CMP
United Business Media
POWER MANAGEMENT DesignLine

HOME | HOW-TO | PRODUCTS | BLOGS | NEWS | FORUMS | TECH LIBRARY | ABOUT | FEEDBACK | NEWSLETTER | RSS | CONTACT

Products

Self-learning switching DC-DC converters meet smart power

By Gabriel A. Rincón-Mora, Senior Member, IEEE, and H. Pooya Forghani-zadeh, Student Member, IEEE; Georgia Tech Analog and Power IC Design Lab

Page 1 of 4

Power Management DesignLine
(10/13/2005 11:19 AM EDT)

PRINT THIS STORY
SEND AS EMAIL
DISCUSS THIS STORY

High-performance, state-of-the-art applications demand smart power supplies to be adaptive, power efficient, and reliably accurate, which is why monitoring inductor current flow in a lossless fashion is desirable and critical for protection, power-moding, and feedback control [1-2]. A handful of lossless current-sensing techniques are available today but their accuracies still do not compete with the traditional series sense-resistor schemes, and that is, for the most part, because the current is sensed by *estimating* the impedance of some series element and extrapolating the value of the current from the voltage across it, as Ohm's law dictates [3].

Estimating the power MOSFET's turn-on resistance R_{on}, for instance, is inherently inaccurate because of its wide process, supply voltage, and temperature dependence, varying from approximately 50% to 200%. Additionally, the measured current only flows within a portion of the period, which requires a switched sample-and-hold circuit, another noise-generating device. Using an embedded current-sensing MOSFET, a power transistor's sister mirroring device sourcing a small fraction of the current (i.e., mirror ratio of typically over 1,000), is better with regard to accuracy but still inaccurate and also discontinuous, and only practical for on-chip power devices. Although accuracies of ±4% are reported [4], mismatch and process sigma variations across such a large spread of mirroring devices can reach ±20% [5].

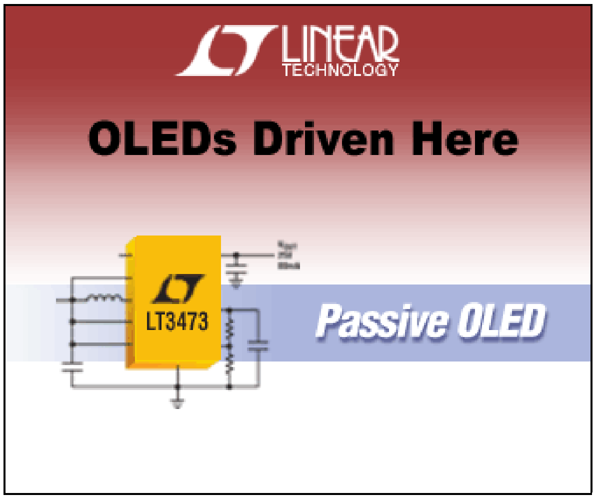
The only continuous and therefore less noisy and more useful scheme for current-mode switching supplies is the matched-filter method [6]. In this scheme, the series impedance of the inductor and its equivalent series resistor (ESR) (that is, Ls + ESR) is matched against the series impedance of an RC network (for example, R + 1/Cs). Since both impedances are equal and they are subjected to the same voltage, their currents are also equal, which is why the displacement current through the RC filter is a direct measure of the inductor current. The accuracy of this technique, however, depends on how well matched the RC network is to the inductor-ESR combination, and that can lead up to ±28% error, given ±15% inductance, ±11% ESR, and temperature (for example, 70 °C) variations, and more if extended to commercial and military temperature ranges. The RC filter is therefore external to the controller IC and typically custom-designed.

Page 2: Know the inductance

Page 1 | 2 | 3 | 4

PRINT THIS STORY
SEND AS EMAIL
DISCUSS THIS STORY

eSearch go Advanced Search



Top 5 Most Read How-To Stories

1. Self-learning switching DC-DC converters meet smart power
2. Self-powered systems -- can they eliminate the need for batteries?
3. Underutilized SEPIC outperforms the flyback topology
4. How to Charge Li-Ion Batteries for Portable Devices More Efficiently
5. How to cut power consumption for high-speed apps with A/D converter architecture

