A Different Approach to Current-Sensing in DC-DC Converters

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October 25, 2002

Abstract

Current-sensing is one of the most important tasks in a smart power chip. Available current-sensing techniques are not lossless and accurate at the same time. For lossless operation, only the information of voltage nodes should be used (no additional resistor), but accurate measurement of current requires the knowledge of passive elements in the circuit branches. The dc-dc controller, integrated circuit designer is incognizant of the values of off-chip elements at the IC design time, and this makes the design of lossless and accurate current-sensing system a challange. To address these issues, a current-sensing scheme is proposed to be integrated, general purpose, lossless and accurate. The proposed system uses a first order Gm-C filter to reconstruct the inductor behavior. At the startup, the Gm-C filter is tuned and calibrated for improving the accuracy. The system level simulations in Cadence Spectre simulator verify the concept.

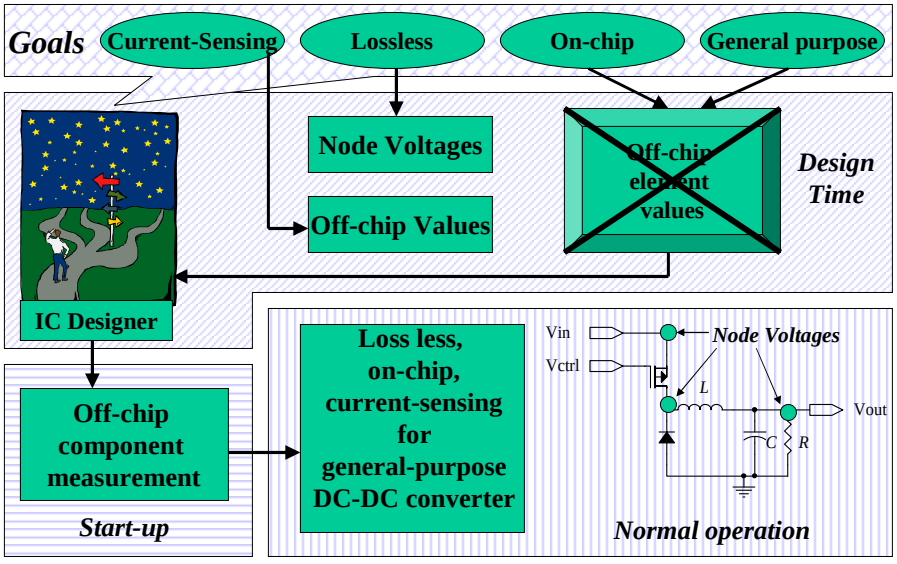
Overview of Available Techniques[1]

Technique	Advantages	Disadvantage
A. R_{SENSE}	Accuracy	High power dissipation
B. R_{DS}	Lossless	Low accuracy
C. L_{Filter}	Lossless	Known L Proper for output current>10A
D. Observer	Lossless	Known L
E. $I_{Average}$	Lossless	Known inductor ESR Average inductor current only
F. Transformer	Lossless	Cost Size Not integratable No I_{DC} information Not practical
G. SENSEFET	Lossless Integratable Practical Moderate Accuracy	Matching issues (N↑→accuracy↓) Special MOSFETs May have low bandwidth

[1] H.P. Forghani-zadeh, G. Rincon-mora, "Current-Sensing Techniques for DC-DC Converters", in proceedings of 45th Midwest Symposium on Circuits and Systems, August 2002.

H. Pooya Forghani-zadeh 3

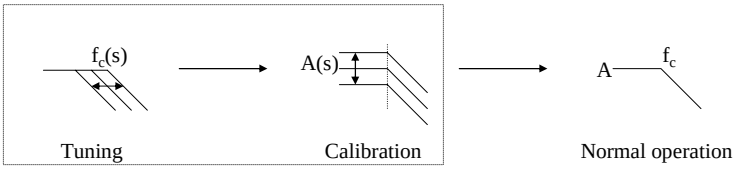
Requirements for Integrated-Circuit Solutions



