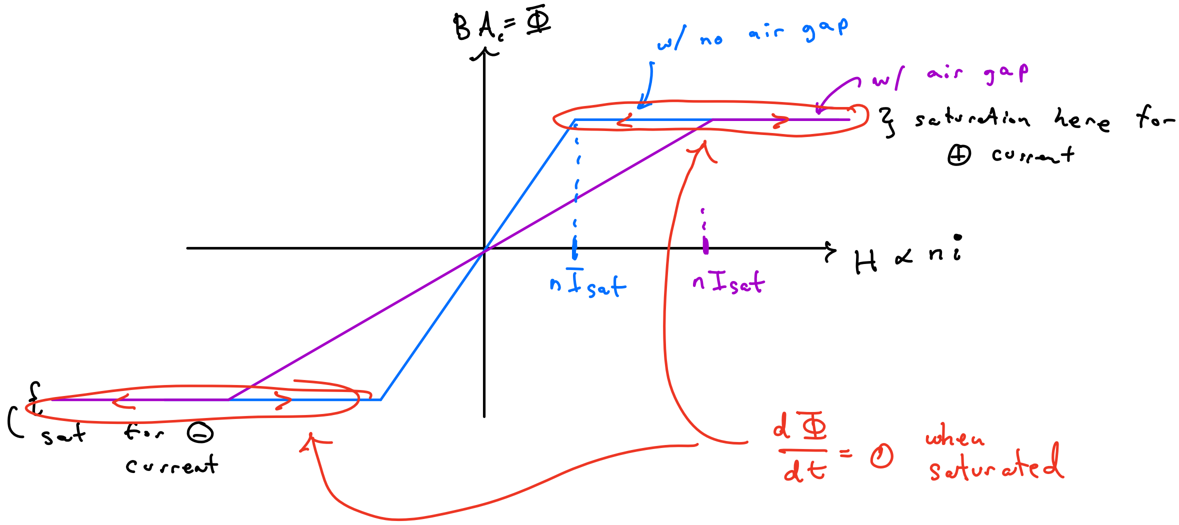
Lecture # 22/23, 11/22/21

- Should have finished first half of Ch 11 (inductors)
- Today and next couple lectures
  - ↳ $\underbrace{\text{Go back to Ch 10}}$ (Magnetics Theory)
    - ↳ Finish rest of Ch 10 over next 1 week
- Look at B-H curve



Q: why does inductor act as a short when saturated?

A: Look @ Faraday

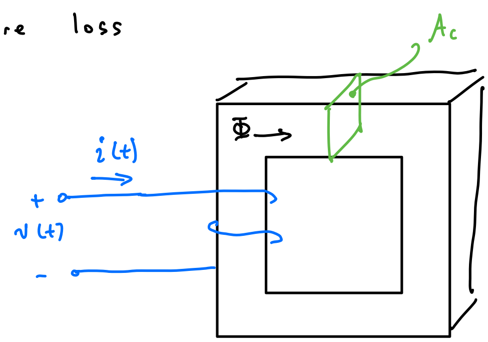
$$v_L = n\frac{d\Phi}{dt} = 0 \text{ when saturated}$$

- Loss Mechanisms in Magnetics (xfmr's & inductors)
  - Ch 10, latter sections

Overview of losses

- Low Freq (ex: 60HZ grid xfmr)
  - DC copper loss
  - Hysteresis Core Loss
- High Freq. (@ switching frequncies ... KHZ & above)
  - Eddy current core loss
  - Eddy currents in conductors
  - Proximity effect

