Application Report
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UCC2897A Peak Current Mode Active-Clamp Forward Converter Small-Signal Modeling Design Consideration

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ABSTRACT

UCC2897A is a peak current mode active-clamp controller. This paper discussed the modeling process and loop compensation for UCC2897A. An example has been implemented with the modeling and compensation.

Contents

FIGURES

1 UCC2897A Introduction:

The UCC2897A PWM controller simplifies implementation of the various active clamp/reset and synchronous rectifier switching power topologies. The UCC2897A is peak current-mode, fixed frequency, high performance pulse width modulator. It includes the logic and the drive capability for the P-channel auxiliary switch along with a simple method of programming the critical delays for proper active clamp operation, as showed in Figure.1.

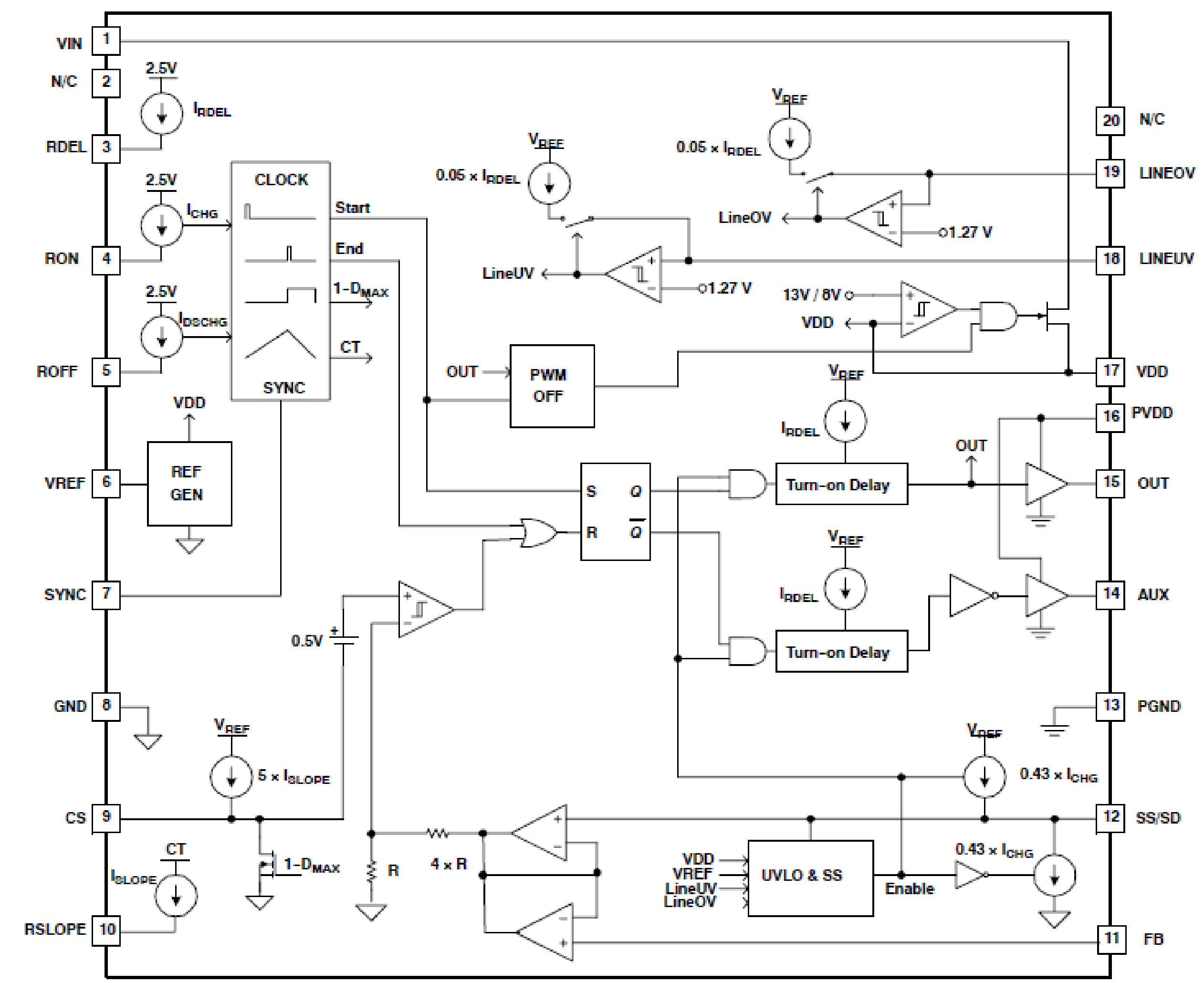

Figure 1. UCC2897A Internal Block Diagram.

2 Peak Current Mode Small-Signal Circuitry.

