

# Switch Mode Power Supplies: SPICE Simulations and Practical Designs

Christophe Basso – August 2008

Compilation of typos, mistakes and errors found by readers (or by the author himself)  
First Edition

## Chapter 1

**Page xvi:** Sorry Monsieur Balocco, your name was misspelled with two “l”. One is enough:  
Dr. Didier Balocco from Saft Power Systems.

**Page 4:** equation (1-1) result is incorrect, it should be  $140 \Omega$  (Fig. 1-1 is ok though)

**Page 21:** I wrongly considered a 5-V output while it is 6 V given the 50% duty ratio. Calculation for  $\Delta I_L$  is thus 300 mA, not 350 mA. Same during the off time as the converter operates in CCM in this mode. When the load current reduces, so does the average inductor current in the buck. At a certain point – the critical load value later calculated – the valley current touches 0 and the converter enters DCM. Should you need to determine the converter operating mode, you look at the inductor current and check what the valley current is within a switching cycle. If non-0 this is CCM if 0, this is DCM. You can also observe it during start up or in a transient loading condition where it is likely that conduction mode transition occurs. Mathematically, you simply compare the inductor average current value to its peak as in Fig. 1-12a.

Contributed by Buddy Miles, March 2014.

**Page 22:** below equation (1-32): “for a buck,  $V_1 = V_{in} - V_{out}$  and not  $V_{out} - V_{in}$ .”  
Contributed by C. Denton, March 2008.

**Page 23:** in Fig. 1-12a, you should read “boundary” conduction mode.  
Contributed by Jason, May 2009

**Page 40/41:** in equation 1-83, I wrongly expressed the equality 1-83. The current starts from  $-\Delta I_L/2$  and needs to go back to that value. Therefore, the correct equation should be:

$$-\frac{\Delta I_L}{2} = \frac{\Delta I_L}{2} - \frac{V_{out}}{L} t_{off} \quad (1-83)$$

Re-arranging to extract  $\Delta I_L$  leads to

$$\Delta I_L = \frac{V_{out}}{L} t_{off} \quad (1-84)$$

Substituting Eq. (1-84) in Eq. (1-82) gives

$$\Delta V = \frac{T_{sw} V_{out}}{8CL} t_{off} \quad (1-85)$$

Knowing that  $t_{on} = DT_{sw}$  and  $t_{off} = (1-D)T_{sw}$  gives us a chance to massage equation 1-85:

$$\Delta V = \frac{T_{sw}^2 V_{out} (1-D)}{8CL} \quad (1-86)$$

...

Replacing  $LC$  in equation 1-86 and introducing  $F_{sw}$ , the switching frequency, it gives:

$$\Delta V = \frac{\pi^2 T_{sw}^2 V_{out} f_0^2 (1-D)}{2} \quad (1-89)$$

To simplify this expression, a possibility exists to normalize the ripple to the output voltage,  $V_{out}$ . Equation 1-89 can thus be updated as:

$$\frac{\Delta V}{V_{out}} = \frac{\pi^2 T_{sw}^2 f_0^2 (1-D)}{2} \quad (1-90)$$

Knowing that  $T_{sw} = \frac{1}{F_{sw}}$ , it comes:

$$\frac{\Delta V}{V_{out}} = \frac{\pi^2}{2} \left( \frac{f_0}{F_{sw}} \right)^2 (1-D) \quad (1-91)$$

Contributed by Wolfgang Kostorz, January 2011

**Page 43:** in the paragraph below Figure 1-27, ...connects to the switching node, not  $V_{out}$ .  
Contributed by Buddy Miles, March 2014.

**Page 50:** in Figure 1-34, the lower curve is incorrectly labelled  $\tau = 0.01$  whereas it should be  $\tau = 0.1$ .

Contributed by Wolfgang Kostorz, January 2011

**Page 57:** to gain a comprehensive understanding of the *buck*-boost operation... The word buck is missing.

Contributed by Kulsangcharoen Ponggorn, June 2008.

**Page 53:** in equation 1-126, the time "t" is missing in one of the terms. The correct equation should be:

$$\frac{1}{C} \int_0^t I_C(t) \cdot dt = \frac{1}{C} \left[ \frac{\Delta I_L}{t_{off}} \left( t_{off} t - \frac{t^2}{2} \right) + \frac{V_{out}}{R_{load}} \left( \frac{1}{D'} - 1 \right) t - \frac{\Delta I_L}{2} t \right] \quad (1-126)$$

