Ultra-High Resolutions Pulsed-Wire Magnet Measurement System

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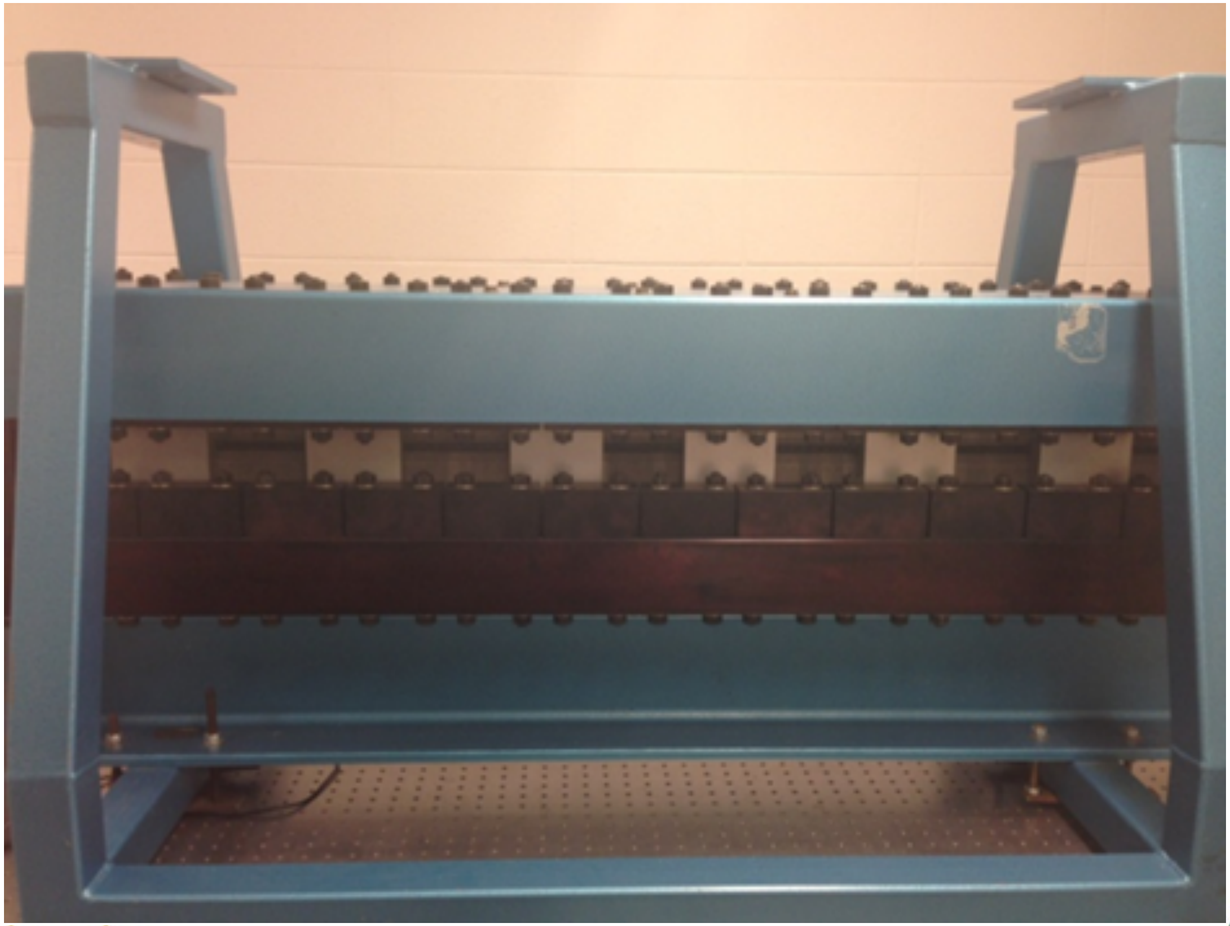
The Advanced Beam Laboratory

The Problem

The Problem, or at least one of them.



The Problem, or at least one of them.

Undulator Characterization: Most Common

- Traditional Hall probe

CSU Undulator Specs

Parameter	Value
K	1 (0.61 T)
Period	2.5 cm
Gap	8 mm
Material	Sm_2CO_5
Periods	50
Length	1.25 m

