Application Report
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TPS53319 DCAP Mode With Ripple Injection Modeling Design Consideration

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ABSTRACT

TPS53319 is high-current buck converter with DCAP mode. To use all the ceramic output capacitors, the DCAP mode buck converter can be configured with external ripple injection. This paper discusses a novel small-signal model and loop frequency response analysis. An example is implemented to verify the modeling and compensation.

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1 TPS53319 Introduction

TPS53319 is a 14-A synchronous switcher with DCAP mode and integrated MOSFETs. The device is designed for ease of use, low external component count, and space-conscious power systems. These devices feature accurate 1%, 0.6-V reference, and integrated boost switch. A sample of competitive features include: a conversion input voltage range of 1.5 V wide to 22 V wide, very low external component count, DCAP mode control for superfast transient, auto-skip mode operation, internal soft-start control, selectable frequency, and no need for compensation. The conversion input voltage range is 1.5 to 22 V, the supply voltage range is 4.5 V to 25 V, and the output voltage range is 0.6 V to 5.5 V, as shown in Figure.1.

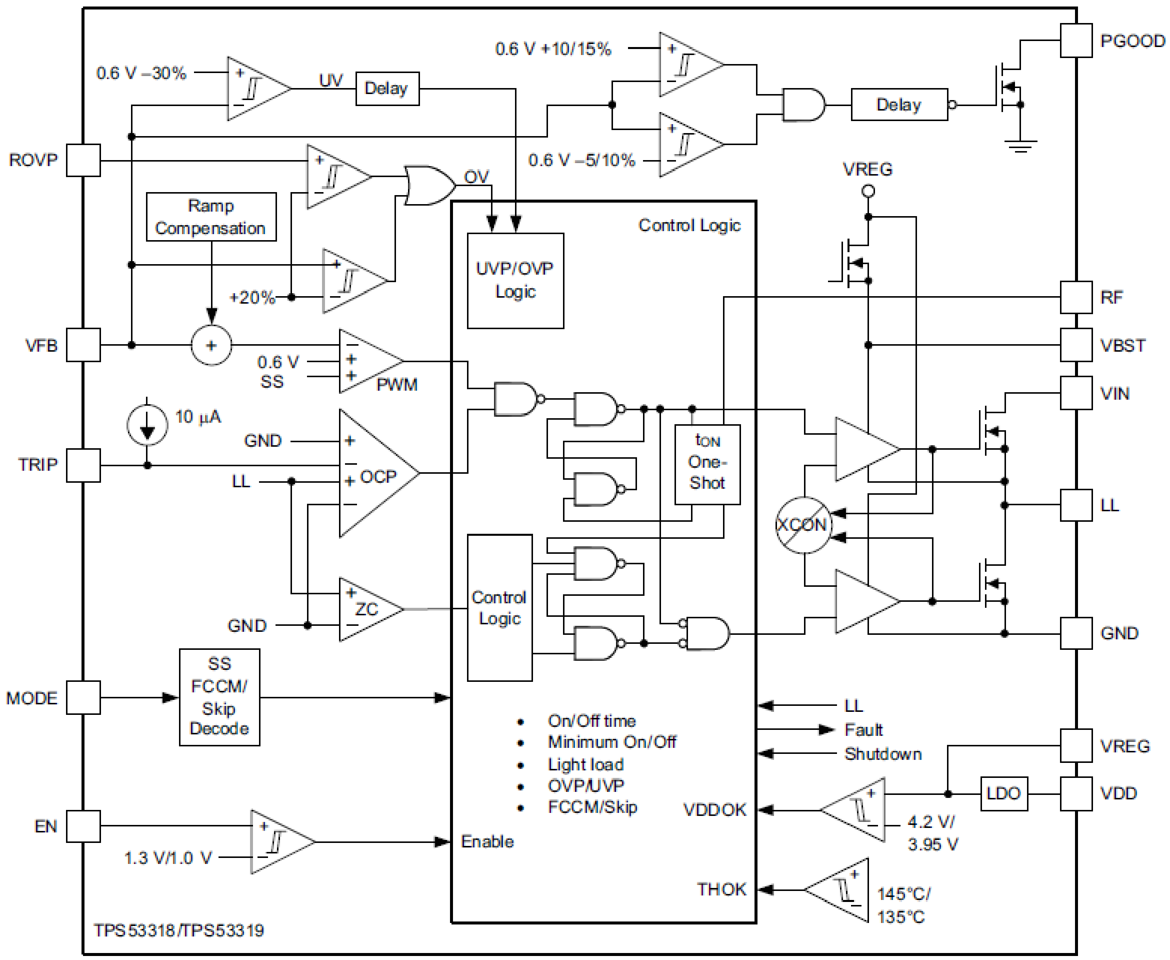

Figure 1. TPS53319 Internal Block Diagram

2 DCAP Mode Small-Signal Circuitry

For a Buck converter with constant on time control mode, a sampling function as below can be introduced to describe the function of constant on time sampling-hold control.

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

Define:

$$G_a(s)=\frac{1}{sR_1C_1};G_b(s)=\frac{(s^2R_1R_2C_1C_2+sR_1C_1+sR_2C_2+1)}{s^2R_1R_2C_1C_2} \tag{2}$$

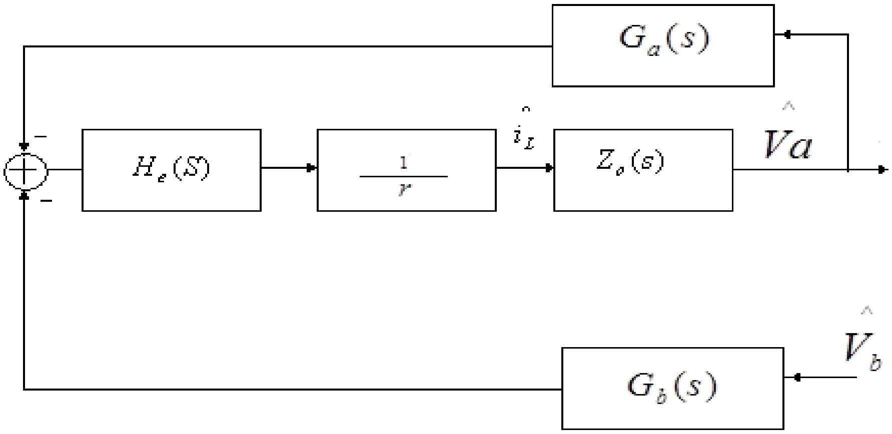

Figure 2. Control Block Diagram for COT Mode Buck Converter

3 DCAP Model Buck Converter Modeling Analysis

Figure 3 shows circuitry for a DCAP mode converter. Figure 4 shows equivalent control circuitry.

