Inductor Design Project – Technical Memo

Objective

To design a 100 μH inductor with a 3A current capability using 3F3 ferrite ceramic core material for operation at 100 kHz. The core shape is EFD30 manufactured by Philips.

Background

List of Symbols:

A_c	Cross-sectional area of core
$A_{c\,eff}$	Nominal cross-sectional area to account for fringing field in air gap
δ	Skin depth in a conductor with finite conductance
ω	Frequency of applied current in conductor
σ	Conductivity of wire (usually copper)
μ_o	Magnetic permeability of free space (air)
μ_r	Relative permeability of magnetic core material (for copper conductor $\mu_r = 1$)
l	Magnetic flux path length
l_g	Air gap length – for a spacer gap, the air gap length is twice the spacer gap length
A_W	Area of Wire
N	Number of turns of wire
W_A	Window area of core through which the windings are laid
Fill Factor	The percent of the window actually filled with conductor (less than 1 because of the use of round wire for the windings and the insulation required on each winding). Typically between 0.3 and 0.7.
R	Reluctance
ϕ	Magnetic flux
L	Inductance
I	Current in a winding

See class notes. Useful design equations include the following:

$$A_{ceff} = 1.3A_c \qquad \text{(to account for fringing field at the air gap)}$$

$$A_W = \frac{(FillFactor)W_A}{N}$$

Fill Factor = 55% for window in an E-core

$$R = \frac{l}{\mu A} \quad \text{core reluctance}$$

$$R_g = \frac{l_g}{\mu_0 A} \quad \text{gap reluctance}$$

$$\phi = \frac{NI}{(R + R_g)}$$

$$L = \frac{N\phi}{I} = \frac{N^2}{(R + R_g)}$$

Design Sequence

This is a possible design sequence to design an inductor. We will NOT use this procedure, since the switching frequency has already been determined.

Step 1: Choose a switching frequency (for this project we will use **100 kHz**)
Step 2: Calculate required inductor in Henries (for this project we will use a target value of **100 μH**)
Step 3: Design inductor for minimum sum of core and conduction loss (vary the gap, and design B). Hence write down total losses.
BEWARE:- for conduction losses in inductor, Skin effect MAY be significant.
Skin depth in copper (note that in copper $\mu_r = 1$):

$$\delta = \sqrt{\frac{2}{\omega \sigma \mu_o \mu_r}}$$

Step 4: Choose a new frequency that you think might reduce total losses, go back to Step 1 and check.
Step 5: Iterate until you believe you have the best possible design.

It is quite difficult to separate out and measure the individual loss components. For very high efficiency circuits, (like this one!) we sometimes have to use calorimetry just to measure the total losses[i]

Prelab

1. Write and turn in at lab time a **pre-lab report** describing the procedure you will follow to measure the inductance and DC resistance of the inductor that you are building. Estimate the expected value of DC resistance based on your inductor design. For the measurement you should use the standard lab bench equipment that is available in the lab: oscilloscope, signal generator, DC power supply, digital multimeter. Note that you do not have a current probe available to you (Hint: a resistor can be used as a current-to-voltage transducer.)
    a. Inductance measurement. Identify at least two possible sources of error that may make the actual inductance different from the value you designed for. Describe the measurement procedure that you plan to use to measure the inductance. What test signal are you planning to use (signal type, magnitude, frequency)? Depending on

the lab equipment that you use for measurement (scope, multimeter, etc) identify the measurement sources of error and estimate the error in your measurement. The lab signal generator has a 100Ω Thevenin resistance. Describe how this may affect your measurement.

   b. DC resistance measurement. Describe a method to measure the inductor DC resistance. Identify at least two sources of error. Describe the measurement procedure that you plan to use. Identify sources of error and estimate the error magnitude. Note that the resistance value is small. How does that affect the accuracy of your measurement? Can you propose a measurement procedure that improves the accuracy?

2. Do a paper design for the inductor. You will be using an EFD 30 ferrite core. The specifications are L = 100µH, peak current capability 3A. Use a maximum flux density of 0.25T. Determine number of turns, wire gauge, air gap thickness (careful about fringing flux). Calculate the DC resistance of the inductor and the AC resistance at 100 kHz and 1MHz using the skin depth. Calculate the reluctance of the gap and the reluctance of the magnetic path in the core, and verify whether neglecting the reluctance of the core was an acceptable approximation.

<u>Lab</u>

1. Design and measure the actual value of inductance at 100 kHz.
2. Produce a voltage and current plot for sinusoidal excitation at 100kHz. Calculate the inductance value. Repeat for square-wave excitation at the same frequency. Do the calculated inductance values agree?
3. Measure the DC resistance of the inductor.
4. Make an estimate of the inductor losses for a current having a DC component of 2A superimposed with a sinusoidal component at 100 kHz with 0.2A amplitude. These are the values that will be used in the Boost converter design. **<u>Submit a technical memo.</u>**

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[i] D J Patterson, “Tricks of the Trade: Simple Calorimetry for Accurate Loss Measurement” Invited paper, IEEE Power Electronics Society Newsletter, October 2000, pp 5 –7, http://www.pels.org/Comm/Publications/Newsletter/Newsletter.html