Copper Strand Thermal Shielding for Third-Scale Magnet

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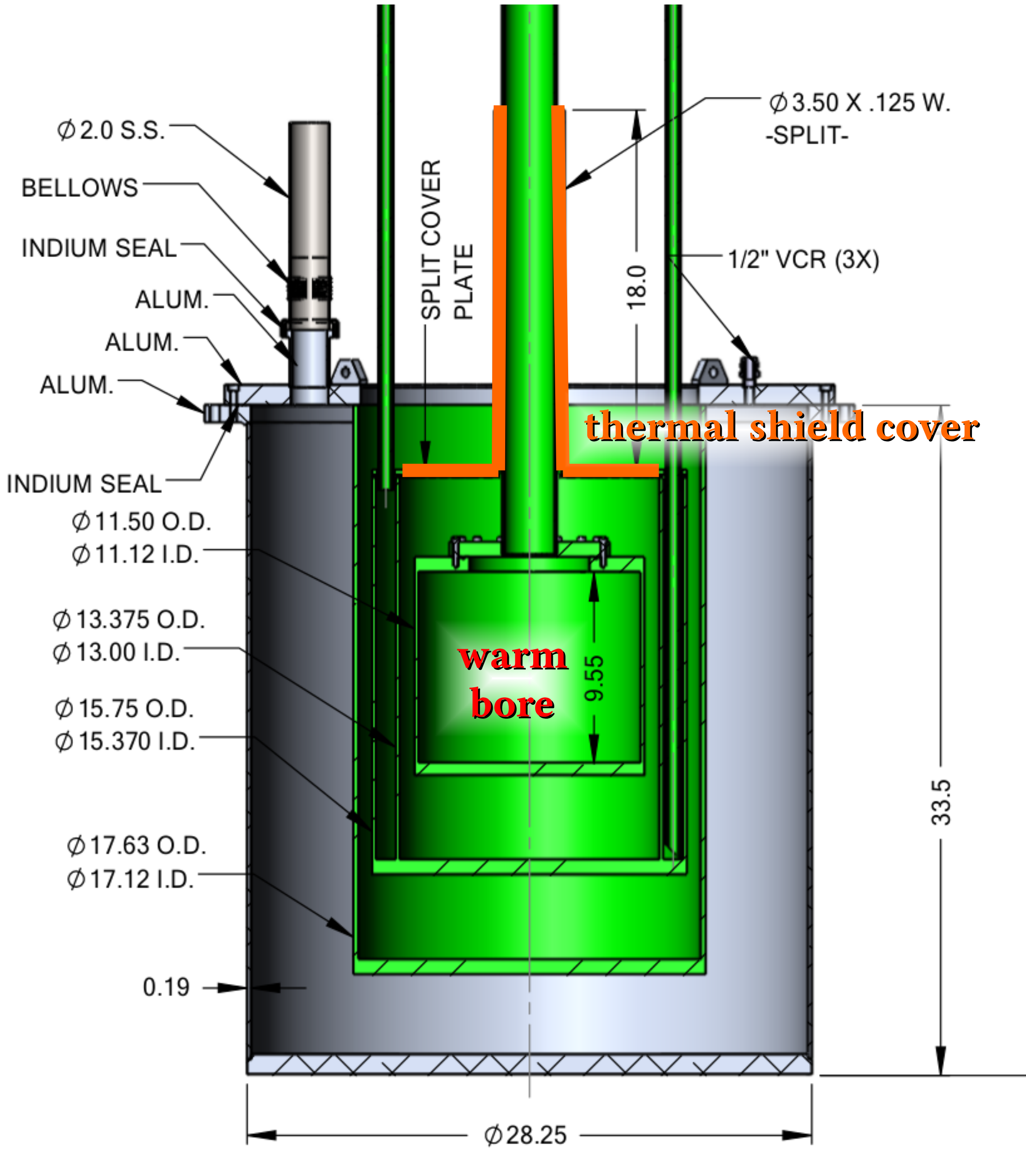
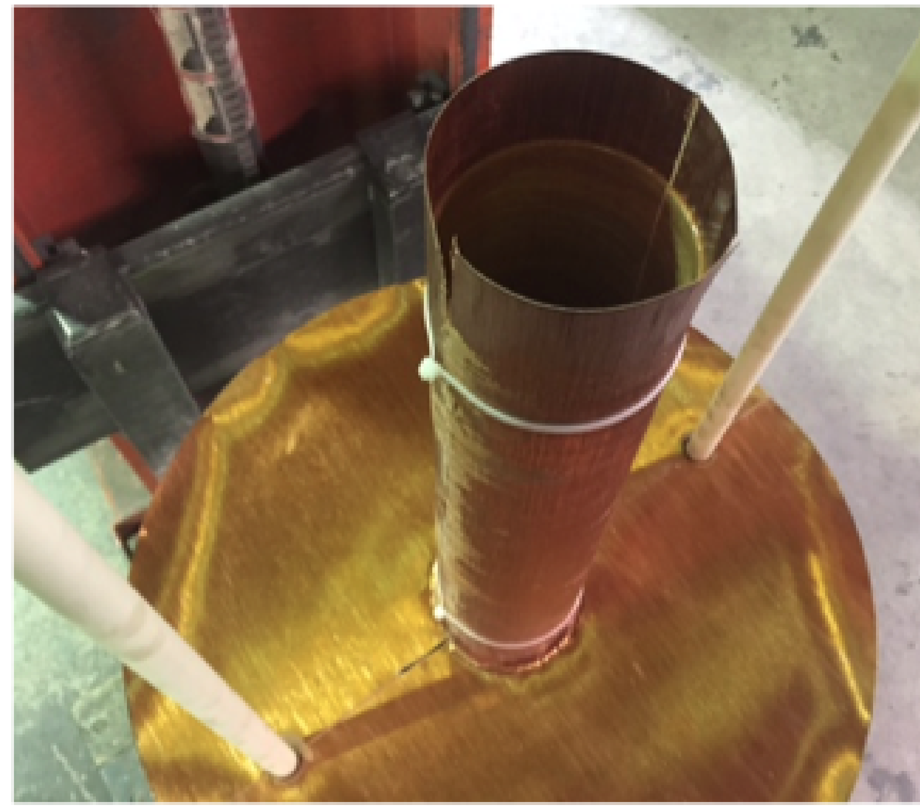
Third-Scale Magnet

