Application Report

SLUA837–October 2017

Slope Compensation Design for UCC2897A

Frank Xiao

Field Application

ABSTRACT

The UCC2897A is a peak-current mode fixed frequency high performance pulse-width modulator, which is ideal for active-clamp forward for the capability of driving the P-channel auxiliary switch. The chip also has internal programmable slope compensation circuit which is important for peak-current mode control method. In addition, this IC can set precise Dmax limit. In order to avoid sub-harmonic oscillation, slope compensation is essential for peak-current mode when duty cycle is above 50%. Even though the duty cycle is below 50%, it is desirable to add a slope compensation to decrease the influence of noise. This application report will show why the sub-harmonic oscillation happens and how to design the slope compensation parameters. Finally, experiment results are given which verify the correctness of the theoretical analysis.

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1 Introduction

The UCC2897A is a peak-current mode controller which is suitable for active clamp forward topology. For the peak-current mode control, it is usually necessary to adopt slope compensation to cancel the sub-harmonic oscillation phenomenon. Too large or too small slope compensation may influence the cycle-by-cycle current limit accuracy. Therefore, the report gives a method for parameter design based on the slope compensation theory.

2 Slope Compensation Theory

Because the forward converter is derived from buck topology by incorporating transformer isolation, buck converter can be used in the slope compensation analysis.

2.1 Sub-harmonic Oscillation

Figure 1 is inductor current waveform. It can be seen from the waveform that when a disturbance happens, it still exists after a period. In order to stabilize the system operation, the disturbance should become smaller and finally disappear after a few switching cycles.

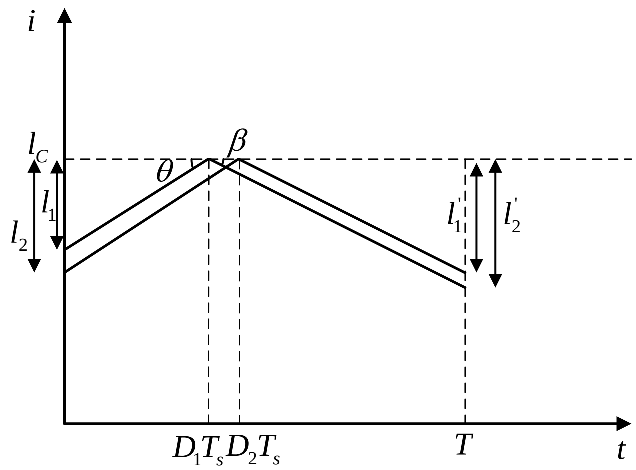

Figure 1. Inductor Current Waveform With Disturbance

Calculation can be performed by using trigonometric formula as follow.

$$l_1 = D_1 \times T_s \times \tan\theta \tag{1}$$

$$l_2 = D_2 \times T_s \times \tan\theta \tag{2}$$

$$l_2 - l_1 = (D_2 - D_1) \times T_s \times \tan\theta \tag{3}$$

$$l_2' - l_1' = (D_2 - D_1) \times T_s \times \tan\beta \tag{4}$$

If the disturbance becomes smaller after one cycle, then:

$$\frac{\Delta l}{\Delta l'} = \frac{(D_2 - D_1) \times T_s \times \tan\theta}{(D_2 - D_1) \times T_s \times \tan\beta} > 1 \tag{5}$$

$$(1 - D)V_{in} > DV_{in} \tag{6}$$

$$D < 0.5 \tag{7}$$

It can be seen from the formula above that if the duty cycle is below 50%, the disturbance is reduced after one cycle. Similarly, if the duty cycle is above 50%, the disturbance is magnified, which leads to system instability. Therefore, proper slope compensation should be used to eliminate the problem.

2.2 Slope Compensation Function

If the inductor current rising, falling and the compensation slopes are set to be m_1, m_2 and m’, respectively then the following formulas could be used to design system parameters when we want to cancel the sub-harmonic oscillation phenomenon.