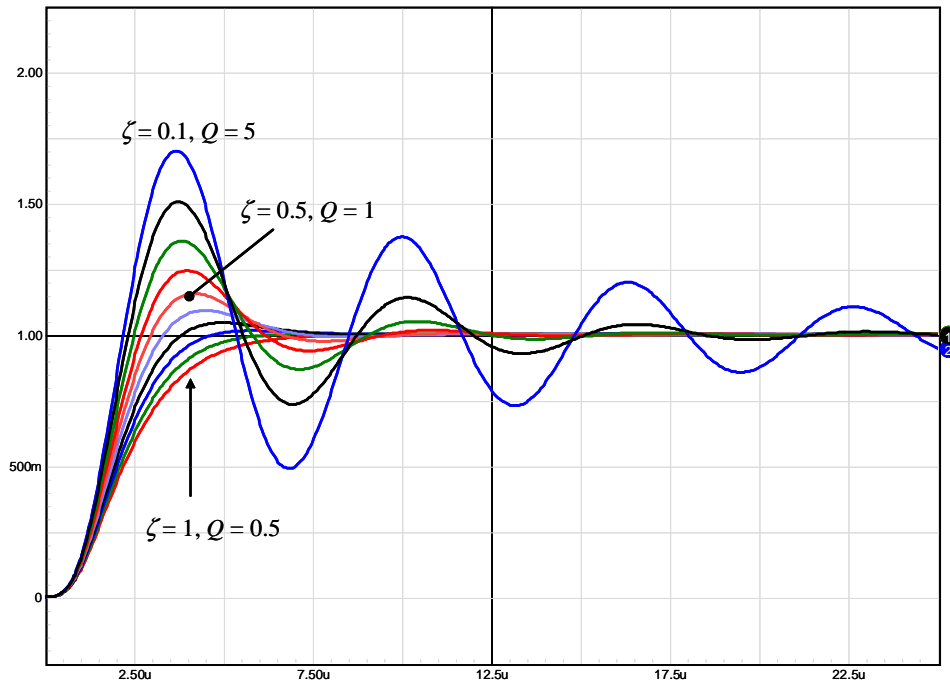
Contributed by Jason Canaday, July 2009

**Page 53:** in equation 1-125, the resistor is  $R_{load}$ , not  $R$ . The correct equation should be:

$$I_C(t) = \Delta I_L \left[ \frac{t_{off} - t}{t_{off}} \right] + \frac{V_{out}}{R_{load}} \left[ \frac{1}{D'} - 1 \right] - \frac{\Delta I_L}{2} \quad (1-125)$$

Contributed by Jason Canaday, July 2009

**Page 69, figure 1-50:** I don't know what happened to the captions on the graph, but those on the picture are certainly not at the right place. Here is the corrected graph:



**Figure 1-50**

**Page 71:** on page 71, in Figure 1-52, the top graph should be labeled 150  $\Omega$  and not 50  $\Omega$ .

Contributed by Michael Schutten, April 2010

**Page 83:** in step 4, you should read  $I_{ac} = 144$  mA rms and not 13 mA rms. Same correction in step 5 where the 13 mA term must be replaced by 144 mA.

Contributed by Hong Gu, June 2009

**Page 88:** in the definition of the **A** matrix, the coefficient  $a_{12}$  should be divided by C and not L:

$$\mathbf{A} = \begin{bmatrix} -\frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{(R_2 + R_3)L} & \frac{-R_3}{(R_2 + R_3)L} \\ \frac{R_3}{(R_2 + R_3)C} & -\frac{1}{(R_2 + R_3)C} \end{bmatrix}$$

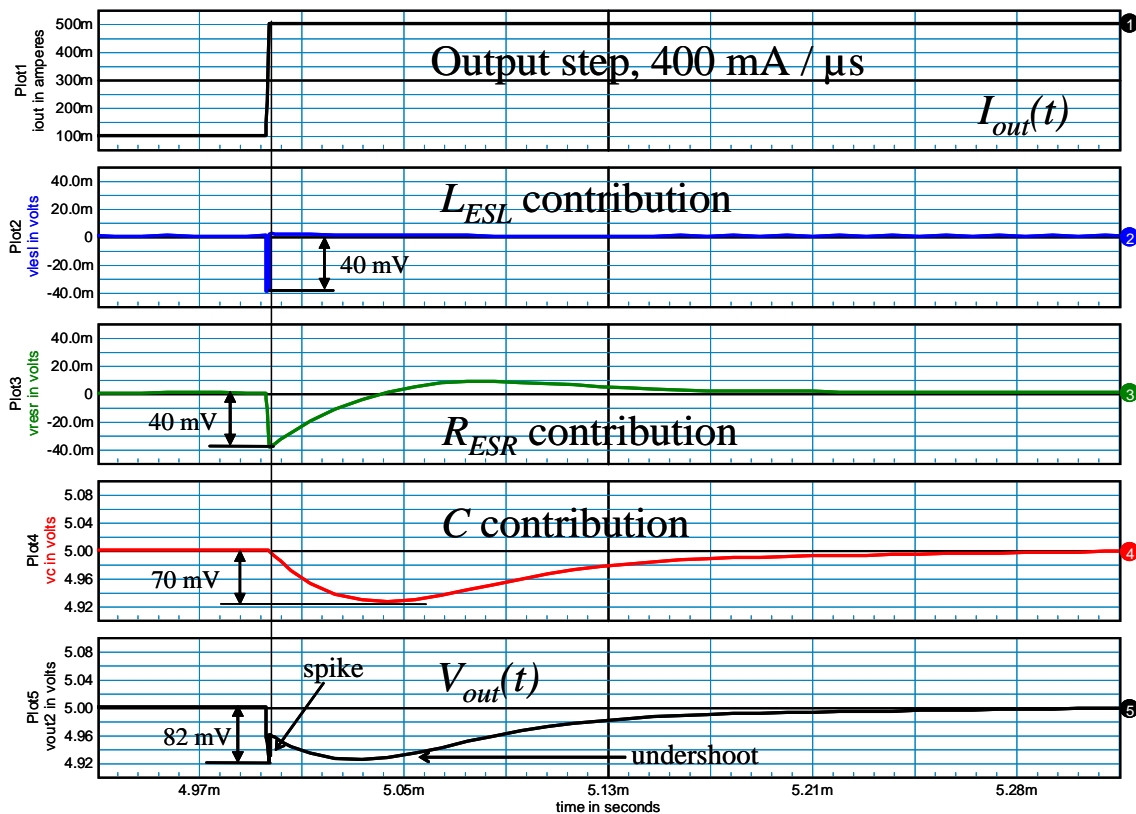
The output current susceptibility is also affected by a sign typo:

$$T_{1,2}(s) = -\frac{R_3}{R_1 + R_3} \frac{1 + sR_2C}{s^2 LC \left( \frac{R_3 + R_2}{R_1 + R_3} \right) + s \frac{L + C(R_2 R_3 + R_1 R_3 + R_2 R_1)}{R_1 + R_3} + 1}$$

Contributed by Mitch Buchowiecki, Nov. 2009

**Page 92, figure 1B-15:** the upper curve caption should be “output step, 400 mA/ $\mu$ s” and not “stemp, 400 mA/ms”!

**Page 92, figure 1B-15:** the amplitude caption in the figure is wrong, the 2 mV does not make sense. The real capacitor contribution alone is 70 mV as corrected in the below figure.



**Figure 1-B5:** ...step,  $S_1 = 400 \text{ mA}/\mu\text{s}$  (not 450 mA)

## Chapter 2

**Page 109:** in Eq. 2-54a, the minus sign has disappeared, you should actually read:

$$\hat{x}_1 = -\frac{1}{L}\hat{x}_2 + \frac{D}{L}\hat{u}_1 + \frac{\hat{d}}{L}u_{10}$$

Contributed by Johannes Eha, May 2009

**Page 111:** in Fig. 2-13, the right end of the x-axis should be labeled 100 kHz and not 110 kHz. Contributed by Thoralf Rosahl, Feb. 2009

**Page 121:** Figure 2-29, the parenthesis around  $(R.d')$  are incorrect. As correctly indicated by 2-75 it should be  $R.(d')^2$ .

Contributed by Dennis Cote, October 2011

**Page 127:** in equation (2-93), the  $/D'^2$  has gone:  $\frac{1}{sC/D'^2} + r_{cf}D'^2 = 0$

Contributed by Alain Laprade, January 2014

**Page 129:** In the text, “here we can read 335 mV or 33.5%” and not 419 mV or 41.9%. Contributed by Jie Yan, Feb. 2009

**Page 129:** the boost in CCM Bode plot does not include the ESR effects. The caption should then read: “Transfer function variations depending on the damping introduced by  $r_{Lf}$  with zero ESR”. Contributed by Thoralf Rosahl, May 2009

**Page 152:** Equation 2-137 should be  $I_L(0) = -S_1 dT_{sw} + \dots$  rather than  $\Delta I_L(0) = -S_1 dT_{sw} + \dots$

Contributed by Alex Kim, August 2009

**Page 159:** Equation 2-173 should be  $D_0 \frac{S_1 S_a}{S_2 S_1} = D_0 - \frac{1}{2}$ , leading to an updated equation 2-174:

$$S_a = \frac{S_2}{D_0} \left( D_0 - \frac{1}{2} \right). \text{ The conclusion in 2-175 is still correct.}$$

Contributed by Ricard Takase, October 2011

### Page 167, CCM PWM switch CM listing

A capacitor has been purposely added between terminals C and P to create the sub harmonic effects at half of the switching frequency. To obtain exactly the same curve as with Ridley models, the capacitor must be connected after the voltage source VM, between nodes cx and p accounting for the presence of this capacitor in the measured current. It was previously connected between c and p, leading to a slight high-frequency deviation. The correction has been included before print, the book listing is thus good.

Contributed by Ekrem Cengelci on May 2007.

**Page 174:** Equation 2-205: the unit should be s not  $\mu$ s, 52.8 kV/s

Contributed by Hawk Shang, August 2009

**Page 228:** there are two small typos in equation (2A-9) and  $H_c$  definition:

$$\frac{V_{out}(s)}{V_{err}(s)} = F_m H_c \frac{1 + \frac{s}{\omega_{z1}}}{\left(1 + \frac{s}{\omega_{p1}'}\right) \left(1 + \frac{s}{\omega_{p2}'}\right)} \text{ and } H_c = \frac{2m_c V_{out}}{D} \frac{1-M}{2m_c - (2+m_c)M}$$

Contributed by Hawk Shang, March 2010

**Page 230:** the definition for  $k_1$  features  $M(1-M)$ . It should actually be  $M(M-1)$ .

Contributed by Thoralf Rosahl, May 2009

**Page 235:** in bullet 2: ...sense resistor  $R_i$  to the secondary side via  $R' = NR_i$ .

Contributed by YangFu, January 2013

**Page 236:** Eq. (2B-6) should be:  $T(t) = 1 - 2e^{-t} + e^{-2t}$

Contributed by Jason Neudorf, May 2008.

