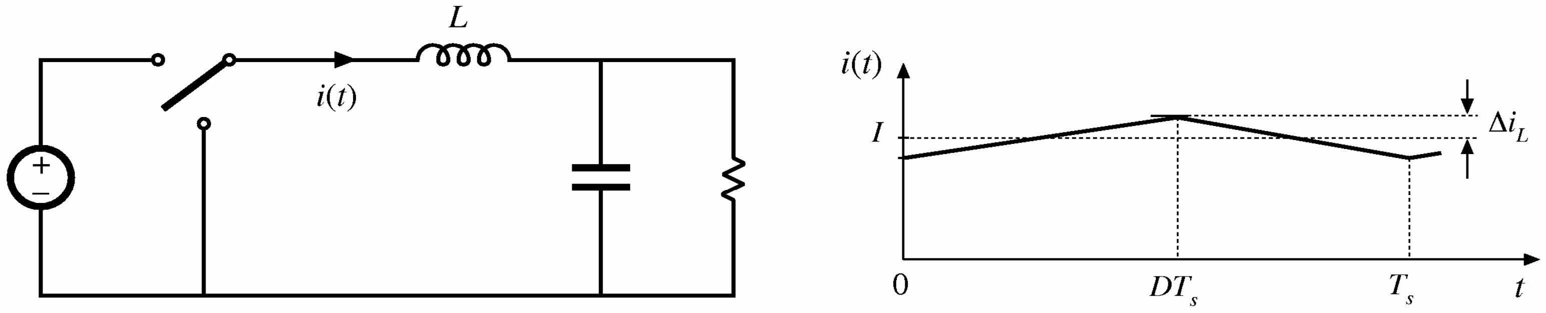
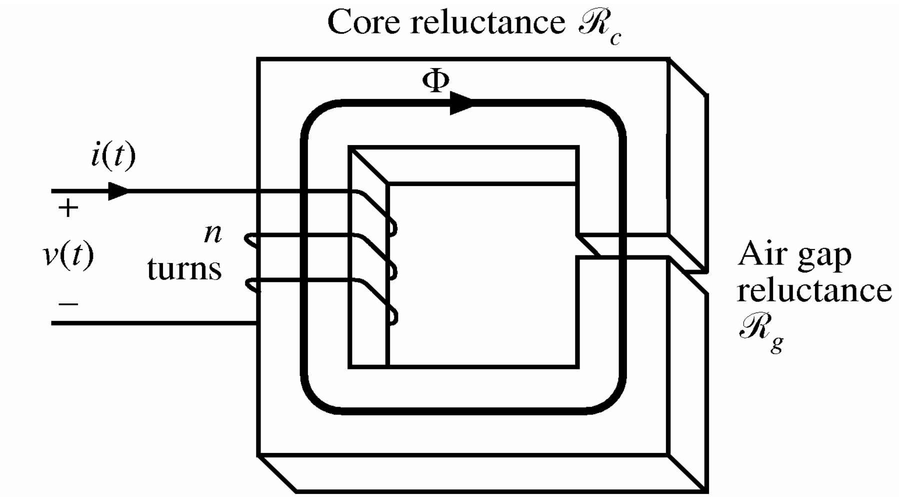
Filter Inductor Design Constraints

