

DESIGN OF RESONANT CHOKE FOR PHASE SHIFTED FULL BRIDGE CONVERTER

Every phase shifted converter contains resonant inductance. This inductance stores energy needed to charge and discharge the (parasitic) capacitances of the PSFB converter switches in order to achieve ZVS. There are 2 choices for the resonant inductor design: use of leakage inductance of the transformer or separate resonant inductor/ choke.

The resonant inductor can be integrated into the power transformer by designing the transformer/ bobbin in such way that coupling between primary and secondary windings loosens. The leakage inductance gets higher and can be used as the converter resonant inductance.

Although this approach reduces component count it complicates transformer construction. It is also difficult to keep the leakage inductance value constant during manufacturing process. This solution is used mostly in low power mass production power supplies.

High power resonant converters usually employ separate resonant chokes.

The task is to design a resonant choke for 10kw PSFB converter.

1. SPECIFICATION

$$L := 12 \mu H$$

$$f := 50 \text{ kHz}$$

$$I_{pp} := 26 \text{ A}$$

$$T_{ambient} := 50 \text{ }^\circ\text{C}$$

$$I_{rms} := 19 \text{ A}$$

$$T_{max} := 100 \text{ }^\circ\text{C}$$

2. CORE MATERIAL

We choose powder core Kool Mu Max as having correct mix of low losses, high Bmax, and reasonable price tag.

Tentatively chosen permeability $\mu = 26$

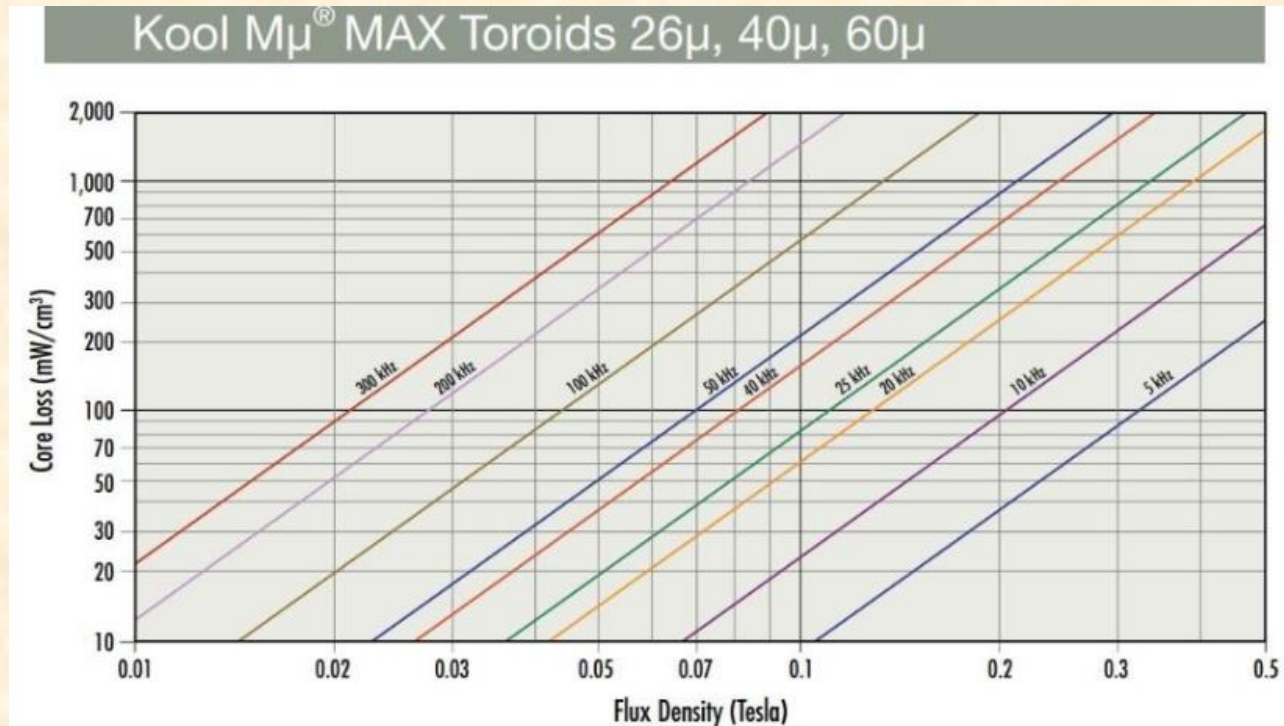
3. CORE SIZE

In the AC inductor the heat generated by core loss becomes a primary design constraint. Temperature rise due to core and copper losses determines the core size.

According to TI slup127, p.5-6, using Product Area and when flux swing is limited by core loss, dBmax may be approximated by assuming a core loss of 100mw/cm³.