A peak current-mode converter, with continuous current mode, introduces a sampling-hold function, as shown in Equations 1 and 2. Figure 2 shows the control block for peak current-mode:

$$H_e(s) = \frac{1 - e^{-S \times t_{SW}}}{s \times t_{SW}} \approx \frac{1}{1 + \frac{s}{2/t_{SW}} + \frac{s^2}{\pi^2/t_{SW}^2}}; \qquad (1)$$

$$H_{vi}(S) = \frac{I_L(S)}{V_I(S)} \approx \frac{D}{SL_m} \qquad (2)$$

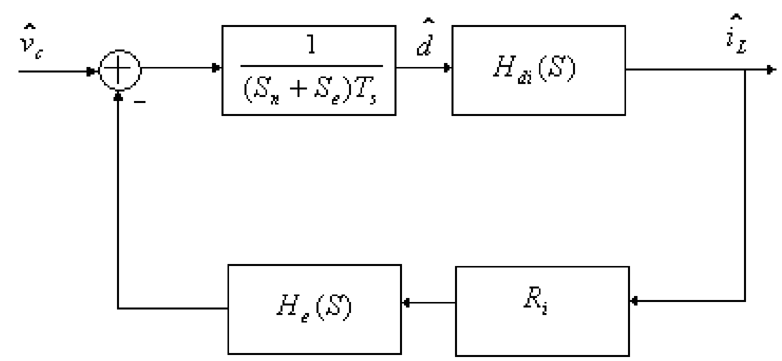

Figure 2. Control Block for Peak Current Mode.

Then, the gain from the error amplifier output to the inductor current can be got:

$$\frac{\hat{i}_L}{\hat{u}_c} = H(S) \qquad (3)$$

$$H(S) \approx \frac{1}{R_i}\frac{1}{1+S[\frac{T_s L_m (S_n + S_e)}{V_I R_i} - \frac{T_s}{2}] + S^2 \frac{T_s^2}{\pi^2}} \qquad (4)$$

Define two components as below:

Resistor: $R_a = \frac{2L_m}{t_{SW}[\frac{2(S_n+S_e)}{(S_n+S_f)} - 1]}$; and Capacitor: $C_a = \frac{t_{SW}^2}{\pi^2 L_m}$ (5)

Where:

- S_n is the rising rate.
- S_f is the falling rate.
- S_e is the slope compensation rate.

Hereby, the equivalent small signal model from control to inductor current can be obtained as shown in Figure 3.