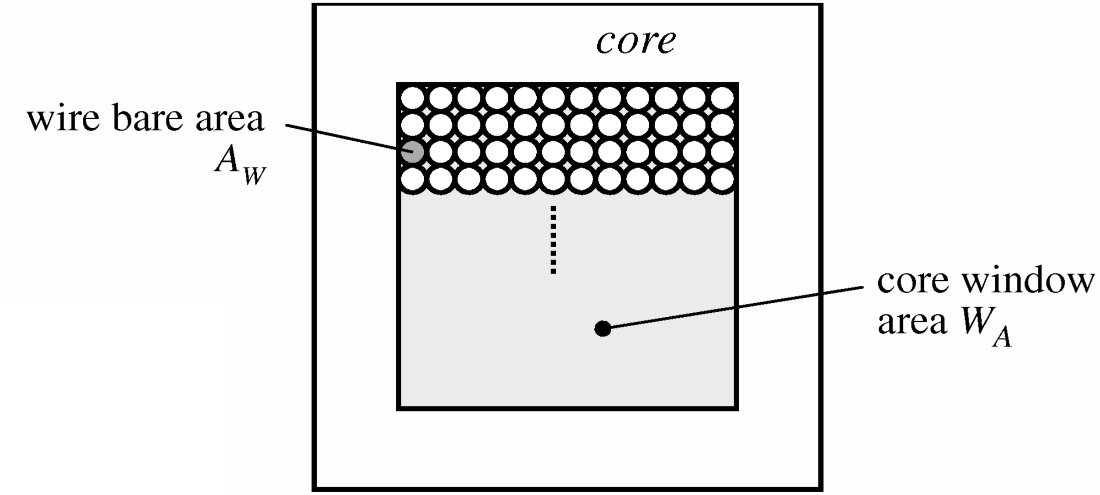
Design Goals

Example: filter inductor in CCM buck converter



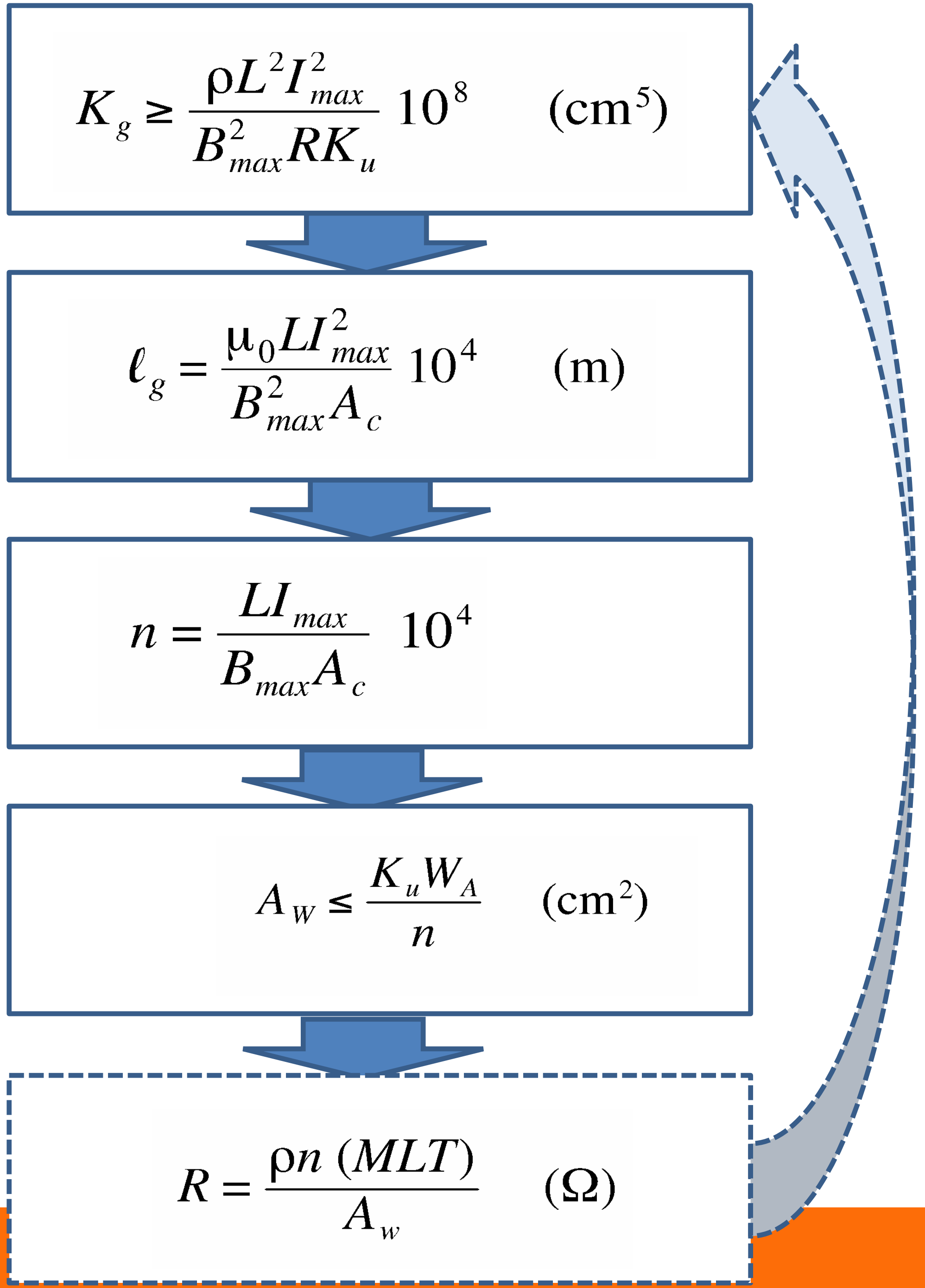
Geometrical Parameters





The K_g Method

K_g Method



$$K_g \geq \frac{\rho L^2 I_{max}^2}{B_{max}^2 R K_u} 10^8 \qquad (\mathrm{cm}^5)$$

