Lab 2C Inductor Design

Monday, November 15, 2021 11:04 PM

- Lab 2 due in 2 weeks (do ASAP)

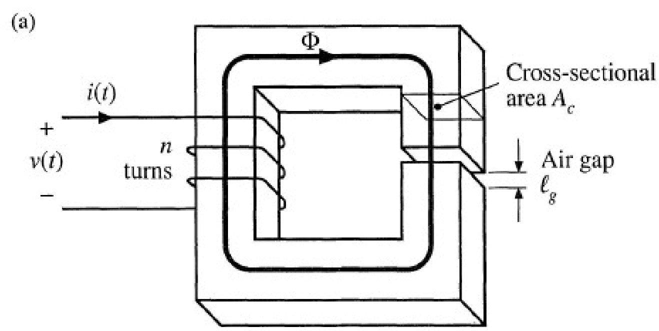
Lab 2C just turn in L, R_L measurements.

- Lab Lecture recorded on Zoom

Inductor Design:

(textbook 14.1 old edition, 11.1 new edition)

- constraints:



1. max flux density

$$n I_{max} \approx \frac{B_{max}\, l_g}{\mu_0}$$

B_{max} → given

μ_0 → perm free space $4\pi \times 10^{-7}$ H/m

2. Inductance

$$L \approx \frac{\mu_0 A_c n^2}{l_g}$$

3. Winding Window Area.

$$K_u W_A \geq n A_w$$

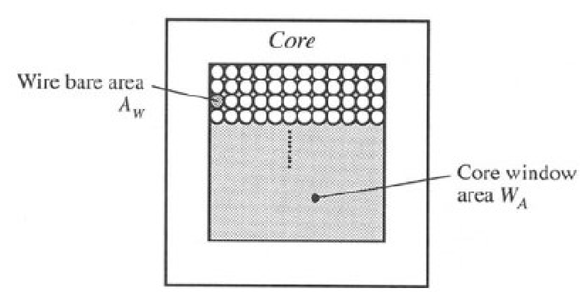


Fig. 14.5 The winding must fit in the core window area.

"The fill factor Ku is the fraction of the core window area that is filled with copper. Ku must lie between zero and one."

4. Winding resistance:

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

(MLT) → mean length turn

A_c, W_A, MLT: core geometry

$I_{max}, B_{max}, \mu_0, K_u, R, \rho$: known / specs

n, l_g, A_w: unknown

- Core Geometrical Constant "K_g"

$$\frac{A_c^2 W_A}{(MLT)} \geq \frac{\rho L^2 I_{max}^2}{B_{max}^2 R K_u} \qquad K_g = \frac{A_c^2 W_A}{(MLT)}$$

K_g is "FOM" that describes effective electrical size of a magnetic core

→ this describes how core geometry relates to specs.

Design Procedure:

The following quantities are specified, using the units noted:

Wire resistivity	ρ	(Ω–cm)
Peak winding current	I_{max}	(A)
Inductance	L	(H)
Winding resistance	R	(Ω)
Winding fill factor	K_u	
Maximum operating flux density	B_{max}	(T)

The core dimensions are expressed in cm:

Core cross-sectional area	A_c	(cm^2)
Core window area	W_A	(cm^2)
Mean length per turn	MLT	(cm)

Step 0: pick L value

For us: $L = \dfrac{V_L \, DT_S}{2\Delta i_L}$ $\quad D = 0.5 \quad T_S = \dfrac{1}{f_{sw}} = 20\mu s$

$V_L \approx 24V$ during DT_S

rate converter for: $P_{out} = 100W \quad I_{in} \approx 4A$

$V_{out} = 48V \quad I_{out} \approx 2A$

$V_{in} = 24V$

rate 15% i-ripple. (usually do better)

$15\% \cdot 4A \approx 0.6A$

$L \approx 0.2\,mH$ $\quad L\uparrow,\ \Delta i\downarrow,$ size of inductor $\uparrow$

Step 1: determine core size:

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

$K_u = 0.5\ cm^2/cm^2$

$I_{max} = I_2 + \Delta i +$ safety factor (15%)

$= 4 + 0.6 + (15\% \times 4.6) \approx 5A$

$B_{max} = 0.3T$ (given)

$P_{cu} \leq 1W$ (copper loss) $\longrightarrow P_{cu} = I_{rms}^2 R = \left(\frac{5}{\sqrt{2}}\right)^2 R$