## Chapter 3

**Page 245:** In Fig. 3-5, the capacitor CoL should be 1 kF and not 1 kH.

Contributed by Aleksander Ansion, Feb. 2009

**Page 256:** the section header 3.5.5 should be better labeled "Type 2 Amplifier - Origin Pole plus Zero-Pole-Pair"

Contributed by Thoralf Rosahl, Feb. 2009

**Page 264:** in equation 3-27a, the compensator gain must be the opposite of that of the plant at the considered crossover frequency. Therefore, the equation must exhibit a minus sign in the exponent:

$$G = 10^{-\frac{G_{fc}}{20}} \quad (3-27a)$$

Contributed by Pascal Fritz, 25/10/2012

**Page 268:** Fig. 3-22, page 268: in the picture,  $R_{load}$  should be 2.5  $\Omega$  and not 2.5 W.

Contributed by C. Denton, March 2008.

**Page 269:** Fig. 3-23a, page 268: in the picture,  $f_c$  should be 5 kHz and not 5 Hz.

Contributed by C. Denton, March 2008

**Page 276:** Fig. 3-28, page 276: in the schematic parameters list,  $f_{p2}$  should be 50k and not 50.

Contributed by C. Denton, March 2008.

**Page 288:** The table describing the TL431 and TLV431 features an obvious typo. The breakdown voltage of the TLV431 is not 1 V but 18 V!

Reference	Vref	Ibias,min	Precision	Max voltage	Max current
TL431I	2.495 V	1 mA	$\pm 2\%$ @ 25 °C	36 V	100 mA
TL431A	2.495 V	1 mA	$\pm 1\%$ @ 25 °C	36 V	100 mA
TL431B	2.495 V	1 mA	$\pm 0.4\%$ @ 25 °C	36 V	100 mA
TLV431A	1.24 V	100 $\mu$ A	$\pm 1\%$ @ 25 °C	18 V	20 mA
TLV431B	1.24 V	100 $\mu$ A	$\pm 0.5\%$ @ 25 °C	18 V	20 mA

Contributed by Chalermkiat, June 2008.

**Page 293:** Fig. 3-39, page 293: in the schematic parameters list, it should be  $f_c = 1k$  and not just “1” and below should be  $pm = 100$  and not  $kpm = 100$ .

Contributed by C. Denton, March 2008.

**Page 308:** In the text: ...phase margin. And this IS an important point. The “is” is missing.

Contributed by Johannes Eha, July. 2012

**Page 349:** Equation 3-29 is obviously missing the imaginary operator:

$$\arg(T(f)) = boost = \arg\left(\frac{1 + j\frac{f}{f_{z_0}}}{1 + j\frac{f}{f_{p_0}}}\right) = \tan^{-1}\left(\frac{f}{f_{z_0}}\right) - \tan^{-1}\left(\frac{f}{f_{p_0}}\right)$$

Contributed by Johannes Eha, July. 2012

**Page 289:** figure 3-37  $k_1/k_2$  coefficients are ok, just add a “-“ sign to  $CTR * R_{pullup}/R_{LED}$ .

Contributed by Simon, May. 2009

**Page 312:** “However, *if* the copper...” and not “*it* the copper...”

Contributed by Jie Yan, Feb. 2009

**Page 322:** Reference 3. → “Note from the author: it’s too old, can’t find place...”. Obviously, this sentence was left over during the editing process!

**Page 331:** “...TL431’s ability...” and not “TL431’a ability...”

Contributed by Jie Yan, Feb. 2009

## Chapter 4

**Page 349:** The in-line equation in 4.3 is wrong, as well as the reference in the text. It should be:

$$B1 \text{ INT GND } V=I(Vdum) < 1.5m ? (Vref) + V(in) * 1m$$

IF the output current is less than 1.5 mA THEN the source delivers  $V_{ref} + V(in) \times 1m$  in series with a  $2.5 \Omega$  resistor. The term  $V_{ref} + V(in) \times 1m$  represents the  $-60$  dB input susceptibility.

Contributed by Johannes Eha, July. 2012

**Page 353:** The *PSpice* code reproduced at the right bottom of the page should be:

*GINT 0 INT* and not *BGINT 0 INT*

Contributed by Jie Yan, Feb. 2009

**Page 359:** The netlist is supposed to be a *PSpice* netlist, the in-line equation for  $B_1$  is actually an *IsPspice* code. The correct version should be:  $E1 \ 4 \ 0 \ Value = \{ IF ( V(3,30) > 5, 5, 0 ) \}$

Contributed by Jie Yan, Feb. 2009

**Page 398:** The sentence “To avoid saturation of the design...” below equation (4A-20) is obviously misplaced. This sentence must actually be placed equation below (4A-22). Why? Because saturation phenomena are different if you talk about an inductor or a transformer. For an inductor, (4A-20) can be rewritten  $NB_{sat}A_e > A_l N^2 I_{L,max}$  which, after simplification by  $N$  gives  $B_{sat}A_e > A_l N I_{L,max}$  in which  $A_l$  is the core specific inductance value. In case you observe saturation in a flyback transformer or in a power inductor, you thus must decrease  $N$  or gap the core (or increase the existing gap):  $A_l$  goes down (so does  $L$ ) and the saturation current increases. In a transformer, flux excursion in the core depends on the magnetizing current  $I_{mag}$ , not on the winding current. Saturation occurs because  $I_{mag}$  runs away in fault conditions where the product  $t_{on}$  by  $V_{in}$  is maximum. Reducing  $N$  in this case or gapping the core does not fix the issue as  $L$  would drop, bringing an even higher  $I_{mag}$ , the opposite you want. So in this case, you must increase  $N$  (to increase  $L_{mag}$ ) and certainly not gap the core. Exceptions exist for active-clamp forward converters where we need magnetizing current circulation to discharge the drain-source lump capacitance.

