BEN-GURION UNIVERSITY OF THE NEGEV
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Collection of Magnetics Equations

Notations

V= Voltage [Volts]
I = Current [Amp]
ϕ= Magnetic flux [Weber]
B= Flux density [Tesla, ; $\frac{\text{Weber}}{\text{m}^2}$; 10,000 Gauss]
L= Inductance [Henry]
A_e = Core effective area [m]
l_e= Core effective length
μ = Magnetic permeability [$\frac{\text{Amperes}}{\text{m}}$]
μ_r =Relative permeability
μ_0= Permeability constant [1.26 10^{-6} $\frac{\text{Henry}}{\text{m}}$]
μ_e= Effective permeability constant [1.26 10^{-6} $\frac{\text{Henry}}{\text{m}}$]
L_g = Effective air gap length [m]
l_c = Core length (less gap) [m]
l_e= Effective core length [m]
H = Magnetic field [$\frac{\text{Amperes}}{\text{m}}$]
H_c= Magnetic field in core [$\frac{\text{Amperes}}{\text{m}}$]
H_g= Magnetic field in gap [$\frac{\text{Amperes}}{\text{m}}$]
Aw = winding window area [m^2]
J = Current density $\left[\frac{\text{Amperes}}{\text{m}^2}\right]$
Irms = effective current [Amperes]
Ipk= Peak current [Amperes]
n = Number of turns
T_s = Switching period [Seconds]
f_s= Switching frequency [$\frac{1}{\text{Seconds}}$]
P_p = Primary power [Watts]
P_s= Secondary power [Watts]
K = Packing coefficient
S = Skin depth [mm]

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1. Inductor

1.1 Basic Equations

$$V = L\frac{dI}{dt} \quad (1)$$

$$V = n\frac{d\phi}{dt} \quad (2) \qquad ; \ \phi = B\,A_e$$

$$\Longrightarrow 1 = \frac{L}{n}\frac{dI}{d\phi} \Longrightarrow n\,A_e \int dB = L\int dI \Longrightarrow n\,A_e\,Bmax = L\,Ipk$$

$$n = \frac{L\,Ipk}{A\,Bmax} \quad (3) \qquad \Longrightarrow \qquad A_e = \frac{L\,Ipk}{n\,Bmax} \quad (4)$$

$$n\,Irms = J\,Aw\,K \quad (5) \qquad \Longrightarrow \qquad n = \frac{Aw\,J\,k}{Irms} \quad (6)$$

$$A_e\,Aw = Ap = \frac{L\,Ipk\,Irms}{J\,K\,Bmax} \quad (7)$$

$$B = \mu\,H = \frac{\mu n I}{l_e} (8); \quad Bmax = \frac{\mu n Ipk}{l_e} \Longrightarrow n = \frac{B\max l_e}{\mu Ipk} \quad (9)$$

$$A_e = \frac{L\,Ipk}{n\,Bmax} \Longrightarrow A_e = \frac{L\,Ipk}{\frac{Bmax\,l_e}{\mu\,Ipk}\,Bmax} \quad (10)$$

$$A_e\,l_e = \text{Volume (core)} = \frac{L\,Ipk^2\,\mu}{B_{max}^2} \quad (11)$$

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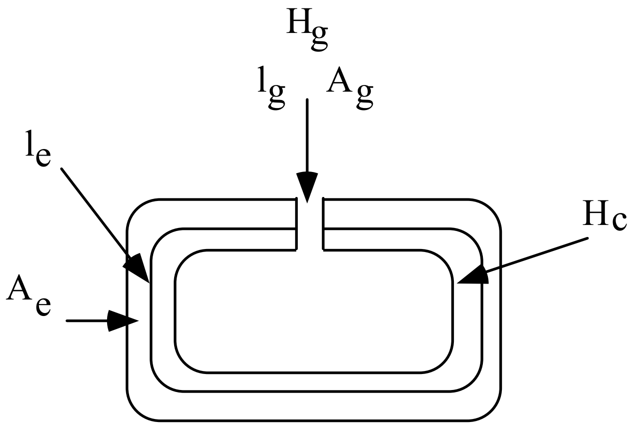
1.2 Air Gapped Inductor



$$B = \mu_e \frac{n\,I}{l_e} \qquad (12)$$

$$n\,I = H_g\, l_g + H_c\, l_c \quad = \frac{B_g}{\mu_g}\, l_g + \frac{B_c}{\mu_c}\, l_c \qquad (13)$$

$$B = B_g = B_c \implies n\,I = B\left(\frac{l_g}{\mu_g} + \frac{l_c}{\mu_c}\right) \implies B = \frac{n\,I}{\frac{l_g}{\mu_g} + \frac{l_c}{\mu_c}} \qquad (14)$$

$$B = \mu_e \frac{n\,I}{l_e} = \frac{n\,I}{\frac{l_g}{\mu_g} + \frac{l_c}{\mu_c}} \implies \mu_e = \frac{l_e}{\frac{l_g}{\mu_g} + \frac{l_c}{\mu_c}} \qquad (15)$$

Assuming:

$$\mu_g << \mu_c \quad ; \quad \frac{l_c}{\mu_c} < \frac{l_g}{\mu_g} \quad ; \; l_e = l_g + l_{c..} \; l_c \; ; \mu_g = \mu_0 \qquad (16)$$

$$\mu_e = \mu_g \frac{l_e}{l_g} \implies \mu_0 \frac{l_e}{l_g} \implies \mu_{r..} \frac{l_c}{l_g} \qquad (17)$$

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2. Square -Wave Transformer

$$V = n A_e \frac{dB}{dt} \implies \int V dt = n A_e \Delta B \implies \frac{V}{2 f_s} = n A_e \Delta B \qquad (18)$$

$$n\, Irms = Aw\, J\, k \implies n = \frac{Aw\, J\, K}{Irms} \qquad (19)$$

$$\frac{V}{2 f_s} = \frac{Aw\, J\, K}{Irms} \Delta B \qquad (20)$$

$$A_e\, Aw = Ap = \frac{V\, Irms}{2 f_s\, J\, K\, \Delta B}$$

$$Ap = \frac{P_p + P_s}{2 f_s\, J\, K\, \Delta B} = \frac{T_s (P_p + P_s)}{2 f_s J K \Delta B} \qquad (21)$$

3. Skin Depth

$$S \approx \frac{72}{\sqrt{f_s}} \qquad (22)$$