

Switched Mode Power Conversion

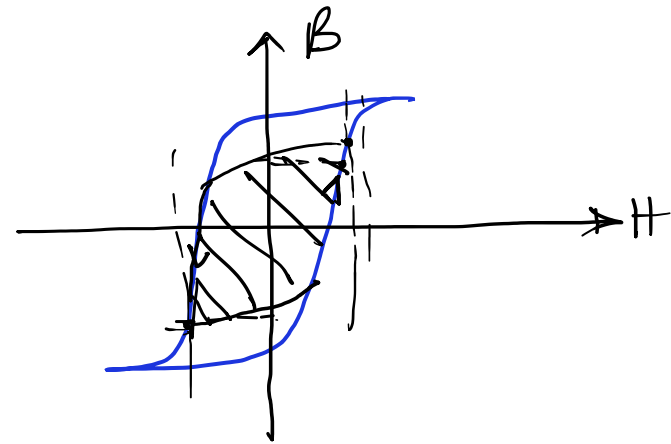
Semester II Academic Year 2025-26

Lecture 32

11th April 2026

Core loss

$$\begin{aligned} W &= \int_1 v i dt \\ &= \int_1 \left(N A_c \frac{dB}{dt} \right) \left(\frac{H l_m}{N} \right) dt \\ &= \underline{\underline{(A_c l_m)}} \int_1 H \cdot dB \\ &= (\text{Volume}) (\text{Area of BH loop}) \end{aligned}$$