Top 5 Most Read News Stories

1. IR wins $6.2 million in IXYS patent suit
2. Alcohol-powered MP3 player
3. Valere powers ahead with

Top 5 Most Read Product Stories

1. LED driver circuit uses non-isolated buck-boost for lighting signs
2. High-voltage IGBT drivers take half the space
3. Half-Bridge N-Channel MOSFET Driver ICs prevent shoot-through current
4. Ultracapacitor modules ease integration of alternatives to batteries
5. Step-down DC-DC converter powers processor in portables

Knowing the inductance

How can IC designers know the impedance? They can't…but the circuit can learn it during start-up and/or through power-on reset events; in other words, the system can measure the inductance-ESR impedance during down-times. Figure 1 illustrates how this approach can be applied to a buck (step-down) DC-DC converter using the above-described continuous filter scheme, where V_{Sense} is directly proportional and calibrated against inductor current I_L. The shaded block is the G_m-C filter whose gain-bandwidth product is *tuned* with transconductor g_{m1} and DC gain *calibrated* with resistor R_2 during a system down-time, aided by transistors M_a and M_b, both of which are off during normal operating conditions. The rest of the circuit is simply the power train of the switching supply, comprised of inductor L and its ESR R_L, output capacitor C_o, and high and low power MOS transistors M_L and M_H. Once the gain-bandwidth product and DC gain are properly adjusted (that is, filters are matched), the values are digitally stored and the DC-DC converter is allowed to power up and operate normally. Since the learning cycle only affects start-up, their associated power losses are non-existent during normal operating conditions, which is why this scheme is considered lossless.

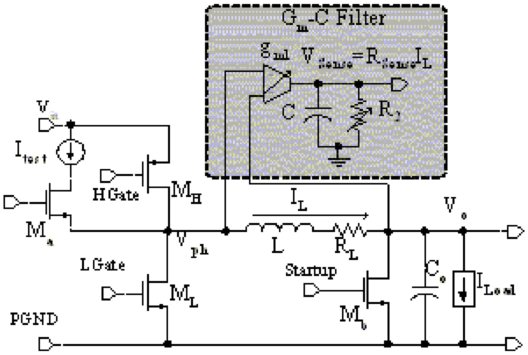


Figure 1. Self-learning current-sensing G_m-C filter

.

The design and self-learning goal of the filter scheme is to match the series impedance of the inductor-R_L combination with the R_2C filter during the learning cycle. Following Ohm's law, inductor current I_L is inversely proportional to its series impedance and directly proportional to the voltage across it (V_L):

$$I_L = V_L\left(\frac{1}{R_L + sL}\right) = \frac{V_L}{R_L}\left(\frac{1}{1 + {}^{sL}/_{R_L}}\right) \quad \textbf{(1)}$$

The R_2C network, in this case, is a G_m-C filter with output voltage V_{Sense} equal to:

$$V_{Sense} = V_L g_{m1} R_2 \left(\frac{1}{1 + sR_2C}\right) \quad \textbf{(2)}$$

Consequently, adjusting R2 to ensure inductor current bandwidth RL/L equals filter bandwidth 1/R2C sets VSense to:

$V_{Sense} = (g_{ml}R_2R_L)\ I_L$ how does this look?

$$V_{Sense} = (g_{m1}R_2R_L)I_L \quad \textbf{(3)}$$

and if $g_{m1}R_2R_L$ is tuned to a known constant R_{Sense}, V_{Sense} is a direct measure of inductor current I_L,

$$V_{Sense} = R_{Sense}I_L \quad \textbf{(4)}$$

Page 3: Set the conditions

Page 1 | 2 | 3 | 4

PRINT THIS STORY
SEND AS EMAIL
DISCUSS THIS STORY

Chinese group

4. Liquid battery power

5. Smart Power

Tech Library

¤ Current research, from Georgia Institute of Technology School of Electrical Engineering.

¤ Get a report on analog power management products from Databeans.

¤ What's your ability to think like an engineer? Test your engineering quotient.