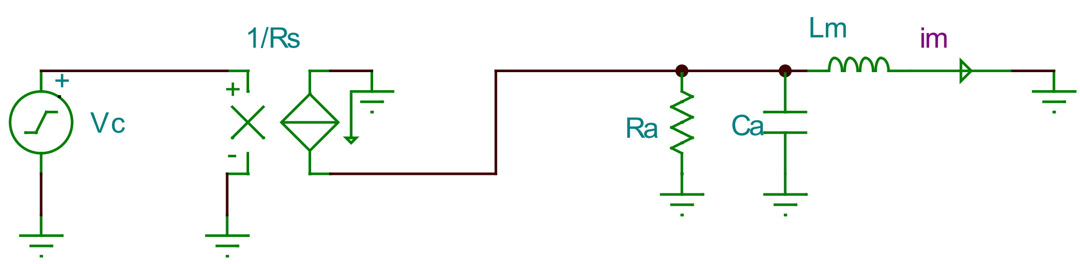

Figure 3. Gain from Control to Inductor Current for Peak Current Mode

3 Active Clamp Peak Current Modeling Analysis:

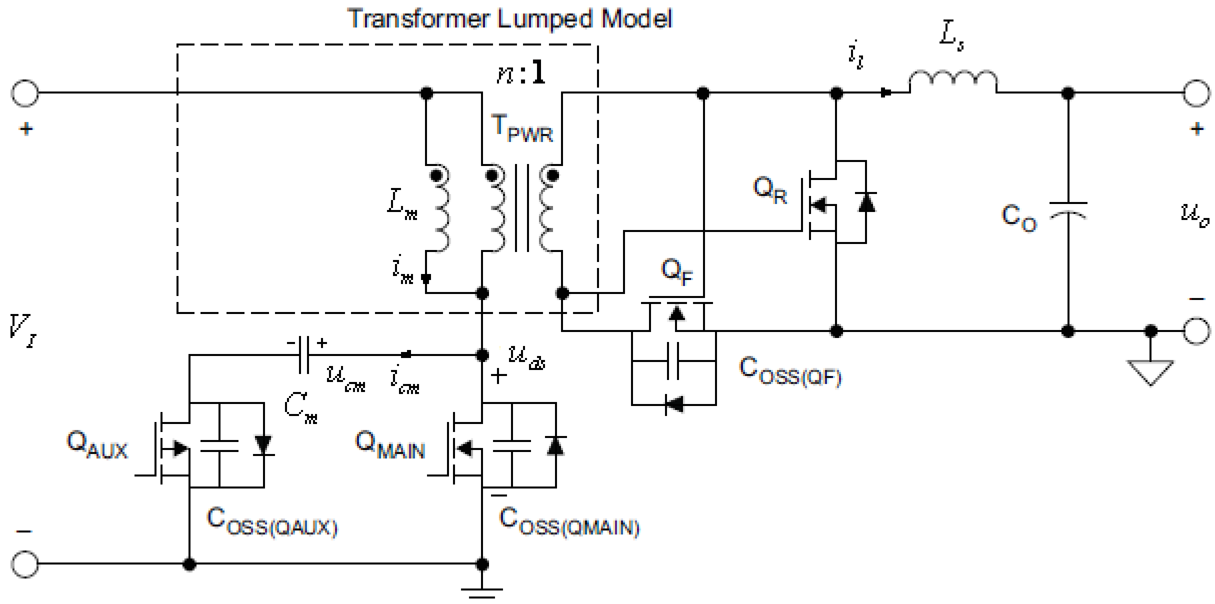

Figure 4. Peak Current Mode Active Clamp Forward Converter Topology.

The control to current gain function can be described in Equation 6:

$$\frac{\hat{u}_c}{R_s}\frac{1}{1+\frac{S}{Q\omega_n}+\frac{S^2}{\omega_n^2}}=\hat{i}_m+\frac{\hat{i}_l}{n} \tag{6}$$

With the active-clamping topology,

$$S_n = (\frac{V_I}{L_m} + \frac{V_I - nV_o}{n^2 L_s})R_s$$
$$S_f = (\frac{DV_I}{(1-D)L_m} + \frac{V_o}{nL_s})R_s \quad (7)$$

n is the transformer turn ratio between primary and secondary side windings.