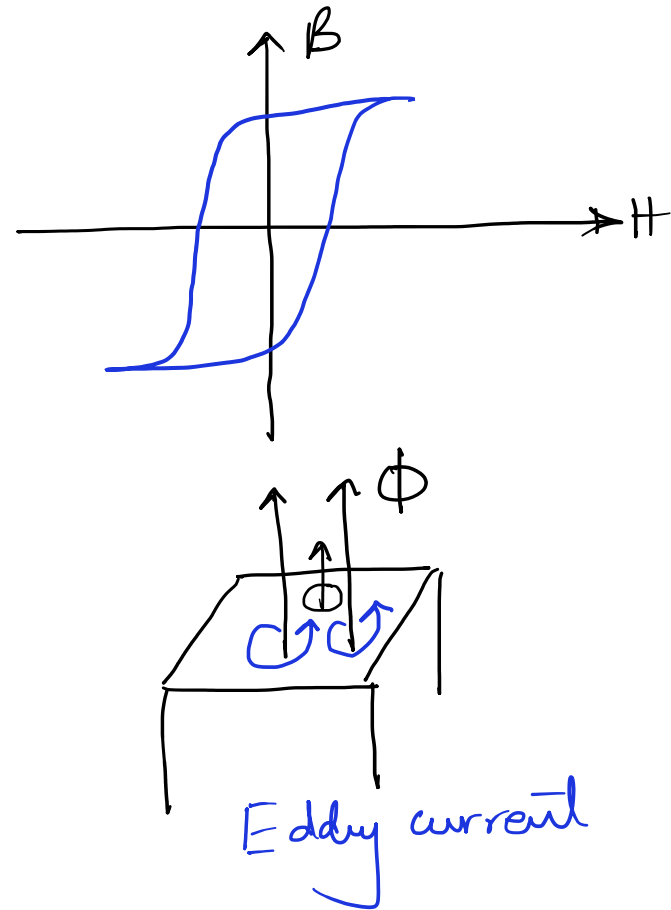
$N \downarrow$

$$H = \frac{Ni}{l_m}$$

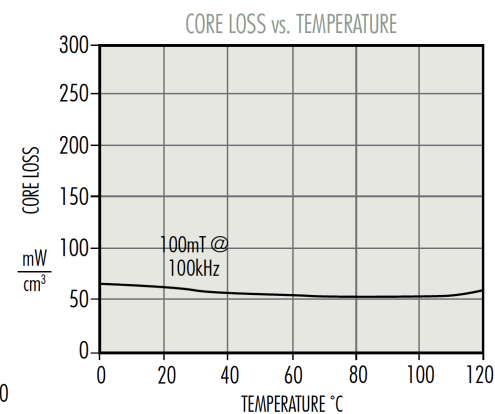
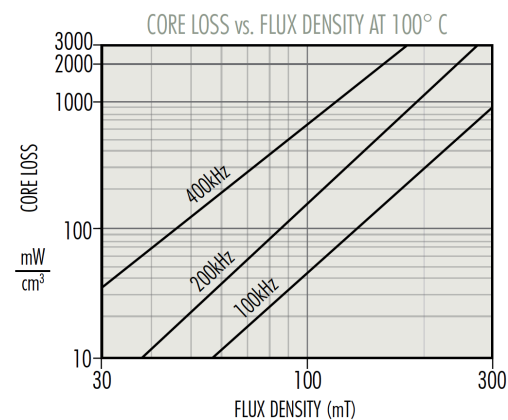
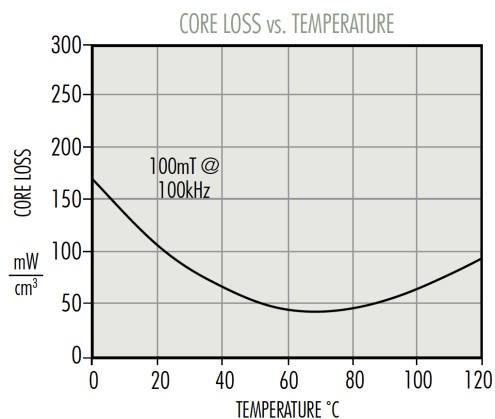
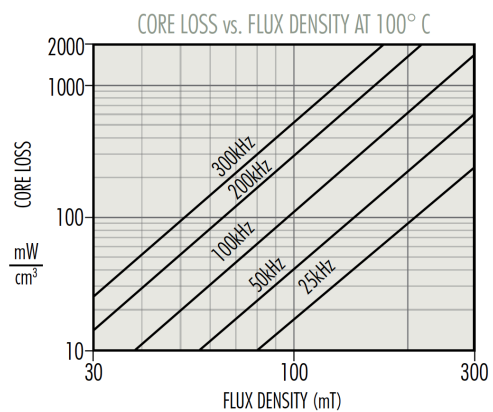
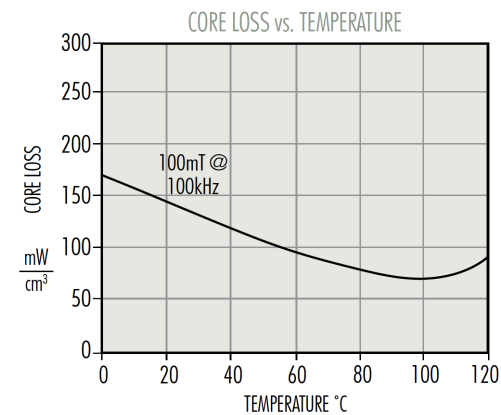
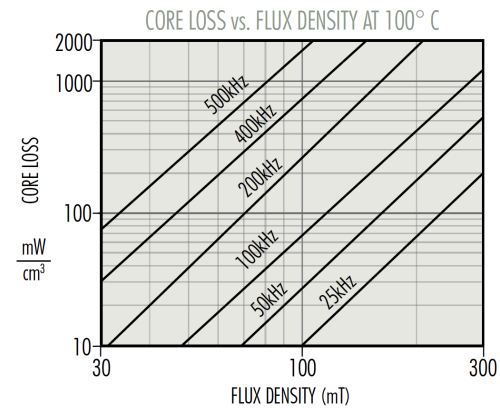
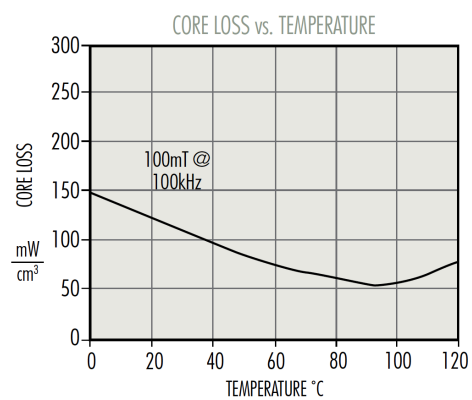
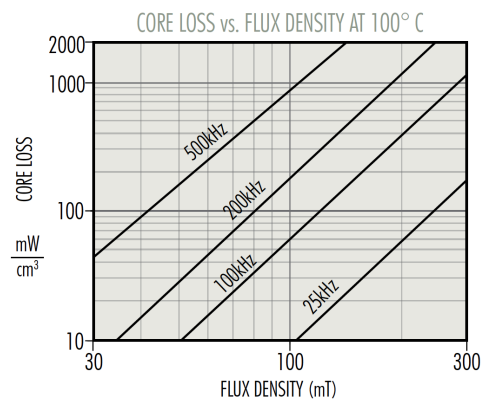
Core loss