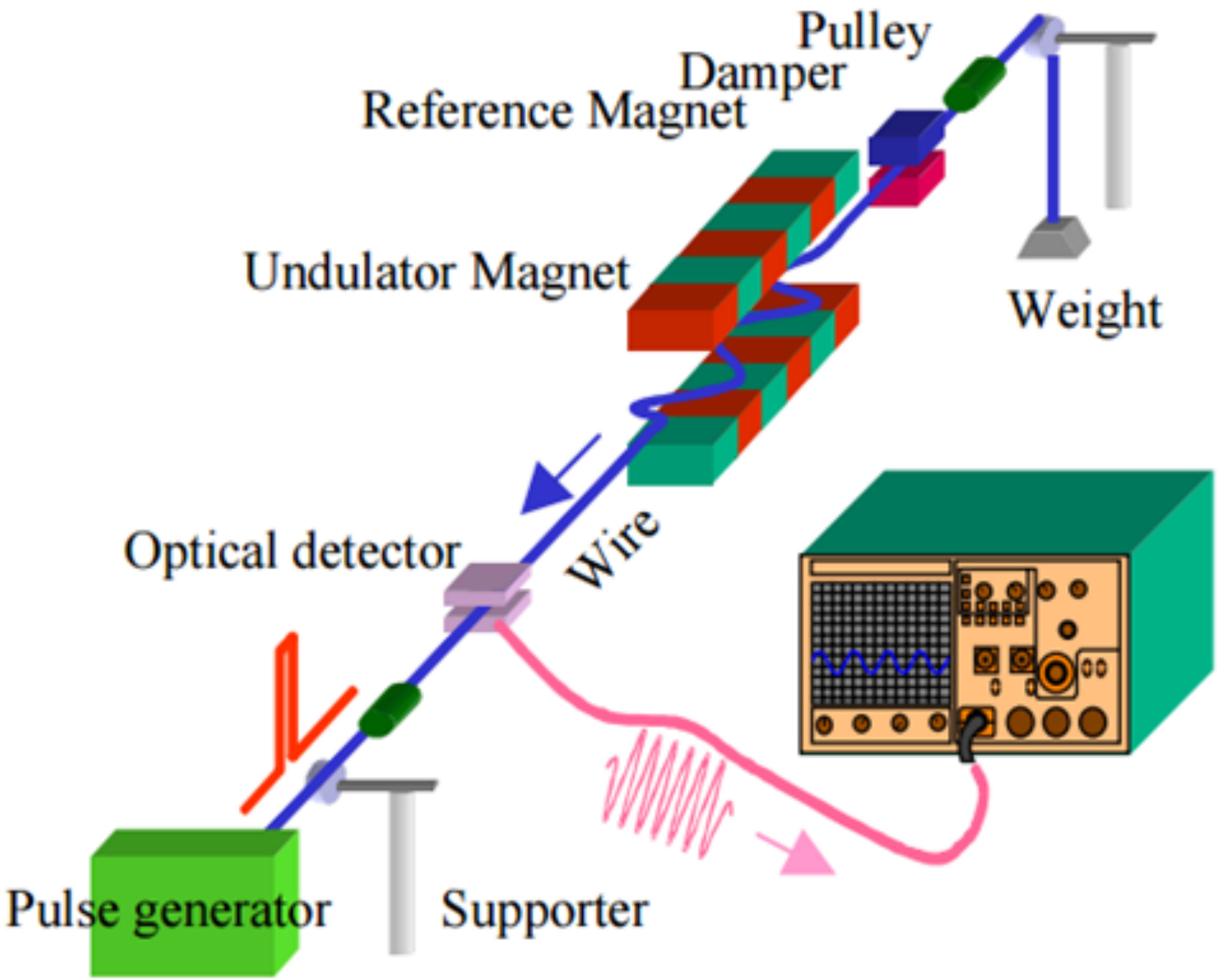
Additional Background

- **Students**
  - Good project for them
    - Measure an undulator
    - Read and understand a paper
    - Build a pulsed current source
    - Buy and assemble the equipment
    - Set up the measurement
    - Make the measurements
    - Write up reports
      - Conference papers
      - Senior design project papers
      - 1 Masters Thesis

PW History

- Concept first developed by R. W. Warren at LANL in 1988.
- Has been used in a variety of specialized cases in the characterization of magnetic fields.
- The method’s accuracy was previously limited due to dispersive effects in the wire and the finite pulse width.
- Newly developed mathematical algorithms can correct for these limitations.

Basic Understanding



Fan, T. C., Lin, F.Y. et al., “Pulsed wire magnetic field measurements on undulator U10P”, Proceedings of PAC2001, Chicago, USA, 2001, p. 2775-2777

LBNL Correction Algorithm

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A dispersion and pulse width correction algorithm for the pulsed wire method

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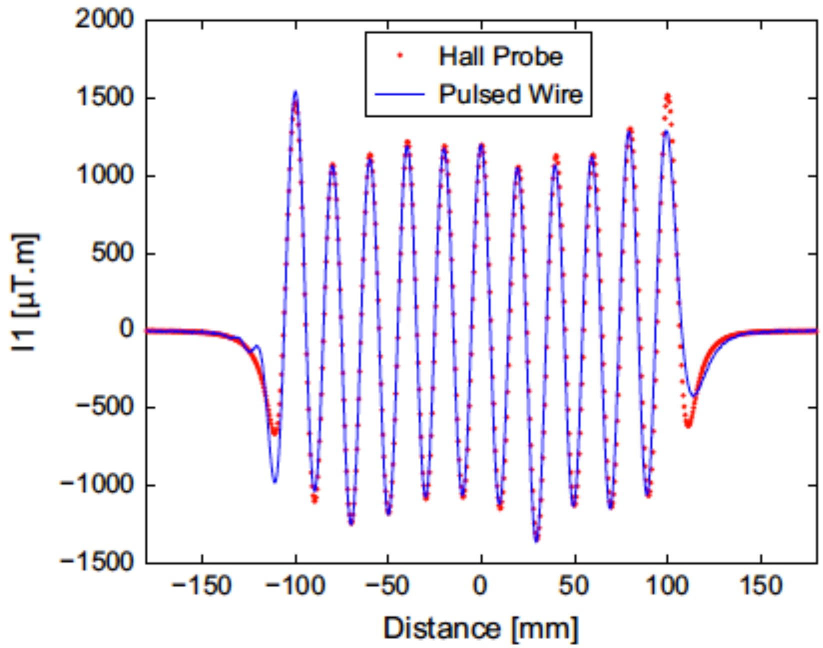
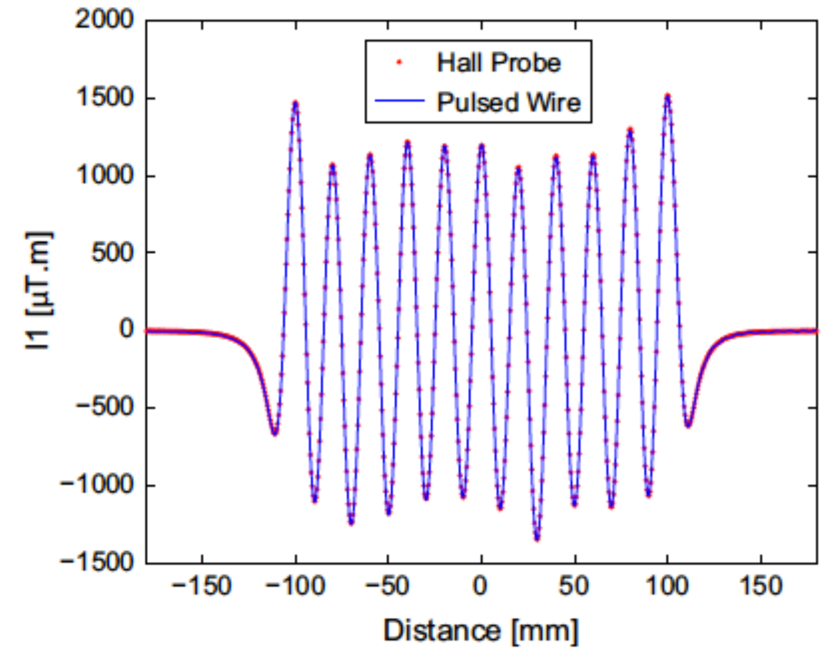
LBNL Results