Contributed by Bullet Bandit, April. 2014

**Page 402:** in equation 4B-11, the word *open* as slipped, it should be put besides ...and the *primary* of course.

Contributed by Jie Yan, Feb. 2009

**Page 402:** in equation 4B-12, the  $A$  should be  $A^2$

$$L_{l1} = L_1 - \sqrt{L_3 L_2 - L_3 L_1 - L_1 L_2 + L_1^2 + \frac{L_4 L_1 - L_4 L_3}{A^2}} = 58.5 \mu\text{H}$$

Contributed by the author

## Chapter 5

**Page 411:** “Numerical application gives a cutoff frequency of 54 kHz” and not 45 kHz.

Contributed by Kulsangcharoen Ponggorn, July 2008.

**Page 418, equation 5-17:**

*This equation defines the diode conduction losses by:*

$$P_{cond,diode} = V_f I_{d,avg} + R_d I_{d,rms}^2 \quad (5-17)$$

In the above expression,  $V_f$  should be replaced by  $V_{T0}$  where  $V_{T0}$  represents the threshold voltage of the junction. If you look at figure 1 (see the appendix at the end), the diode model appears on the right side. It combines a constant voltage source,  $V_{T0}$ , in series with a dynamic resistor  $R_d$ . The total voltage drop  $V_f$  measured at a given current  $I_{d0}$ , combines  $V_{T0}$  and the dynamic resistor drop. If you use  $V_f$  as in Eq. (5-17), the term  $R_d$  is counted twice. Therefore, the total average power dissipated by the diode is correctly expressed by:

$$P_{cond} = V_{T0} I_{d,avg} + R_d I_{d,rms}^2 \approx V_f I_{d,avg}$$

$V_{T0}$  depends on the diode technology. It is measured when the diode starts conducting (a few hundred of  $\mu A$ ). The drop is roughly 0.4 V for a Schottky and 0.6 V for a PN diode.

### **The correction is as follows:**

... The conduction losses for a diode are given by

$$P_{cond} = V_{T0} I_{d,avg} + R_d I_{d,rms}^2 \approx V_f I_{d,avg} \quad (5-17)$$

where  $I_{d,avg}$  = average current in the diode

$V_f$  = forward voltage at the considered diode current

$V_{T0}$  = forward voltage at which the diode starts to conduct ( $\approx 0.4$  V for a Schottky,  $\approx 0.6$  V for a PN diode)

$R_d$  = .....

**Page 445:** the first term of the formula 5-63 is wrong, the formula should be:

$$f_0 = \frac{1}{2\pi\sqrt{L_e C}} = \frac{1-D}{2\pi\sqrt{LC}}$$

Contributed by Jie Yan, Feb. 2009

**Page 455:** below Fig. 5-10a: ...we have installed a divider by **11** such that the upper current limit (2.5 A) corresponds to a **1.1-V** output voltage.

Contributed by Umut DEMIREZEN, 5/10/2008

**Page 456:** the slope of (5-81) is obviously kV/s. Then  $D'_0$  is  $1-D_0$  so the denominator of (5-82) is (1-464m) and the result is 1.52. (5-83) updates to 284 kV/s and (5-84) is  $S'_a$  equal to 11.4 kV/s. The pole  $f_p$  is lightly affected and now it equals 357 Hz (replace x 1.76 by x 1.52). (5-86) updates to 223 k $\Omega$ .

Contributed by Wayne Fit, January 2013.

**Page 457:** in bullet 4., the calculation refers to a 70- $^\circ$  phase margin and not a 60- $^\circ$  target.

Contributed by Umut DEMIREZEN, 5/10/2008

**Page 460:** in the sentence, the *and* is wrong: “we display the input current at low input voltage” and not “...*and* low input voltage.”

Contributed by Jie Yan, Feb. 2009



**Page 467:** in equation 5-98, the first denominator factor (0.1) needs to be 1:

$$L = \frac{0.9 \times 15^2 \times 12^2}{1 \times 100k \times 24 \times (15 + 12)(12 + 0.9 \times 15)} = 17.6 \mu\text{H}$$

Contributed by Ektoras, April. 2013

**Page 469: figure 5-14a:**

The caption should say ...The CCM *buck-boost* converter...