$$\begin{aligned} W &= \int_1 v i dt \\ &= \int_1 \left(N A_c \frac{dB}{dt} \right) \left(\frac{H l_m}{N} \right) dt \\ &= (A_c l_m) \int_1 H \cdot dB \\ &= (\text{Volume}) (\text{Area of BH loop}) \end{aligned}$$

$$P_{\text{core}} = K_{fe} (AB)^{\beta} A_c l_m$$



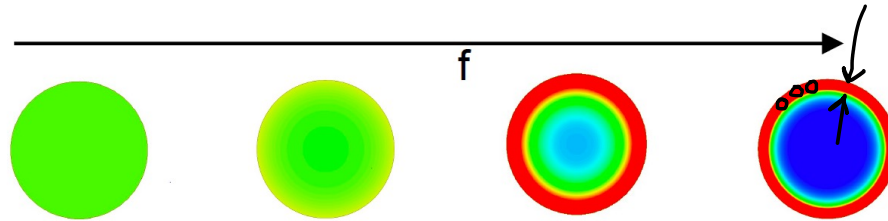
Core Loss



Core Type

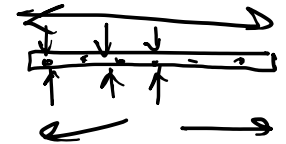
Ferrite	$0.25 - 0.5 \text{ T}$	High Resistivity
Amorphous Alloy	$0.6 - 1.5 \text{ T}$	Loss lower than powdered iron but higher than ferrite
Powdered Iron	$0.6 - 0.8 \text{ T}$	Lower permeability

Skin effect



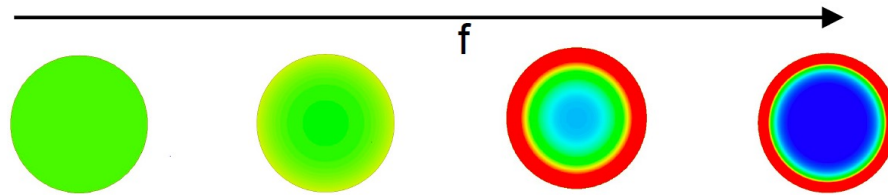
$$\text{Skin depth} = \delta = \sqrt{\frac{\rho}{\pi \mu f}}$$

$$R_{dc} \ll R_{ac}$$



$$d \ll \delta$$

Skin effect



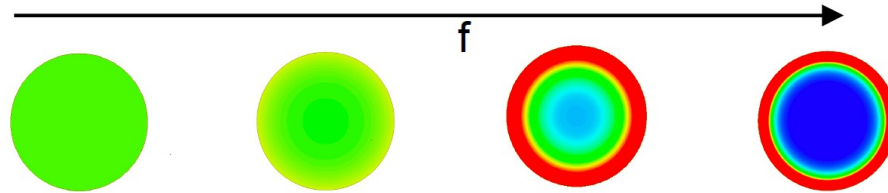
$$\text{Skin depth} = \delta = \sqrt{\frac{\rho}{\pi \mu f}}$$