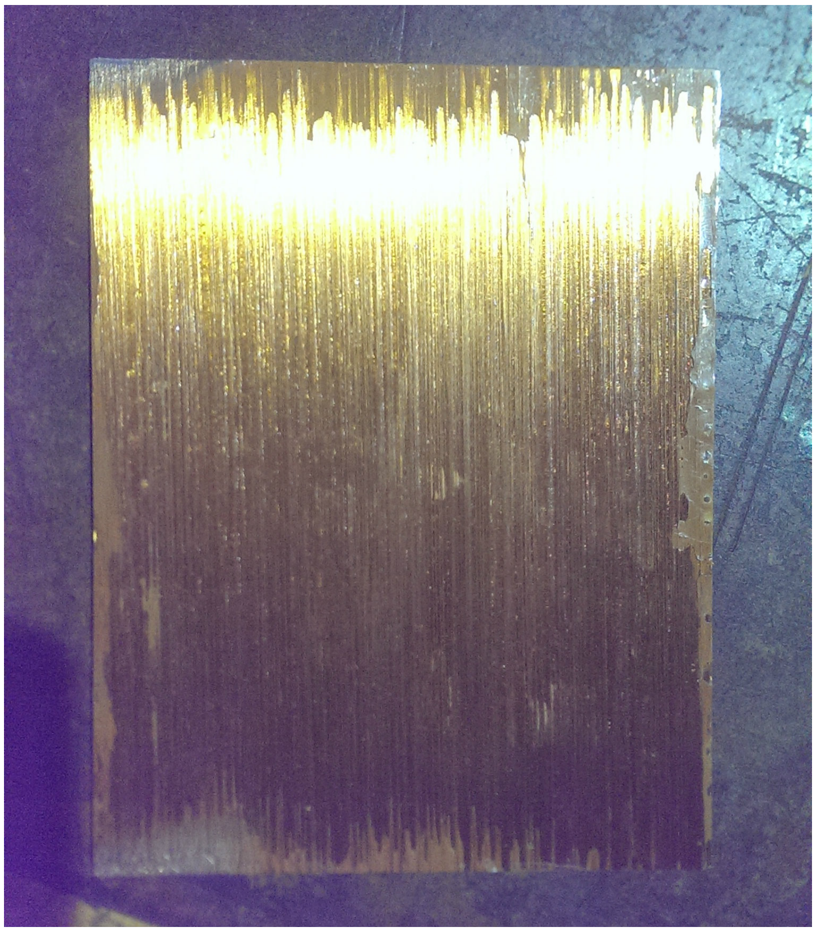


- superconducting lead (T_c = 7.2 K) for **B** field uniformity
- thermally-shielded warm bore to map **B** field
- copper plating on G-10 for insulation
- can't interfere with **B** field

Our Thermal Shield