- Core loss



l_m = path length

$$W = \text{energy loss per cycle} = \int_{\text{cycle}} v(t)\, i(t)\, dt$$

Faraday gives us $v(t)$

$$v(t) = n \frac{d\Phi}{dt} = n A_c \frac{dB(t)}{dt}$$

Ampere gives $i(t)$

$$H(t)\, l_m = n\, i(t)$$

$$\Longrightarrow i(t) = \frac{H(t)\, l_m}{n}$$

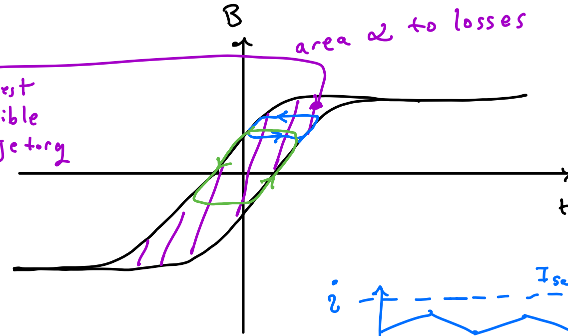
Put into integral

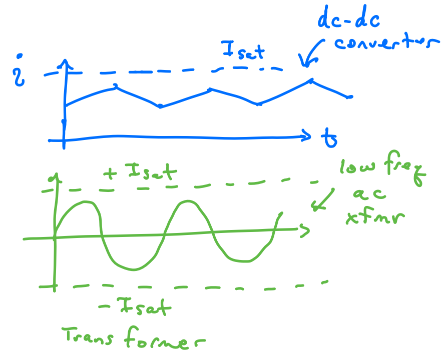
$$w = \int_0^{T_s} \underbrace{\left(\cancel{n} A_c \frac{dB(t)}{\cancel{dt}}\right)}_{v(t)} \underbrace{\left(\frac{H(t)\, l_m}{\cancel{n}}\right)}_{i(t)} \cancel{dt}$$

look @ B-H curve.

$$= \underbrace{A_c l_m}_{\text{volume}} \int_{\text{one B cycle}} H\,dB$$

largest possible trajectory





Now get power

$$P_H = f_s W$$

$$= f_s \times \text{volume} \times \underbrace{(\text{area of BH loop})}_{\text{depends on current flowing thru your magnetics}}$$

- Hyst loss model
  - Loss depends on applied current & flux density waveforms
  - Emperical model = Steinmitz Eqn

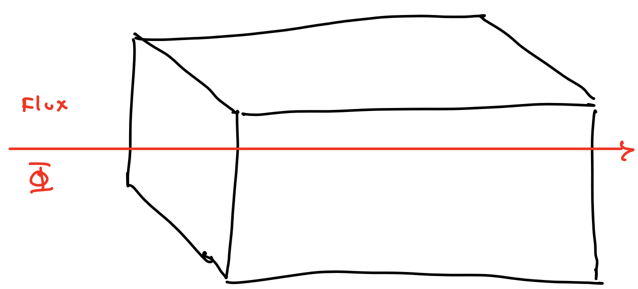
$$P_H \approx \boxed{K_H} f_s B_{max}^{\alpha} \times (\text{core volume})$$

computed from measurements.

- Core Eddy Current Loss

Problem: - Core material is conductive.

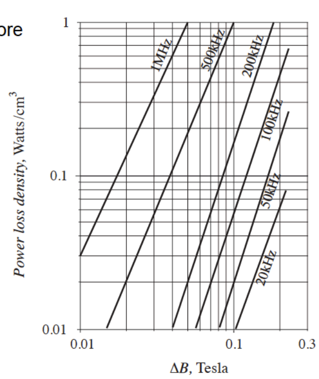
- Lenz's Law says B fields in core induce "eddy currents" to flow in core.
- Eddy currents create flux to oppose change in $\Phi(t)$.
- Eddy currents prevent flux penetrating core.



Another "Stenmitz" Emperical model

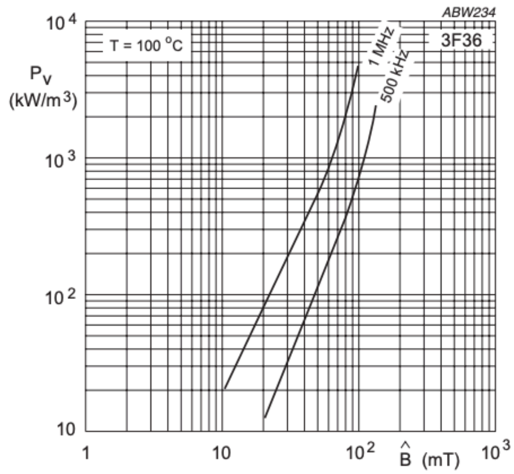
$$P_E = K_E f^2 B_{max}^2 \times (\text{core volume})$$