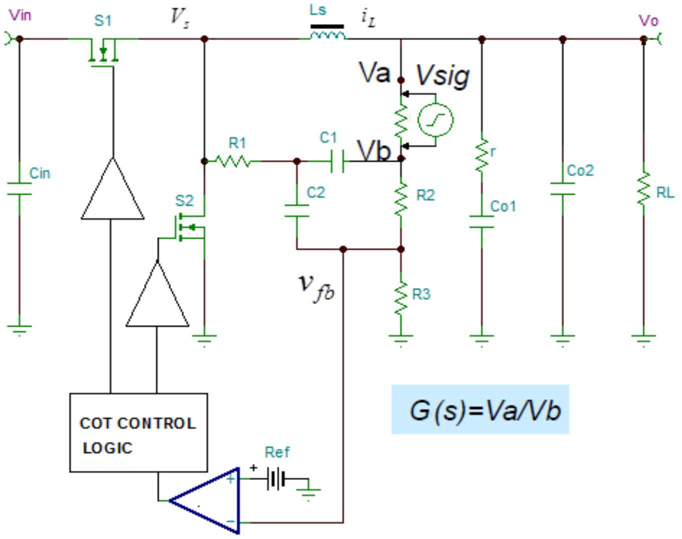

Figure 3. DCAP Mode Buck Converter

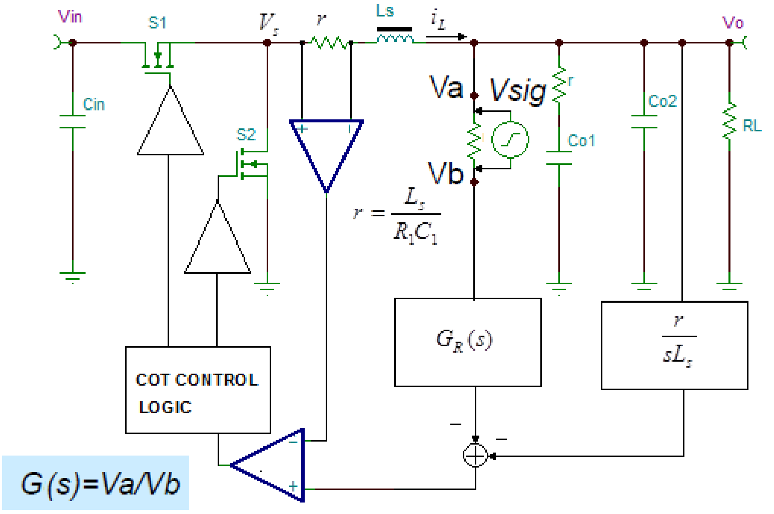

Figure 4. Equivalent Control Circuitry

$$G_2(s) = \frac{(1 + sR_1C_1)(1 + \frac{R_2}{R_3} + sR_2C_2) + sR_1C_2(1 + \frac{R_2}{R_3})}{sR_2C_2} \tag{3}$$

$$G_1(s) = \frac{s^2R_1R_2C_1C_2 + s(R_1C_1 + R_1C_2) + 1}{(1 + sR_1C_1)(1 + \frac{R_2}{R_3} + sR_2C_2) + sR_1C_2(1 + \frac{R_2}{R_3})} \tag{4}$$

Then:

$$\frac{< V_s > - < V_o > + < Vo > + < V_b > G_1(s)G_2(s)}{G_2(s)} = < V_{fb} > \tag{5}$$

Considering:

$$< V_s > - < V_o > = sL_s < i_L >, \tag{6}$$

Meanwhile, defining:

$$r = \frac{L_s}{R_1C_1} \tag{7}$$

Then:

$$\left[\frac{< i_L > r + < V_o > \frac{r}{sL_s} + < V_b > \frac{G_1(s)G_2(s)}{sR_1C1}}{G_2(s)} \right] sR_1C_1 = < V_{fb} > \tag{8}$$

With small-signal transaction, then:

$$r\hat{i}_L + \hat{V}_o \frac{r}{sL_s} + \hat{V}_b \frac{G_1(s)G_2(s)}{sR_1C_1} = 0 \tag{9}$$

And define:

$$Z_o(s) = Z_c(s) = \frac{R_L\left(1 + sEsrC_{o1}\right)}{\left(1 + sR_L(C_{o1} + C_{o2})\right)} \tag{10}$$

Considering the COT control with sampling-hold function *H*$_e$*(s),* the loop gain can be described as shown in Equations 11 through 13.

$$\begin{aligned} G(s) &= -\frac{\left[G_1(s)G_2(s)\right]}{srR_1C_1}\frac{H_e(s)}{\left[1 + \dfrac{H_e(s)}{sL_s}\right]}Z_o(s) \\ &= -\frac{\left(s^2R_1R_2C_1C_2 + sR_1(C_1 + C_2) + 1\right)}{s^2R_1R_2C_1C_2}\frac{H_e(s)}{\left[1 + \dfrac{H_e(s)}{sL_s}\right]}\frac{R_L\left(1 + sEsrC_{o1}\right)}{r\left(1 + sR_L(C_{o1} + C_{o2})\right)} \end{aligned} \tag{11}$$

$$G(s) = -\frac{\left(\dfrac{s^2}{\omega_a^2} + \dfrac{s}{\omega_a Q_a} + 1\right)}{\dfrac{s^2}{\omega_a^2}}\frac{H_e(s)}{\left[1 + \dfrac{H_e(s)}{sL_s}\right]}\frac{R_L(1 + sEsrC_{o1})}{r[1 + sR_L(C_{o1} + C_{o2})]} \tag{12}$$

$$\omega_a = \frac{1}{\sqrt{R_1R_2C_1C_2}}; Q_a = \frac{\sqrt{R_1R_2C_1C_2}}{R_1\left(C_1 + C_2\right)} \tag{13}$$