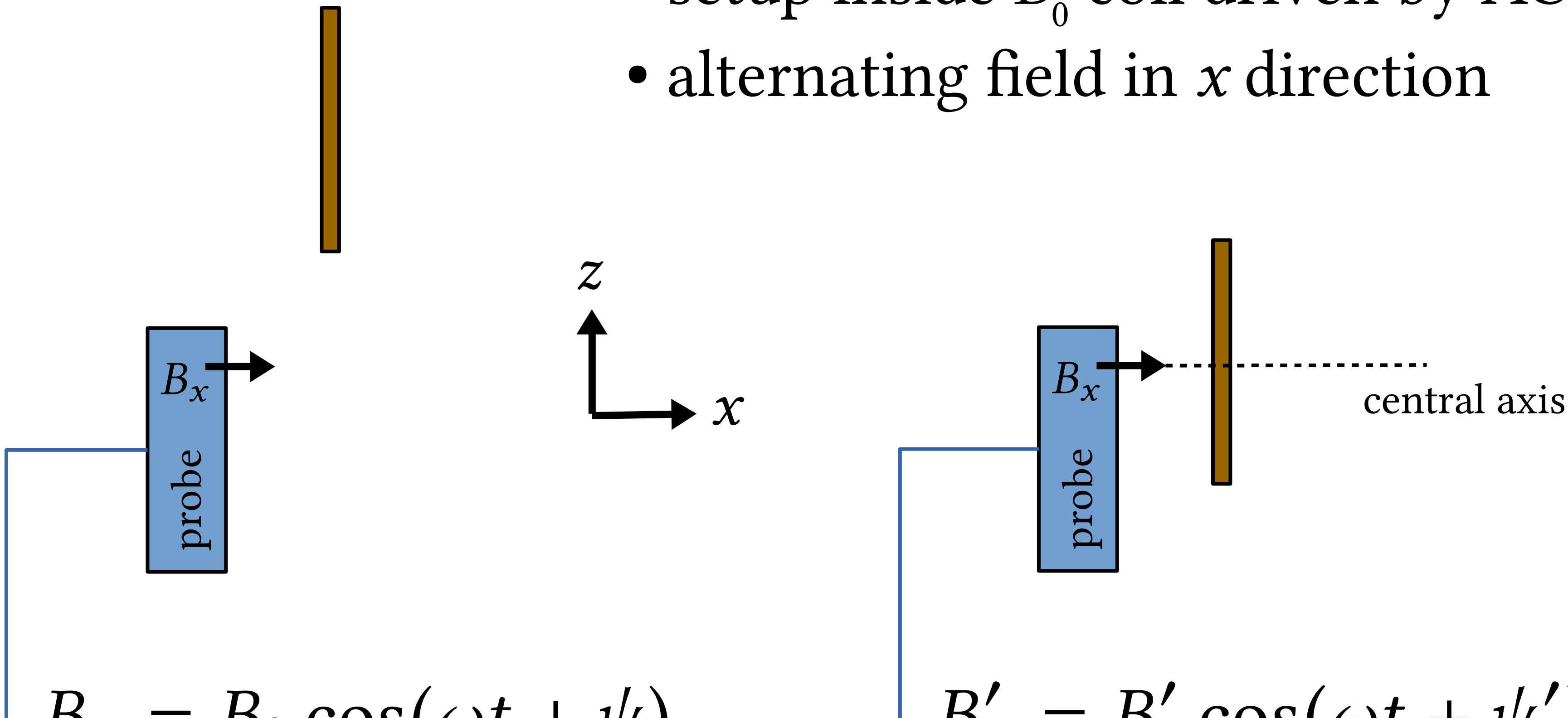


Our Thermal Shield



- strands of copper held together by epoxy
- currents can't jump between insulated strands
- no large-scale eddy currents
- measure **B** field effect and compare with copper plate