## Chapter 6

**Page 501:** Equation 6-41b is wrong but the result is ok:

$$I_{d,avg} = \frac{P_{conv}}{2\eta V_{bulk,avg}} = 0.56 \text{ A} \quad (6-41b)$$

**Page 513:** in equation 6-59, the *rms* subscript is missing:

$$P_{in,apparent} = V_{1,rms} \sqrt{\sum_{n=1}^{\infty} I_{n,rms}^2} = V_{1,rms} I_{rms}$$

Contributed by Jie Yan, Feb. 2009

**Page 514:** "...extracting  $k_d$  from eq. (6-66)..." and not (6-67).

Contributed by Jie Yan, Feb. 2009

**Page 562: equation 6-166**

It should be  $R_1$  not  $R_3$ :

$$R_1 = \frac{275 \times \sqrt{2} - 3}{250u} = 1.6 \text{ M}\Omega$$

**Page 564: equation 6-173**

The square should be a factor 2

$$C_{bulk} = \dots = \frac{P_{out}}{2\pi F_{line} V_{out} \Delta V} = \frac{P_{out}}{\omega V_{out} \Delta V}$$

## Chapter 7

**Page 583: FIGURE 7-3a**

The PWL definition in the figure should be: V2 4 0 Pulse 0 5 0 10n 10n 5u 10u

Contributed by R. MacIvain, July 2008.

**Page 586: FIGURE 7-4a**

The PWL definition in the figure should be: V2 4 0 Pulse 0 5 0 10n 10n 5u 10u

Contributed by R. MacIvain, July 2008.

**Page 588:** "...the equation affecting the plot n°3 in figure 7-4c should be: ...+  $V_{in}$  +  $V_{leak}$  and not  $V_{teak}$ .

Contributed by Mohammad Monfared, Nov. 2009

**Page 623:** equation 7-79 should be:  $V_{DS} = V_{in} + \frac{V_{out} + V_f}{N} + V_{leak}$

Contributed by Mohammad Monfared, Nov. 2009

**Page 623:** in equation 7-80, the right term must be multiplied by  $F_{sw}$ :

$$V_{DS} \approx V_{in,max} + \frac{V_{out} + V_f}{N} + \frac{2L_{leak} P_{out} F_{sw}}{\eta V_{in,max} D_{min} (1 - D_{min})}$$

Contributed by Zaikin Denis, Dec. 2009

**Page 624:** in equation 7-88, the right term must be multiplied by  $F_{sw}$ :

$$V_{C_{clamp},max} \approx \frac{V_{out} + V_f}{N} + \frac{2L_{leak} P_{out} F_{sw}}{\eta V_{in,max} D_{min} (1 - D_{min})}$$

$$= \frac{19+1}{0.166} + \frac{2 \times 20u \times 76 \times 65k}{0.85 \times 370 \times 0.236 \times (0.764)} = 124 \text{ V}$$

Contributed by Zaikin Denis, Dec. 2009

### Page 633: voltage-mode control table

The dc gain,  $V_{out}/V_{error}$ , should be:

$$\frac{NV_{in}}{(1-D)^2 V_{peak}} \quad \text{The } N \text{ is missing}$$

**Page 646:** the notation for the current is misleading. Rather than  $IC_{V_{cc}}$  it should be  $I_{CV_{cc}}$

Contributed by Jie Yan, Feb. 2009

**Page 647:** in equation 7-116 it should be  $V_{ac,peak}$  and not  $V_{act...}$

Contributed by Mohammad Monfared, Nov. 2009

**Page 649:** in Figure 7-39, the MOSFET reference for M1 is wrong. A LND150 is a depletion-mode (always on) type of device from Supertex. You can nicely use it in this application but blocking it requires a different architecture (see AN-D25 on Supertex site). For the figure, a Zetex reference such as ZXMN0545G4 will work fine.

Contributed by Buddy Miles, April 2014

**Page 651:** in equation 7-127, the term  $V_{bulk,max}$  is missing in the middle of the equation. It should be:  $P_{DSS} = I_{CC} V_{bulk,max} = (I_4 + Q_G F_{sw}) V_{bulk,max} = \dots$

Contributed by Mohammad Monfared, Nov. 2009

**Page 652:** ...below 15 V, then there is no arm to let the driver... → there is no harm!

Contributed by C. Denton, April 2008.

**Page 660:** in figure 7-52, the label on the upper left corner should be  $L_s$  and not  $Laux$ .

Contributed by Mohammad Monfared, Nov. 2009

**Page 663:** after (see Early effect). With an output...  
Contributed by Mohammad Monfared, Nov. 2009

**Page 663:** "...if the controller hosts..." and not ...*it* the controller...  
Contributed by Jie Yan, Feb. 2009

**Page 679, equation 7-166:**

$$P_d = V_{T0} I_{d,avg} + R_d I_{d,rms}^2 + DI_R PIV \approx V_f I_{d,avg} \quad (7-166)$$

**Page 693, equation 7-204:**

$$P_d = V_{T0} I_{d,avg} + R_d I_{d,rms}^2 + DI_R PIV \approx V_f I_{d,avg} \quad (7-204)$$

**Page 705:** In Fig. 7-85, the emitter U1 (the optocoupler) should of course go the primary ground and not the secondary one!  
Contributed by Aleksander Ansion, Feb. 2009

**Page 712:** Below equation 7-252: ... selecting a 860  $\mu$ H *inductor* and not indicator...  
Contributed by Simon Buchwald, June. 2009

**Page 713:** Figure 7-90 vertical axis:  $P_{out}$  must be replaced by  $P(W)$   
Contributed by Boris Popov, December 2012