From this previous analysis, it is critical that we can use the COT current mode to simulate the loop function. We can define the following parameters:

$$L_a = L_s; C_a = \frac{t_{on}^2}{\pi^2L_s}; R_a = \frac{2L_s}{t_{on}} \tag{14}$$

$$L_c = R_1R_2C_2; R_c = R_1(1 + \frac{C_2}{C_1}) \tag{15}$$

$$G_m = {}^1\!/_r; G_a = G_c = G_{v1} = 1 \tag{16}$$

With the previous definition, Figure 5 shows a small-signal circuitry implementation:

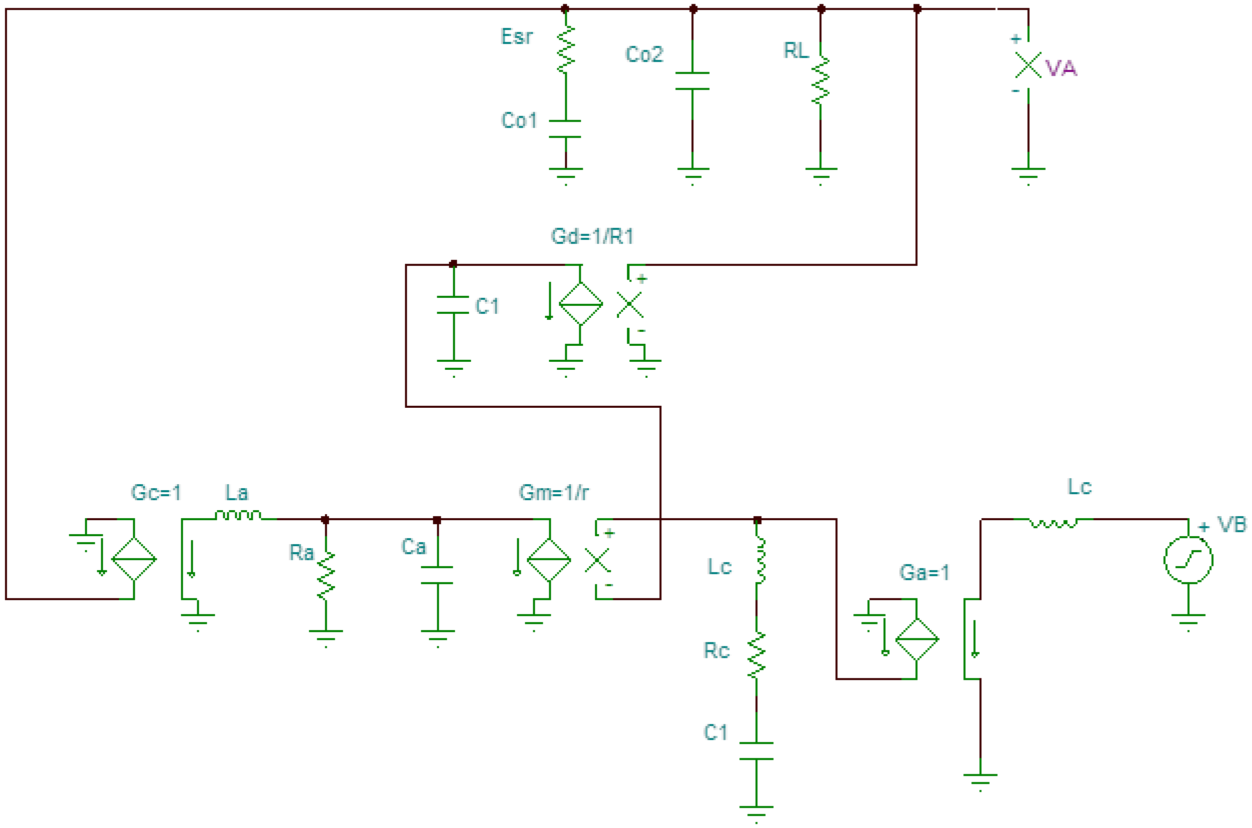

Figure 5. Small-Signal Implementation From Control to Output

For the COT mode with ripple injection, according to Routh Criterion, the related stability criteria as in Equation 17:

$$\frac{R_1 R_2 C_1 C_2}{R_1 (C_1 + C_2) + R_2 C_2} > \frac{L_s}{R_1 C_1} C_{out} > \frac{T_{on}}{2} \tag{17}$$

