

Introduction

The new trend in modern power supplies is toward high-power density and reduced volume, this demands for higher efficiency from the power converters. Efficiency is the most critical and important parameter for any power supply. The higher the efficiency the less is the dissipation, reducing the need for heat extraction and increased power density.

In a synchronous buck current mode converter, current sense information is extracted from a dissipative current sense resistor in the output load current path. Lower the sense voltage more noise susceptibility and higher the sense voltage higher the chances of hurting efficiency.

The other alternative means is lossless inductor current sensing. This is a simple and inexpensive way of extracting the current information of an inductor in a current mode control topology.

Operation

Figure 1 shows the circuit for a current mode synchronous buck converter using the MIC2198, a high-power 500kHz synchronous buck DC-to-DC controller housed in a small 12-pin 4mm x 4mm MFL[®] package. The MIC2198 operates from a wide 4.5V to 32V input and can be programmed for output voltages from 0.8V to 6V. The wide input voltage capability makes the MIC2198 an ideal solution for point-of-load DC-to-DC conversion in 5V, 12V and higher systems.

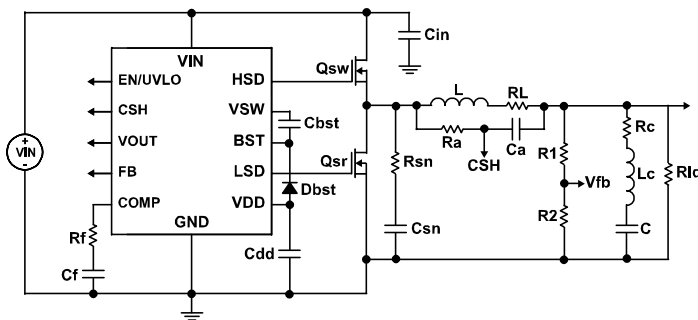


Figure 1. MIC2198 Synchronous Buck Converter

The current flowing through an inductor has two voltage drops. One voltage is V_{XL} across its reactive impedance X_L and V_{RL} across its resistive impedance R_L as shown in Figure 2.

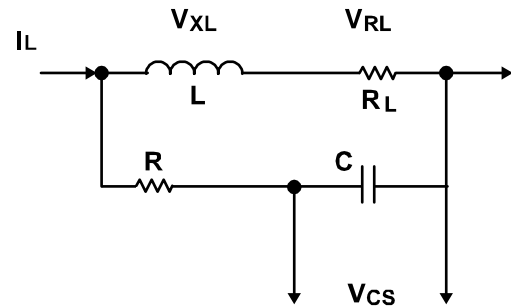


Figure 2.

The voltage across inductor is V_{XL}

$$V_{XL} = I_L \times X_L$$

This voltage appears across capacitor C as V_C with R and C forming a divider.

$$V_C = V_{XL} \times \frac{X_C}{R + X_C}$$

Now substitute V_{XL} in the above equation then

$$V_C = I_L \times X_L \times \frac{X_C}{R + X_C}$$

Now writing X_L and X_C in s domain

$$X_L = R_L + sL$$

and

$$X_C = \frac{1}{sC}$$

$$V_C = I_L \times (R_L + sL) \times \frac{1/sC}{R + 1/sC}$$

Solving this equation V_C becomes

$$V_C = I_L \times R_L \frac{(1 + sL/R_L)}{(1 + sRC)}$$

If the following condition is satisfied

$$1 + sL/R_L = 1 + sRC$$

then

$$V_C = I_L \times R_L$$

Then voltage V_C of capacitor C represents inductor current I_L

$$V_C = I_L \times R_L \quad (1)$$

There are certain conditions to be satisfied for true sensing of inductor current.

The term L/R_L should be much greater than T_{SW}

$$L/R_L \gg T_{SW} \quad (2)$$

Select the component values such that

$$L/R_L = R \times C \quad (3)$$

Then this inductor current sensing could be used for over current protections.

The condition of equation (2) is usually true as switching periods are in microseconds and inductances and associated DC resistances usually make L/R_L in milliseconds.

The condition for equation (3) has some uncertainty. Resistance R has a tolerances of 1%, 5% or even higher. Capacitor C also has tolerances as well as dependency on temperatures. Then comes the inductance which has some initial tolerances and a large inductance variation with DC biasing currents.

It is certain that equation (3) is definitely changes with temp as well as DC load conditions which in turn affects the current sensing behavior

The transfer function for current sense gain is

$$T(s) = \frac{V_C(s)}{I_L(s)} = R_L \frac{(1 + sL/R_L)}{1 + sRC}$$

If equation (3) is true then $T(s) = R_L$ then the V_C has a response as in Figure 3.