Therefore, $Q = \frac{1}{\pi(\frac{S_n + S_e}{S_n + S_f} - 0.5)}$; $\omega_n = \frac{\pi}{T_{sw}}$ (8)

The clamping circuitry modeling:

$$< i_{cm} >= (1- < d >) < i_m >; < i_{cm} >= I_{cm} + \hat{i}_{cm}; < d >= D + \hat{d}; < i_m >= I_m + \hat{i}_m \quad (9)$$

Where:

- <> means the cycle average function.
- ^ means the perturbation element.
- d is the duty cycle of the main switch;

Considering the magnetic operating in symmetrically, the average current I_c and I_m are zero.

$$\hat{i}_{cm} = (1-D)\hat{i}_m \quad (10)$$

The Vds of MOSFET modeling:

$$\hat{u}_{ds} = -\frac{D}{(1-D)} V_{in} \hat{d} + (1-D)\hat{u}_{cm} \quad (11)$$

And: $\hat{u}_{ds} = -SL_m \hat{i}_m$; $\hat{u}_{cm} = -\frac{1}{SC_m}\hat{i}_{cm}$ (12)

As result, $V_{in}\hat{d} = [S\frac{(1-D)L_m}{D} + \frac{(1-D)^3}{SDC_m}]\hat{i}_m$ (13)

Define: $L_e = \frac{(1-D)}{D}L_m; C_e = \frac{D}{(1-D)^3}C_m$ (14)

Then: $$\frac{V_{in}\hat{d}}{n} = \frac{(SL_e + \frac{1}{SC_e})\hat{i}_m}{n};$$ (15)

And: $$\hat{i}_l = \frac{1}{(SL_s + \frac{R_L}{1+SC_oR_L})}\frac{V_{in}\hat{d}}{n}$$ (16)

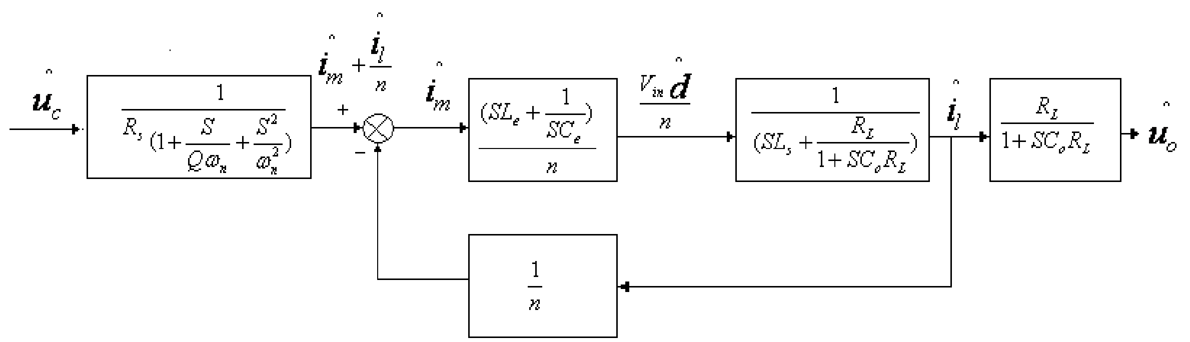

Figure 5. The Peak current active clamp control block diagram.

$$G_{co}(S) = \frac{\hat{u}_o}{\hat{u}_c} = \frac{R_L(1+S^2L_eC_e)}{R_s(1+\frac{S}{Q\omega_n}+\frac{S^2}{\omega_n^2})[S^3(L_e+n^2L_s)C_oC_eR_L + S^2(L_e+n^2L_s)C_e + S(C_o+n^2C_e)R_L + 1]}$$ (17)

With $C_o >> n^2C_e$, this formula can be simplified as in Equation 18:

$$G_{co}(S) = \frac{\hat{u}_o}{\hat{u}_c} \approx \frac{R_L(1+S^2L_eC_e)}{R_s(1+\frac{S}{Q\omega_n}+\frac{S^2}{\omega_n^2})[S^2(L_e+n^2L_s)C_e + 1](SC_oR_L+1)}$$ (18)