Uncorrected



Corrected



Output

- 1st and 2nd magnetic field integrals.
- Simulates both the transverse velocity and oscillation trajectory of a charged particle passing along the axis of the undulator.

$$u_{s0}(t) = \frac{Ic_0\delta t}{2T}\int_0^{c_0 t} B(\tilde{x})d\tilde{x} \longleftrightarrow v_x(z) = \frac{1}{\gamma m_e}\int_0^z qB_y(\tilde{z})d\tilde{z}$$

$$u_{s0}(t) = \frac{I}{2T}\int_0^{c_0 t}\int_0^{\hat{x}} B(\hat{x})d\hat{x}d\tilde{x} \longleftrightarrow x(z) = \frac{1}{\gamma m_e v_z}\iint_0^z qB_y(\tilde{z})d\tilde{z}d\hat{z}$$

Dispersion Correction

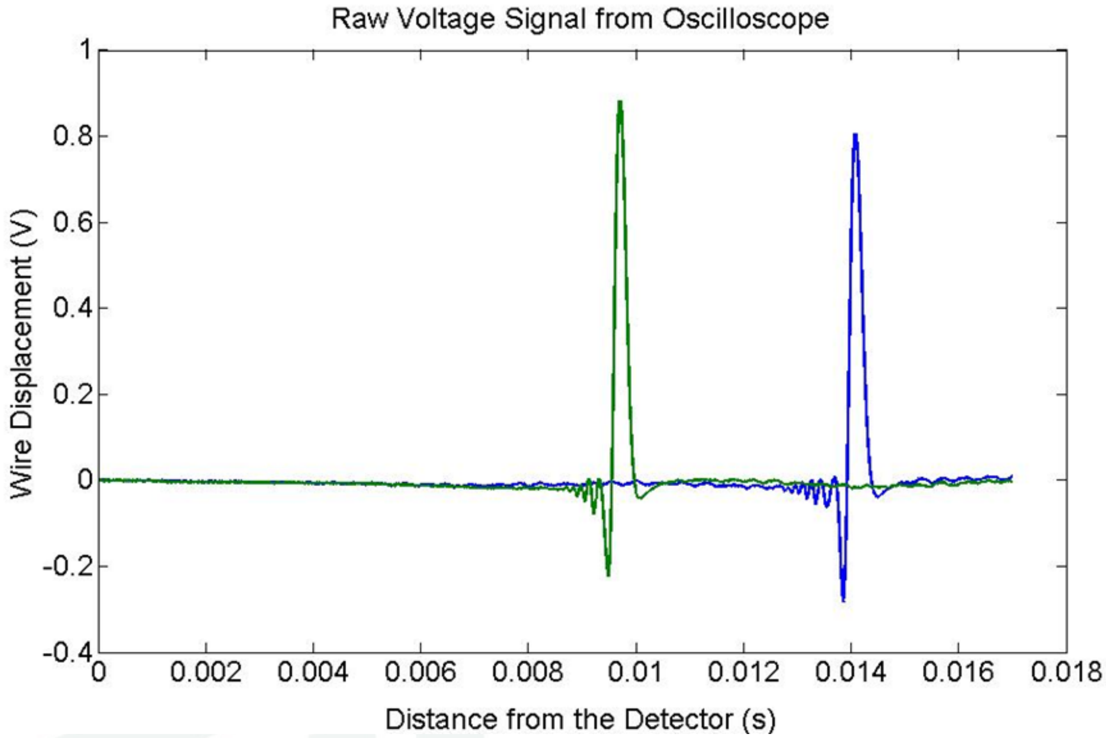
- From the Euler-Bernoulli equation for the bending of thin rods:

$$c(\kappa) = c_0\sqrt{1 + \frac{EI_W}{T}\kappa^2}.$$

$$c_0 = \sqrt{T / \mu}$$

- Need to find c_0 and EI_W experimentally.