The simplified criteria as in Equation 18:

$$C_2 < C_1 ; R_2 > R_1 ; f_{sw} > \frac{1}{2\pi \sqrt{L_s C_{out}}} > \frac{1}{2\pi R_2 C_2} ; \frac{L_s C_{out}}{R_1 C_1} > \frac{T_{on}}{2} \tag{18}$$

Defining the gain function of the ripple injection circuitry:

$$G_R(s) = -\frac{\left(s^2 R_1 R_2 C_1 C_2 + s R_1 (C_1 + C_2) + 1\right)}{s^2 R_1 R_2 C_1 C_2} = -\frac{\frac{s^2}{\omega_a^2} + \frac{s}{\omega_a Q_a} + 1}{\frac{s^2}{\omega_a^2}} \tag{19}$$

Therefore, the closed-loop gain function as in Equation 20:

$$G(s) = G_R(s)\frac{H_e(s)}{\left[1+\frac{H_e(s)}{sL_s}\right]}\frac{R_L\left(1+sEsrC_{o1}\right)}{r\left(1+sR_L(C_{o1}+C_{o2})\right)} \tag{20}$$

The closed-loop gain and phase have the following additional impact:

$$\left|G_R(j2\pi f_c)\right| \approx \frac{\omega_a}{2\pi f_c Q_a}; \quad PhaseDelay \approx -A\tan\left(\frac{\omega_a}{2\pi f_c Q_a}\right) \tag{21}$$

Then, without loading and ignoring the Esr resistor, the crossover frequency and phase margin can be approximately deduced as follows:

$$f_c \approx \frac{\sqrt{\frac{\omega_a}{rQ_aC_{out}}}}{2\pi}; \quad PhaseM\arg in \approx 90^o - A\tan\left(\frac{\omega_a}{2\pi f_c Q_a}\right) \tag{22}$$

4 TPS53319 Design Example

Based on the COT buck converter schematic design (see Figure 6), using the small-signal analysis, we can get the overall simulation model according to Figure 5. Figure 7 shows the simulated Bode plot results.