$$\delta = 0.023 \text{ cm}$$



Litz wire

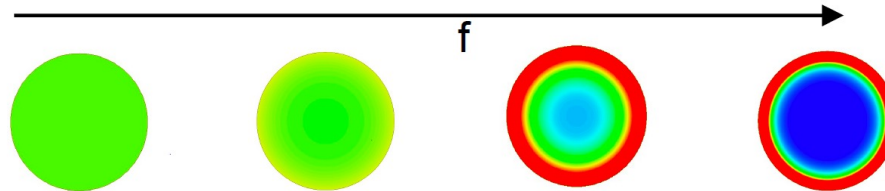
Skin effect



$$\text{Skin depth} = \delta = \sqrt{\frac{\rho}{\pi \mu f}}$$

$$\delta = 0.023 \text{ cm}$$

Skin effect



Current	3A	3A	5A	6A	18A	20A (polyimide film)	20A (No Silk)	40A (No Silk)	40A	70A
Strand Size (mm)	0.1	0.07	0.2	0.15	0.05	0.05	0.2	0.1	0.1	0.1
No. of Strands	75	160	25	60	1500	1740	100	1000	1000	2000

- Selection of core
- Design steps for transformer
- Characteristics of core
- Types of core
- Design considerations for windings at high frequency

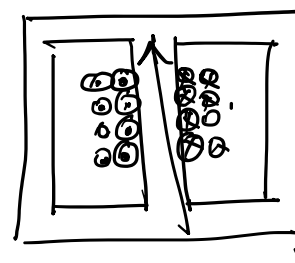
Proximity effect



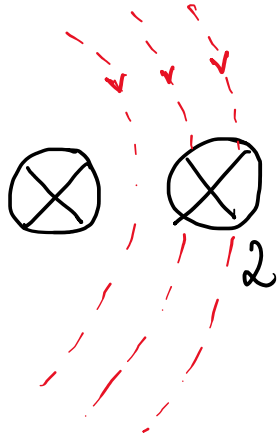
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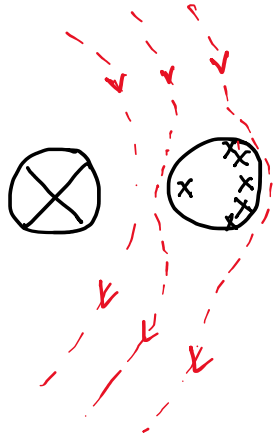
2



