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OS-M1-AM-1 (Tuesday, 22nd June)

Electromagnetic coupling between filaments in multifilament coated conductors with finite transverse conductance

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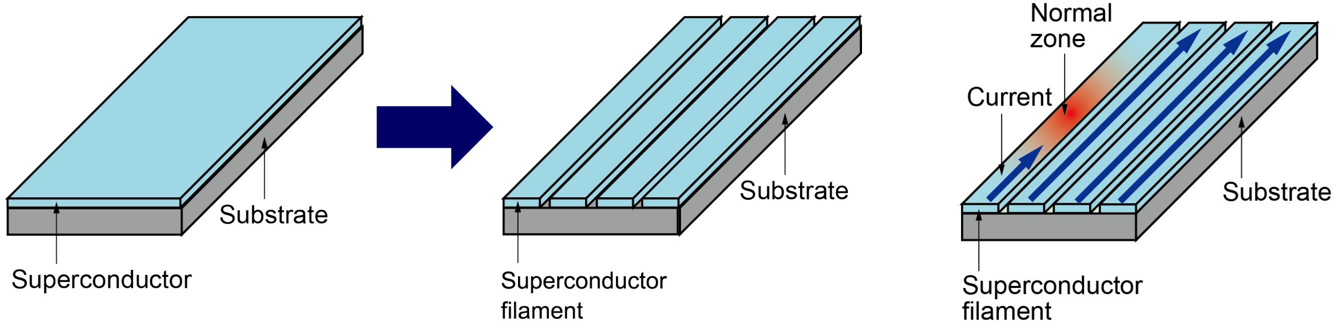
Various systems consisting of copper-plated multifilament coated conductors

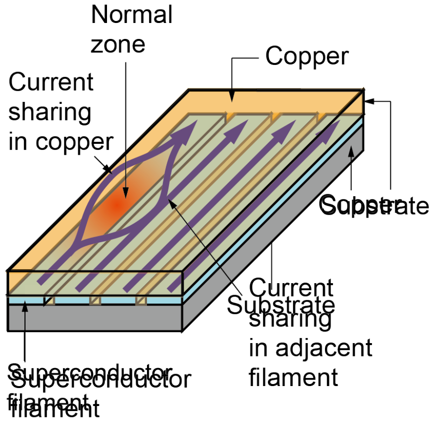
- Single tape
- Pancake coil
- Layer-wound solenoid coil
- Assembled conductors (Roebel, CORC, etc.)

How to ensure compatibility of low AC loss and robustness against normal transition in coated conductors?

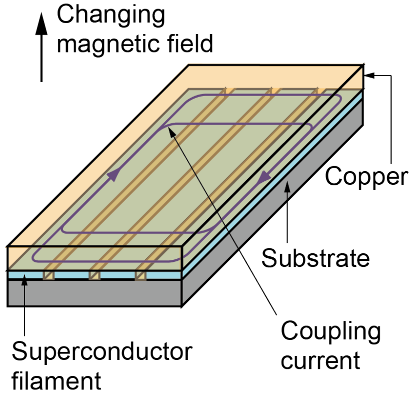


Striation blocks current sharing between filaments and affects the robustness against local normal transition.

AC loss can be reduced by striation to form multifilament structure.



If we plate copper on the entire group of filaments,
plated copper allows current sharing between filaments and improves robustness.



Filaments are coupled by coupling current, which flowing between filaments through plated copper.

At this state, AC loss cannot be reduced.

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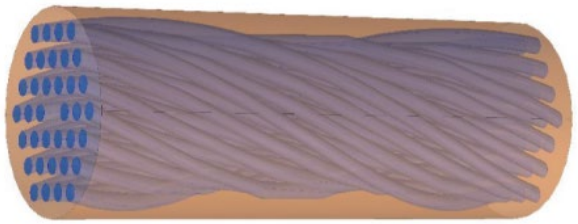
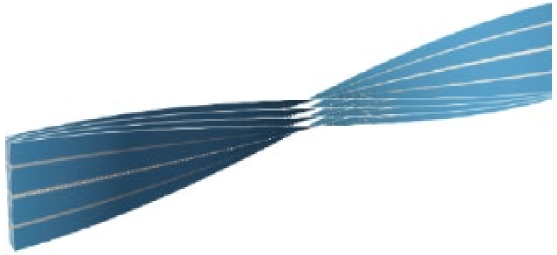
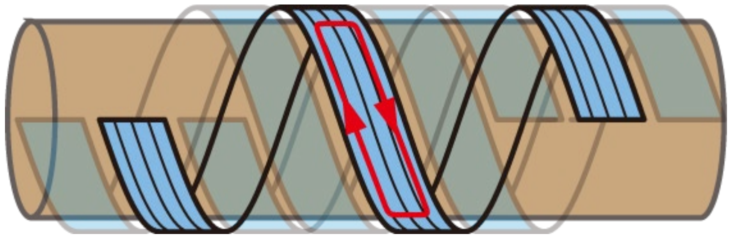
How to decay coupling current quickly?