$$\ell_g = \frac{\mu_0 L I_{max}^2}{B_{max}^2 A_c} 10^4 \qquad (\mathrm{m})$$

$$n = \frac{L I_{max}}{B_{max} A_c} 10^4$$

$$A_W \leq \frac{K_u W_A}{n} \qquad (\mathrm{cm}^2)$$

$$R = \frac{\rho n\,(MLT)}{A_w} \qquad (\Omega)$$

Appendix B

D.2 EE CORE DATA

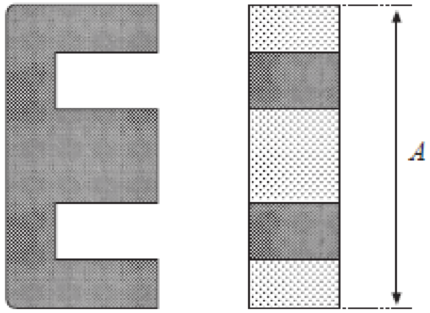


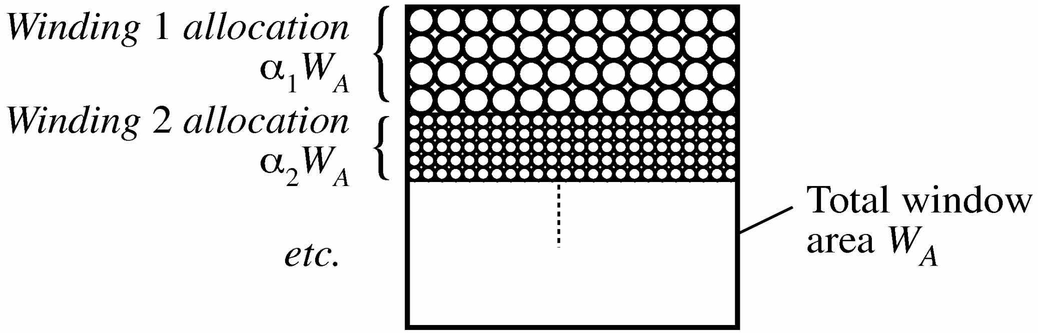
Fig. D.2

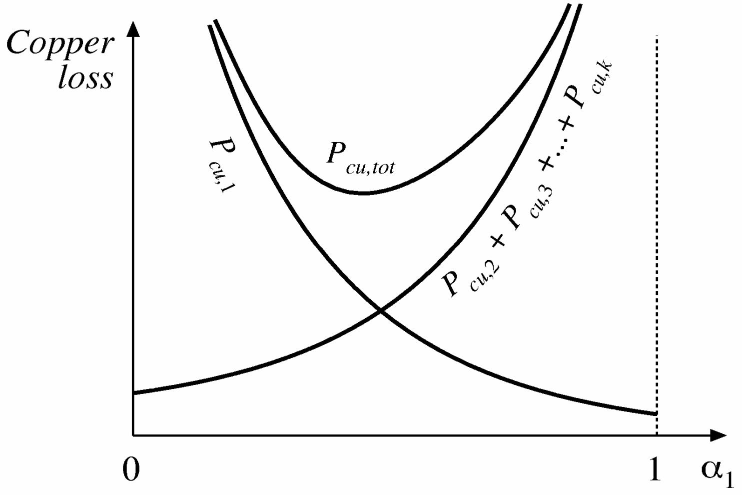
Core type (A) (mm)	Geometrical constant K_g (cm^5)	Geometrical constant K_{gfe} (cm^x)	Cross-sectional area A_c (cm^2)	Bobbin winding area W_A (cm^2)	Mean length per turn MLT (cm)	Magnetic path length ℓ_m (cm)	Core weight (g)
EE12	$0.731 \cdot 10^{-3}$	$0.458 \cdot 10^{-3}$	0.14	0.085	2.28	2.7	2.34
EE16	$2.02 \cdot 10^{-3}$	$0.842 \cdot 10^{-3}$	0.19	0.190	3.40	3.45	3.29
EE19	$4.07 \cdot 10^{-3}$	$1.3 \cdot 10^{-3}$	0.23	0.284	3.69	3.94	4.83
EE22	$8.26 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$	0.41	0.196	3.99	3.96	8.81
EE30	$85.7 \cdot 10^{-3}$	$6.7 \cdot 10^{-3}$	1.09	0.476	6.60	5.77	32.4
EE40	0.209	$11.8 \cdot 10^{-3}$	1.27	1.10	8.50	7.70	50.3
EE50	0.909	$28.4 \cdot 10^{-3}$	2.26	1.78	10.0	9.58	116
EE60	1.38	$36.4 \cdot 10^{-3}$	2.47	2.89	12.8	11.0	135
EE70/68/19	5.06	$75.9 \cdot 10^{-3}$	3.24	6.75	14.0	18.0	280