**Page 726:** bullet 1, ...for a given printed circuit board (pcb) area.  
Contributed by Mohammad Monfared, Nov. 2009

**Page 735:** a disambiguation is needed here. The conclusion that "no gap is needed" could lead to the wrong conclusion. You actually always need a gap in a flyback transformer, it helps reduce the remanent flux density  $B_r$  by tilting the  $B-H$  curve: energy storage is greatly improved and saturation current – not  $B_{sat}$  – is increased. Having a gap creates other problems besides mechanical operations to grind the central leg. Fringing flux near the central leg (where the gap is introduced) frying the wires in high-power designs is a known failure mechanism. Companies such as Magnetics offer what they call a distributed air-gap. They trap non-magnetic particles while building the core and distribute the gap in the core itself. Precision is good as they claim an  $A_l$  at +/-8%. The Kool-M $\mu$ <sup>®</sup> core used in the example features a distributed air gap and does not need an extra one, this is what the conclusion implied. Of course, for all other non distributed air gap cores, you absolutely need to gap the core.

Contributed by Bullet Bandit, April. 2014

## Chapter 8

**Page 765:** Equation 8-24 has an extra letter for the  $C_{lump}$  term. It should read:

$$P_{sw,lump} = \frac{1}{2} C_{lump} V_{in}^2 F_{sw} \quad (8-24)$$

Contributed by Prapat Chumchairat, 30/8/2008

**Page 767:** the unequality sign is not on the right direction for Eq. (8-28). It should be:

$$\frac{1}{2\pi\sqrt{L_{mag}C_T}} \gg \frac{1}{2T_{sw}(1-D_{max})} \quad (8-28)$$

Contributed by Prapat Chumchairat, 30/8/2008

**Page 809:** in fig. 8-50, the label in the right bottom should be  $(1-d)T_{sw}$  and not  $(1-d)dT_{sw}$ .

Contributed by Jie Yan, Feb. 2009

**Page 810:** in fig. 8-51, the label in the lower left side be  $N_{s_1} = \frac{N_{s_2}}{n}$  and not  $N_{s_1} = nN_{s_2}$ .

Contributed by John Tsinetakes, Dec. 2011

**Page 825, table 8-2:**

In the “where” section, the definition for  $S_n$  has to be changed:

$S_n = \frac{NV_{in} - V_{out}}{L} NR_{sense}$  this is the on-time secondary slope reflected to the primary.

The equation given in the page,  $S_n = \frac{V_{in}}{L_p} R_{sense}$ , corresponds to the magnetizing current slope.

It can, by the way, be considered as a free external ramp.

**Page 827:** the equivalent inductor calculation for the forward was actually carried for non-coupled inductors. This correction has been reported to me by Mr Arturo Galgani who kindly shared his derived formulas.

In a transformer respectively featuring primary and secondary inductors  $L_1$ ,  $L_2$ , respectively affected by turns  $N_{L1}$  and  $N_{L2}$ , the input voltage  $V_1$  and output voltage  $V_2$  are linked by:

$$V_1 = L_1 \frac{dI_{L_1}}{dt} + M \frac{dI_{L_2}}{dt} = L_1 S_1 + M \cdot S_2$$

$$V_2 = L_2 \frac{dI_{L_2}}{dt} + M \frac{dI_{L_1}}{dt} = L_2 S_2 + M \cdot S_1$$

Where  $S$  is current slope in each inductor and  $M$  represents the mutual inductance defined by:

$$M = k\sqrt{L_1 L_2} \quad \text{with } k \text{ the coupling coefficient}$$

Solving for the respective slopes:

$$S_1 = -\frac{L_2 V_1 - M V_2}{M^2 - L_1 L_2} \quad S_2 = -\frac{L_1 V_2 - M V_1}{M^2 - L_1 L_2}$$

We know that  $N$  turns wound on a magnetic medium affected by a specific inductor factor  $A_l$  give an inductor  $L$  equal to:  $L = A_l N^2$

$$L_1 = N_{L1}^2 A_l \text{ and } L_2 = N_{L2}^2 A_l$$

$$M = k\sqrt{L_1 L_2} = kN_{L1} N_{L2} A_l$$

For proper current balance in the coupled inductors, we have  $\frac{N_{L2}}{N_{L1}} = \frac{N_2}{N_1}$ . Therefore,

$N_{L2} = \frac{N_2}{N_1} N_{L1}$  where  $N_1$  and  $N_2$  are the turns ratios of the forward transformer respectively delivering  $V_{o1}$  and  $V_{o2}$ , where  $N_{L1}$  and  $N_{L2}$  are the turns ratios of the coupled inductors.