The above Equation (18) introduced dual zeros and dual poles.

$$f_z = \frac{1}{2\pi\sqrt{L_eC_e}} = \frac{(1-D)}{2\pi\sqrt{L_mC_m}};\ f_p = \frac{1}{2\pi\sqrt{(L_e+n^2L_s)C_e}} = \frac{(1-D)}{2\pi\sqrt{(L_m + \frac{D}{1-D}n^2L_s)C_m}}$$ (19)

Generally, to avoid the instability, the closed-loop crossover frequency “fc”, should be far less than half of the pole frequency “fp”. Here, “fp” should be the value with the maximum limited duty cycle “D”.

Figure 6 shows a small-signal circuitry implementation:

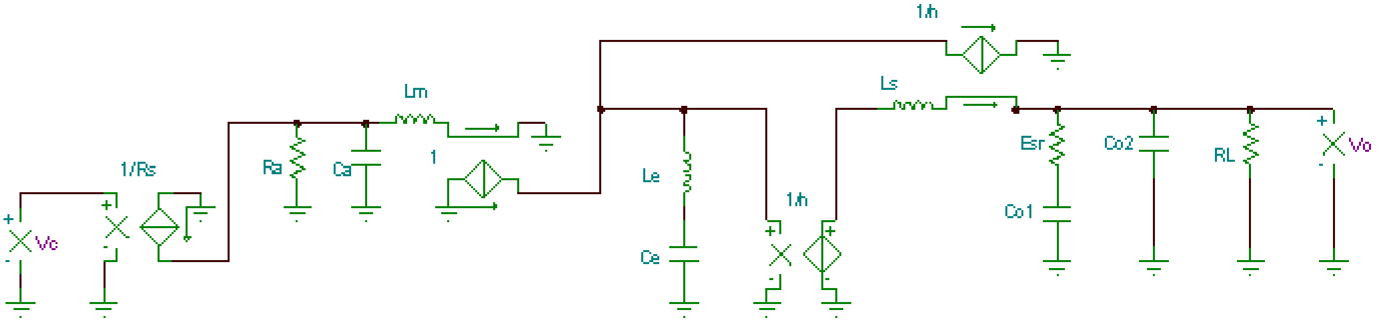

Figure 6. Small Signal Implementation from Control to Output.

4 A Design Example:

The design schematic (see Figure 7) and electric specification follow.

