Integrated Current Sensing Circuit Techniques for DC-DC Converters

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Abstract

Current Sensing is used widely in smart power chips, especially DC/DC controllers. Conventional current sensing methods apply a resistor in the path of the current to be sensed. This method incurs significant power losses in high output currents. Six alternative lossless current-sensing techniques are presented and problems of each technique are discussed.

Objective

Design and develop current sensing techniques with the following properties:

- Loss less (Low Power Dissipation)
- Accurate
- Independent of value of discrete components such as inductor and filter capacitor

Applications of Current Sensing

- Over current protection
- As a part of feedback control loop in current mode controllers
- Mode Hoping for increasing efficiency
  A.PWM constant frequency, DCM ⇔ PWM constant frequency, CCM [1]
  B.PWM constant frequency, CCM ⇔ Constant on time control, DCM [2]

[1] A. Prodic and D. Maksimovic,"Digital PWM controller and current estimator for a low-power switching converter" , The 7th Workshop on Computers in Power Electronics,COMPEL 2000, pp. 123 –128, 2000
[2] *T. Wang , X. Zhou and F. Lee* ,"A low voltage high efficiency and high power density DC/DC converter", 28th Annual IEEE Power Electronics Specialists Conference 1997, Vol.1, pp. 240 –245,1997

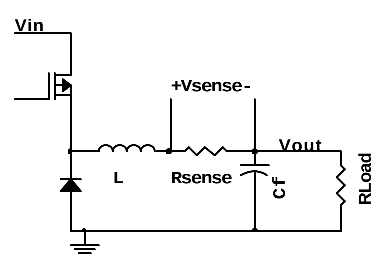
Traditional way of current sensing

This technique inserts a sense resistor in the path of current and sense the voltage across the sense resistor. The same technique is used in ampere-meters.

$$I_{sense} = \frac{V_{sense}}{R_{sense}}$$

Main Drawback:
Power Dissipation
(Not Lossless)

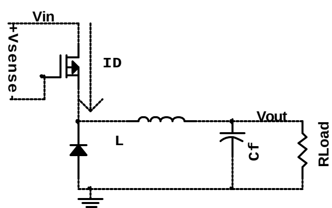
Application: Desktop computers ;
High accuracy is achievable



For high accuracy V_{sense}=100mv at full load ; If I_{rmsmax}=1A → R_{sense}=0.1Ω
Conduction loss due to this sense resistor is 0.1watt at full load
If V_{out}=2.5v → P_{out}=2.5 watt at full load → Efficiency is decreased about 4%
This technique would cause in higher power dissipation as the output voltage decreases

Lossless Current Sensing Techniques(1)

A.MOSFET R_{DS} Current Sensing

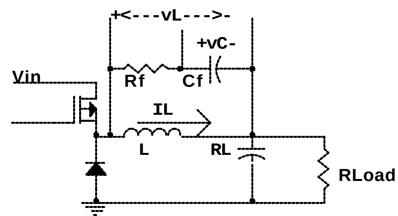


$$V_{sense} = R_{DS} I_D$$

$$R_{DS} = \frac{L}{WmC_{ox}(V_{GS} - V_T)}$$

Disadvantage : Low accuracy; Accuracy is about 30%-40%
Application: Over current protection

B.Inductor Sensing (Filter)



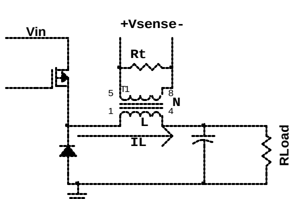
$$v_c = \frac{1}{1+R_f C_f s} v_L = \frac{R_L + Ls}{1+R_f C_f s} I_L = R_L \frac{1+L/R_L s}{1+R_f C_f s} I_L$$

If $L/R_L = R_f C_f \rightarrow v_c = R_L I_L$

Problem: C_f and R_f depend on R_L and $L \rightarrow$ Good for discrete implementation $\rightarrow$Low accuracy if proper values of C_f and R_f are not selected.

Lossless Current Sensing Techniques(2)

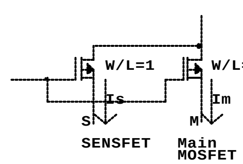
C.Transformer Current Sensing



$$V_{sense}(AC) = \frac{I_L(AC)}{N} R_t$$

If $N >> 1 \rightarrow I_L(AC)/N << I_L(AC) \rightarrow$ Low power dissipation
Problem:The transformer only passes the *AC* part of $I_L \rightarrow$ No information about the average current $\rightarrow$ Not proper for over-load protection

D.SENSEFET Technique

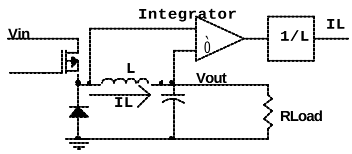


$$I_s = \frac{I_m}{N}$$

N- $\rightarrow$ (I_s/I_m)¯ $\rightarrow$
Current sensing loss ¯
Problems*:*
1. *N*- ® *Accuracy of N*¯ ® *Accuracy of Technique* ¯
2. The accuracy of current mirrors degrades in high frequencies

Lossless Current Sensing Techniques(3)

E.Sensor-less Current-Sensing

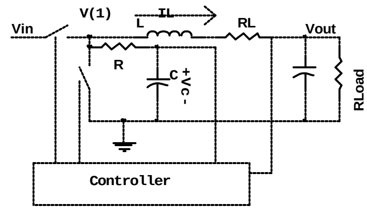


$$V_L = L\frac{dI_L}{dt}$$

$$I_L = \frac{1}{L}\int V_L dt$$

Problem:
For accurate current sensing the value of L should be known.

F.Average Current Sensing



It can be shown that the average inductor current can be found as:

$$<I_L> = \frac{V_o - <V_c>}{R_L}$$

Problems:
1.For accurate current sensing the value of R_L should be known.
2.Only information about average current is available.
Application: Current sharing

Conclusion and Future Work Direction

- A lossless current sensing technique should estimate current from the node voltages.
- For calculating the accurate current in a circuit branch from the node voltages, the accurate value of passive elements in the branch should be known ($i=v/R$, $i=C\,dv/dt$ and $i=1/L\int v dt$).
- The accurate value of discrete elements (i.e. inductor and filter capacitor) are not known. DC-DC controllers are designed to perform with a range of discrete inductors and filter capacitors.
- For accurate integrated circuit current sensing techniques, developing measurement techniques for measuring the off-chip elements (i.e. inductor) seems like a viable solution.