Proximity effect

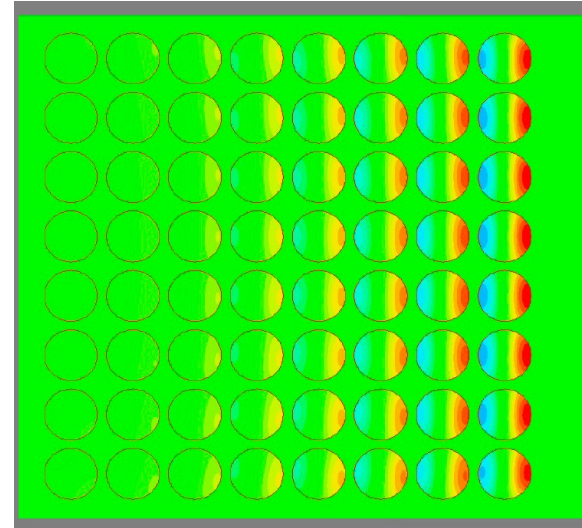


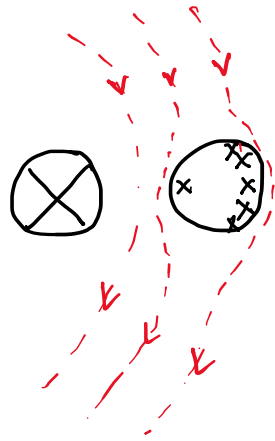
Proximity effect



Lenz law

$$R_{ac} = \frac{d}{8} R_{dc}$$



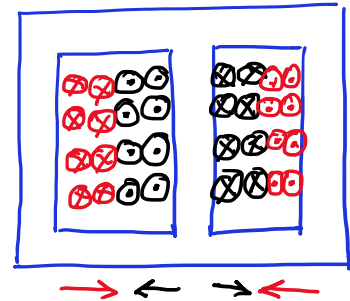


Lenz law

$$R_{ac} = \frac{d}{s} R_{dc}$$

Proximity effect

○ Primary ○ Secondary

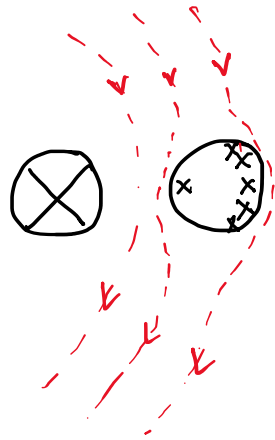


Multilayered winding

Primary currents will be pushed to outer layer

Secondary current will be pushed to inner layer

$R_{ac} \uparrow$
 Increased copper loss at high freq.



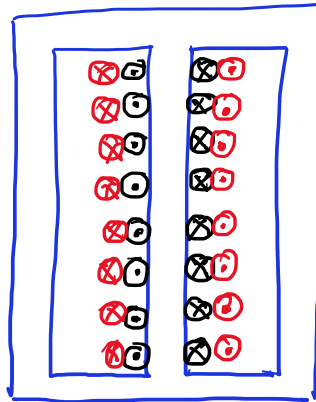
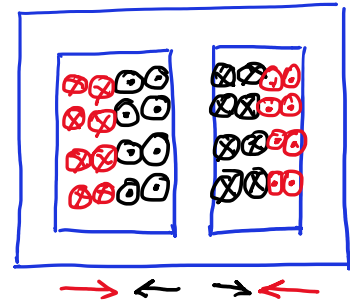
Lenz law

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

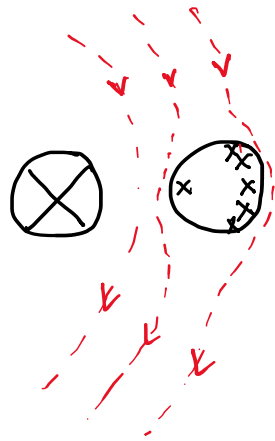
Proximity effect

○ Primary ○ Secondary

Multilayered winding



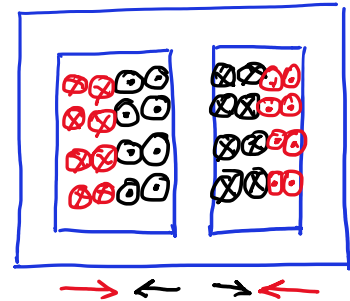
[Reducing no. of layers]
Form factor changes



Lenz law

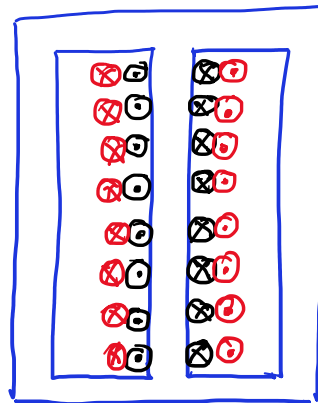
$$R_{ac} = \frac{d}{8} R_{dc}$$

Proximity effect

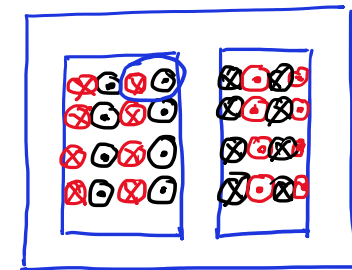


○ Primary ○ Secondary

Multilayered winding



[Reducing no. of layers]
Form factor changes



[Interleaved winding]

Inductor Design

— Specification of a power converter $\Rightarrow$ Value of L at a rated current.

$$E_L = \frac{1}{2} L i^2$$

Inductor Design

— Specification of a power converter $\Rightarrow$ Value of L at a rated current.