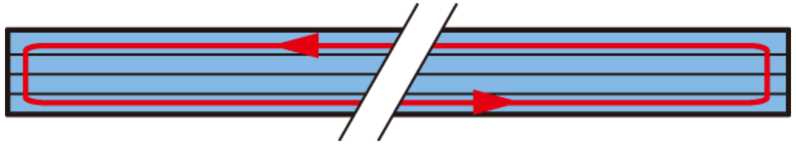


Twisting is the standard approach to reduce coupling time constants in round LTS wires.



Twisting flat HTS tape is far from practical method.





$L_c \sim$ half pitch of spiral along coated conductor $(L_{p1}/2)$

$L_c \sim$ entire length of coated conductor (L_s)

SCSC cable (double “SC” cable)

Spiral Copper-plated Striated Coated-conductor cable

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Key issues of electromagnetic field analyses of SCSC cable consisting of copper-plated multifilament coated conductors

- 3D geometry of thin superconductor layer of coated conductor in a cable.
- Finite electric field (*E*) – current density (*J*) characteristics of superconductors
- Transverse conductance between filaments

Particular issue in copper-plated multifilament coated conductors

Governing equation formulated by using *T* and thin-strip approximation / constitutive equation

Current vector potential

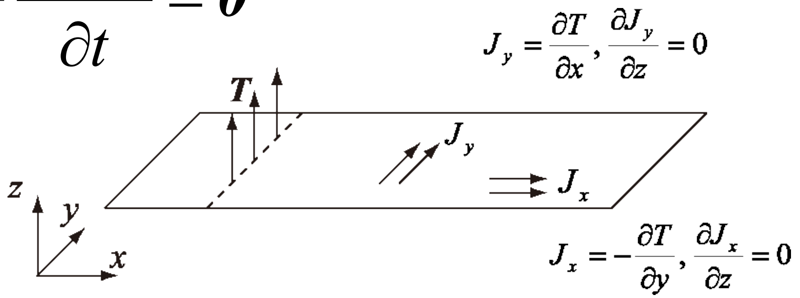
$$\boldsymbol{J} = \nabla \times \boldsymbol{T}$$

$$\boldsymbol{E} = \boldsymbol{J} / \sigma(J) \qquad \nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = \boldsymbol{0} \qquad \boldsymbol{B} = \frac{\mu_0}{4\pi} \int_V \frac{\boldsymbol{J} \times \boldsymbol{r}}{r^3} dV$$

Extended Ohm's law | Faraday's law | Biot-Savart's law

$$\nabla \times \left(\frac{1}{\sigma} \nabla \times \boldsymbol{T} \right) + \frac{\partial}{\partial t} \frac{\mu_0}{4\pi} \int_V \frac{(\nabla \times \boldsymbol{T}') \times \boldsymbol{r}}{r^3} \mathrm{d}V + \frac{\partial \boldsymbol{B}_{\mathrm{ext}}}{\partial t} = \boldsymbol{0}$$