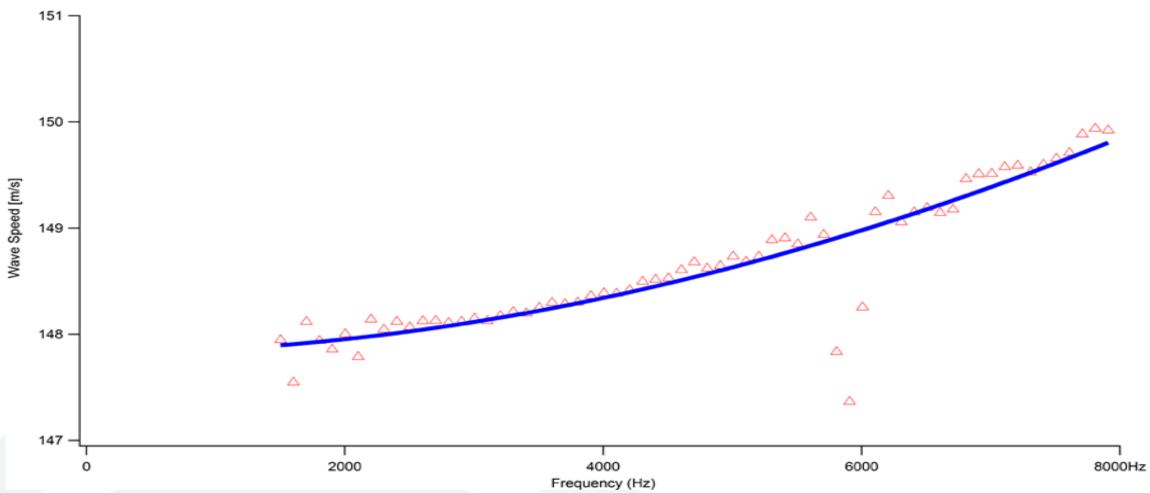
Wave Speed Determination

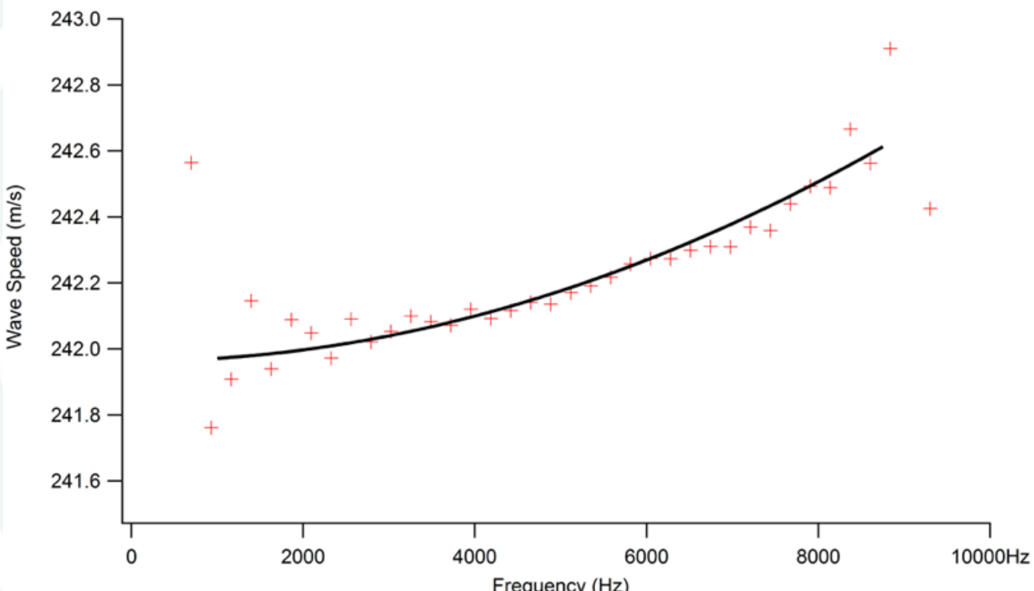


$$\bar{u}_s^*(\omega)\bar{u}_{s\Delta z}(\omega) = |G(\omega)|^2 e^{i\kappa\Delta z}$$