D.6 AMERICAN WIRE GAUGE DATA

AWG#	Bare area, 10^{-3} cm^2	Resistance, 10^{-6} Ω/cm	Diameter, cm
0000	1072.3	1.608	1.168
000	850.3	2.027	1.040
00	674.2	2.557	0.927
0	534.8	3.224	0.825
1	424.1	4.065	0.735
2	336.3	5.128	0.654
3	266.7	6.463	0.583
4	211.5	8.153	0.519
5	167.7	10.28	0.462
6	133.0	13.0	0.411
7	105.5	16.3	0.366
8	83.67	20.6	0.326
9	66.32	26.0	0.291
10	52.41	32.9	0.267
11	41.60	41.37	0.238
12	33.08	52.09	0.213
13	26.26	69.64	0.190
14	20.02	82.80	0.171
15	16.51	104.3	0.153
16	13.07	131.8	0.137
17	10.39	165.8	0.122
18	8.228	209.5	0.109
19	6.531	263.9	0.0948
20	5.188	332.3	0.0874
21	4.116	418.9	0.0785
22	3.243	531.4	0.0701
23	2.508	666.0	0.0632
24	2.047	842.1	0.0566
25	1.623	1062.0	0.0505
26	1.280	1345.0	0.0452
27	1.021	1687.6	0.0409
28	0.8046	2142.7	0.0366
29	0.6470	2664.3	0.0330

