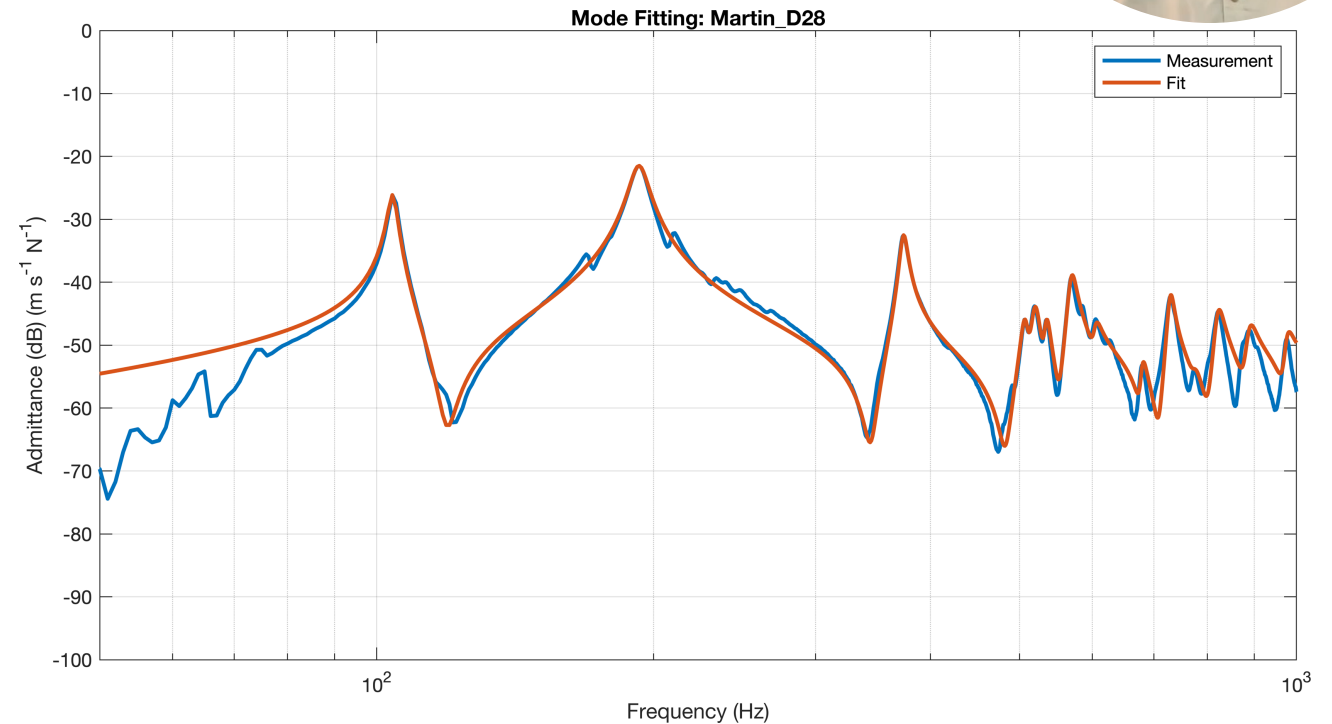
where

$m = 1, 2, \dots, M$  is the mode number

$\alpha_m$  = complex amplitude

$f_m$  = mode frequency

$\zeta_m$  = mode damping ratio





# Equipment Used



- Guitar
  - Martin D18V
- Data Acquisition
  - National Instruments USB-4431
- Laser Doppler vibrometer
  - Polytec PDV-100
- Accelerometers
  - PCB 352C22 (video)
  - PCB 352A24 (plots)
- Impact Hammers
  - PCB 086C01
  - PCB 086E80
- Shaker
  - B&K 5961 (video)
  - Modal Shop 2004E (plots)
- Force Sensor
  - B&K 8203 (video)
  - PCB 208C01 (plots)

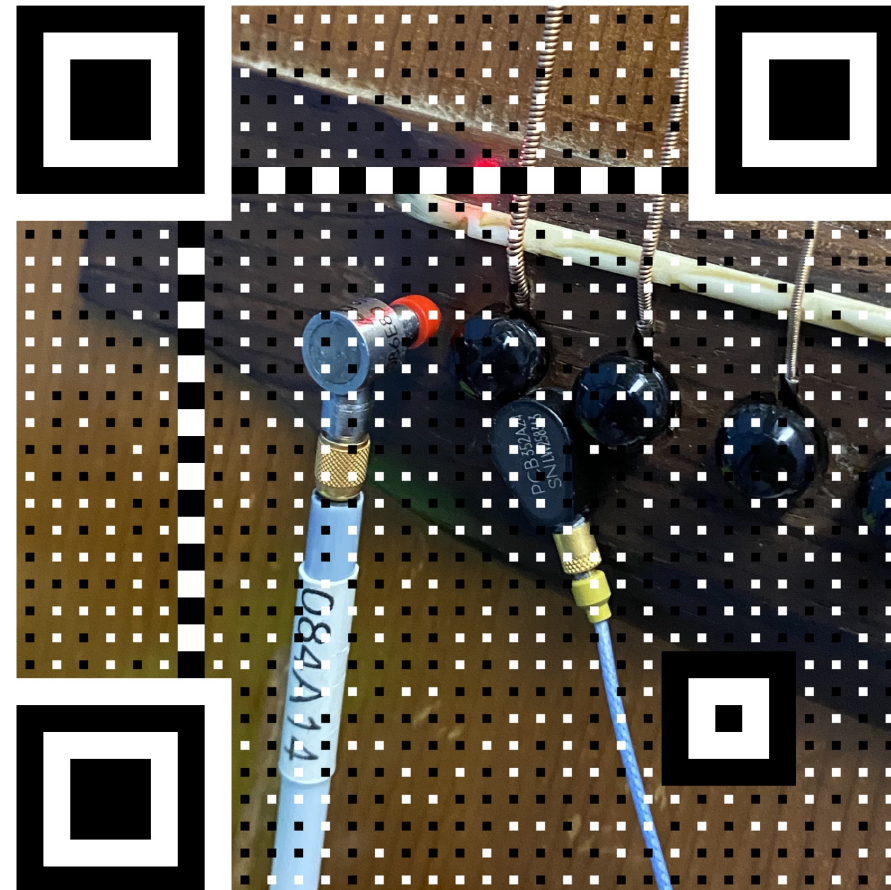
# References



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- Ewins, David J. *Modal testing: theory, practice and application*. John Wiley & Sons, 2009.
- Rossing, Thomas, ed. *Springer handbook of acoustics*. Springer Science & Business Media, 2007.
- Tehnologies, Agilent. "The fundamentals of modal testing." (2000).



# Measurements, Code, and Video





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