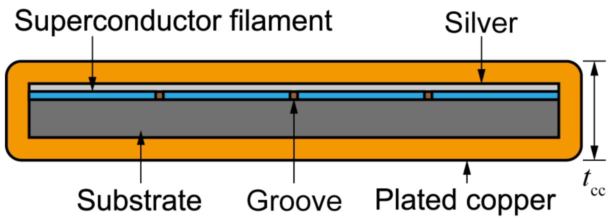
Thin-strip approximation

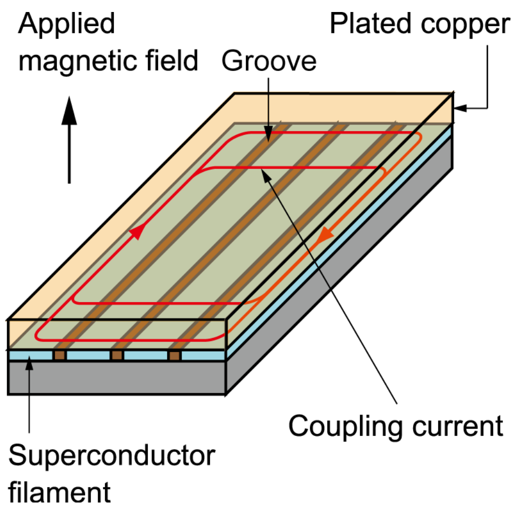


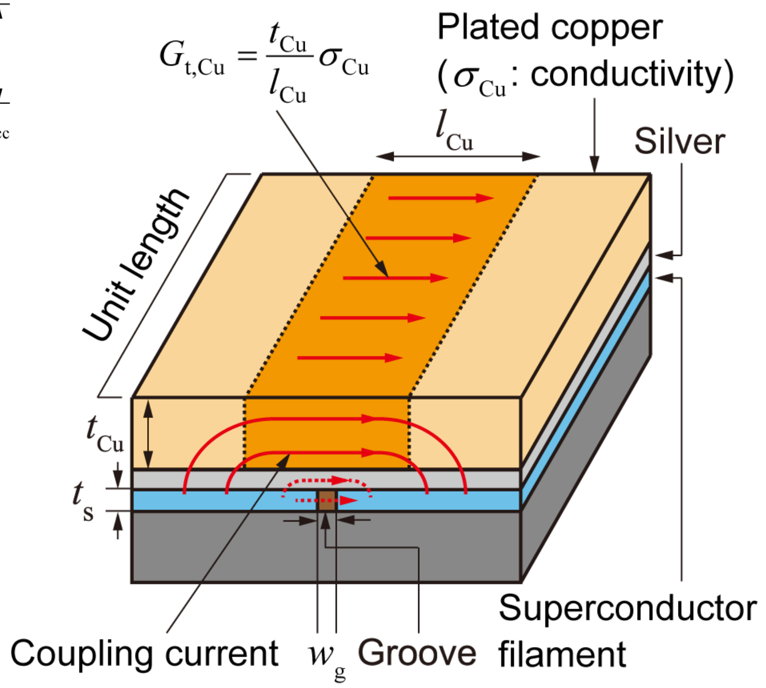
Governing equation in which constitutive equation is implemented

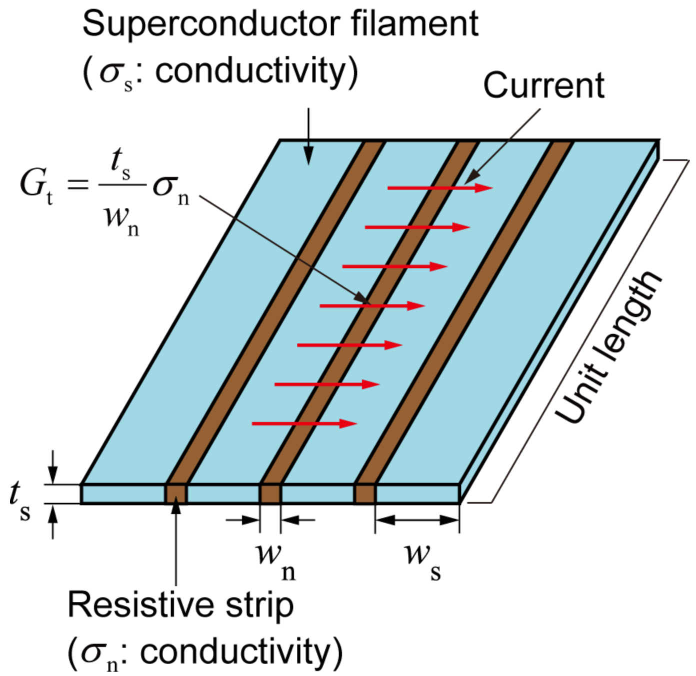
$$\nabla \times \left(\frac{1}{\sigma} \nabla \times \boldsymbol{n} T \right) \cdot \boldsymbol{n} + \frac{\partial}{\partial t} \left(\frac{\mu_0 t_{\mathrm{s}}}{4\pi} \int_{S'} \frac{(\nabla \times \boldsymbol{n}' T') \times \boldsymbol{r} \cdot \boldsymbol{n}}{r^3} \mathrm{d}S' + \boldsymbol{B}_{\mathrm{ext}} \cdot \boldsymbol{n} \right) = 0$$