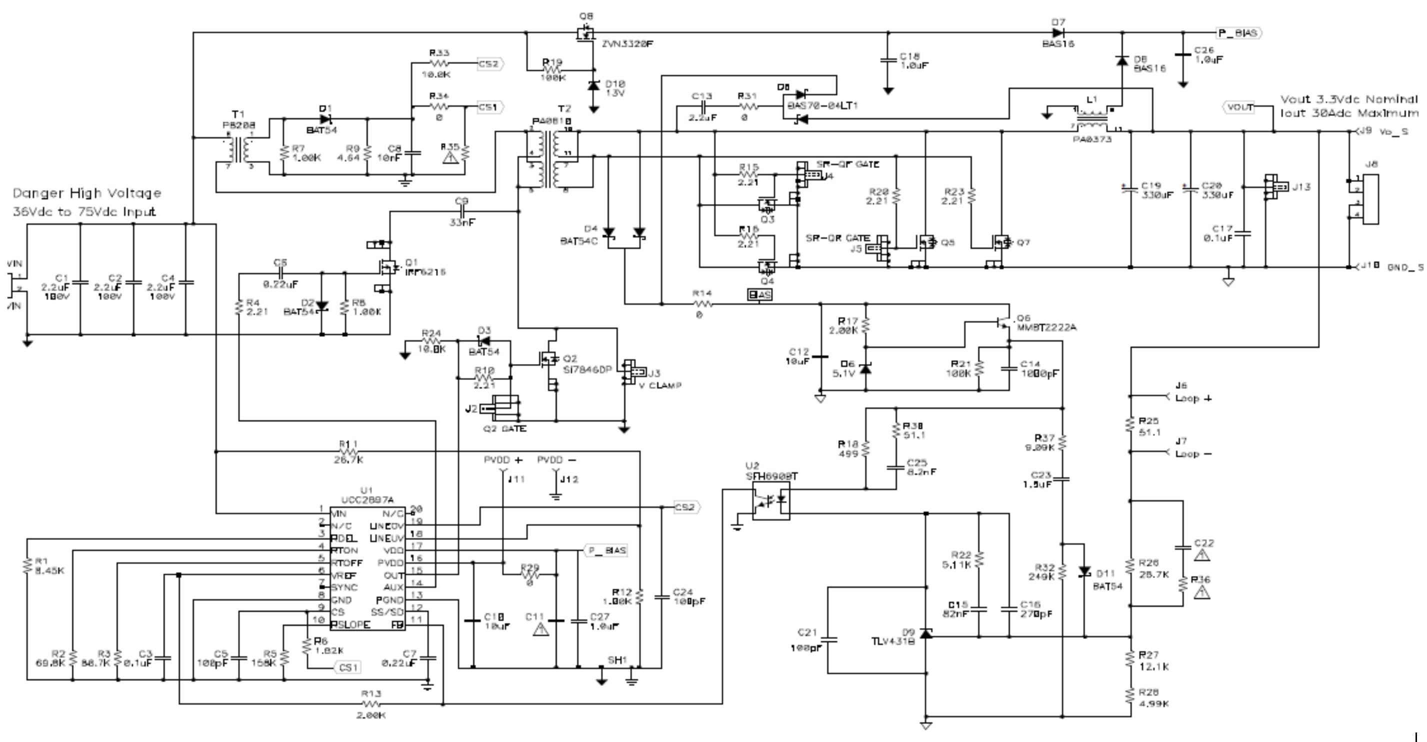

Figure 7. 100-W Isolated Power Module with UCC2897A Device

T1: Current transformer specification is: turn ratio is 1:100;

T2: Transformer specification is: PA0810NL; turn ratio is 6:1; Lm is 345 μH.

L1 inductor specification is: PA0373; 2.1 μH;

$$Vin = 72V; Vout = 3.3V; I_{out} = 30A$$

Based on the schematic design in Figure.7, and the small signal analysis, we can get the overall simulation model as Figure.8:

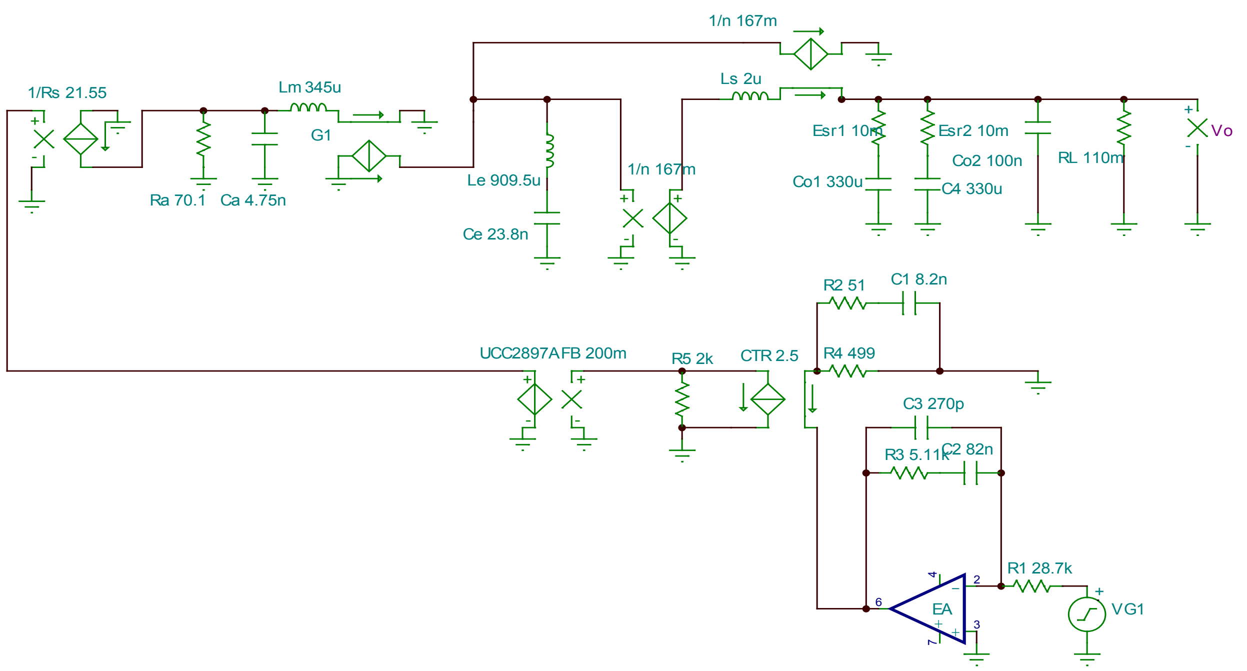

Figure 8. Overall Small Signal Circuitry Implementation

Figure 9 shows the simulation results.

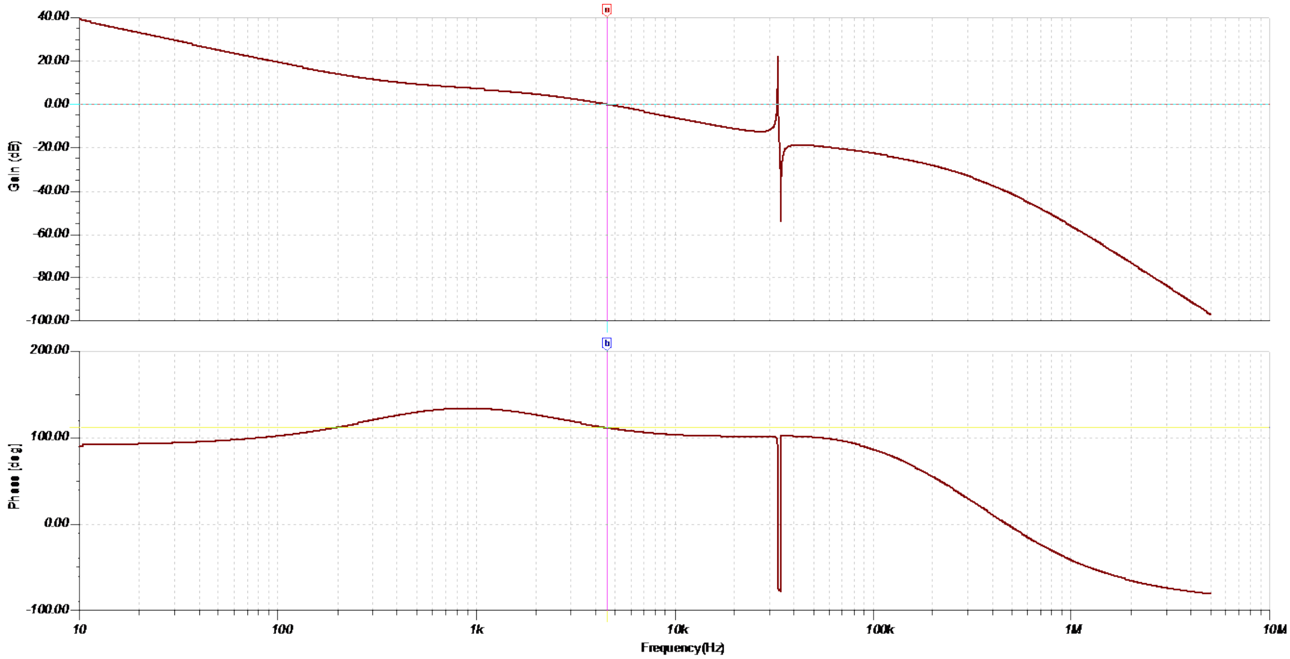

Figure 9. Simulation Results.