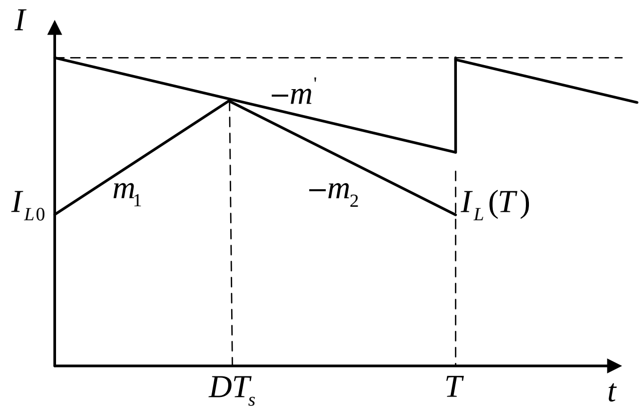

Figure 2. Inductor Current and Slope Compensation Waveform

$$\left|\frac{m_2 - m'}{m_1 + m'}\right| < 1 \tag{8}$$

$$\left|\frac{1 - \frac{m'}{m_2}}{\frac{1-D}{D} + \frac{m'}{m^2}}\right| < 1 \tag{9}$$

If D increases, then $\frac{1-D}{D}$ decreased, which means that $\left|\frac{1 - \frac{m'}{m_2}}{\frac{1-D}{D} + \frac{m'}{m^2}}\right|$ id higher.

Therefore, Dmax is the worst case.

If D = 1, the turning point is at m’ = 0.5 m_2.

From the waveform and formulas above, if m’ = 0.5 m_2, the disturbance decreases cycle-by-cycle and finally disappear. Especially, if m’ = m_2, the disturbance will vanish after one cycle (deadbeat control).

If Dmax is smaller, m’ can also set to be lower. If the Dmax = 0.66, m’ should be higher than 0.24 m_2, correspondingly.

2.3 Accuracy of the Output Current

For buck topology, sometimes enough slope compensation is helpful to achieve current accuracy. However, if the slope compensation is too large, it also influences the accuracy of output current.

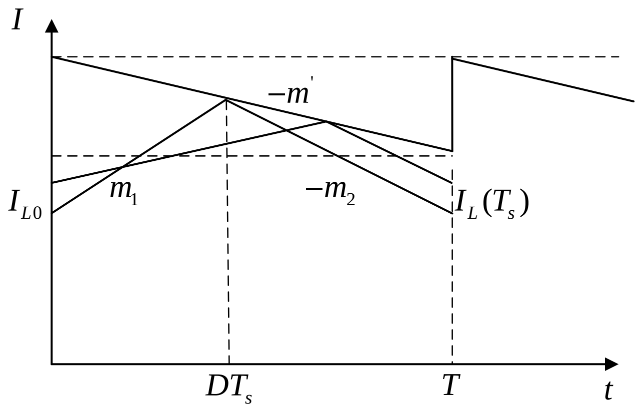

Figure 3. Inductor Current and Slope Compensation Waveform

When consider I_{c0} as the peak current without slope compensation (the dotted line), I_{avg} is the average current, m' is the slope compensation, so:

$$i_L(DT_s) = I_{c0} - m'DT_s \tag{10}$$

$$i_L(T_s) = I_{c0} - m'DT_s - m_2D'T_s = i_L(0) \tag{11}$$

$$I_{avg} = I_{c0} - m'DT_s - \frac{m_2(1-D)T_s}{2} \tag{12}$$

$$I_{avg} = I_{c0} - \frac{m_2T_s}{2} + \left(\frac{m_2 - 2m'}{2}\right)DT_s \tag{13}$$

When set $m' > \frac{m_2}{2}$, if D↑, the I_{avg} will ↓.

When set $m' < \frac{m_2}{2}$, if D↑, the I_{avg} will ↑.

When set $m' = \frac{m_2}{2}$.

$$I_{avg} = I_{c0} - \frac{m_2T_s}{2} \tag{14}$$

From the waveforms and formulas above, it can be seen that when m' = 0.5 m_2, the output current does not change with input voltage. If m' < 0.5 m_2, the output inductor current will be larger for low input voltage condition, and if m' > 0.5 m_2, the output inductor current will be larger for high input voltage condition.

From all the analysis above, the m' can be chosen to be 0.5 m_2 in the slope compensation design

3 UCC2897A Slope Compensation Design

From the analysis and the function block diagram of the UCC2897A above, the following formulas can be derived.