Thin strip approximation of copper-plated multifilament coated conductor









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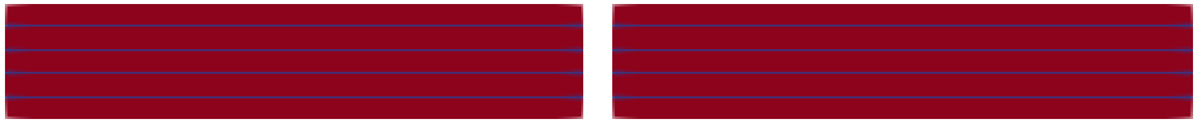
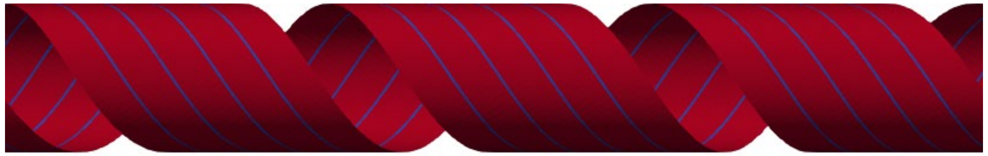
Specifications of analyzed and measured samples

Sample-ID	20210212-1	Sample-ID	20210226-1
Shape	Longitudinally aligned straight tapes	Shape	Single-layer spirally wound tapes
Tape length	20 mm	C length	99 mm
Number of tapes	5	Core diameter	3 mm
Space between tapes	1 mm	Tape number per layer	1
Sample length	104 mm	Winding angle	55°
J_c (A/m^2)	2.08×10^{10}	J_c (A/m^2)	2.08×10^{10}
n-value	28.4	n-value	17.4



20210212-1 (Only show 2 tapes)

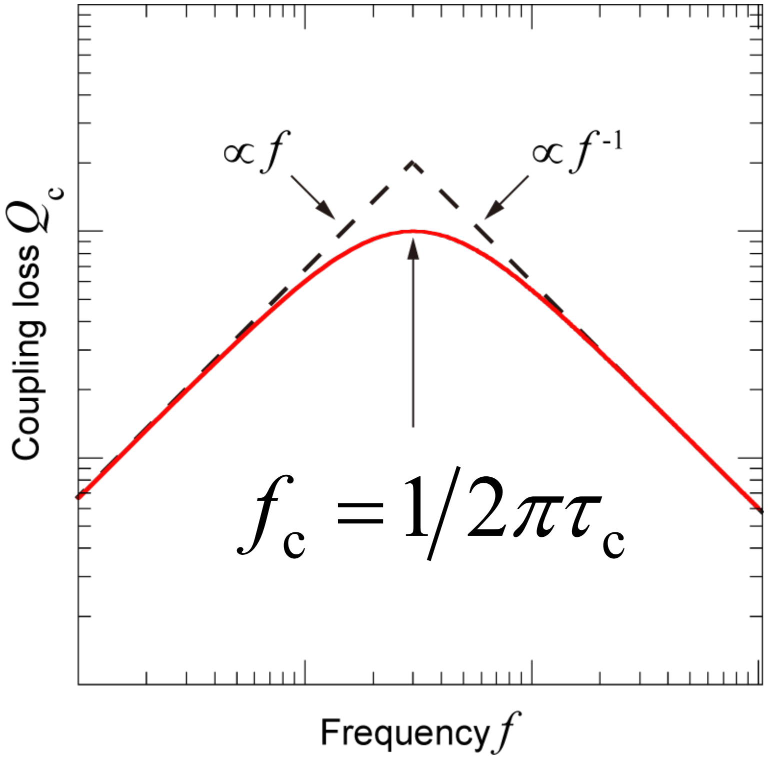


20210226-1 (Only show 3 pitches)

A general expression of coupling loss

$$Q_c = A_c \cdot \frac{\mu_0 {H_m}^2}{2} \frac{2\pi f \tau_c}{(2\pi f \tau_c)^2 + 1}$$

- A_c is determined by the geometry.
  - Q_c at peak = $A_c \cdot \frac{\mu_0 {H_m}^2}{4}$
- τ_c is determined by the transverse conductance and self inductance of coupling current loop.
  - $f_c = 1/2\pi\tau_c$ gives the peak of $Q_c - f$ curve.