Using core loss curve below:

For 100mW/cm³ and 50kHz frequency curve Flux Density scale shows B = 0.07T. Double this number to obtain peak-peak flux density, B_{max} = 2*0.07 = 0.14T



4. CALCULATE PRODUCT AREA FOR FLUX SWING LIMITED BY CORE LOSS

When flux swing is limited by core loss:

$$AP = A_w A_E = \left(\frac{L \Delta I}{\Delta B_{\max}} \cdot \frac{I_{FL}}{K_2} \right)^{4/3} \text{ cm}^4 \quad (2b)$$

where:

- L = inductance, Henrys
- I_{SCpk} = max pk short-circuit current, A
- B_{MAX} = saturation limited flux density, T
- ΔI = current swing, Amps (primary)
- ΔB_{max} = max flux density swing, Tesla
- I_{FL} = rms current, full load (primary)

$$K_1, K_2 = J_{MAX} K_{PRI} \times 10^{-4}$$

where:

- J_{MAX} = max. current density, A/cm²
- K_{PRI} = primary copper area/window area
- 10⁻⁴ = converts dimensions from meters to cm

$$K2 := 0.006 \frac{A}{\text{cm}^2} \quad I_{ppn} := 26$$

$$Ln := 12 \cdot 10^{-6} \quad I_{rmsn} := 19$$

$$K2n := 0.006 \quad Bn := 0.14$$

$$Ap := \left(Ln \cdot I_{ppn} \cdot \frac{I_{rmsn}}{Bn \cdot K2n} \right)^3 = 13.536 \text{ (cm}^4)$$

5. CHOOSE CORE SIZE USING CALCULATED AP:

Tentatively choose Kool Mu Max 79191A7

$$OD := 57.15 \text{ mm}$$

$$A := OD$$

$$ID := 26.39 \text{ mm}$$

$$B := ID$$

$$HT := 15.24 \text{ mm}$$

$$C := HT$$

$$Mass := 0.175 \text{ kg}$$

$$Ae := 2.29 \text{ cm}^2$$

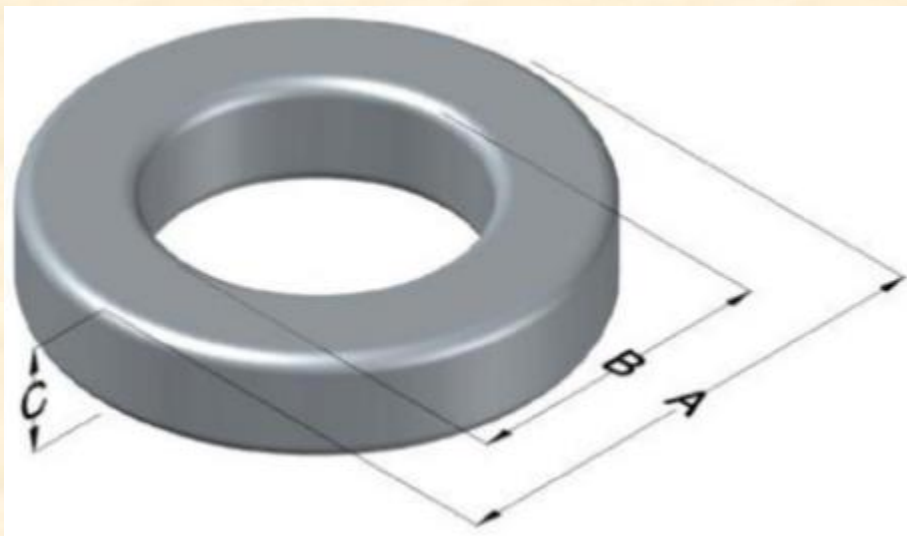
$$Aw := 5.14 \text{ cm}^2$$

Product Area:

$$Ap := Ae \cdot Aw = 11.771 \text{ cm}^4$$

$$Le := 12.5 \text{ cm}$$

$$Ve := 28.6 \text{ cm}^3$$



Surface area from datasheet is extrapolated for 20% winding factor

$$Asurface := 102 \text{ cm}^2$$

$$mlt := 7.12 \text{ cm}$$

$$f := 50 \text{ kHz}$$

$$L := 12 \text{ } \mu\text{H}$$

$$Ip := 24 \text{ A}$$

6. NUMBER OF TURNS

$$l_{in} := ID \cdot \pi = 82.907 \text{ mm}$$

Choose AWG10

$$D_{awg10} := 2.73 \text{ mm}$$

$$N_{max} := \text{floor}\left(\frac{l_{in}}{D_{awg10}}\right) = 30$$

Check if there is still place after winding one layer of awg10 wire:

$$Al := 60 \cdot 10^{-9} \text{ H}$$

$$Nt := \sqrt{\frac{L}{Al}} = 14.142$$

$$Nt := \text{floor}(Nt) = 14$$

Less than 30

7. RECALCULATE FLUX DENSITY B AND FIELD INTENSITY H:

$$H := Nt \cdot \frac{I_{pp}}{L_e} = 36.593 \text{ Oe}$$

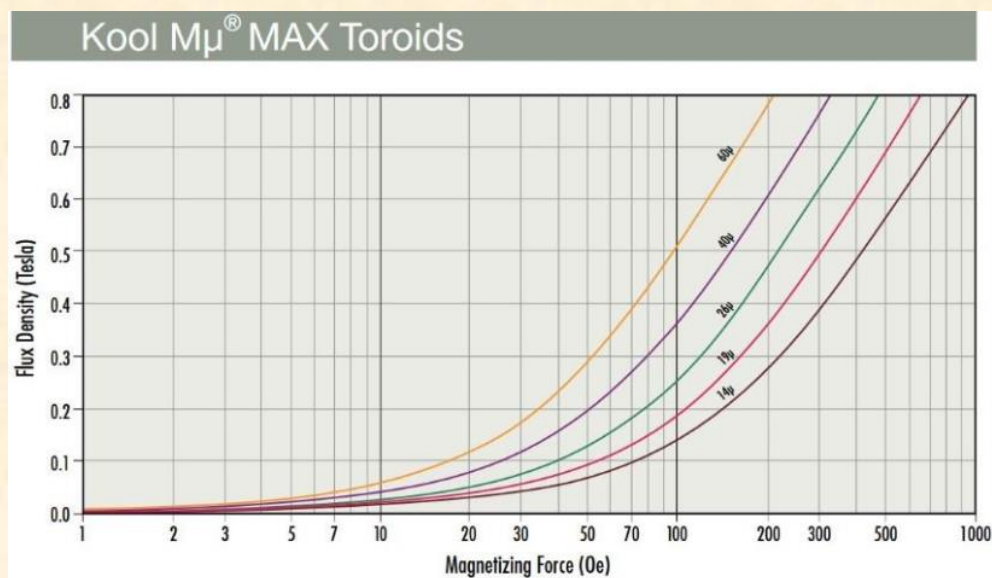
$$\mu := 26$$

$$\mu_0 = (1.257 \cdot 10^{-6}) \frac{\text{kg} \cdot \text{m}}{\text{s}^2 \cdot \text{A}^2}$$

$$B := \mu \cdot \mu_0 \cdot H = 0.095 \text{ T}$$

Other way to calculate B:

$$B := L \cdot \frac{I_{pp}}{Nt \cdot Ae} = 0.097 \text{ T}$$



Using formula for calculating B:

Fit Formula

$$B = \left[\frac{a + bH + cH^2}{1 + dH + eH^2} \right]^x \text{ where } B = \text{Tesla (T)}, H = \text{Oersteds (Oe)}$$

	Perm	a	b	c	d	e	x
Kool M μ [®] MAX Toroids	14 μ	3.945E-02	1.922E-02	4.882E-04	1.430E-01	4.217E-04	1.895
	19 μ	3.915E-02	1.866E-02	5.237E-04	1.225E-01	4.368E-04	1.859
	26 μ	6.405E-02	1.572E-02	5.541E-04	9.685E-02	4.568E-04	1.813
	40 μ	3.810E-02	1.720E-02	5.982E-04	8.225E-02	4.852E-04	1.684
	60 μ	3.589E-02	1.862E-02	6.201E-04	6.341E-02	4.897E-04	1.630

$$a := 6.405 \cdot 10^{-2}$$

$$b := 1.572 \cdot 10^{-2}$$

$$c := 5.541 \cdot 10^{-4}$$

$$d := 9.685 \cdot 10^{-2}$$

$$e := 4.568 \cdot 10^{-4}$$

$$x := 1.813$$

$$I_p = 24 \text{ A}$$

$$H := Nt \cdot \frac{I_p}{L_e} = 33.778 \text{ Oe}$$

$$H := 33.778$$

$$B := \left(\frac{a + b \cdot H + c \cdot H^2}{1 + d \cdot H + e \cdot H^2} \right)^x \cdot 1 \text{ T} = 0.085 \text{ T}$$

$$H := 33.778 \text{ Oe}$$

$$\mu := 26$$

$$B := \mu \cdot \mu_0 \cdot H = 0.088 \text{ T}$$

“or”