$$c = \frac{\omega\Delta z}{\phi}$$

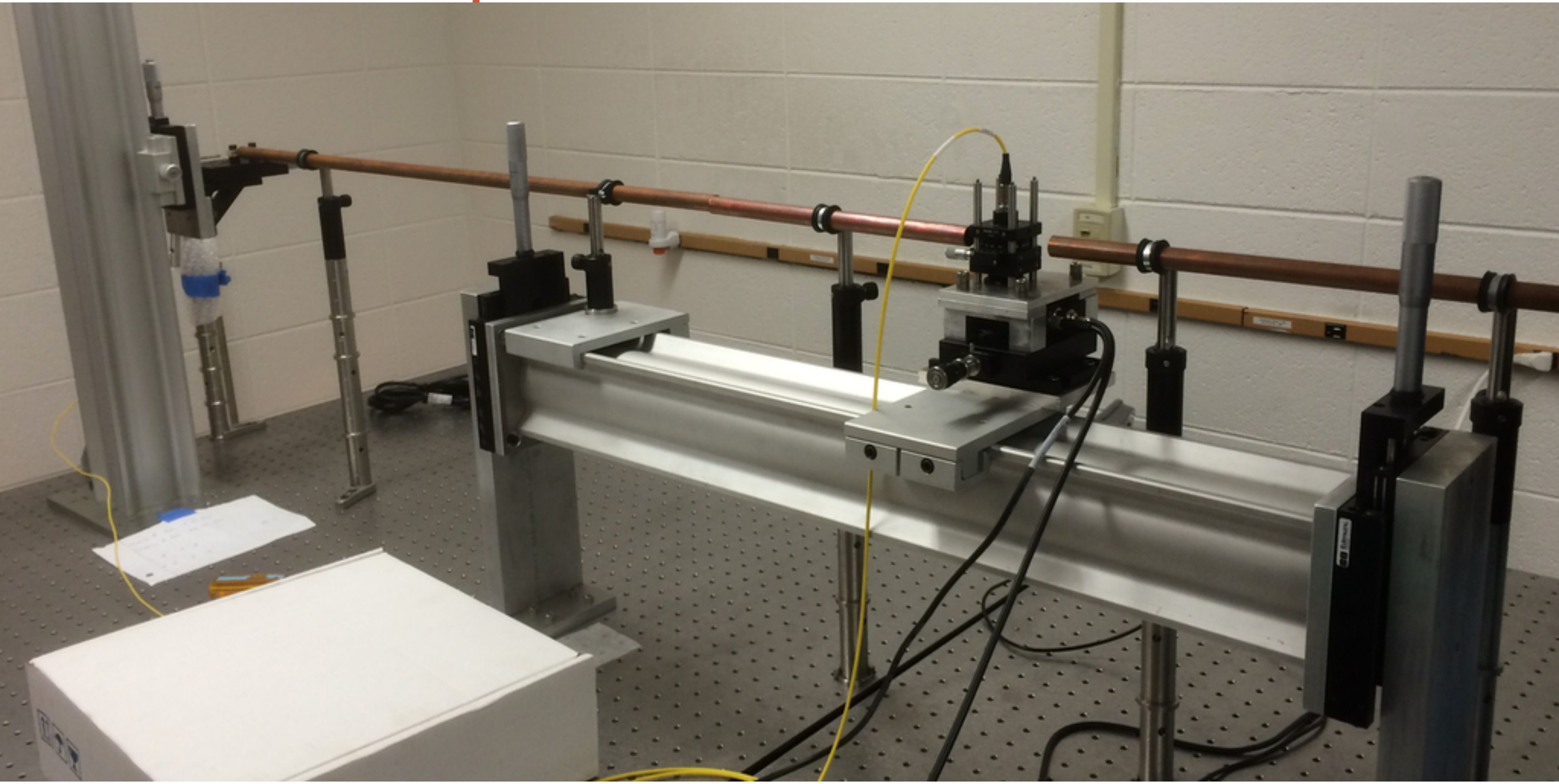
Dispersive Wave Speed



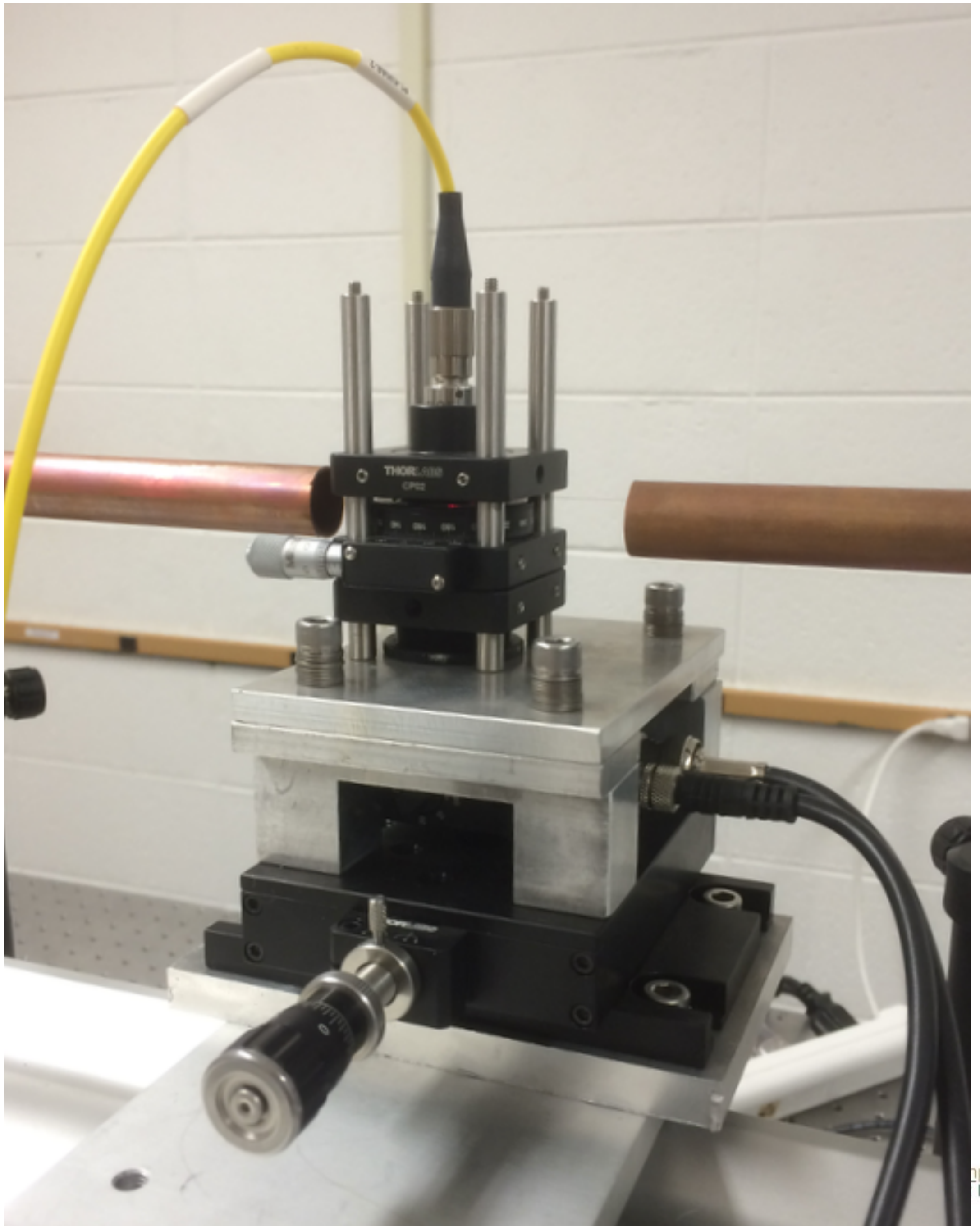