$R = 0.04\,\Omega = 40\,m\Omega$

use $\rho = 2.3 \times 10^{-6}$ (ρ of copper at $100^\circ C$). $(1.724 \times 10^{-6}$ @ room temp)

plug it all in:

$K_g \geq 0.13\ cm^5$ and $B_{sat} > B_{max}$

Core Size Tables: we chose ETD39 (Kg = 0.397, Bsat_min = 0.33T)
http://web.eecs.utk.edu/~dcostine/ECE482/Spring2014/materials/magnetics/MagneticsTables.pdf

Based on chosen core:

$A_c = 1.25\ cm^2$ $\quad W_A = 1.74\ cm^2$ $\quad MLT = 6.86\ cm$

Step 3: pick airgap:

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

Plug in values:

$l_g = 5.58 \times 10^{-4}$ m

$= 0.0558$ cm (shim)

Step #3: pick turns

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

$n = 27$

Step #4: wire size

$$A_W \leq \frac{K_u W_A}{n} \quad (\text{cm}^2)$$ (use AWG table)

$A_w \leq 0.03 \text{ cm}^2$

pick largest wire possible, account for insulation

we have 16 AWG wire.

-can calculate $R_L = \frac{\rho n (MLT)}{A_w}$ (Ω)

Notes:

- this procedure considers: saturation, fill-factor limits, etc.
  NOT: insulation req, eddy current loss, temp rise, etc.
- Sanity Check:
  - LCR meter

- datasheet A_L, plug in l_g

$$L = \underbrace{A_L(l_g)}_{A_L \text{ function of } l_g} n^2$$

https://www.ferroxcube.com/upload/media/product/file/Pr_ds/ETD39_20_13.pdf

$\rightarrow$ nH / turns^2

FEK0053-8

Ungapped

Material	A_L value nH	μ_e	B_S* mT	P_V W/set	Ordering code
N27	2550 +30/–20%	1500	320	< 2.22 (200 mT, 25 kHz, 100 °C)	B66363G0000X127
N87	2700 +30/–20%	1600	320	< 6.00 (200 mT, 100 kHz, 100 °C)	B66363G0000X187
N97	2800 +30/–20%	1650	320	< 5.10 (200 mT, 100 kHz, 100 °C)	B66363G0000X197

* H = 250 A/m; f = 10 kHz; T = 100 °C

*just example. fine for air core (ETD39 shape) (material 3C97)

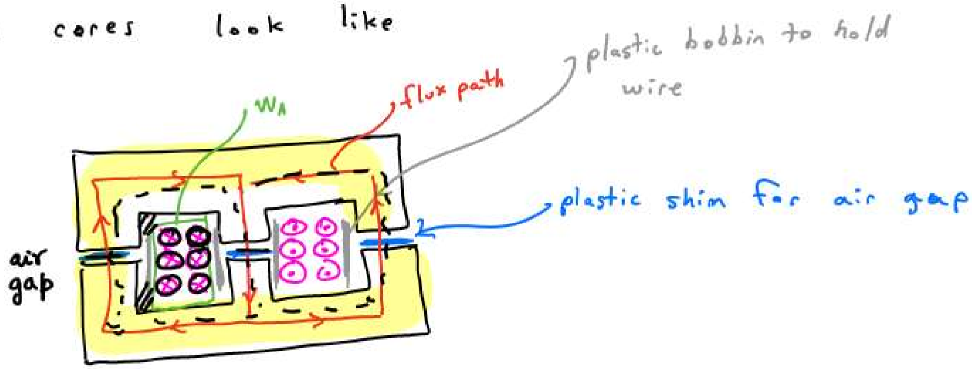
Gapped (A_L values/air gaps examples) $\rightarrow$ use gap size.

Material	g mm	A_L value approx. nH	μ_e	Ordering code ** = 27 (N27) = 87 (N87)
N27, N87	0.10 ±0.02	1062	622	B66363G0100X1**
	0.20 ±0.02	639	374	B66363G0200X1**
	0.50 ±0.05	326	191	B66363G0500X1**
	1.00 ±0.05	196	115	B66363G1000X1**
	2.00 ±0.05	115	65	B66363G2000X1**

The A_L value in the table applies to a core set comprising one ungapped core (dimension g = 0 mm) and one gapped core (dimension g > 0 mm).