K_g Method: Multi-Winding Magnetics





$$0 < \alpha_j < 1$$

$$\alpha_1 + \alpha_2 + \cdots + \alpha_k = 1$$

$$\alpha_m = \frac{V_m I_m}{\sum_{n=1}^{\infty} V_j I_j}$$

Apparent power in winding *j* is

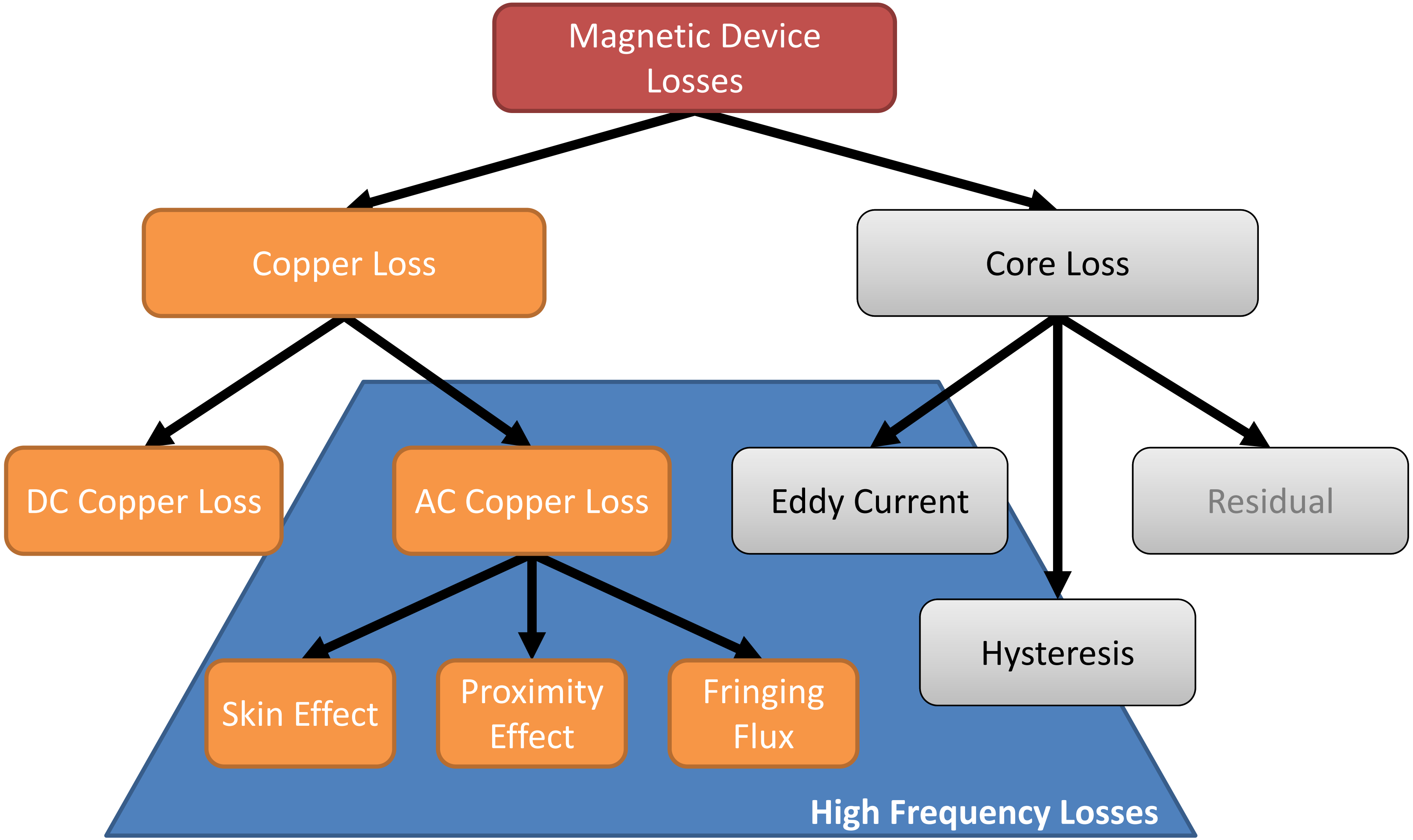
$$V_j I_j$$

where V_j is the rms or peak applied voltage

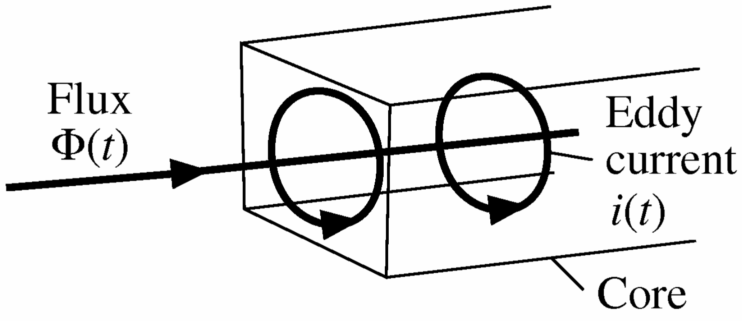
I_j is the rms current

Window area should be allocated according to the apparent powers of the windings