$$B := L \cdot \frac{I_p}{Nt \cdot Ae} = 0.09 \text{ T}$$

8. CALCULATE POWER LOSSES

8.1 CORE LOSSES:

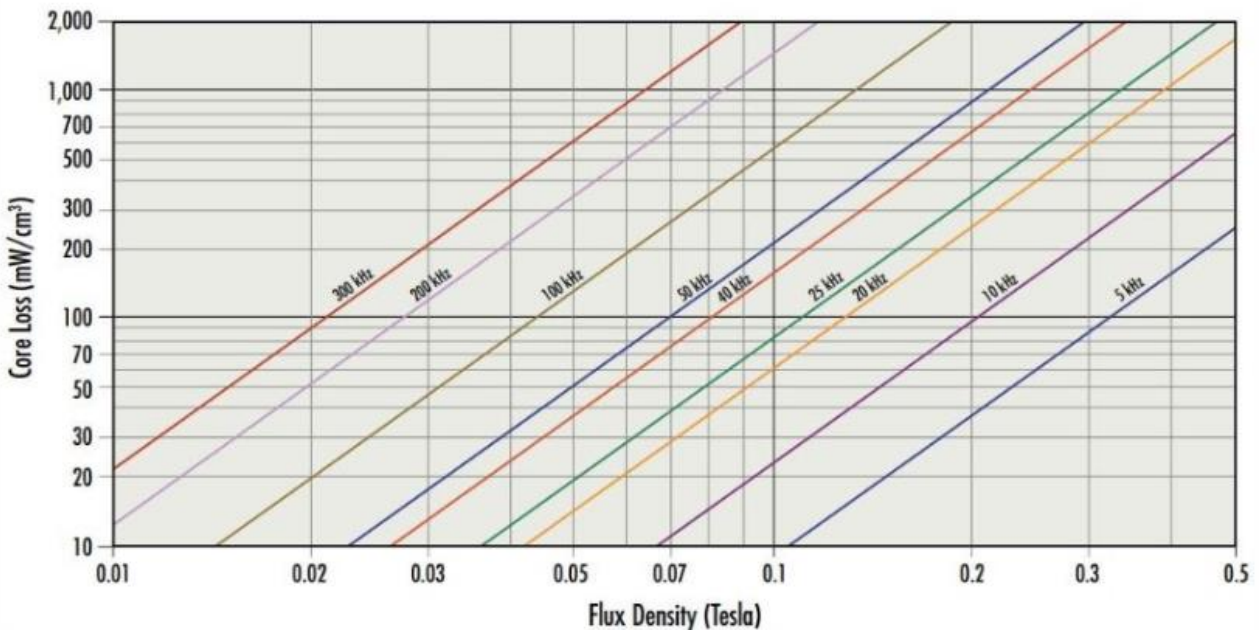
Core Loss Density Curves

Fit Formula

$$P = aB^{bp}f^{cp} \text{ where } B = \text{Tesla (T)}, f = \text{kilohertz (kHz)}$$

	Perm	a	b	c
Kool M μ [®] MAX Toroids	14 μ	144.49	2.072	1.379
	19 μ	128.84	2.072	1.379
	26 μ , 40 μ , 60 μ	113.53	2.072	1.379

Kool M μ [®] MAX Toroids 26 μ , 40 μ , 60 μ



$$ap := 113.53$$

$$bp := 2.072$$

$$cp := 1.379$$

$$Bp := 0.09$$

$$fp := 50$$

$$P_{core} := ap \cdot Bp^{bp} \cdot fp^{cp} = 170.287$$

$$P_{core} := 170 \frac{mW}{cm^3}$$

From graph for 50kHz and 0.09T Pcore is appx. 200mW/2 = 170mW

$$P_{core} := 170 \frac{mW}{cm^3}$$

$$P_{losscore} := P_{core} \cdot Ve = 4.862 \text{ W}$$

8.2 WIRE LOSSES

$$R_{\text{wire10awg}} := 3.277 \cdot 10^{-3} \frac{\Omega}{\text{m}}$$

$$\text{Length} := \text{mlt} \cdot \text{Nt} = 0.997 \text{ m}$$

$$R_{\text{wire}} := R_{\text{wire10awg}} \cdot \text{Length} = 0.003 \Omega$$

$$P_{\text{losswire}} := I_p^2 \cdot R_{\text{wire}} = 1.882 \text{ W}$$

$$P_{\text{loss}} := P_{\text{losscore}} + P_{\text{losswire}} = 6.744 \text{ W}$$

9. THERMAL RESISTANCE AND TEMPERATURE RISE

Thermal resistance approximation (TI slup132):

$$R_{\text{eas}} := 800 \frac{\Delta^\circ\text{C} \cdot \text{cm}^2}{\text{W}}$$

$$R_{\text{e}} := \frac{R_{\text{eas}}}{A_{\text{surface}}} = 7.843 \frac{\Delta^\circ\text{C}}{\text{W}}$$

$$T_{\text{rise}} := R_{\text{e}} \cdot P_{\text{loss}} = 52.89 \Delta^\circ\text{C}$$

$$dT_{\text{max}} := T_{\text{max}} - T_{\text{ambient}} = 50 \Delta^\circ\text{C}$$