$$c = \frac{\omega \Delta z}{\phi}$$

Isolation required

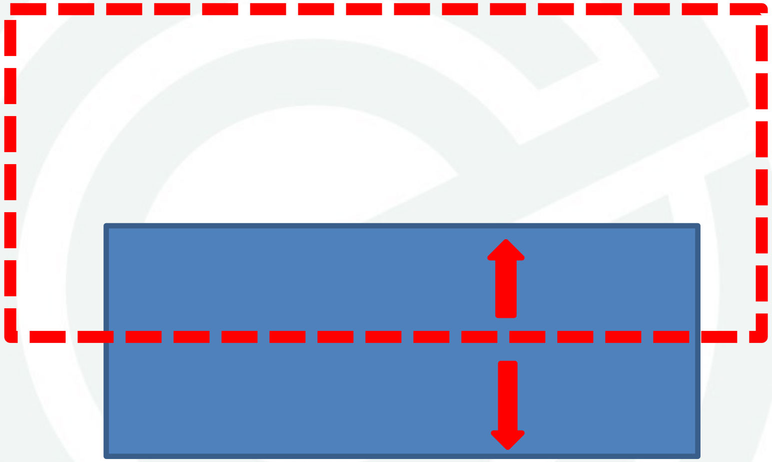


Detector region

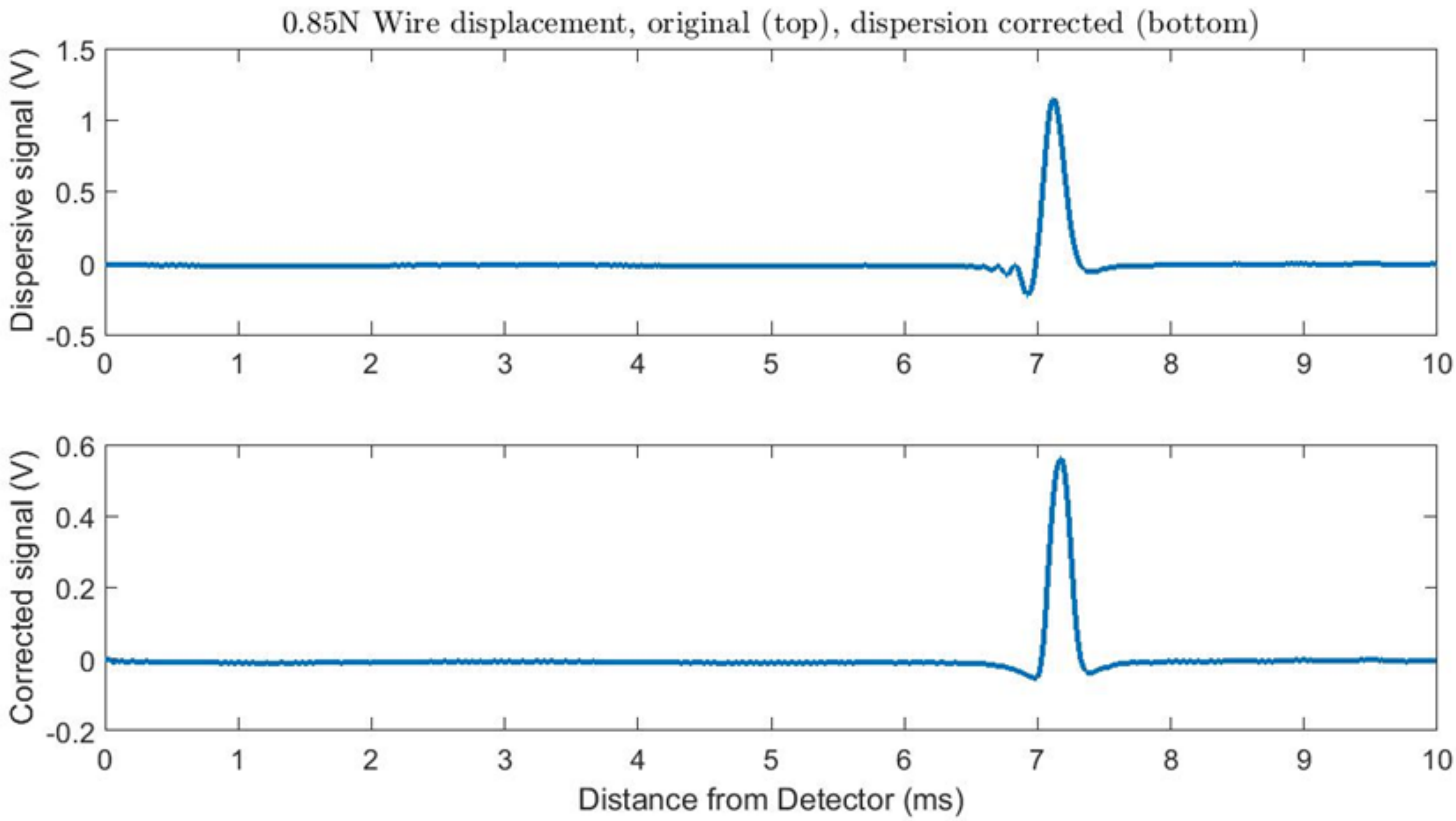