$$B = \frac{\mu N i}{l_m}$$

$$\phi = \frac{\mu N A_c i}{l_m}$$

$$e = -N \frac{d\phi}{dt}$$

$$= - \frac{\mu N^2 A_c}{l_m} \frac{di}{dt}$$

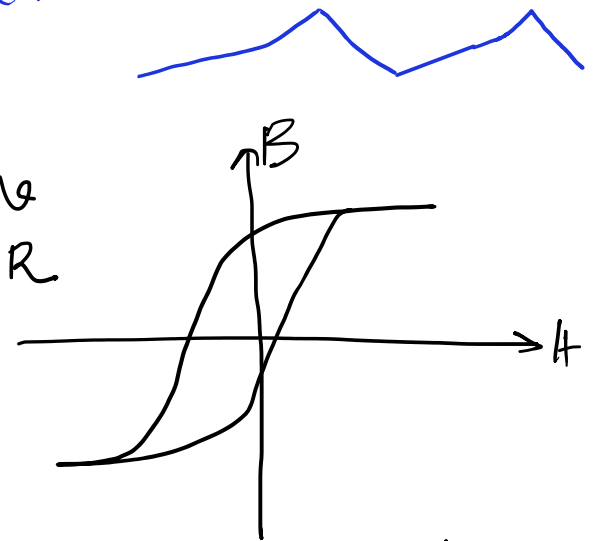
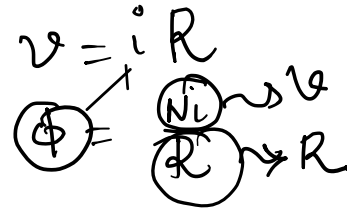
$$E_L = \frac{1}{2} L i^2$$

$$L = \frac{N^2}{(l_m / \mu A_c)}$$

$$\frac{l_m}{\mu A_c} = \text{Reluctance } (l_m^2 / H)$$

$$= \mathcal{R}$$

$$\Lambda = \frac{1}{\mathcal{R}} [\text{Permeance}]$$



Near saturation

$$\frac{d\phi}{dt} \approx 0$$

$$L \downarrow \left[\begin{array}{l} \text{Current} \\ \text{rises} \end{array} \right]$$

Inductor Design

— Specification of a power converter $\Rightarrow$ Value of L at a rated current.

$$E_L = \frac{1}{2} L i^2$$

$$K_w A_w = N \frac{i}{J}$$

$$\Rightarrow K_w A_w J = N i$$

$$K_c K_w A_w J = N i_{pk}$$

$$K_c = \frac{i_{pk}}{i_{rms}} = \text{Crest factor}$$

Inductor Design

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$$L \frac{di}{dt} = N \frac{d\phi}{dt} = N A_c \frac{dB}{dt}$$

$$\therefore L i_{pk} = N A_c B_{pk}$$

Inductor Design

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$$\therefore L i_{pk} = N A_c B_{pk}$$

$$E_{L_{pk}} = \frac{1}{2} (L i_{pk}) i_{pk}$$

$$= \frac{1}{2} N A_c B_{pk} \frac{K_c K_w A_w J}{N}$$

$$A_w A_c = \frac{2 E_{L_{pk}}}{K_c K_w J B_{pk}}$$

Inductor Design

$$L = 0.216 \text{ mH} \quad I_L = 20.83 \text{ A} \\ f_{\text{sw}} = 10 \text{ kHz} \quad (20\% \text{ ripple})$$

$$I_{Lpk} \approx 23 \text{ A}$$

$$E_L = \frac{1}{2} L i_{pk}^2 = 0.057 \text{ J}$$

$$J = 5 \text{ A/mm}^2$$

$$\therefore A_p = \frac{2 \times 0.057}{\frac{5}{10^{-6}} \times 0.3 \times 0.3}$$

