6.334 Power Electronics
Spring 2007

6.334 Power Electronics   Issued: March 2, 2007
Problem Set 4   Due: March 9, 2007

Reading: KSV Chapter 7

Problem 4.1   KSV Problem 20.10

Problem 4.2

Figure 1 shows a tapped-inductor boost converter. This approach is sometimes used to achieve larger conversion ratios as compared to a conventional boost design. The inductor winding contains a total of (N_1+N_2) turns. The switch is placed N_1 turns from the left side of the inductor, as shown. The tapped inductor can be viewed as a two-winding $(N_1:N_2)$ transformer, in which the two windings are connected in series. The inductance of the entire (N_1+N_2) turn winding is L.

   a.   Sketch an equivalent circuit model for the tapped inductor that includes a magnetizing inductance and an ideal transformer. Label the values of the magnetizing inductance and turns ratio.
   b.   Determine an analytical expression for the conversion ratio V_2/V_1 assuming that all components are lossless, and that the converter operates in continuous conduction mode.
   c.   Plot the conversion ratio as a function of duty ratio D for the case $N_1=N_2$, and compare to the conventional non-tapped case $(N_2 = 0)$.
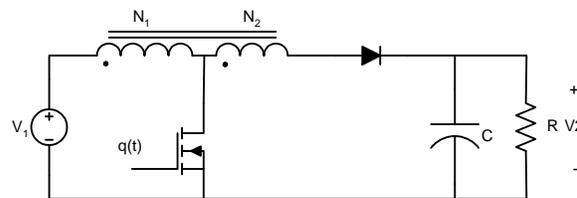

Figure 1   A tapped-inductor boost converter.

Problem 4.3   KSV Problem 20.7

Notes: 1. You may optionally elect to use aluminum conductor in your design. Silver is disallowed for cost reasons.
          2. **There will be a small prize for the "best" design, as judged by the 6.334 staff.** Judging will be based on the following three factors:
             a. Lowest total weight of the transformer
             b. The degree to which the proposed design meets the specifications and is expected to match the performance of a real implementation.
             c. The degree to which the proposed design and its expected performance are well analyzed and documented.

Problem 4.4

Consider the magnetic circuit of Fig. 2(a). All legs are 1 cm wide, except for the right leg, which is 0.5 cm wide. You may neglect any nonuniformities in flux distribution at the corners.

    a.   Find a magnetic circuit model for the device, and find the inductance of the winding.

A second winding is added, as shown in Fig. 2(b).

    b.   Modify the circuit model of part (a) to include this second winding.

    c.   Derive the matrix description for this magnetic circuit, and find the numerical values of L_{11}, L_{12}, and L_{22}. The matrix representation has the form:

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} \\ L_{12} & L_{22} \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$

Problem 4.5

Design an inductor for a 150 W, 140 kHz boost converter operating in continuous conduction mode from a nominal input voltage of 14 V into an output voltage of 42 V. The desired inductance is 6 µH, and it is specified that the inductor be implemented with 3F3 Ferrite material in an RM form factor core. Data for RM10 and RM12 sized cores are included below. Various values of A_L (nH for one turn) are available in each core (recall that inductance is proportional to the number of turns squared.) For 3F3 core material you may assume a maximum allowable flux density of 3000 gauss (0.3 T). You should also assume a maximum allowable current density in the windings of 500 A/cm^2. (Of course, the specified windings must fit within the winding area of the core.)

a.   Calculate the ripple ratio and peak inductor current for operation at full load (150 W).

b.   Design an inductor that meets the required specification. For simplicity, you may neglect inductor core and winding losses and inductor temperature rise. You should provide key information regarding your design (e.g., core, A_L value, number of turns, wire gauge) along with calculations necessary for evaluating your design (e.g., peak core flux density, current density, etc.).