Substituting the above in  $M$  gives us:

$$M = kN_{L1} \frac{N_2}{N_1} N_{L1} A_l = kN_{L1}^2 \frac{N_2}{N_1} A_l$$

In CCM, both output voltages are linked by a coefficient  $\alpha$ :

$$N_2 = \alpha N_1 \quad \text{and} \quad V_{o2} = \alpha V_{o1}$$

The voltage across the inductors is defined by:

$$V_2 = V_{in} N_2 - V_{o2} \quad \text{and} \quad V_1 = V_{in} N_1 - V_{o1}$$

$M$  can be updated to become:  $M = kN_{L1}^2 \frac{\alpha N_1}{N_1} A_l = kN_{L1}^2 \alpha A_l$

The output voltage  $V_{o2}$  and the second inductor  $L_2$  can be re-defined in relationship to  $V_{o1}$  and  $L_1$ :

$$V_2 = V_{in} \alpha N_1 - \alpha V_{o1} = \alpha (N_1 V_{in} - V_{o1})$$

$$L_2 = (N_{L1} \alpha)^2 A_l$$

Substituting the above in the first transformer definitions leads us to:

$$S_1 = -\frac{V_{o1} - N_1 V_{in}}{A_l N_{L1}^2 (k+1)} \quad S_2 = -\frac{V_{o1} - N_1 V_{in}}{A_l N_{L1}^2 \alpha (k+1)}$$

The primary reflected slope is simply the sum of the individual slopes:

$$S_p = s_1 N_1 + S_2 N_2$$

We know that  $N_2 = \alpha N_1$ , therefore :  $S_p = N_1 (S_1 + \alpha S_2)$ . Finally, we have :

$$S_p = -\frac{2N_1(V_{o1} - N_1V_{in})}{A_l N_{L1}^2 (k+1)} \quad \text{by replacing } A_l N_{L1}^2 \text{ by } L_1 \text{ and divided by } N_1, \text{ we have:}$$

$$S_p = \frac{V_{in} - \frac{V_{o1}}{N_1}}{\frac{L_1}{N_1^2} (k+1)} \quad \text{from which we can extract the equivalent inductor seen from the}$$

$$\text{primary: } L_{eq} = \frac{L_1}{N_1^2} \frac{(k+1)}{2}$$

For a converter featuring  $p$  outputs, the equivalent inductor is :

$$L_{eq} = \frac{L_1}{N_1^2} \frac{(p-1)k+1}{p}$$

For those interested by the small-signal model of the multi-output forward converter with coupled inductors, please read the following paper written by Milan Jovanovic:

["Small-signal modeling and analysis of current-mode control for multiple-output forward converters."](#) Q. Chen, M. M. Jovanovic, and F. C. Lee, *IEEE Power Electronics Specialists Conference (PESC) Rec.*, Taipei, Taiwan, June 20-24, 1994, pp. 1026-1033

Contributed by Arturo Galgani, 15/11/2008

**Page 834:** in the equation 8-124, this is  $I_p$  and not  $I_D$  that is used:

$$P_{cond} = I_{p,rms}^2 R_{DS(on)} @ T_j = \dots \quad (8-124)$$

**Page 834:** in the equation 8-125c, the voltage across the MOSFETs in a 2-SW forward converter before turn-on is actually half the bulk voltage if the  $DS$  capacitances are balanced. Therefore the equation has to be updated with a further division by 2:

$$P_{SW,on} = \frac{I_{valley} V_{bulk,max} \Delta t}{12} F_{sw} = \frac{1.56 \times 400 \times 45n}{12} \times 100k \approx 235 \text{ mW} \quad (8-125c)$$

**Page 834:** small typo on the current  $I_{valley}$  (or  $I_{peak}$ ) should be  $I_{p,valley}$  or  $I_{p,peak}$  :

$$P_{SW,on} = \frac{I_{p,valley} V_{bulk} \Delta t}{12} F_{sw} \quad \text{eq. 8-125a}$$

$$P_{SW,on} = \frac{I_{p,valley} V_{bulk,max} \Delta t}{12} F_{sw} = \frac{1.56 \times 400 \times 45n}{12} \times 100k \approx 235 \text{ mW} \quad \text{eq. 8-125c}$$

$$P_{SW,off} = \frac{I_{p,peak} V_{bulk} \Delta t}{2} F_{sw} \quad \text{eq. 8-125d}$$

$$P_{SW,off} = \frac{I_{p,peak} V_{bulk,max} \Delta t}{2} F_{sw} = \frac{1.84 \times 400 \times 45n}{2} \times 100k = 1.65 W \quad \text{eq. 8-125e}$$

Contributed by T. Sutto, May 2008.

**Page 838:** the formula 8-137 has to be updated since eq. 8-125C delivers 235 mW and not 470 mW:  $P_{tot} = P_{cond} + P_{SW,on} + P_{SW,off} = 1 + 0.235 + 0.48 \approx 1.715 W$

Contributed by Jie Yan, Feb. 2009

**Page 856:** equation 8B-12

The equation should be:  $C_{eq} = C_{L2} \left( \frac{N_3}{N_2} \right)^2 \parallel C_{L1}$ , the  $C_{L2}$  sub term is missing.

For equations 8B-13c and 8B-13d,  $F_{sw}$  should be replaced by  $f$ , where  $f$  is a sinusoidal signal of course.

**Page 860:** equation 8C-2

In the numerical application, the  $10^4$  is gone, but the result is correct:

$$W_a A_c = \frac{P_{out}}{K_c K_t B_{max} F_{sw} J} 10^4 = \frac{250 \times 10000}{507 \times 0.0005 \times 0.11 \times 100000 \times 400} = 2.24 cm^4 \quad \text{eq. 8C-2}$$

Contributed by T. Sutto, May 2008.

**Page 869:** the word “to” is missing ...an active clamp circuit **to** improve the converter’s...