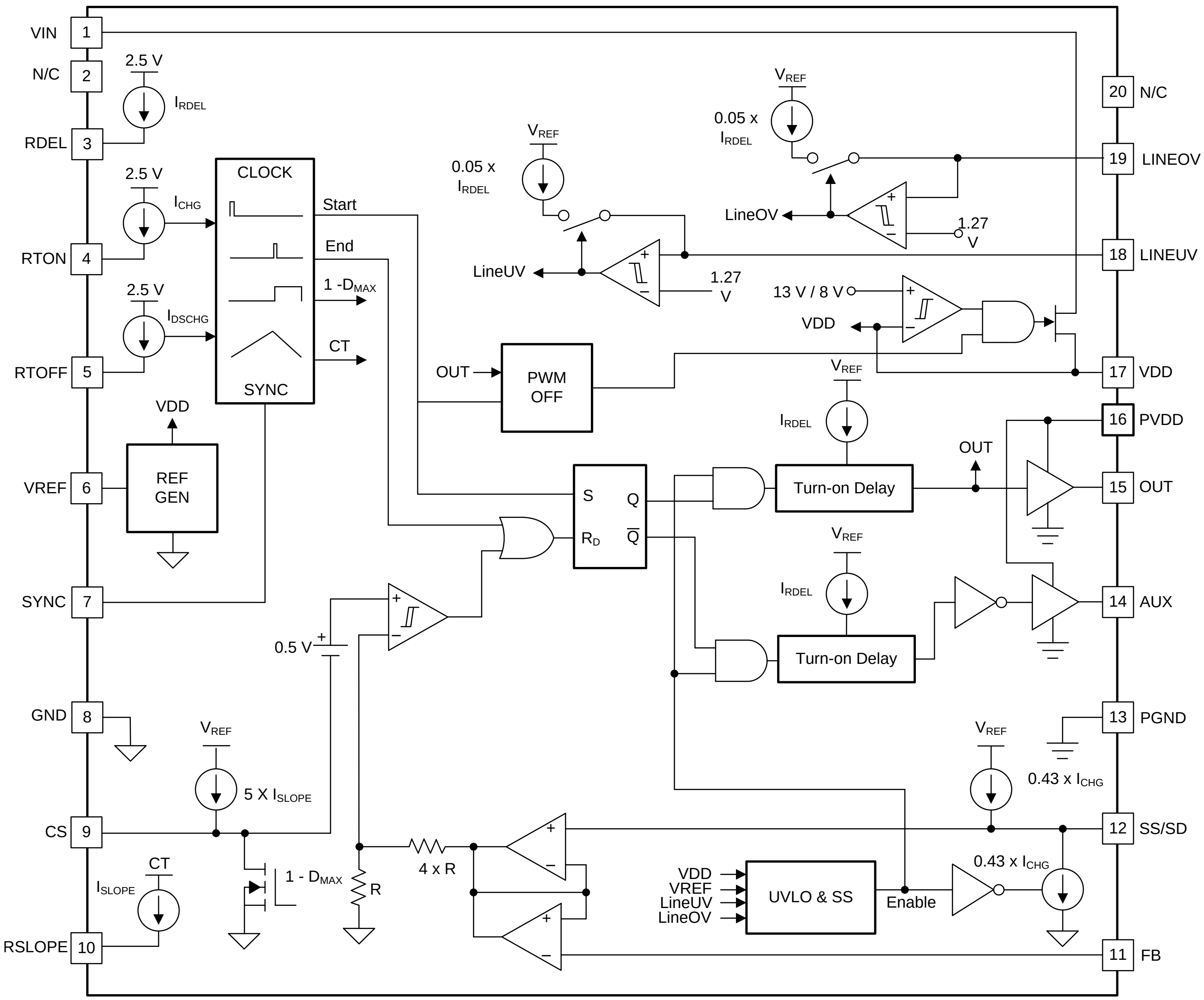

Figure 4. Figure 4. UCC2897A Function Block Diagram

The slope compensation insertion current I_{slope}:

$$I_{slope} = \frac{2}{T_{onmax} R_{slope}} \tag{15}$$

So the slope compensation insertion voltage V_{slope}:

$$V_{slope} = 5 I_{slope} R_2 \tag{16}$$

$$m_{sec} = \frac{V_{out}}{L} \tag{17}$$

$$m_p = \frac{m_{sec}}{N_p / N_s} \tag{18}$$

$$V_{cs} = m_p R_{cs} \tag{19}$$

The m' = 0.5 m2 can derive the following formula:

$$V_{slope} = \frac{V_{cs}}{2} \tag{20}$$

$$\frac{5 \times 2 \times 2}{T_{onmax} R_{slope}} R_2 = \frac{V_{out}}{LN_p} N_s R_{cs} \tag{21}$$