c.   *(Optional – not graded)* Ambitious students may make an approximate calculation of inductor loss. To do so, compute the (approximate) losses in the inductor as the sum of winding and core losses. Winding power loss may be (crudely) approximated as the dc winding resistance times the rms inductor current squared. (In more sophisticated calculations, skin effect may be considered in the windings.) Core power loss in a 3F3 material core can be computed by approximating the ac flux in the core as sinusoidal, and calculating the core loss as:

$$P_{core} = 9.16 \times 10^{-13} \cdot \left(10^{-3} \cdot f_{sw} \right)^{1.231} \cdot \left(0.5 \cdot B_{pk} \right)^{2.793} \cdot V_{core}$$

where P_{core} is the core loss in Watts, f_{sw} is the switching frequency in kHz, B_{pk} is the peak *ac* flux swing in gauss, and V_{core} is the volume of the core in cm^3.
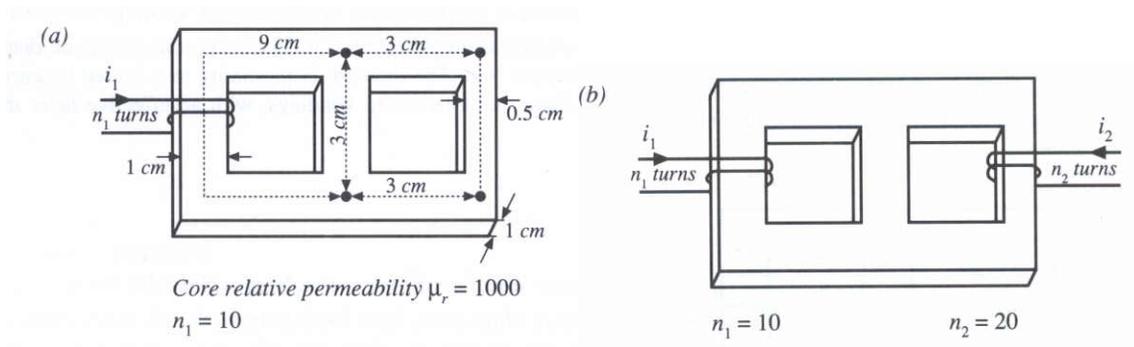
Figure 2 (a) A single-winding magnetic circuit. (b) A coupled-winding magnetic circuit.

RM cores and accessories   RM10/I

CORE SETS

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.462	mm^{-1}
V_e	effective volume	4310	mm^3
l_e	effective length	44.6	mm
A_e	effective area	96.6	mm^2
A_{min}	minimum area	89.1	mm^2
m	mass of set	≈ 22	g

Dimensions in mm.

Fig. 1 RM10/I core set.
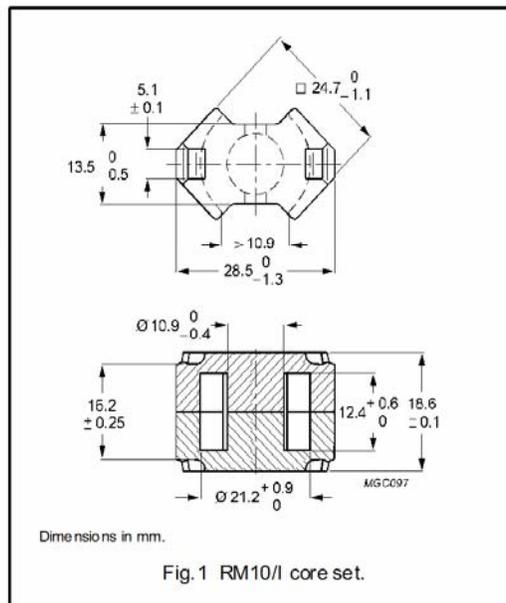
Core sets for filter applications