- setup inside B_0 coil driven by AC
- alternating field in x direction



$$B_x = B_0 \cos(\omega t + \psi)$$

$$B'_x = B'_0 \cos(\omega t + \psi')$$

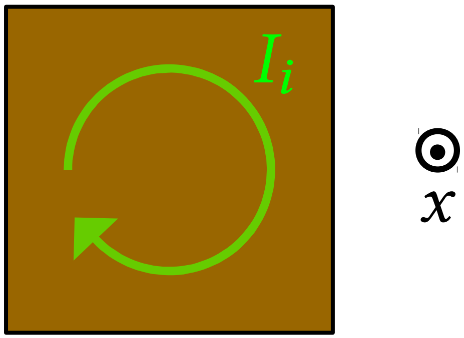
gain: $\gamma \equiv \dfrac{B'_0}{B_0}$

phase shift: $\Delta\psi \equiv \psi' - \psi$

Predicting $\gamma(\omega)$ and $\Delta\psi(\omega)$

$$B_{x,\text{applied}} = B_0 \cos(\omega t + \psi)$$

induction on plate

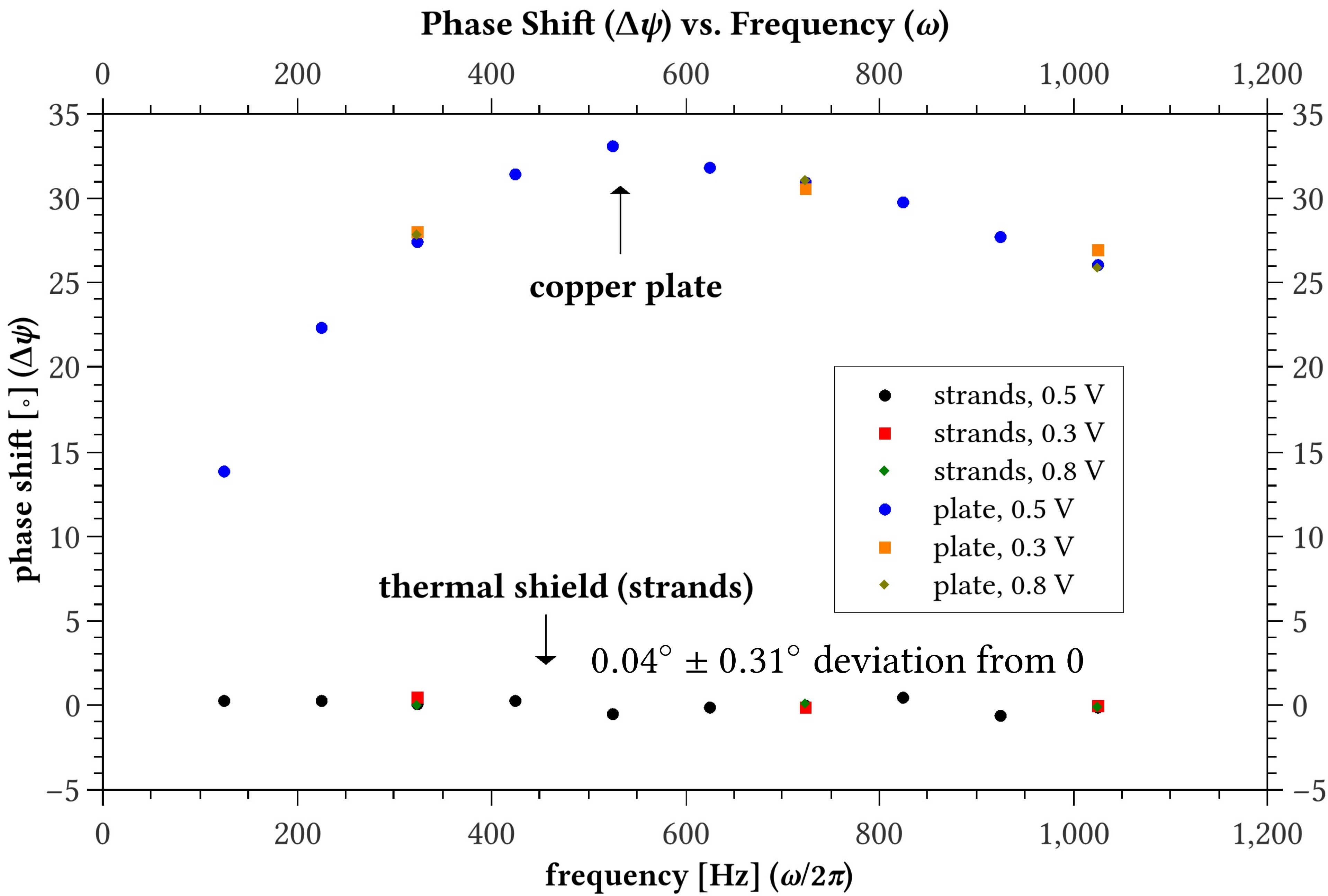


$$I_i = \frac{\mathcal{E}_i}{R_i} \sim \frac{\partial}{\partial t}[B_{x,\text{applied}}]$$

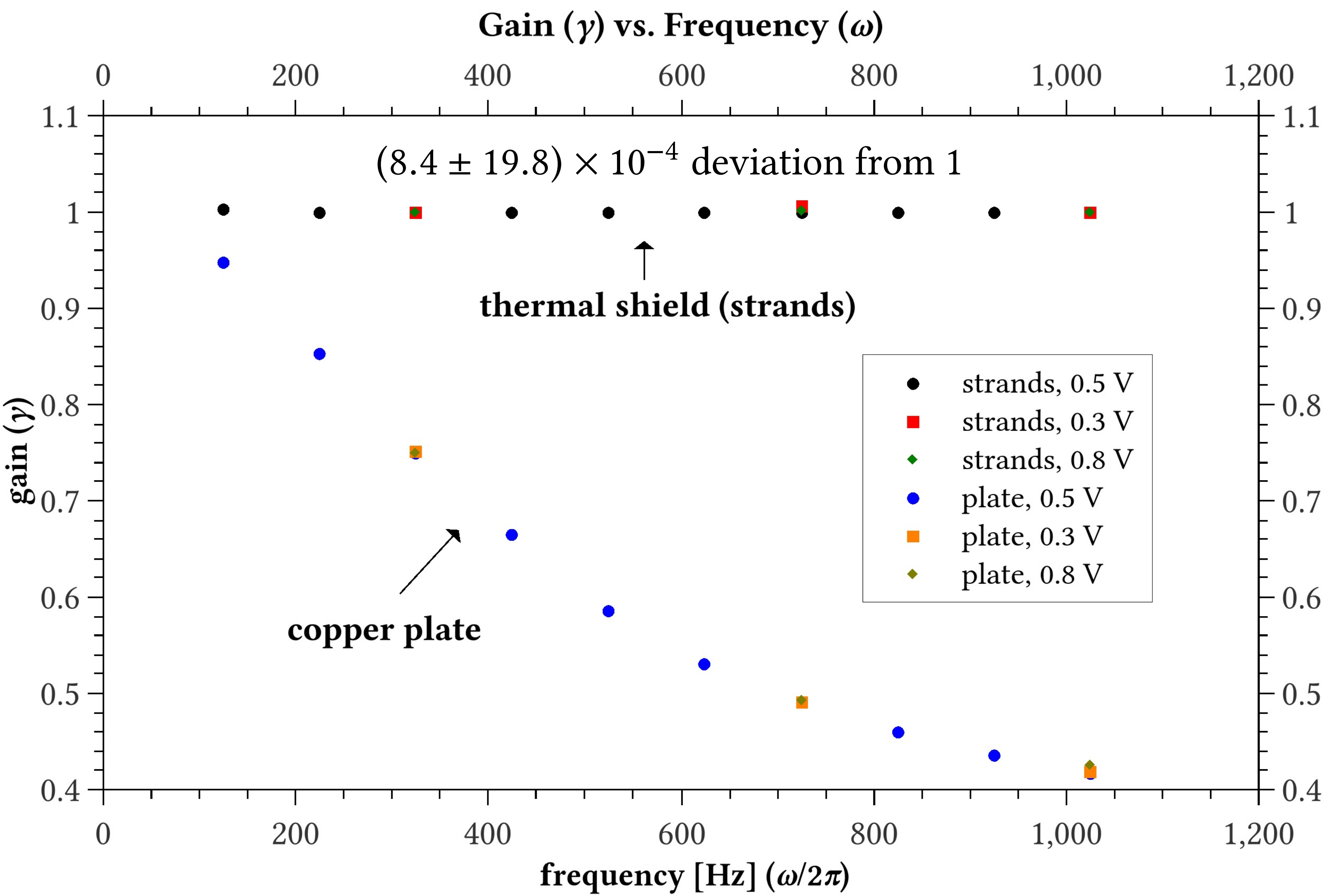
$$B_{x,\text{induced}} \sim \frac{\partial B_{x,\text{a}}}{\partial t} = \alpha B_0 \sin(\omega t + \psi)$$