Setup: Wire Vibration Detection

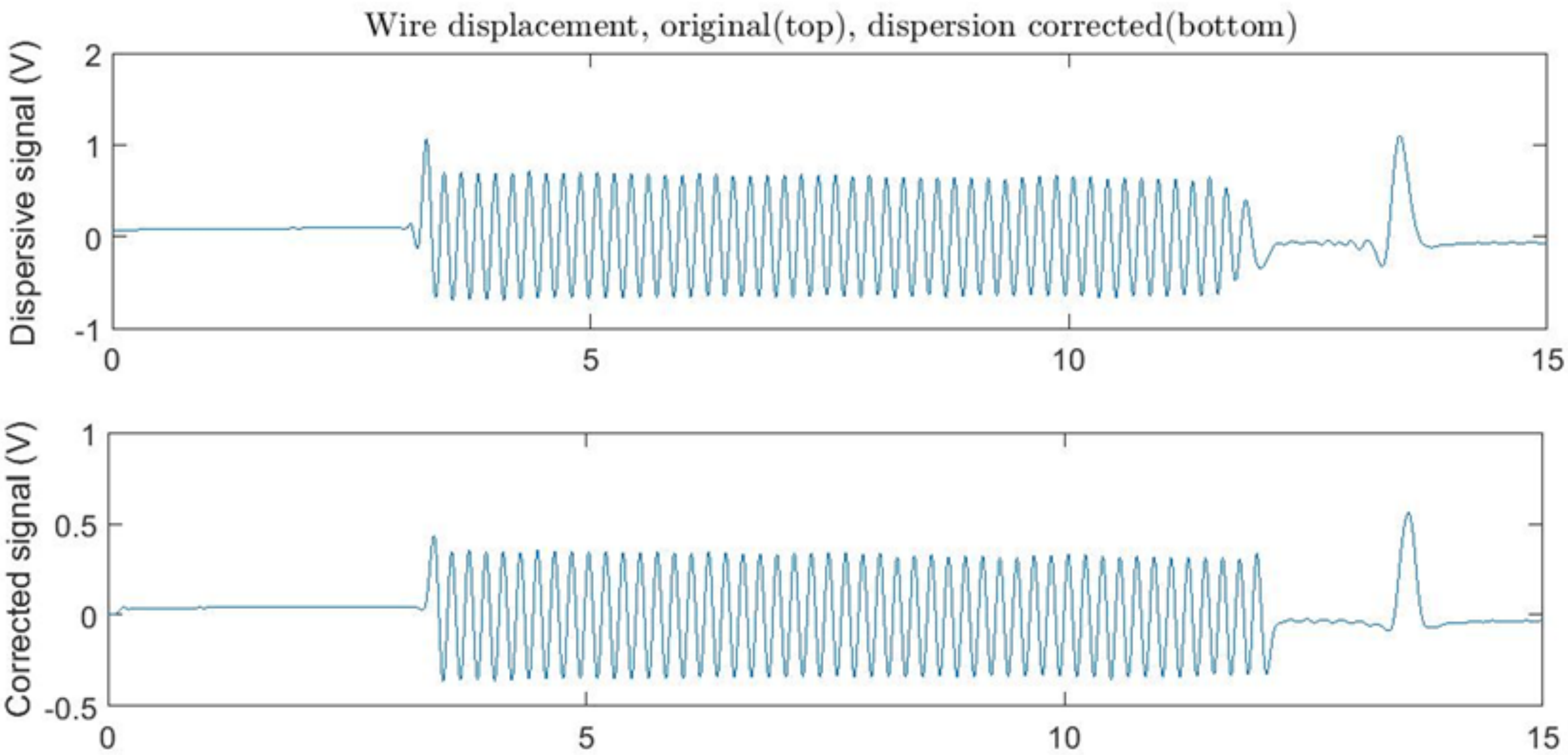
- 635nm fiber laser
- 40µm Slit
- Amplified Si photo-detector