More from TechLibrary

CMP
United Business Media

POWER MANAGEMENT DesignLine

HOME | HOW-TO | PRODUCTS | BLOGS | NEWS | FORUMS | TECH LIBRARY | ABOUT | FEEDBACK | NEWSLETTER | RSS | CONTACT

Products

Self-learning switching DC-DC converters meet smart power

Set the conditions

By Gabriel A. Rincón-Mora, Senior Member, IEEE, and H. Pooya Forghani-zadeh, Student Member, IEEE; Georgia Tech Analog and Power IC Design Lab

Page 3 of 4

Power Management DesignLine
(10/13/2005 11:19 AM EDT)

PRINT THIS STORY
SEND AS EMAIL
DISCUSS THIS STORY

To set these conditions, the circuit is subjected to a programming sequence during its down-time, but only after all start-up and power-on-reset functions are asserted and stabilized. First, a triangular current with a frequency significantly higher than inductor and G_m-C bandwidths R_L/L and $1/R_2C$, respectively, is injected into the inductor-R_L network to ensure resistances R_L and R_2 are negligibly smaller and larger than the inductor and capacitor's impedances, respectively (Figure 2). Consequently, a mostly square waveform appears across the inductor (that is, V_L L dI_p/dt), which the g_{m1}/C filter integrates back into a triangle (that is, dV_{Sense}/dt I_{gm1}/C),

$$V_{Sense} = I_{gm} Z_C = (V_L g_{m1})\left(\frac{1}{Cs}\right) = (I_L [L s] g_{m1})\left(\frac{1}{Cs}\right) = \left(\frac{g_{m1}L}{C}\right) I_L$$

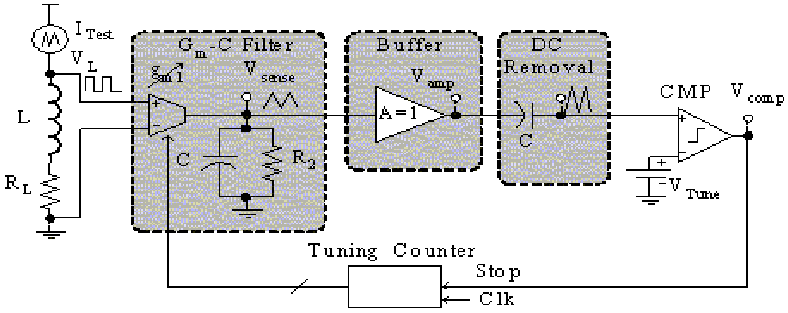
(5)

The ac portion of V_{Sense} is compared against V_{Tune} and the counter gradually tunes g_{m1} until the peak of V_{Sense} equals V_{Tune}, at which point the filter gain-bandwidth product (that is, g_{m1}/C) is set, setting and storing g_{m1} to:

$$g_{m1} = \frac{C V_{Tune}}{L I_{Peak}}$$

(6)

where I_{Peak} is the peak value of the triangular input test current.



eSearch [go] Advanced Search

Top 5 Most Read How-To Stories

1. Self-learning switching DC-DC converters meet smart power

2. Self-powered systems -- can they eliminate the need for batteries?

3. Underutilized SEPIC outperforms the flyback topology

4. How to Charge Li-Ion Batteries for Portable Devices More Efficiently

5. How to cut power consumption for high-speed apps with A/D converter architecture

Top 5 Most Read News Stories

Top 5 Most Read Product Stories

1. LED driver circuit uses non-isolated buck-boost for lighting signs

2. High-voltage IGBT drivers take half the space

3. Half-Bridge N-Channel MOSFET Driver ICs prevent shoot-through current

4. Ultracapacitor modules ease integration of alternatives to batteries

5. Step-down DC-DC converter powers processor in portables

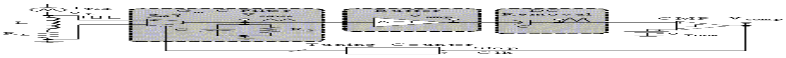


Figure 2. Tuning circuit.

.

The end of the tuning cycle marks the onset of the calibration phase, at which point a DC test input current equal to I_{Peak} is injected into the inductor-R_L network, as shown in Figure 3. The impedance across inductor L and capacitor C at DC are significantly smaller than R_L and larger than R_2, respectively. The resulting sense voltage is therefore:

$$V_{Sense} = (I_{Peak} R_L)(g_{m1} R_2) \quad (7)$$

which is subsequently compared against V_{Tune}. Like before, the counter cycles and adjusts R_2 until V_{Sense} is equal to V_{Tune}, setting the DC transimpedance gain (that is, $R_{Lgm1}R_2$) of the network, or:

$$R_2 = \frac{V_{Tune}}{I_{Peak} R_L g_{m1}} = \left(\frac{V_{Tune}}{I_{Peak} R_L}\right) \cdot \left(\frac{L I_{Peak}}{C V_{Tune}}\right) = \frac{L}{R_L C} \quad (8)$$

where the previously set g_{m1} (Equation. 6) is substituted in. The new relation satisfies the original intent of equating inductor current bandwidth R_L/L to filter bandwidth 1/R(sub>2C, and by setting V_{Tune}/I_{Peak} to known constant R_{Sense}, $g_{m1}R_2R_L$ is similarly defined to R_{Sense}:

$$g_{m1} R_2 R_L = \left(\frac{C V_{Tune}}{L I_{Peak}}\right) \cdot \left(\frac{L}{R_L C}\right) \cdot R_L = \frac{V_{Tune}}{I_{Peak}} \equiv R_{Sense} \quad (9)$$

and Equation. 4 is satisfied.

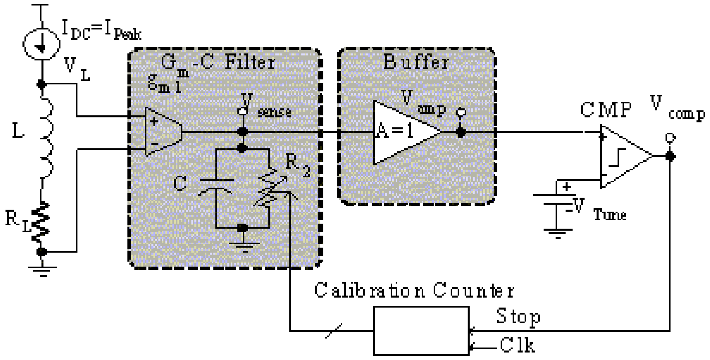


Figure 3. Calibration circuit.

.

Page 4: Summary

Page 1 | 2 | 3 | 4

PRINT THIS STORY
SEND AS EMAIL
DISCUSS THIS STORY

Power Management DesignLine Marketplace (sponsored links)

Measurement Computing: $99 for USB 24 DIO bits
The best value in DAQ. USB-1024LS offers 24 bits for just $99. USB-DIO96H offers 96 DIO bits (with high current 64mA sink, 24mA source outputs) for $299. USB-PDISO8 offers 8 electromechanical relays, 8 isolated digital inputs for $299.

Free Guide to Processor Bus Fundamentals Webinar
Join Brian Holden, Principal Engineer of PMC-Sierra, for a guide to different processor bus aspects and technologies including common older standards such as ISA, EISA, PCI and PCI-X, and newer standards such as HyperTransport, PCI Express and RIO.

Intel Communications Alliance
Join the Intel Communications Alliance community, accelerate time-to-market, and find the latest technical information committed to the development of modular, standards-based solutions based on Intel technologies.

FREE National Instruments TestStand 3.1 Evaluation
NI TestStand is a ready-to-run, commercial-off-the-shelf test management environment and framework for organizing, controlling, and executing automated prototype, validation, and manufacturing test systems.

1. IR wins $6.2 million in IXYS patent suit

2. Alcohol-powered MP3 player

3. Valere powers ahead with Chinese group

4. Liquid battery power

5. Smart Power

NetSeminar Services
A list of upcoming NetSeminars, plus a link to the archive.

- Looking at the World Different(ial)ly
- New Horizons for Batteries and Portable Power
- TTI's Technical Seminar Series: Be Smart - Choose the Right Part
- Software Build Toolbox: Build Your Own Makefile Debugger
- Low-cost ARM microcontrollers with full-speed, fully compliant USB 2.0

Welcome to our DesignLine network of web communities. On these sites, we provide practical how-to design information for **automotive**, **audio**, **digital TV**, **industrial control**, **mobile handset**, **networking**, **power management**, **programmable logic**, **video/imaging** and **wireless networking** engineers and system designers. Check out the sites and let us know your thoughts.

Center gives designers a deeper understanding of how to use the unique advantages of DirectFET devices and how they increase electrical and thermal performance. To learn more, click here.

Tech Library

¤ Current research, from Georgia Institute of Technology School of Electrical Engineering.

¤ Get a report on analog power management products from Databeans.

¤ What's your ability to think like an engineer? Test your engineering quotient.