13.3 Magnetics Losses

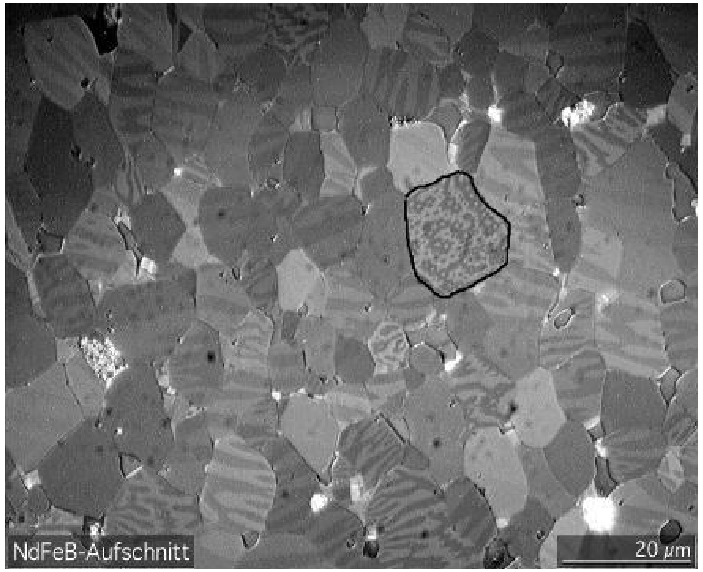


Eddy Currents in Magnetic Materials

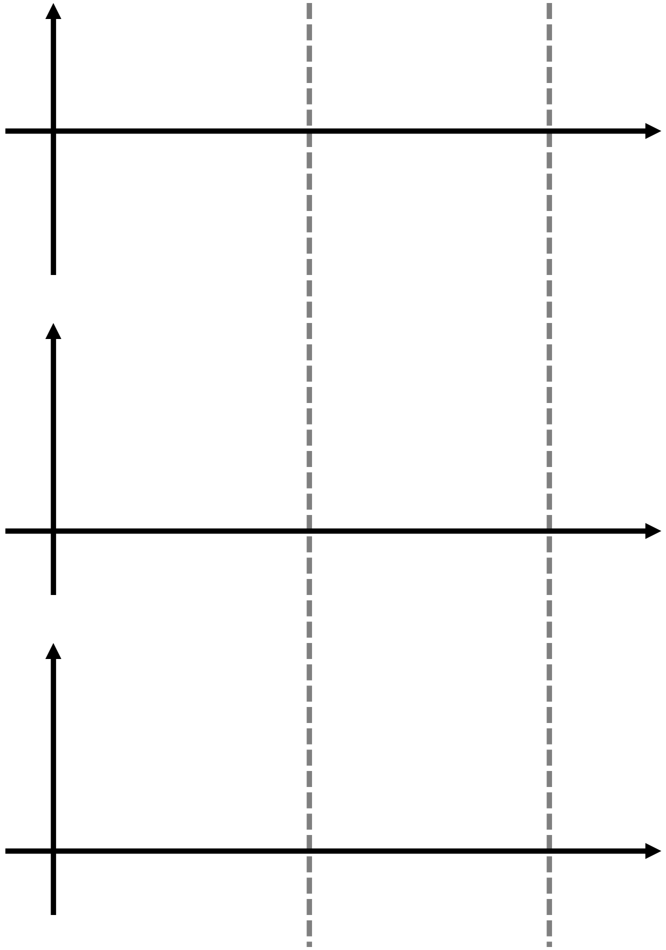


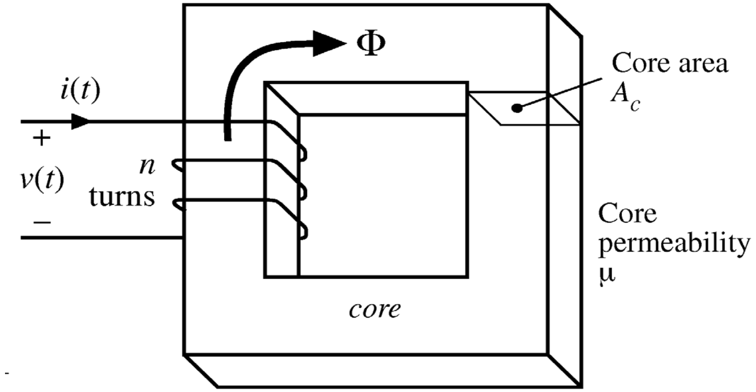
Core Loss

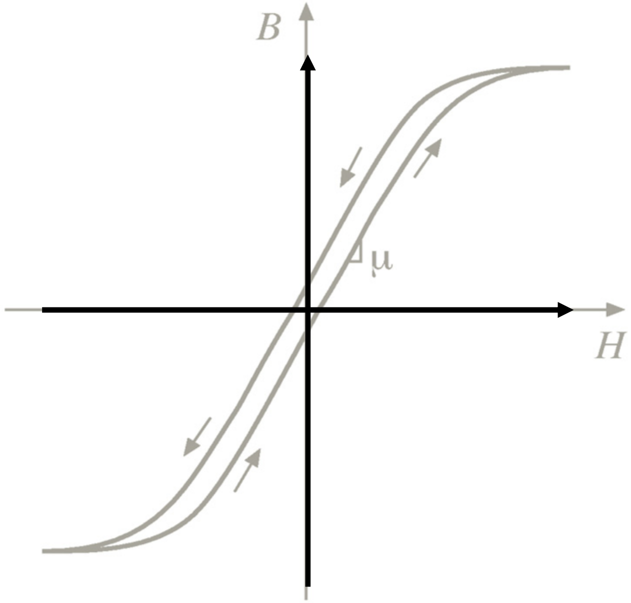
- Physical origin due to magnetic domains
- Modeling Approaches
  - Empirical (curve fit) models of materials
  - Direct measurement-based models
  - Physics-based models