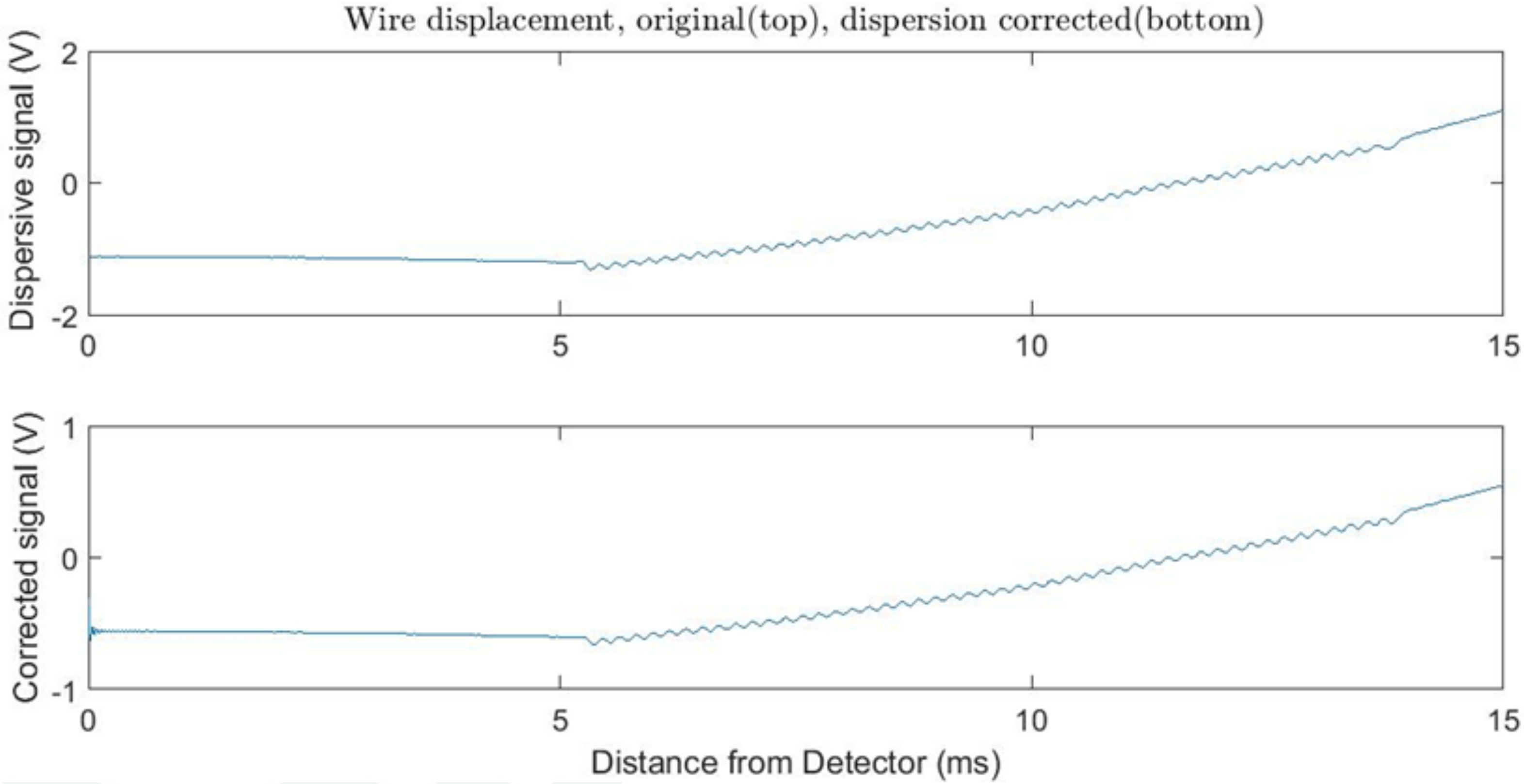
Dispersion Corrected: Short Pulse (1st Integral)



1st Integral of the Undulator and Ref. Magnet



2nd Integral of the Undulator



System Difficulties

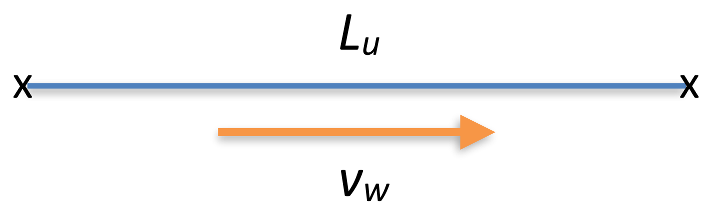
- **Large amount of noise was prominent.**
  - Air
  - Poor table isolation from ground
  - Electrical
- **Limitations**
  - Oscilloscope resolution

Additional (Potential) Sources of Error

- Electrical
  - Dispersion of current pulse
    - Not a problem for the relatively short length of the wire and low frequencies employed
  - Wire resistance
    - It is roughly 50 Ω so there is a significant voltage drop across it; however,
    - It is the current that matters, so this is not a real problem.

Additional (Potential) Sources of Error

- Mechanical
  - Vibration damping time.



$$A(t) = A_o e^{-t/\tau} \qquad t_u = L_u / v_w$$

$$1 - \frac{A(t_u)}{A_o} = 1 - e^{-t_u/\tau}$$

Assume

$\tau = 2 \text{ sec}$

$v_w = 200 \text{ m/s}$

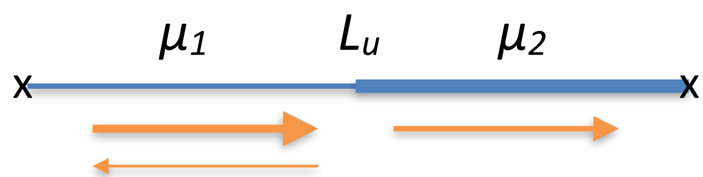
$L_u = 1.5 \text{ m}$

Then

$t_u = 7.5 \text{ ms} \qquad 1 - \frac{A(t_u)}{A_o} \simeq 0.0038$

Additional (Potential) Sources of Error

- Mechanical
  - Reflections
    - Wire discontinuities



$$\Gamma = \frac{v_2 - v_1}{v_2 + v_1}$$ Reflection Coefficient

$$v = \sqrt{\frac{T}{\mu}}$$ Wave speed

Assume

$$\mu_2 = \mu_1 + \Delta\mu$$

where $\Delta\mu \ll \mu_1$ or μ_2

Then $\Gamma \simeq \frac{1}{4}\frac{\Delta\mu}{\mu_1}$

Example $\frac{\Delta\mu}{\mu_1} = 1\%, \quad \Gamma = 0.25\%$

Improvements

- Better pulser
  - Originally used a home made current pulse
    - Noisy
  - Bought an AvTech Pulser
    - Very nice but expensive (~$11k)
    - Computer interface to NI available
      - Works well
- Better digitizer
  - Originally used an available scope
    - Limited dynamic range
    - Limited memory
  - Bought a 16-bit NI digitizer
    - Very nice
- Better environmental isolation
  - The area we were in was VERY noisy and “windy”
- Better reference magnet
  - We were limited to what we had and so ours had a non-zero 2nd integral
  - Would like it as short as possible
    - Higher frequency content

Additional steps

- Technology transferred to industry
  - KYMA S.r.L.
  - Special thanks to Giuseppi Fiorito and Raffaella Geometranta
- Find another student to tune the device

Thank you