Figure.9 showed the cross-over frequency is 4.5 kHz, and phase margin is 111 degrees.

By lab test results, we can get the results as shown in Figure.10.

The test results showed cross-over frequency is 4.5 kHz and phase margin is 80 degrees.

Comparing the simulation and test results, they matched fully.

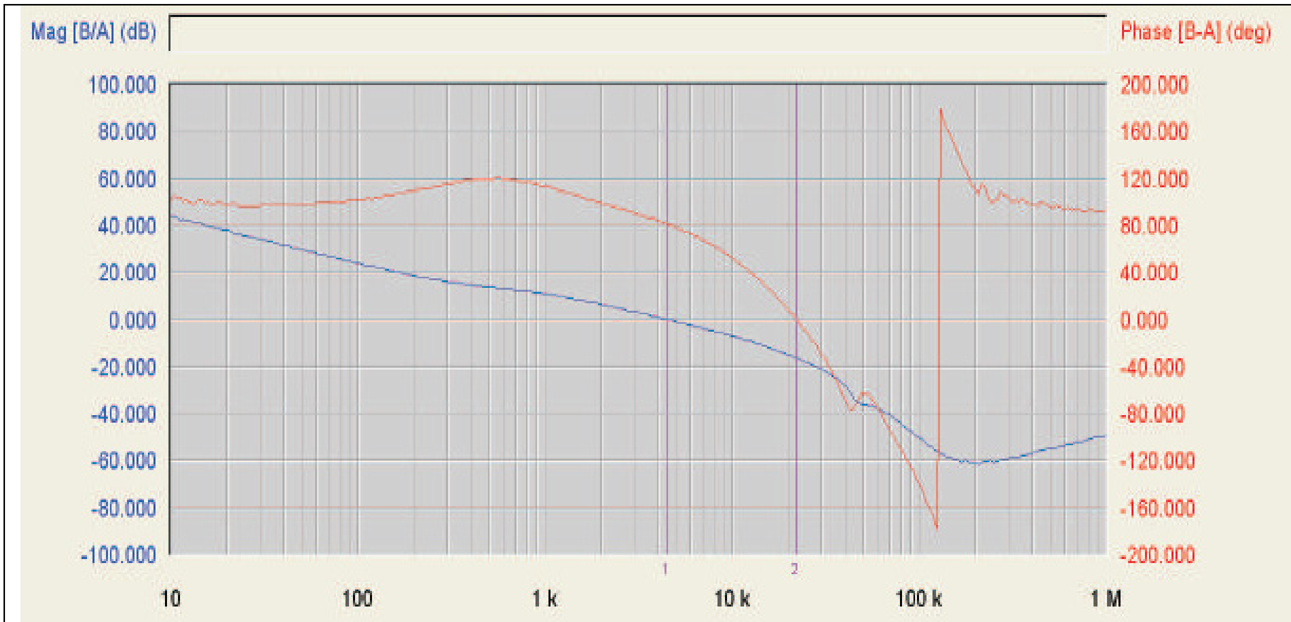

Figure 10. Lab Test Results (V_{in} = 72, I_o = 30 A)

5 Conclusion:

The analysis shows the modeling and compensation is effective. The analysis revealed the zero and poles of the peak current mode control active-clamp forward converter, which is critical for the design of the active-clamp converter.

Reference:

1. Texas instruments, SLUS829D, UCC2897A datasheet.
2. Texas instruments, SLUU357, UCC2897A EVM User's Guide.