GRADE	A_L (nH)	μ_e	AIR GAP (μm)	TYPE NUMBER
3C90	160 ±3%	≈ 59	≈ 980	RM10/I-3C90-A160
	250 ±3%	≈ 92	≈ 570	RM10/I-3C90-A250
	315 ±3%	≈ 116	≈ 430	RM10/I-3C90-A315
	400 ±3%	≈ 147	≈ 330	RM10/I-3C90-A400
	630 ±3%	≈ 232	≈ 190	RM10/I-3C90-A630
	4500 ±25%	≈ 1650	≈ 0	RM10/I-3C90
3C91 des	5500 ±25%	≈ 2020	≈ 0	RM10/I-3C91
3C94	160 ±3%	≈ 59	≈ 980	RM10/I-3C94-A160
	250 ±3%	≈ 92	≈ 570	RM10/I-3C94-A250
	315 ±3%	≈ 116	≈ 430	RM10/I-3C94-A315
	400 ±3%	≈ 147	≈ 330	RM10/I-3C94-A400
	630 ±3%	≈ 232	≈ 190	RM10/I-3C94-A630
	4500 ±25%	≈ 1650	≈ 0	RM10/I-3C94
3C96 des	4050 ±25%	≈ 1680	≈ 0	RM10/I-3C96
3F3	160 ±3%	≈ 59	≈ 980	RM10/I-3F3-A160
	250 ±3%	≈ 92	≈ 570	RM10/I-3F3-A250
	315 ±3%	≈ 116	≈ 430	RM10/I-3F3-A315
	400 ±3%	≈ 147	≈ 330	RM10/I-3F3-A400
	630 ±3%	≈ 232	≈ 190	RM10/I-3F3-A630
	4050 ±25%	≈ 1490	≈ 0	RM10/I-3F3
3F35 prot	3100 ±25%	≈ 1190	≈ 0	RM10/I-3F35

COIL FORMER

General data

PARAMETER	SPECIFICATION
Coil former material	polybutyleneterephtalate (PBT), glass-reinforced, flame retardant in accordance with UL 94V-0; UL file number E45329(R)
Pin material	copper-tin alloy (CuSn), tin-lead alloy (SnPb) plated, transition to lead-free (Sn) ongoing
Maximum operating temperature	155 °C, "IEC 60085", class F
Resistance to soldering heat	"IEC 60068-2-20", Part 2, Test Tb, method 1B, 350 °C, 3.5 s
Solderability	"IEC 60068-2-20", Part 2, Test Ta, method 1

Dimensions in mm.

Fig.2 RM10/I coil former (DIL).
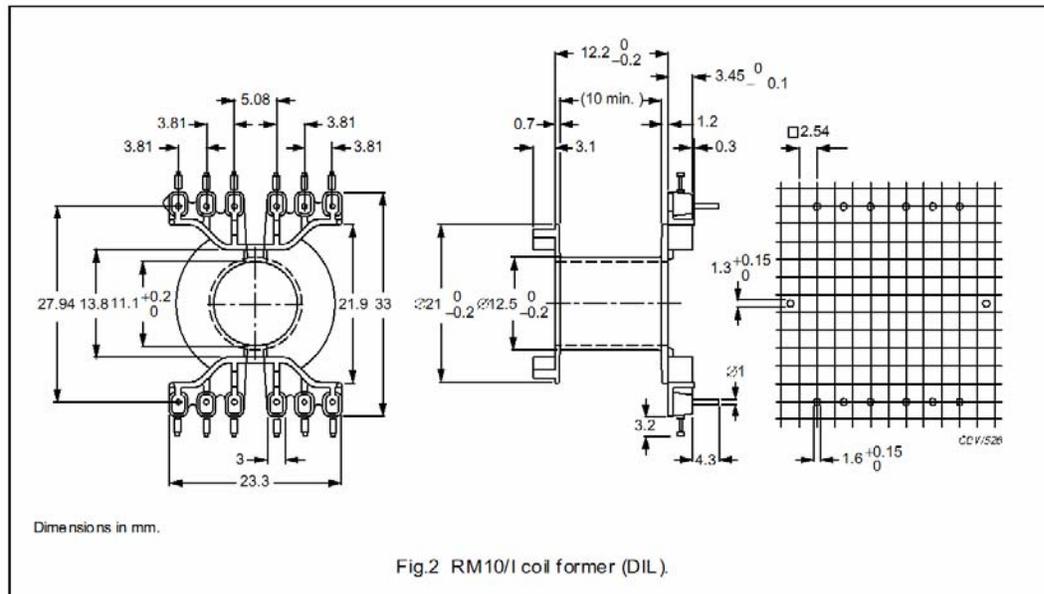
Winding data for RM10 coil former (DIL)

NUMBER OF SECTIONS	AVERAGE LENGTH OF TURN (mm)	WINDING AREA (mm²)	WINDING WIDTH (mm)	TYPE NUMBER
1	52	44.2	10.0	CPV-RM10-1S-12PD

CORE SETS

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.388	mm^{-1}
V_e	effective volume	8340	mm^3
l_e	effective length	56.6	mm
A_e	effective area	146	mm^2
A_{min}	minimum area	125	mm^2
m	mass of set	≈ 46	g

Dimensions in mm.