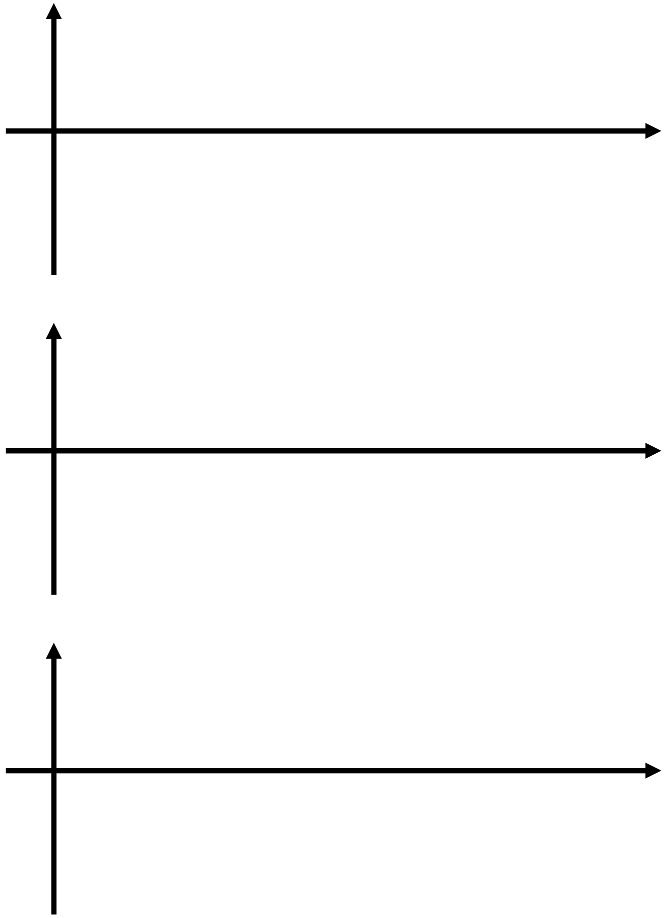
B-H Curve: Filter Inductor

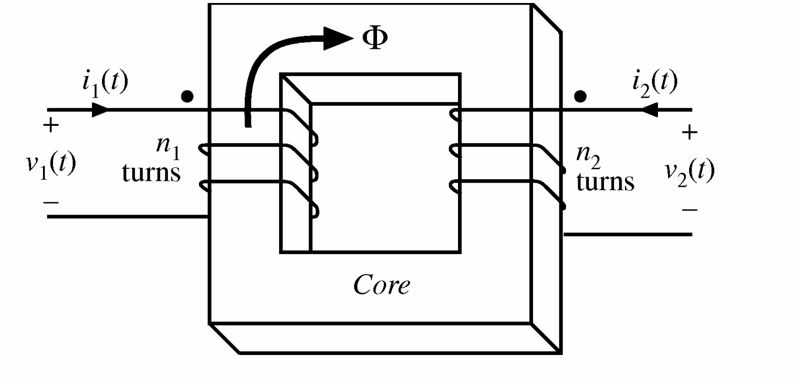


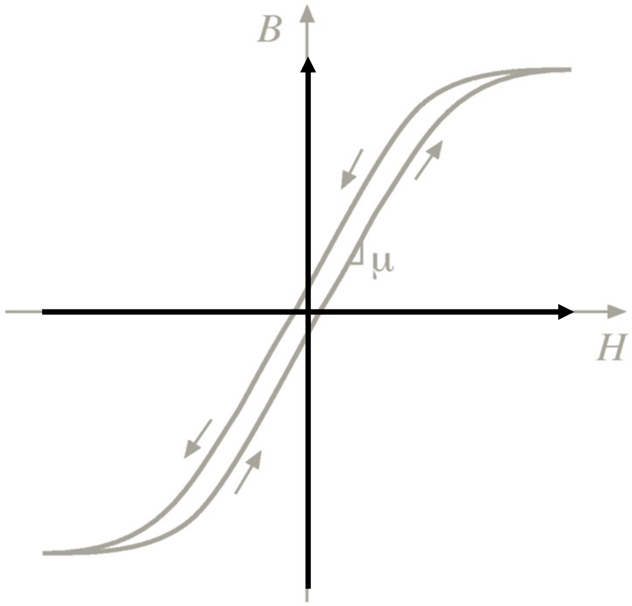




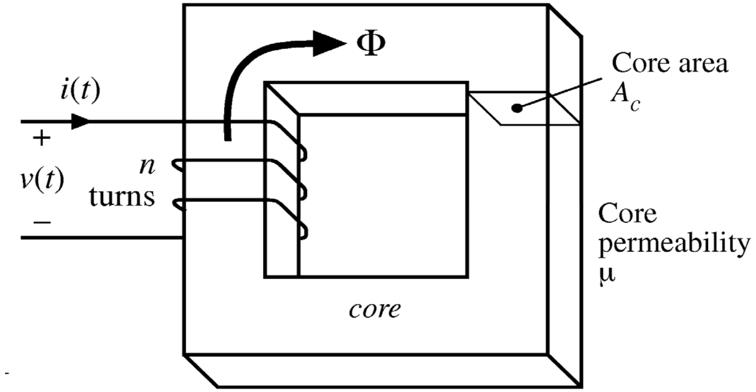
B-H Curve: Transformer

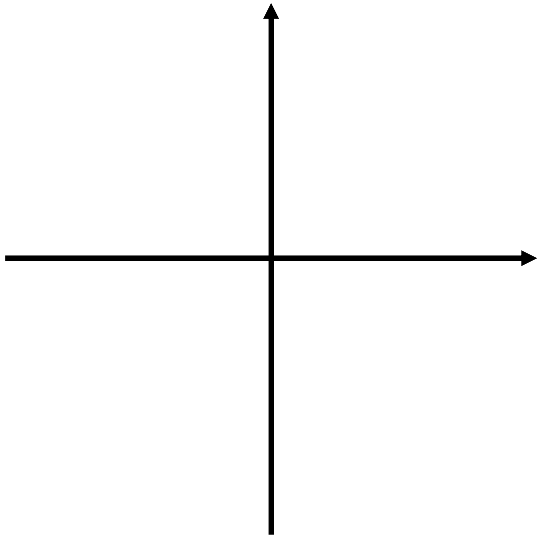






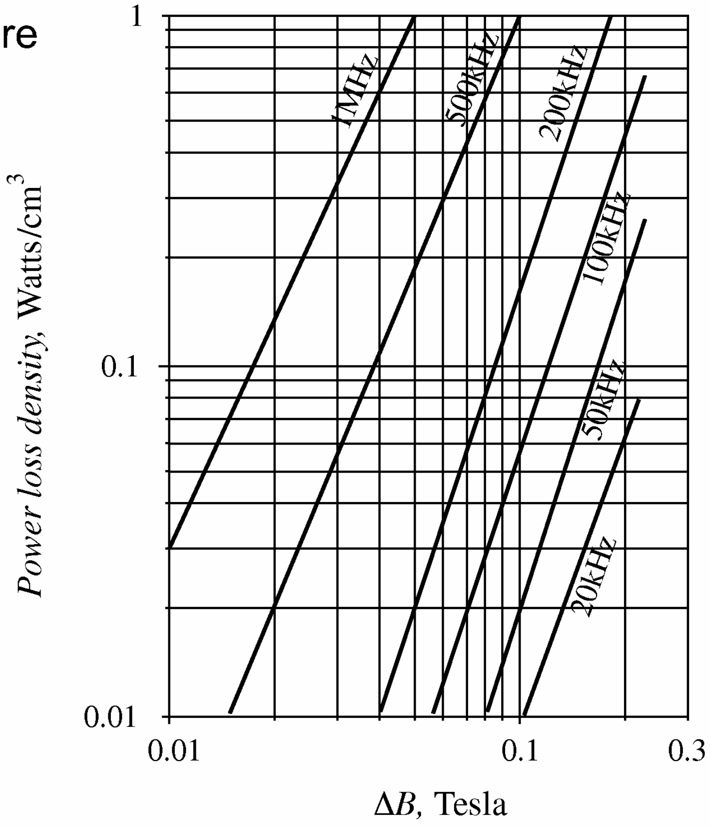
Hysteresis Loss





The Steinmetz Equation

Ferrite core material



Empirical equation, at a fixed frequency:

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

Alternately:

$$P_v = K m f^{\alpha} (\Delta B)^{\beta}$$

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Steinmetz Equation: Notes

- Purely empirical; not physics-based
- Parameters α, β, K vary with frequency
- Correct only for sinusoidal excitation
  - Nonlinear; Fourier expansion of waveforms cannot be used
- Modified empirical equations perform better with nonsinusoidal waveforms
  - MSE
  - GSE
  - iGSE
  - i^{2}GSE