$$= 2.533 \times 10^{-7} \text{ m}^4$$

$$= 25.3 \text{ cm}^4$$

Inductor Design

		MAGNETIC DATA						HARDWARE
SIZE (mm)	ORDERING CODE	l_e (mm)	A_e (mm ²)	V_e (mm ³)	Window Area (cm ²)	WaAc (cm ⁴)	Weight (grams per piece)	Headers & Mounts
49.1 x 33.8 x 15.9	0_44916TC	127	120	15,298	8.99	10.6	75.3	TVH49164A
49.1 x 31.8 x 15.9	0_44920TC	123.2	135.4	16,676	7.94	9.45	83	TVH49164A
49.1 x 31.8 x 19.05	0_44925TC	123	162	20,000	7.94	12.8	98	TVH49164A
49.1 x 33.8 x 31.3	0_44932TC	127	237	30,100	8.99	21.2	150.6	TVH49164A
60.96 x 41.78 x 12.7	0_46013TC	157.6	120.4	18,968	13.68	16.48	94	
60.96 x 41.78 x 19.05	0_46019TC	157.6	180.5	28,453	13.68	24.7	141	
61 x 35.6 x 12.7	0_46113TC	144.6	157.4	22,774	9.93	15.5	113	TVH49164A
63 x 38 x 24.5	0_46325TC	152	300	45,598	11.1	33.2	225	TVH49164A
63 x 38 x 24.5	0_46326TC	152	300	45,600	11.3	33.9	225	TVH49164A
73.7 x 38.9 x 12.5	0_47313TC	165	210	34,771	11.9	25	172	
73.7 x 38.9 x 25.2	0_47325TC	165	423	70,099	11.9	50.3	347	
73.7 x 38.9 x 25.4	0_47326TC	165	427	70,595	11.9	50.8	350	
85.7 x 55.5 x 12.7	0_48613TC	214.9	188.8	40,582	24.2	45.7	201	
85.7 x 55.5 x 25.4	0_48625TC	215	375	80,700	24.2	90.8	399	
85.7 x 55.5 x 25.4	0_48626TC	215	377	81,165	24.2	91.2	402	
102 x 65.8 x 15	0_49715TC	255.3	267.2	68,821	34	90.8	341	
107 x 65 x 18	0_49718TC	259.31	370.27	96,013	28.6	106	475	
107 x 65 x 25	0_49725TC	259.31	514.3	133,351	33.2	171	660	
140 x 106 x 25	0_49740TC	381.5	422.3	161,086	88.2	372	797	

Inductor Design

		COATING			NOMINAL A _L (mH/1000T)				
SIZE (mm)	ORDERING CODE	V	Y	Z	R ± 25%	P ± 25%	F ± 20%	J ± 20%	W ± 30%
49.1 x 33.8 x 15.9	0_44916TC			✓	2,710	2,950	3,540	5,900	11,800
49.1 x 31.8 x 15.9	0_44920TC			✓	2,790	3,032	3,640	6,065	12,130
49.1 x 31.8 x 19.05	0_44925TC			✓	3,420	3,718	4,460	7,435	14,870
49.1 x 33.8 x 31.3	0_44932TC			✓	5,430	5,900	7,080	11,800	23,600
60.96 x 41.78 x 12.7	0_46013TC			✓				4,800	9,483
60.96 x 41.78 x 19.05	0_46019TC			✓				7,100	
61 x 35.6 x 12.7	0_46113TC			✓	3,140	3,491	4,107	6,845	13,690
63 x 38 x 24.5	0_46325TC			✓					21,056
63 x 38 x 24.5	0_46326TC			✓	5,770	6,270	7,530	12,500	
73.7 x 38.9 x 12.5	0_47313TC			✓	3,700	4,024	4,880	8,140	16,280
73.7 x 38.9 x 25.2	0_47325TC			✓	7,400	8,050	9,760	16,280	
73.7 x 38.9 x 25.4	0_47326TC			✓					27,610
85.7 x 55.5 x 12.7	0_48613TC			✓	2,510	2,726	3,310	5,520	11,040
85.7 x 55.5 x 25.4	0_48625TC			✓	5,040	5,480	6,570	10,960	
85.7 x 55.5 x 25.4	0_48626TC			✓					18,760
102 x 65.8 x 15	0_49715TC			✓	3,025	3,464	3,945	6,575	11,178
107 x 65 x 18	0_49718TC			✓	4,127	4,486	5,383	8,972	15,252
107 x 65 x 25	0_49725TC			✓	5,732	6,230	7,477	12,461	21,184
140 x 106 x 25	0_49740TC			✓	3,200	3,477	4,173	6,955	11,823