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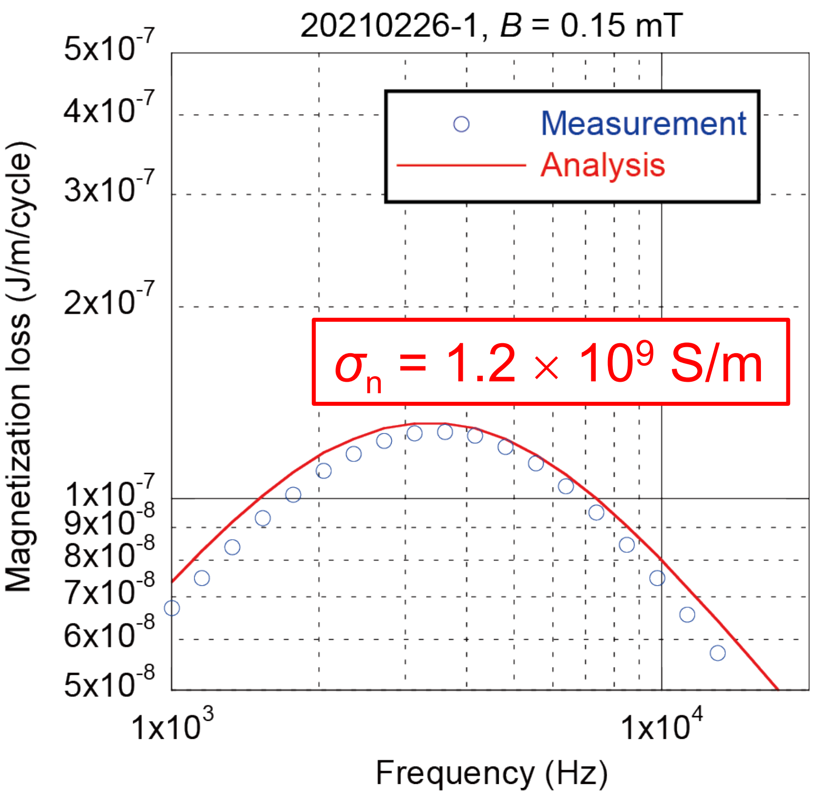
Results: spiral, 3-mm diameter core