Fig. 1 RM12/I core set.
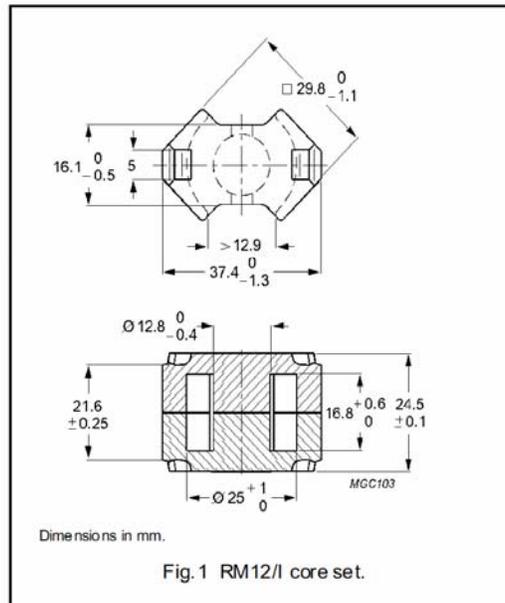
Core sets for general purpose transformers and power applications

GRADE	A_L (nH)	μ_e	AIR GAP (μm)	TYPE NUMBER
3F3	160 ±3%	≈ 49	≈ 1570	RM12/I-3F3-A160
	250 ±3%	≈ 77	≈ 900	RM12/I-3F3-A250
	315 ±5%	≈ 97	≈ 680	RM12/I-3F3-A315
	400 ±5%	≈ 123	≈ 510	RM12/I-3F3-A400
	630 ±5%	≈ 194	≈ 300	RM12/I-3F3-A630
	5050 ±25%	≈ 1560	≈ 0	RM12/I-3F3

Fig.2 RM12/I coil former (DIL).

Dimensions in mm.
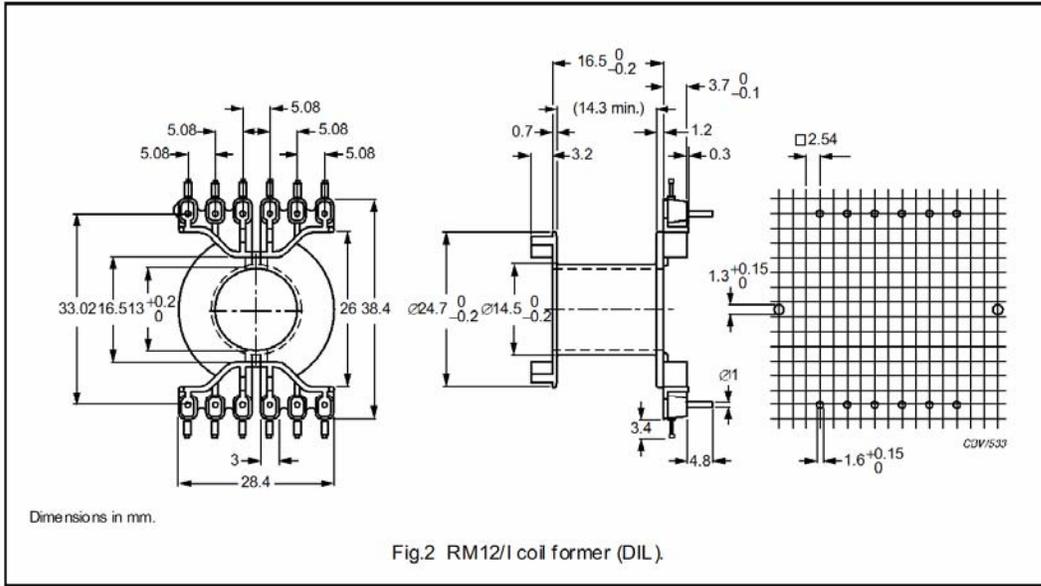
Winding data for RM12/I coil former (DIL)

NUMBER OF SECTIONS	AVERAGE LENGTH OF TURN (mm)	WINDING AREA (mm²)	WINDING WIDTH (mm)	TYPE NUMBER
1	61	75.0	14.3	CPV-RM12/I-1S-12PD