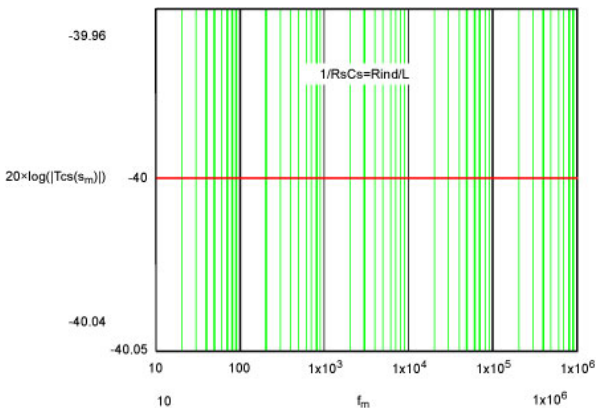


Figure 3.

If the following condition is true

$$L/R_L > R \times C$$

Then V_C has a response as in Figure 4.

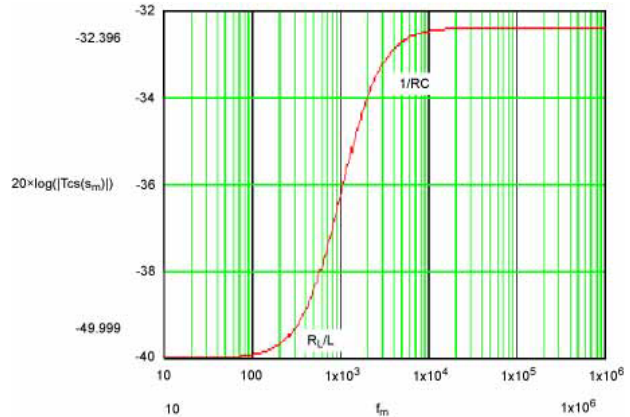


Figure 4.

The current information for step loads will over react and OCP occurs earlier than the actual value. This is shown in Figure 5a.

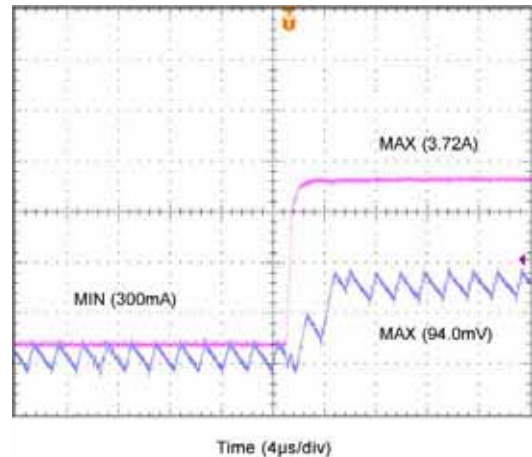


Figure 5a.

This is a load step of 0.3A to 3.7A. Here the V_C calculated is 34mV but the measured value on the oscilloscope is about 80mV.

For steady-state condition the calculated inductor current is 0.94A which gives V_C as 9.4mV. But the measurement taken on the scope shows about 30mV. This is shown in Figure 5b below.

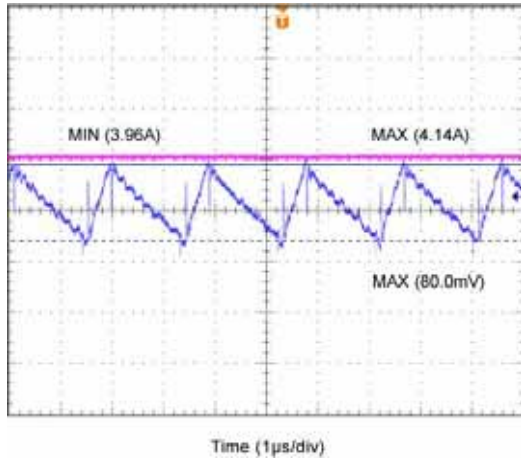


Figure 5b.

The response to a load transient 1A to 3A is also associated with some ringing on the output as shown in Figure 5c below.