H. Pooya Forghani-zadeh 4

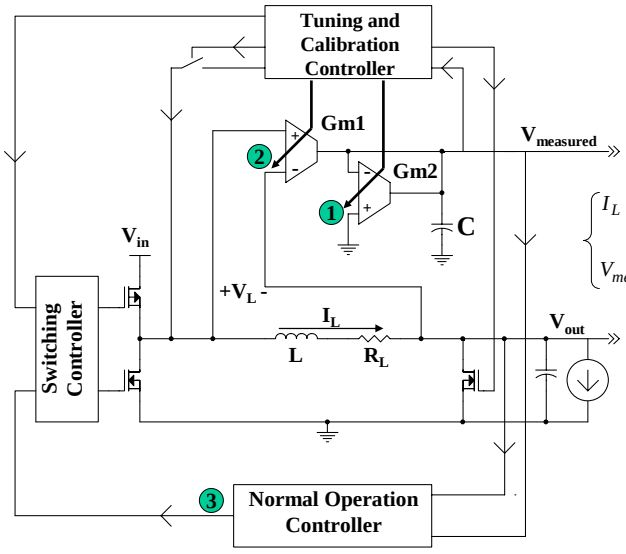
Proposed System at a Glance

- Proposed system uses a first order low pass Gm-C filter to imitate the inductor behavior
- The Gm-C filter input is the voltage across the inductor
- If the cutoff frequency of Gm-C low-pass filter is equal to the cutoff frequency of the inductor (caused by L and R_L), the Gm-C filter output is proportional to the inductor current
- The operation of proposed system consists of three stages:
  1- Tuning (during startup)
  2- Calibration (during startup)
  3- Normal operation



H. Pooya Forghani-zadeh 5

Proposed System Block diagram



Operation Stages:
1. Tune (Gm2)
2. Calibrate (Gm1)
3. Normal operation

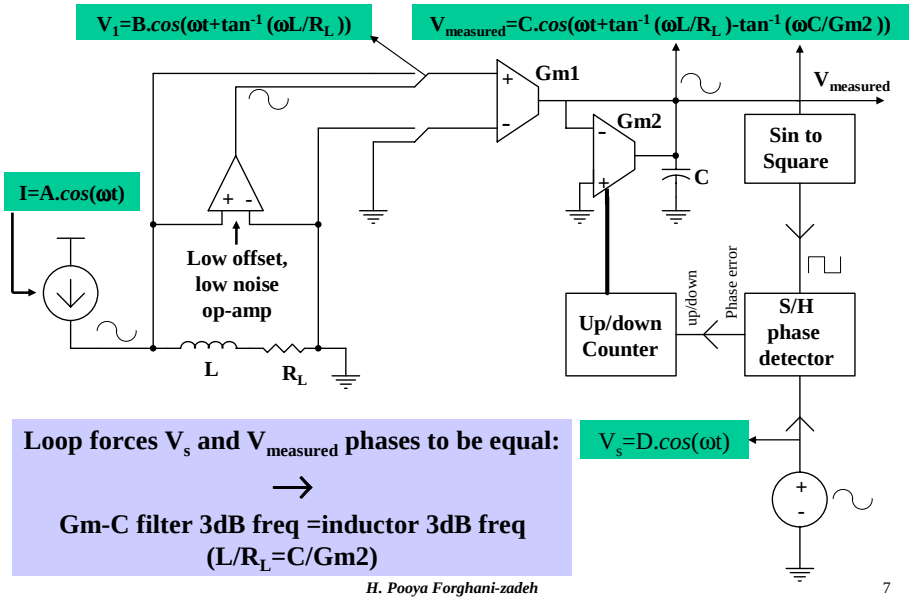
$$\begin{cases} I_L = \dfrac{1}{(R_L + sL)} V_L \\ V_{measured} = \dfrac{Gm1}{Gm2}\left(\dfrac{1}{1+s(C/Gm2)}\right) V_L \end{cases}$$

If $(L/R_L)=(C/Gm2)$

$$V_{measured} = \frac{Gm1}{Gm2} R_L I_L$$

H. Pooya Forghani-zadeh 6

Tuning Operation



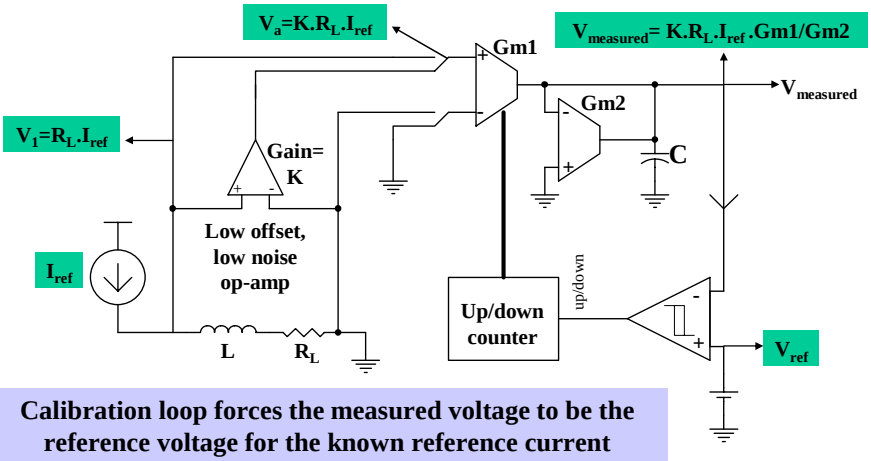
Loop forces V_s and $V_{measured}$ phases to be equal:

→

Gm-C filter 3dB freq =inductor 3dB freq
($L/R_L=C/Gm2$)

H. Pooya Forghani-zadeh 7

Calibration Operation

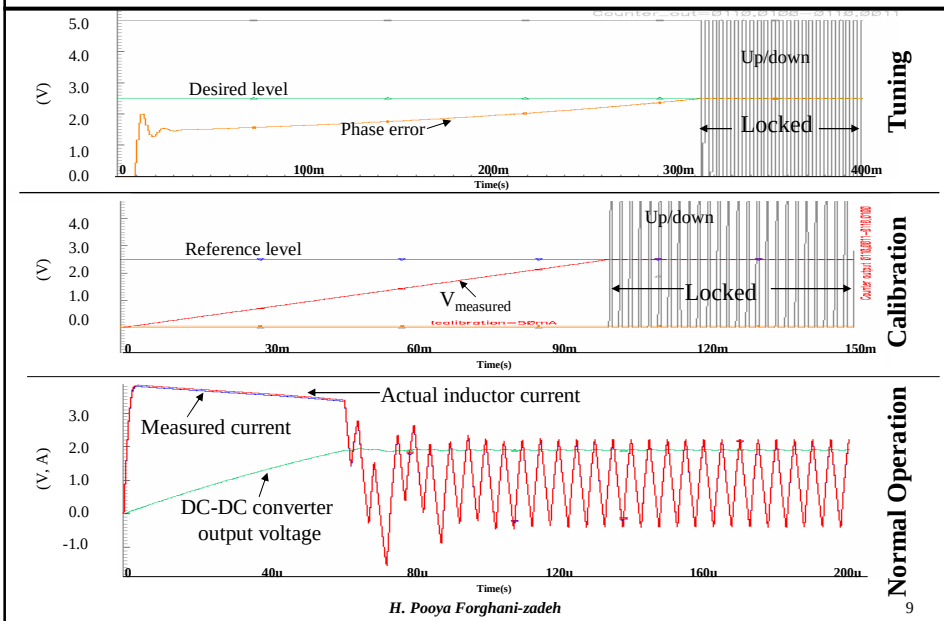


Calibration loop forces the measured voltage to be the reference voltage for the known reference current
($V_{measured}= V_{ref} \rightarrow I_{ref}.R_L.K.Gm1/Gm2=V_{ref}$)

→ For Normal operation:
$V_{measured}=I_L.R_L.Gm1/Gm2= I_L\{V_{ref}/(K\ I_{ref})\}$

H. Pooya Forghani-zadeh 8

Simulations

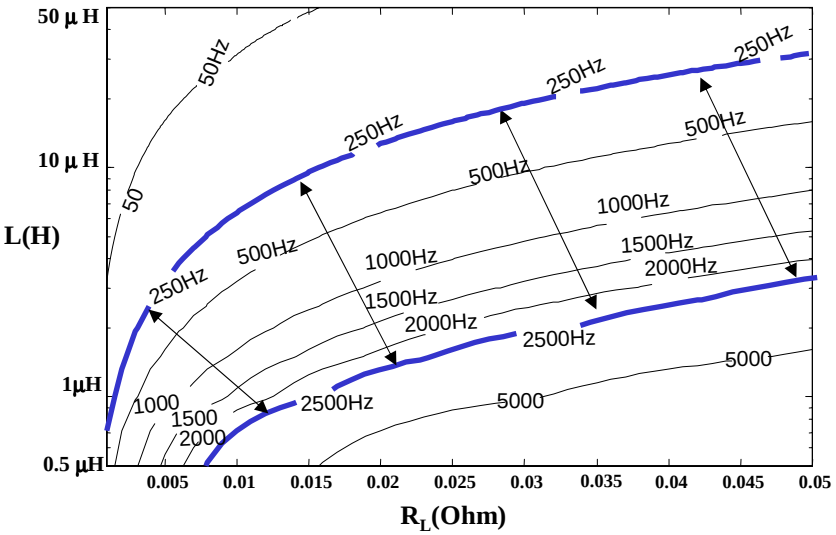


H. Pooya Forghani-zadeh

9

Acceptable L/ESR Range for 5% Error

C=200pF, Gm1=1uA/V-256uA/V (1uA/V steps) and Gm2=10nA/V-2.56uA/V (10nA/V steps)



H. Pooya Forghani-zadeh

10

Conclusions and Future Work

- Implementation challenges:
  1. Low offset op-amp (offset in the order of 10μV)
  2. Linear, digitally programmable Gm (transconductance) cells
- Accuracy is a function of Gm cell programmability, voltage and current references
- Temperature variations, resulting in changes in inductor specifications, may cause errors in the measurement system, but such is the case in other techniques
- To address the above problem, calibrating and tuning can be done again whenever it is possible in this system
- Future work:
  Prototype system