$$\begin{aligned} B_{x,\text{meas}} &= B_{x,\text{appl}} + B_{x,\text{ind}} \\ &= \gamma B_0 \cos(\omega t + \psi + \Delta\psi) \end{aligned}$$

$$\gamma = \sqrt{\alpha^2 + 1} \qquad \Delta\psi = -\arctan(-\alpha)$$



Phase Shift (Δψ) vs. Frequency (ω)
0
200
400
600
800
1,000
1,200
35
30
25
20
15
10
5
0
−5
phase shift [∘] (Δψ)
frequency [Hz] (ω/2π)
copper plate
thermal shield (strands)
0.04° ± 0.31° deviation from 0
strands, 0.5 V
strands, 0.3 V
strands, 0.8 V
plate, 0.5 V
plate, 0.3 V
plate, 0.8 V

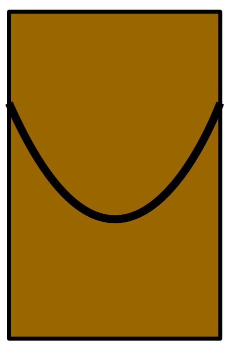

Gain (γ) vs. Frequency (ω)
$(8.4 \pm 19.8) \times 10^{-4}$ deviation from 1
thermal shield (strands)
copper plate
strands, 0.5 V
strands, 0.3 V
strands, 0.8 V
plate, 0.5 V
plate, 0.3 V
plate, 0.8 V
gain (γ)
frequency [Hz] ($\omega/2\pi$)
0
200
400
600
800
1,000
1,200
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1

Predicting $\gamma(\omega)$ and $\Delta\psi(\omega)$

$$B_{x,\,\text{applied}} = B_0 \cos(\omega t + \psi)$$

skin depth attenuation

$x \longrightarrow$

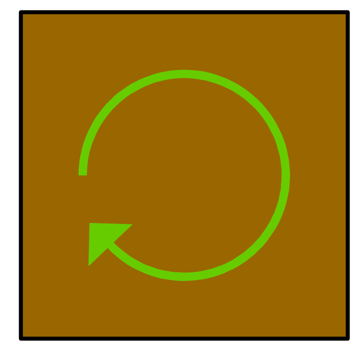


$$\cosh\left(\frac{z}{\delta}\right)$$

$$\beta B_0 \cos(\omega t + \psi)$$

induction on plate

$$-\frac{\partial \Phi}{\partial t}$$



$\odot$
x

$$\alpha B_0 \sin(\omega t + \psi)$$

$$B_{x,\,\text{meas}} = \gamma B_0 \cos(\omega t + \psi + \Delta\psi)$$

$$\gamma = \sqrt{\alpha^2 + \beta^2} \qquad \Delta\psi = -\arctan(-\alpha/\beta)$$

Remarks

- gain from thermal shield, eddy current suppresion:

$$\lesssim 2 \times 10^{-3} \text{ deviation from } 1$$

- attenuation parameters:

$$\beta \sim \frac{1 + e^{-c/\delta}}{2} \qquad \alpha \sim \omega \delta e^{-c/2\delta} \sinh\left(\frac{c}{2\delta}\right)$$

$$\delta = \sqrt{\frac{2\rho}{\omega \mu_r \mu_0}}$$