So the R_{slope} should be:

$$R_{slope} = \frac{20 R_2 L N_p}{T_{onmax} V_{out} N_s R_{cs}} \tag{22}$$

In the formulas, T_{onmax} is the max primary side mosfet turn on time, R_{cs} is the primary side current sample resistor, R_2 is the V_{Rcs} filter resistor, L is the output inductor, N_p is the primary side turns of transformer, and N_s is the second side turns of transformer.

If R_{slope} is a standard value, it can be selected based on the T_{onmax} to cancel the sub-harmonic oscillation.

$$V''_{slope} + V_{cs1} + V_{cs2} = 0.43v \tag{23}$$

V_{slope} is the slope compensation voltage added, V_{cs1} is the primary side current resistor voltage derived by second side load current, and V_{cs2} is the primary side current resistor voltage derived by the magnetic inductance field current.

$$\frac{V_{out}(1-D)T}{2L} = \frac{\Delta I}{2} \tag{24}$$

$$V_{cs1} = \left(I_o + \frac{\Delta I}{2} \right) \frac{N_s}{N_p} R_{cs} \tag{25}$$

$$V_{cs2} = \frac{V_{in}}{2L_m} R_{cs} DT \tag{26}$$

$$V''_{slope} = V_{slope} T_{on} = \frac{2 \times 5 R_2}{R_{slope} D_{max}} D \tag{27}$$

$$\frac{10 R_2}{R_{slope} D_{max}} D + \frac{V_{in}}{2L_m} R_{cs} DT + \left[\frac{V_{out}(1-D)T}{2L} + I_o \right] \frac{N_s}{N_p} R_{cs} = 0.43 \tag{28}$$

4 Experiment

The application report uses the PMP6547 to verify the theory, and does the changes below. Change the R_{cs} to 50 mΩ, and change the R_{slope} to 68 kΩ.

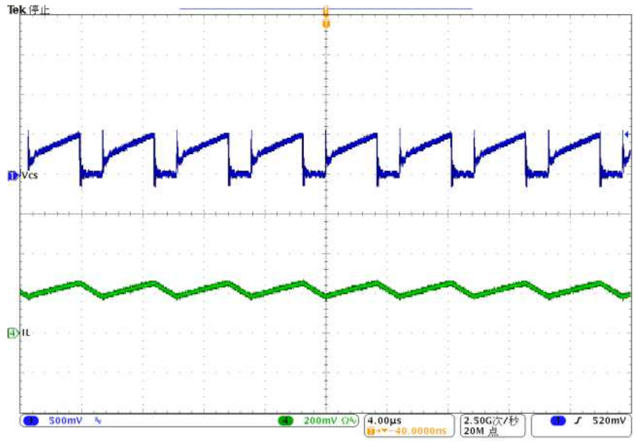

Figure 5. UCC2897A 18-V Input (Blue is the V_{cs}, Green is the Inductor Current)

The bench results are similar to the calculation results, which verifies the analysis above. In this case, the document sets the slope compensation with margin. If the customers want to get better accuracy performance, a larger value for R_{slope} can be chosen.

Table 1. Bench Results

INPUT VOLTAGE	CALCULATION RESULT IO	TEST RESULT IO
18 V	5.2 A	5 A
48 V	5.37 A	5.78 A
60 V	5.39 A	6.09 A

5 Summary

UCC2897A is an ideal peak current mode controller for active-clamp forward. For peak current mode controller, slope compensation is needed to cancel the sub-harmonic oscillation phenomenon. The application report shows why the sub-harmonic oscillation happens and how to design the slope compensation parameters. Finally, the report does experiments with PMP6547. Experimental results show the accuracy of the theoretical analysis.

6 References

- Datasheet: UCC2897A Current-Mode Active Clamp PWM Controller, SLUS829.
- Application Report: Understanding and Designing an Active Clamp Current Mode Controlled Converter, SLUA535.

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