Ferrite core material



Empirical equation, at a fixed frequency:

$$P_{fe} = K_{fe} (\Delta B)^{\beta} A_c \ell_m$$



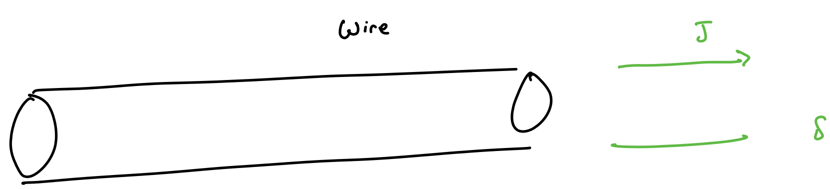
- Low Freq Copper loss

$R =$ $\rho = 1.724 \times 10^{-6}\ \Omega\cdot cm$ @ $20°C$

$= 2.3 \times 10^{-6}\ \Omega\cdot cm$ @ $100°C$

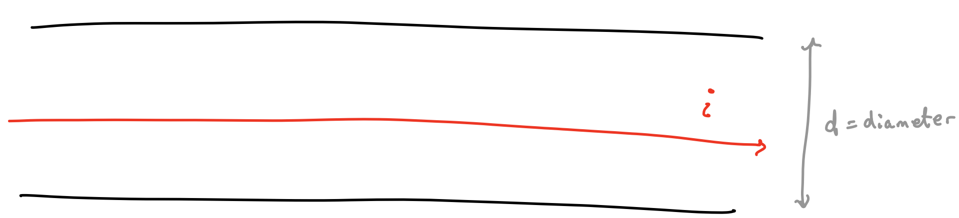
$P_{cu} =$

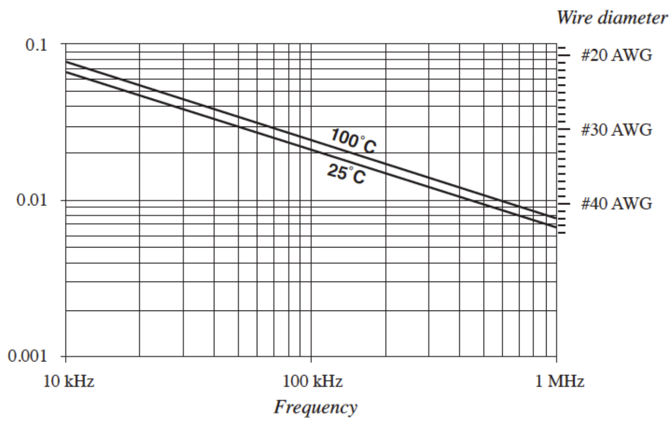
- High Freq Eddy Currents in Conductors (Skin Effect)



• Penetration Depth

$\delta =$ $\approx$ cm @ room temp





$\frac{d}{\delta} = 1$ for

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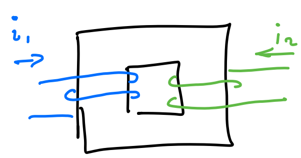
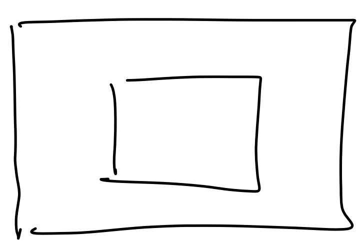
$$R_{ac} = \frac{\delta}{d} \underbrace{R_{dc}}$$

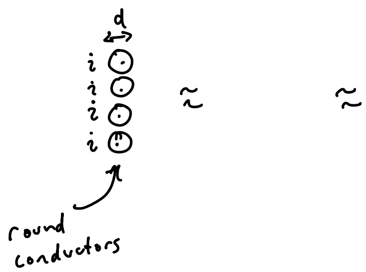
↳ resistance of wire @ dc

– Proximity Effect in Multiwinding circuits (Transformers).