$$\mu_r = 10,000 \quad l_m = 152 \text{ mm} \quad A_c = 300 \text{ mm}^2$$

$$L = \frac{N^2}{l_m / \mu A_c}$$

$$\lambda = \frac{\mu A_c}{l_m} = 25 \mu\text{H} / \text{turn}^2$$

$$\therefore N = \sqrt{\frac{0.216 \times 10^{-3}}{25 \times 10^{-6}}} \approx 3 \text{ turns}$$

$$A_c = \frac{20.83}{5} = 4.16 \text{ mm}^2 \quad \left[\begin{array}{l} 11.1 \text{ AWG} \\ 4.17 \text{ mm}^2 \end{array} \right]$$

$$N A_c = 3 \times 4.16 \text{ mm}^2$$

$$\begin{aligned} K_w &= \frac{12.48}{11.1 \times 10^2} \\ &= 0.011 \end{aligned}$$

$$\mu_r = 10,000 \quad l_m = 152 \text{ mm} \quad A_c = 300 \text{ mm}^2$$

$$L = \frac{N^2}{l_m / \mu A_c}$$

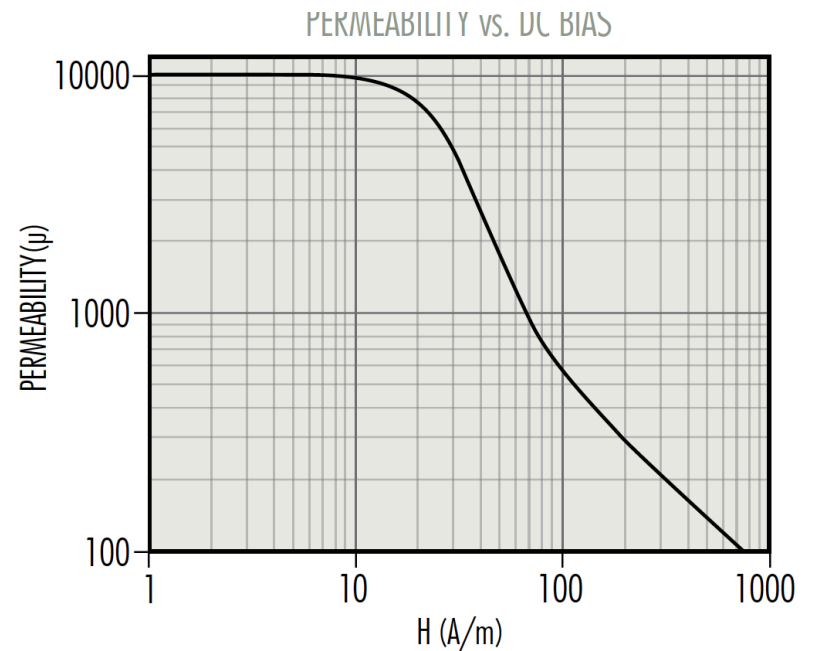
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$$N = \sqrt{\frac{0.216 \times 10^{-3}}{25 \times 10^{-6}}} \approx 3 \text{ turns}$$

$$H = \frac{N i}{l_m} = 453 \text{ A/m}$$

$$\Lambda = 0.4 \mu\text{H} / \text{turn}^2$$

$$L = 3.6 \mu\text{H}$$



Air gap in core to avoid saturation

$$R = \frac{l_m \overset{\text{core}}{\uparrow}}{\mu A_c} + \frac{l_g \overset{\text{Air gap}}{\uparrow}}{\mu_0 A_c}$$

$$\because \mu \gg \mu_0$$

$$R \approx \frac{l_g}{\mu_0 A_c}$$