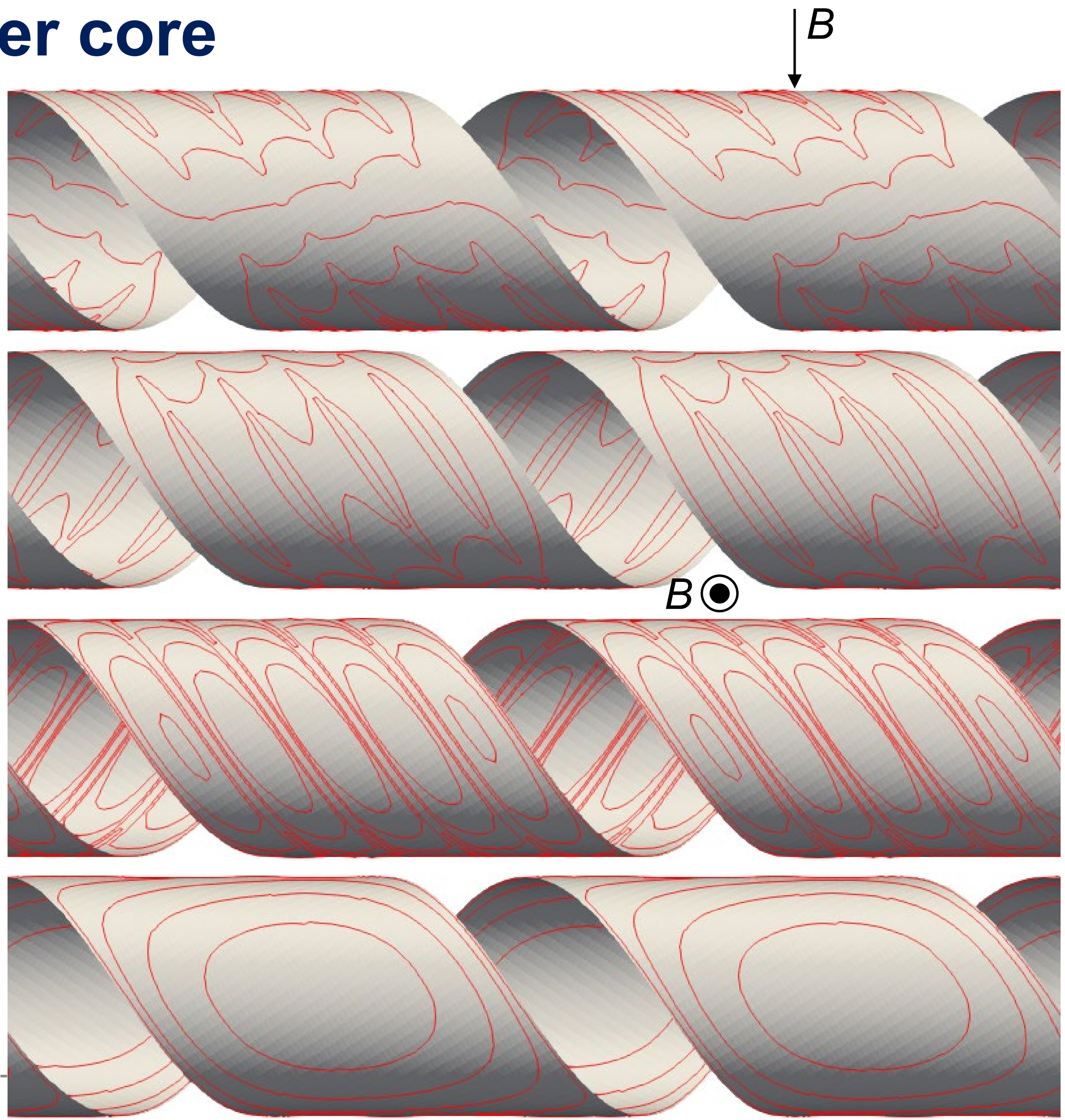


σ_n = 1.2 × 10⁹ S/m

Both A_c and τ_c in experiments can be reproduced by analyses:

$$Q_c = A_c \cdot \frac{\mu_0 {H_m}^2}{2} \frac{2\pi f \tau_c}{(2\pi f \tau_c)^2 + 1}$$