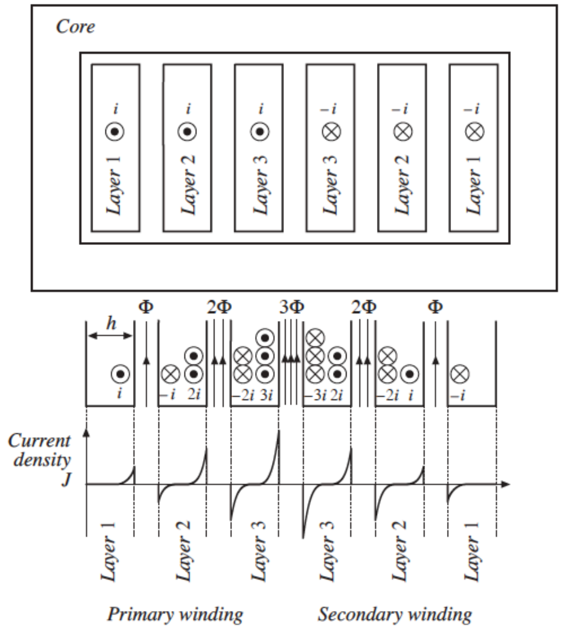




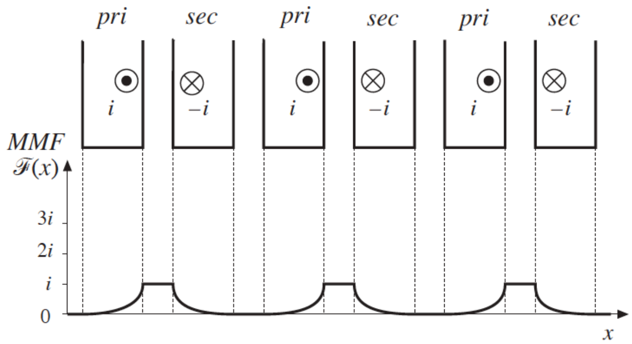
- To simplify analysis:



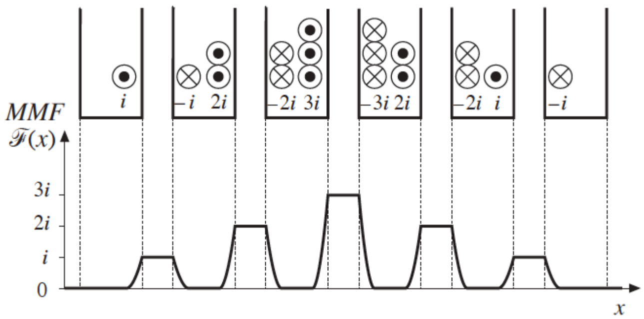
Two foil strips



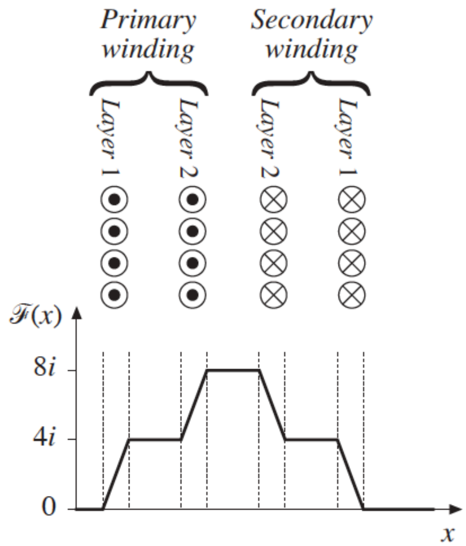
Core
Layer 1
Layer 2
Layer 3
Layer 3
Layer 2
Layer 1
i
i
i
−i
−i
−i
h
Φ
2Φ
3Φ
2Φ
Φ
−i
2i
−2i
3i
−3i
2i
−2i
i
−i
Current density J
Primary winding
Secondary winding



Greatly reduces the peak MMF, leakage flux, and proximity losses



i
−i
2i
−2i
3i
−3i
2i
−2i
i
−i
MMF
ℱ(x)
3i
2i
i
0
x


Primary winding
Secondary winding
Layer 1
Layer 2
Layer 2
Layer 1
$\mathscr{F}(x)$
8i
4i
0
x