More from TechLibrary

CMP
United Business Media
POWER MANAGEMENT DesignLine

HOME | HOW-TO | PRODUCTS | BLOGS | NEWS | FORUMS | TECH LIBRARY | ABOUT | FEEDBACK | NEWSLETTER | RSS | CONTACT

Products

Self-learning switching DC-DC converters meet smart power

Summary

By Gabriel A. Rincón-Mora, Senior Member, IEEE, and H. Pooya Forghani-zadeh, Student Member, IEEE; Georgia Tech Analog and Power IC Design Lab

Page 4 of 4

Power Management DesignLine
(10/13/2005 11:19 AM EDT)

PRINT THIS STORY
SEND AS EMAIL
DISCUSS THIS STORY

In spite of self-learning, bias-induced and trimming accuracy errors still exist in the system. Current density and temperature settings, for instance, change from the self-learning sequence to the normal operating mode (the test current is for the most part smaller than the load current because of power and associated on-board real-estate concerns). These errors can be adjusted empirically, but not exactly. A first-order temperature dependence, for example, can be superimposed onto R_{Sense}. The input-referred offset and linearity of the transconductor across its wide input-common mode range (ICMR) will also impose errors. A linear, low offset transconductor with wide ICMR limits is therefore required. Nevertheless, a PCB prototype implementation of the technique presented exhibited overall full-load DC and AC gain errors of less than 2.3% and 5%, respectively, which is significantly better than previously reported lossless techniques [7]. A complete on-chip prototype is currently under development [8].

For additional details, questions, and/or comments on this article, please contact us, the Georgia Tech Analog and Power IC Design Lab, at gtap@ece.gatech.edu. More information about our research can be found at http://www.rincon-mora.com/research.

References

[1] R. Erickson and D. Maksimovic, Fundamentals of power electronics. Norwell, MA: Kluwer, 2001.
[2] M. Gildersleeve, H. P. Forghani-zadeh, and G. Rincón-Mora "A comprehensive power analysis and a highly efficient, mode-hopping DC-DC converter," in Proc. 2002 IEEE Asian Pasific-ASIC, pp. 153-156.
[3] H.P. Forghani-zadeh and G.A. Rincón-Mora, "Current-sensing techniques for dc-dc converters," in Proc. 2002 Midwest Symposium on Circuits and Systems, pp. 577-580.
[4] C. Lee and P. Mok, "A monolithic current-mode CMOS DC-DC converter with on-chip current-sensing technique," IEEE Journal of Solid States Circuits, vol. 39, Jan. 2004, pp. 3-14.
[5] P. Drennan and C. McAndrew, "Understanding MOSFET mismatch for analog design," IEEE Journal of Solid States, pp. 450-459, March 2003.
[6] E. Dallago, M. Passoni and G. Sassone, "Lossless current sensing in low voltage high current dc/dc modular supplies," IEEE Trans. Industrial Electronics, vol. 47, pp. 1249-1252, Dec. 2000.
[7] H.P. Forghani-zadeh and G.A. Rincón-Mora, "A Lossless, Accurate, Self Calibrating Current-Sensing Technique for DC-DC Converters," IEEE's Industrial Electronics Conference (IECON), Raleigh, North Carolina, November 6-10, 2005.
[8] H.P. Forghani-zadeh and G.A. Rincón-Mora, "A Low Glitch, Continuous Low-Offset, Programmable Gain and Bandwidth, Gm-C Filter," IEEE's 48th Midwest Symposium on Circuits and Systems (MWSCAS), Cincinnati, Ohio, August 7-10, 2005.

eSearch go Advanced Search

Top 5 Most Read How-To Stories

1. Self-learning switching DC-DC converters meet smart power

2. Self-powered systems -- can they eliminate the need for batteries?

3. Underutilized SEPIC outperforms the flyback topology

4. How to Charge Li-Ion Batteries for Portable Devices More Efficiently

5. How to cut power consumption for high-speed apps with A/D converter architecture

Top 5 Most Read News Stories

1. IR wins $6.2 million in IXYS patent suit

2. Alcohol-powered MP3 player

3. Valere powers ahead with

Top 5 Most Read Product Stories

1. LED driver circuit uses non-isolated buck-boost for lighting signs

2. High-voltage IGBT drivers take half the space

3. Half-Bridge N-Channel MOSFET Driver ICs prevent shoot-through current

4. Ultracapacitor modules ease integration of alternatives to batteries

5. Step-down DC-DC converter powers processor in portables