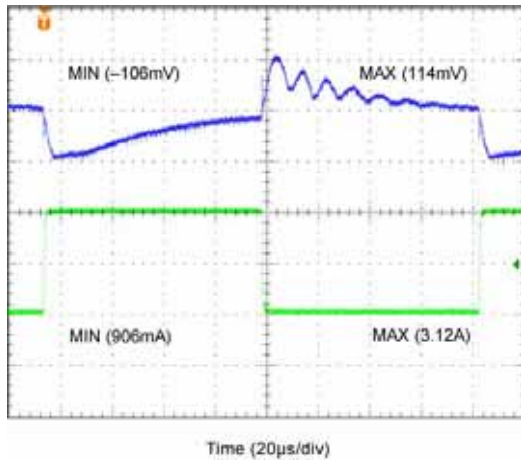


Figure 5c.

If the time constants are in the opposite value i.e.

$$L/R_L < R \times C$$

Then V_C has a response as in Figure 6.

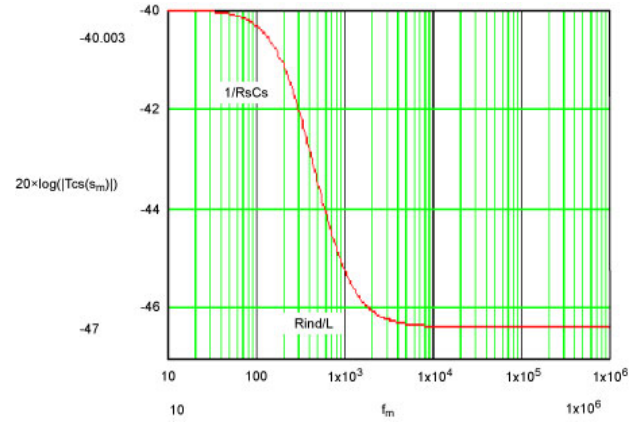


Figure 6.

The current sense for load step is slower but this will help to filter out noise related issues. This is shown below in Figures 7a and 7b.

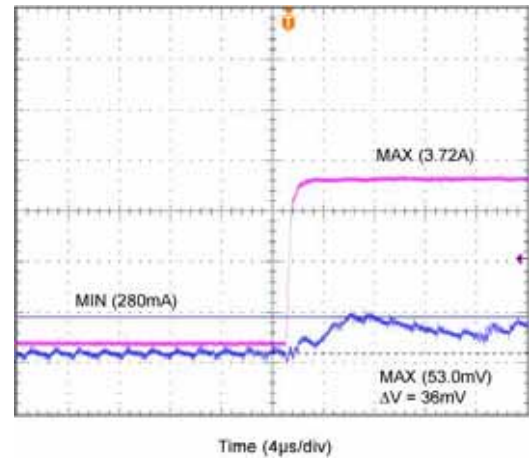
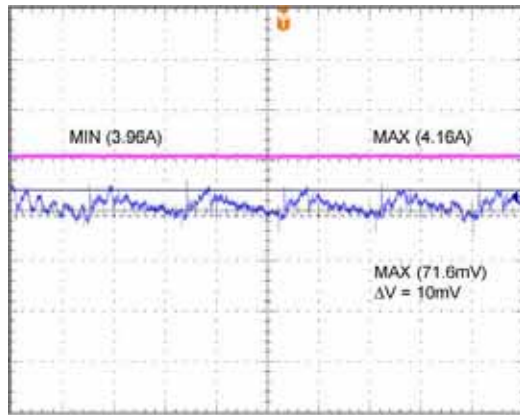
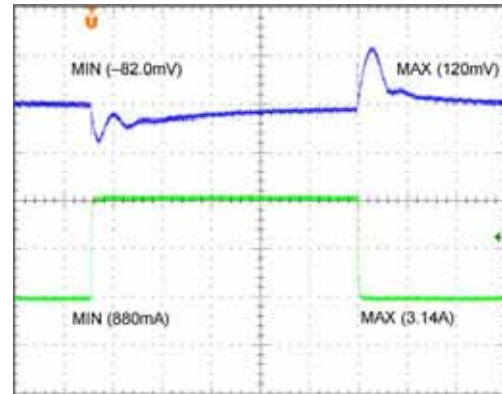


Figure 7a.

The measured V_C is 36mV which is nearly equal to calculated value 36mV.

Time (1 μ s/div)**Figure 7b.**

For steady state condition the measured V_C is about 10mV which is nearly equal to 9.4mV.

Time (20 μ s/div)**Figure 7c.**

The response to a load transient 1A to 3A is associated with only one undershoot and one overshoot on the output as shown in Figure 7c above.

References

1. G. Garcea, S. Saggini, D. Zambotti, M. Ghioni, "Digital auto-tuning system for inductor current sensing in VRM applications." **APEC 2006**

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