EE 452 – Power Electronic Converters
Inductor Design Tips

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Introduction

The purpose of this document is to provide a primer on inductor design. It follows the procedure laid out in Chapter 14 (11 in 3rd edition) of Erickson closely. We recommend that this document be used in conjunction with the data sheets corresponding to the inductor cores supplied in your lab kits.

Available parts

The EE 452 lab kits include the following inductor cores. Furthermore, enameled magnet wire will be made available in 16 AWG.

Core geometry	Core material
ETD39	Ferroxcube 3C97

Pay particular attention to the parameter A_L listed in the core data sheets. This value is in units of nH, and relates the inductance to the number of turns squared for a given core, *i.e.*,

$$L = n^2 A_L \implies n = \sqrt{L/A_L}. \tag{1}$$

Compare the number of turns computed using this expression to the number computed using Equation (4). The numbers will likely be in the same ballpark, and can help you sanity check your designs. Make sure to use the A_L associated with the airgap you choose.

Lab 2C Deliverable:

For this lab, we will go through inductor design as a class. For the Lab 2C Report, measure the inductance and resistance of your inductor and comment on how close it is to your expected values. Expected values: $L = 0.2mH, R = 40m\Omega$. **(10pts)**

Design Procedure

The simple filter inductor design procedure presented here should be regarded as a first-pass approach. Numerous issues have been neglected, such as detailed insulation requirements, conductor eddy current losses, temperature rise, and roundoff of number of turns.

The following quantities are specified, using the units noted in Table 1. The use of centimeters rather than meters requires that appropriate factors be included in the design equations.

Table 1: Variables and their meanings.

Physical meaning	Variable	Units
wire resistivity	ρ	Ω·cm
peak winding current	$I_{\max}$	A
inductance	L	H
winding resistance	R	Ω
winding fill factor	K_u	$\mathrm{cm}^2/\mathrm{cm}^2$
core maximum flux density	$B_{\max}$	T
core cross-sectional area	A_c	cm^2
core window area	W_A	cm^2
mean length per turn	MLT	cm

1. *Determine core size.* Choose a core size such that

$$K_g \geq \left(\frac{\rho L^2 I_{\max}^2}{B_{\max}^2 R K_u} \right) 10^8 \quad (\mathrm{cm}^5), \tag{2}$$

   where K_g is the so-called core geometrical constant. Note the values of A_c, W_A, and MLT for this core. The resistivity ρ of copper wire is $1.724 \times 10^{-6}\ \Omega \cdot \mathrm{cm}$ at room temperature, and approximately $2.3 \times 10^{-6}\ \Omega \cdot \mathrm{cm}$ at 100 °C.

2. *Determine the air gap length.* To help mitigate the effects of saturation, determine the air gap length using the expression

$$\ell_g = \left(\frac{\mu_0 L I_{\max}^2}{B_{\max}^2 A_c} \right) 10^4 \quad (\mathrm{m}), \tag{3}$$

   where A_c is expressed in cm^2 and $\mu_0 = 4\pi \cdot 10^{-7}\ \mathrm{H\,m^{-1}}$. The air gap length is given in meters. The expression above is somewhat approximate because it neglects certain nonidealities, such as fringing flux. (*Note*: Some manufacturers sell gapped cores. We will not use these in class, but they are discussed in Chapter 14 of Erickson.)

3. *Determine the number of turns.* Given the peak winding current, the number of turns can be stated as

$$n = \left(\frac{L I_{\max}}{B_{\max} A_c} \right) 10^4, \tag{4}$$

   where A_c is the cross-sectional area of the selected core.

4. *Evaluate wire size.* Select wire with a bare copper area less than or equal to the value given by

$$A_W \leq \frac{K_u W_A}{n} \quad (\mathrm{cm}^2), \tag{5}$$

where K_u is the winding *fill factor*, and A_W is the cross-sectional area (or *bare area*) of the magnet wire. As illustrated in Figure 1, the winding must fit through the window, *i.e.*, the hole in the center of the core. If the winding has n turns, then the area of copper conductor in the window is nA_W. If the core has window area W_A, then we can express the area available for the winding conductors as $W_A K_u$. Putting these expressions together gives rise to the design constraint in (5).

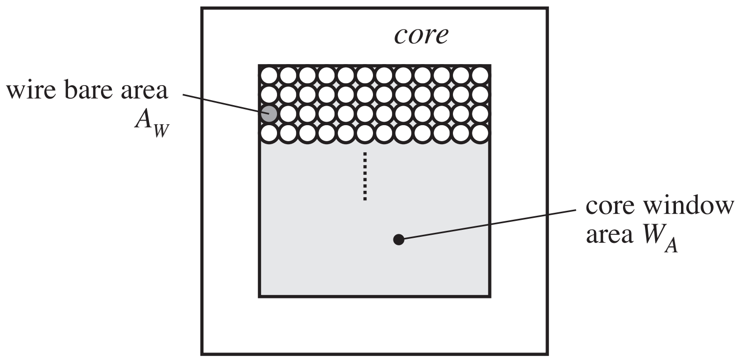

Figure 1: Comparison of the winding area and the window area.

The fill factor K_u is the fraction of the core window area that is filled with copper. This fraction must lie between zero and one. In practice K_u is less than unity because round wire does not pack perfectly. Depending on the winding technique, this effect reduces K_u to a maximum between roughly 0.55–0.70. Furthermore, magnet wire has insulation, often in the form of enamel coating. The ratio of wire conductor area to total wire area varies from approximately 0.95–0.65, depending on the wire size and type of insulation. The bobbin also uses some of the window area. Insulation may be required between windings and/or winding layers. Typical values of K_u for cores with winding bobbins are: 0.5 for a simple low-voltage inductor, 0.25–0.30 for an off-line transformer, 0.05–0.20 for a high-voltage transformer supplying several kV, and 0.65 for a low-voltage foil transformer or inductor. In this class, a fill factor in the neighborhood of 0.5 is achievable (perhaps slightly higher if the windings are packed tightly).

The wire size must also be sufficient to carry the maximum current that will pass through the inductor. An American Wire Gauge table is included in Appendix D of Erickson. As a sanity check, the winding resistance can be computed by

$$R = \frac{\rho n \cdot MLT}{A_W} \quad (\Omega). \tag{6}$$