Only show 2 pitches

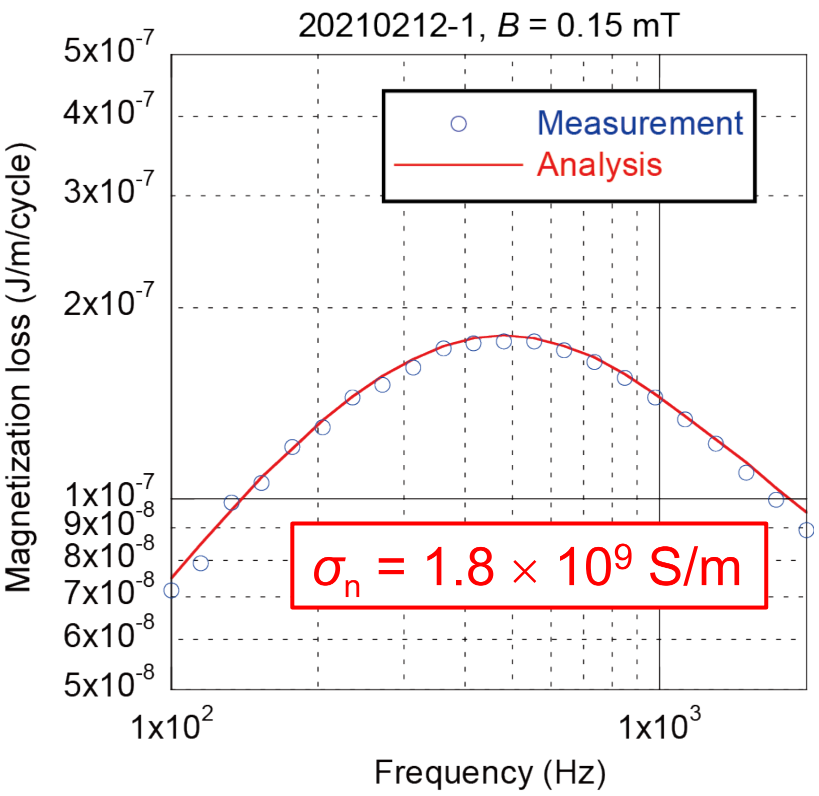


f = 3,611 Hz

f = 1,000 Hz

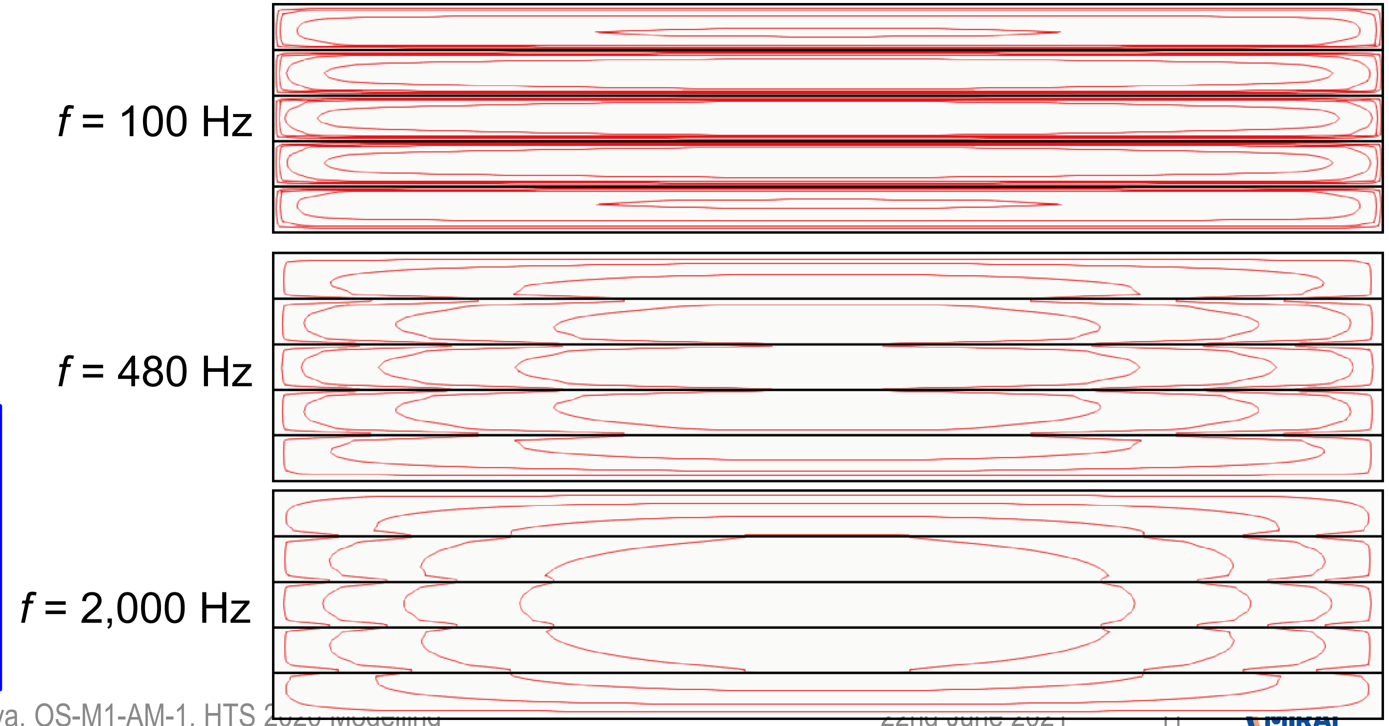
f = 20,000 Hz

Results: straight, 20 mm × 5 tapes



Loss density (f = 480 Hz)

Only show 1 tape



Both A_c and τ_c in experiments can be reproduced by analyses for this "straight, 20 mm × 5 tapes" sample but not for other sample.

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Summary

- Our numerical model can reproduce the measured coupling loss following a Debye curve using only one fitting parameter: transverse conductance of striation by thin strip model.
- More detailed discussion is needed for the nature of transverse conductance of striation in order to use thin strip approximation better.

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