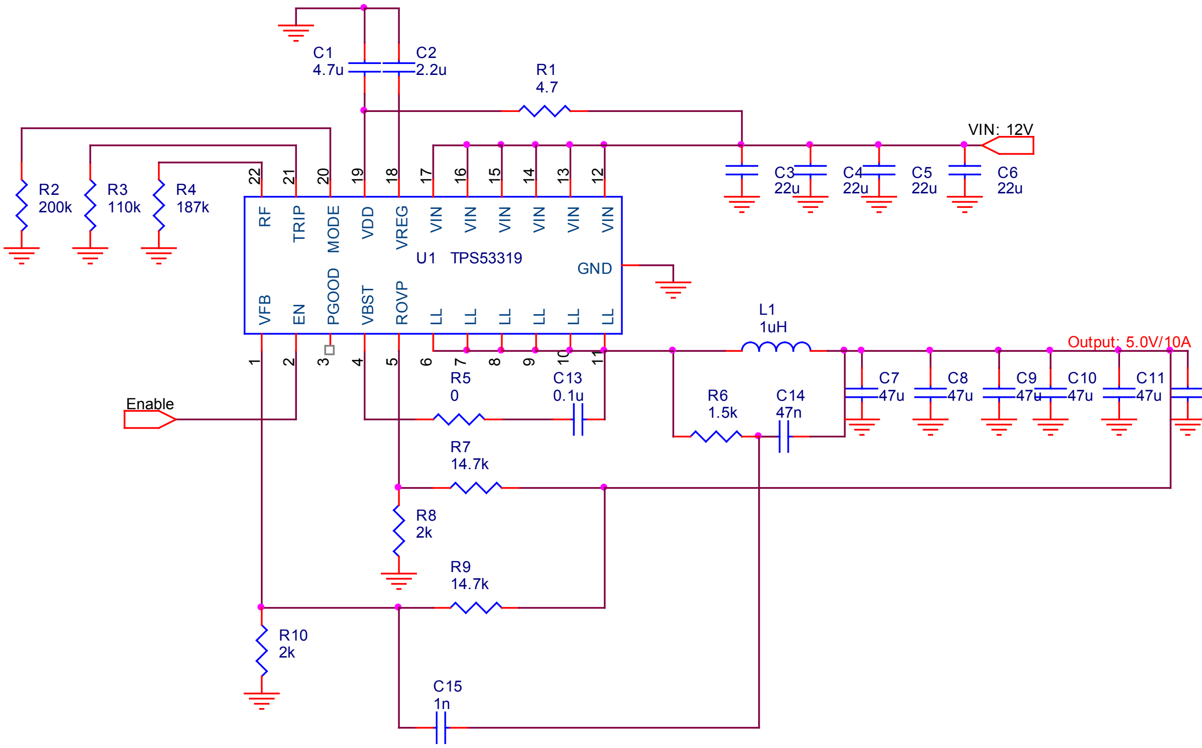

Figure 6. TPS53319 Buck Converter With 5.0-V, 10-A Output

The test results showed the crossover frequency, 41.3 kHz, and the phase margin, 63.1 degrees.

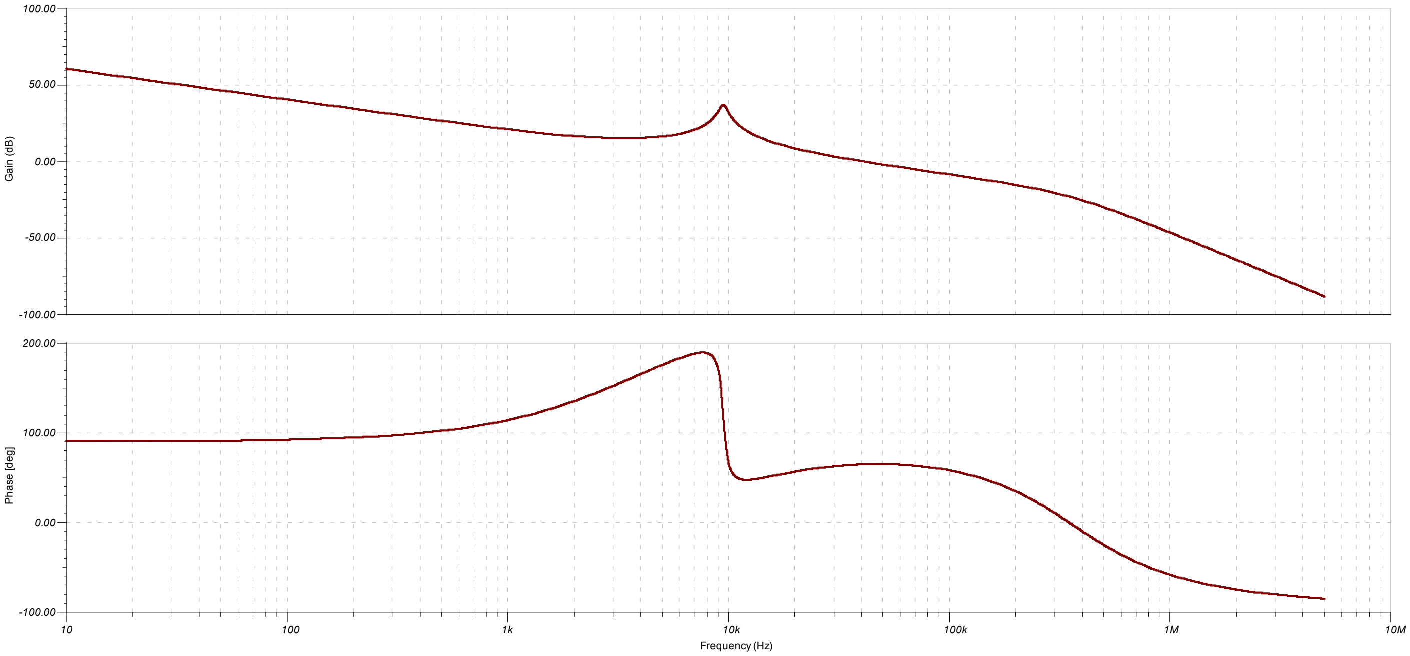

Figure 7. Simulation Results With the Bode Plot Based on the Modeling

5 Conclusion

The analysis has shown that novel modeling and analysis is effective and critical to the design of the DCAP mode converter. In addition, this paper has provided the control block diagram and the simulation circuitry.

6 References

1. Texas instruments, SLUSAY8B, TPS53319 data sheet.
2. Texas instruments, SLVU728, TPS53319 EVM-136 User’s Guide

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