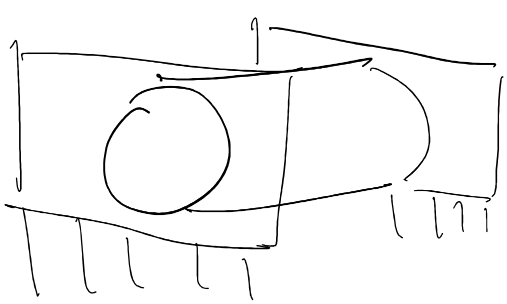
Other A_L values/air gaps and materials available on request – see Processing remarks on page 5.

Our cores look like



ETD 39 core

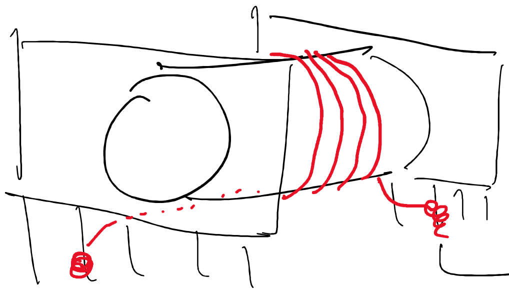
Building Inductor:



Bobbin

1) wind wire: $n=27$ turns

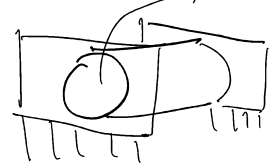
→ magnetic wire



to get continuity at pin, will need to scrape away wire coating

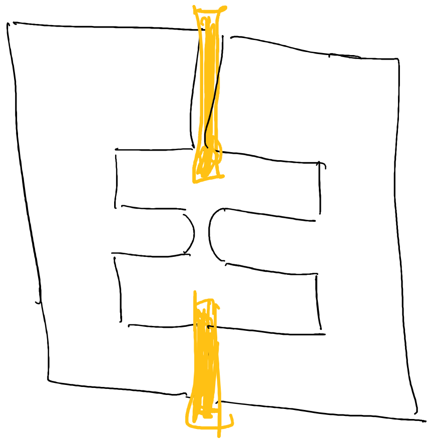
2) add magnetic cores:

→ round part goes in Bobbin hole.

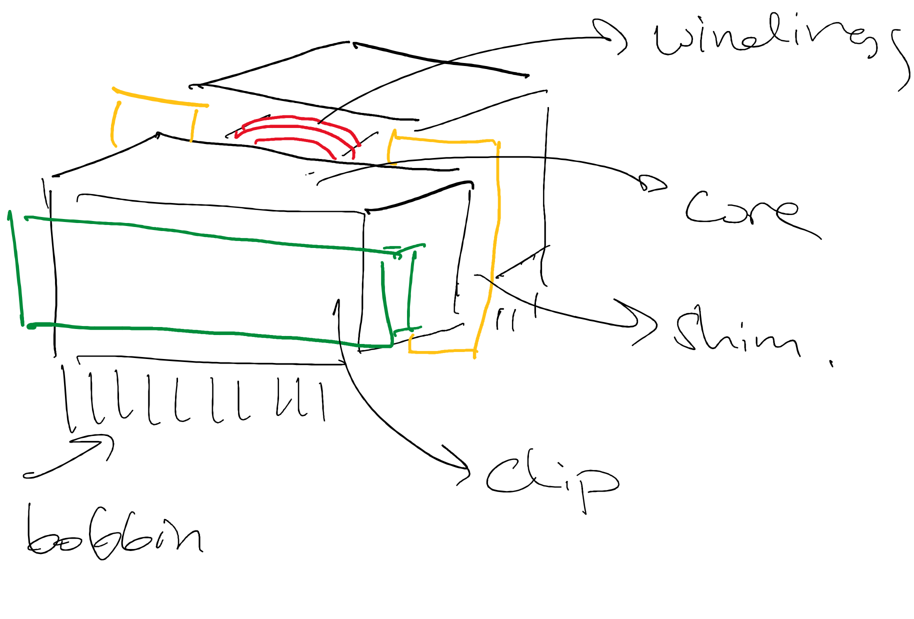


on both sides

3. add shims for airgap (use brown one)

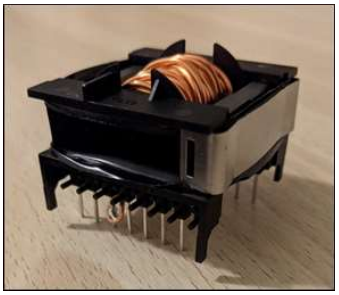


4. add clips to sleeve cores to bobbin and hold shims in place.



5. Test with LCR meter!

turn in measured L, R



Note: I also used electrical tape, you do not need this as each group has at least 2 Bobbin clips