Application Report

SLVA834–November 2016

Feedforward Capacitor Makes TPS61021A Boost Converter Fast and Stable

Helen Chen

Low-Power DC/DC Converters

ABSTRACT

A common method to improve the stability and bandwidth of an internally-compensated boost converter is to add a feedforward capacitor (Cff) to the circuit. This capacitor is placed across the high-side feedback resistor. It introduces a zero f_Z and a pole f_P into the control loop and helps improve the phase margin and the load transient. This application note describes how to choose this feedforward capacitor for the internally-compensated TPS61021A boost converter.

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1 Introduction

An internally-compensated dc-dc converter simplifies the design process while minimizing the number of the external components at the same time. But this simplification narrows the ability of a designer to optimize the stability and the load transient of the converter. Adding a feedback capacitor in the feedback network is a good way to make up for the deficiencies. Using the measured load transient or bode plot of a boost converter, a feedforward capacitor can be chosen such that the load transient can be significantly improved while still maintaining an adequate phase margin.

2 Feedback Network With the Feedforward Capacitor

Figure 1 shows the feedback network with the feedforward capacitor Cff. Cff introduces a zero and a pole into the control loop. The zero f_Z and the pole f_p can be calculated using Equation 1:

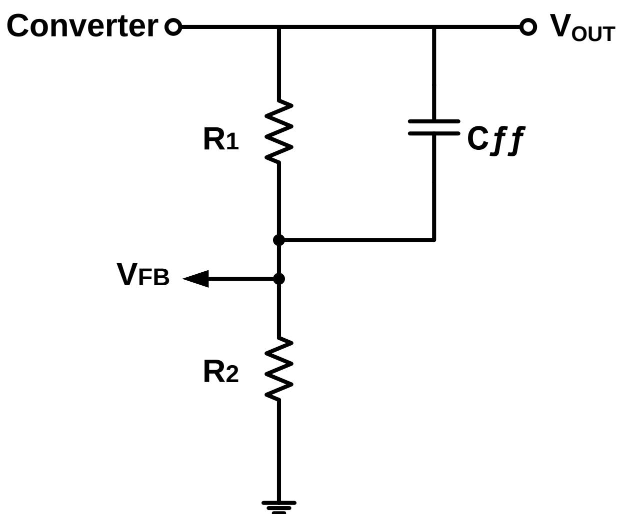

Figure 1. Feedback Network With Feedforward Capacitor Cff

$$f_Z = \frac{1}{2\pi \times R1 \times Cff} \tag{1}$$

$$f_P = \frac{1}{2\pi \times Cff}\left(\frac{1}{R1} + \frac{1}{R2}\right) \tag{2}$$

Equation 2 shows the frequency of f_Z is lower than the frequency of f_P. Increasing the value of Cff shifts the zero and the pole to lower frequencies, while decreasing the value of Cff shifts the zero and the pole to higher frequencies. Cff shifts the crossover frequency of the converter to a higher frequency. If the value of the Cff is too large, it will make the new crossover frequency very high and results in insufficient phase margin and stability problems. Calculate Cff properly according to the different application conditions. If the phase margin is low while the loop response is fast enough for the application, then a relatively smaller Cff can be chosen to boost the phase margin while making the bandwidth increase a little. If the loop response is too slow while the phase margin is high enough for the application, then a higher Cff can be chosen to boost the bandwidth while keeping enough phase margin.

3 Design Example With the TPS61021A Boost Converter

3.1 Calculating the Feedforward Capacitor for Higher Phase Margin

Figure 2 shows the schematic of the TPS61021A boost converter without the feedforward capacitor.

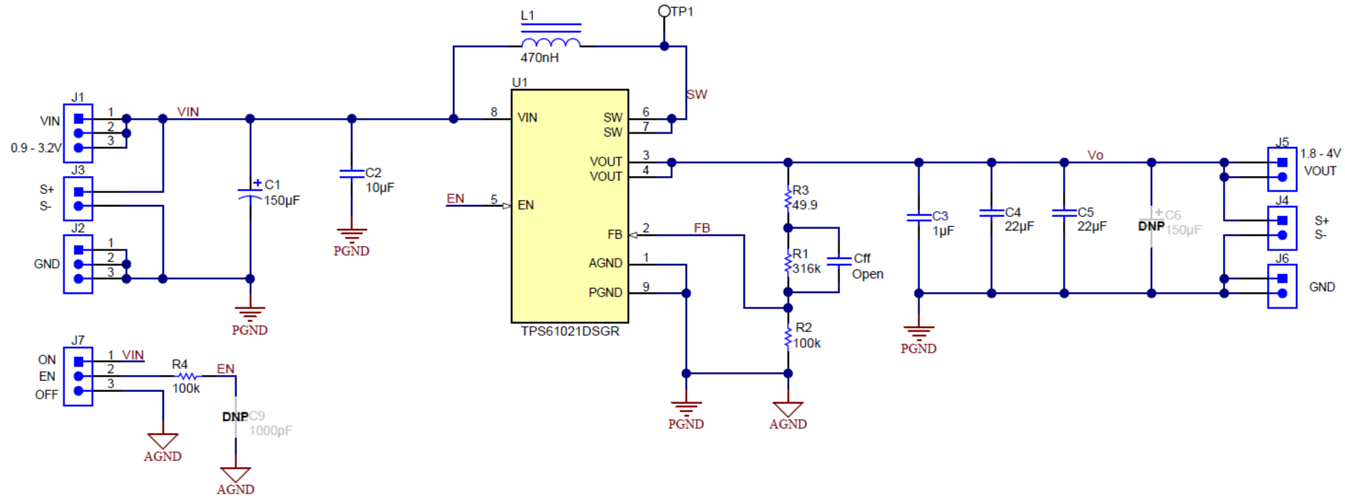

Figure 2. TPS61021A Boost Converter Without the C_{ff}

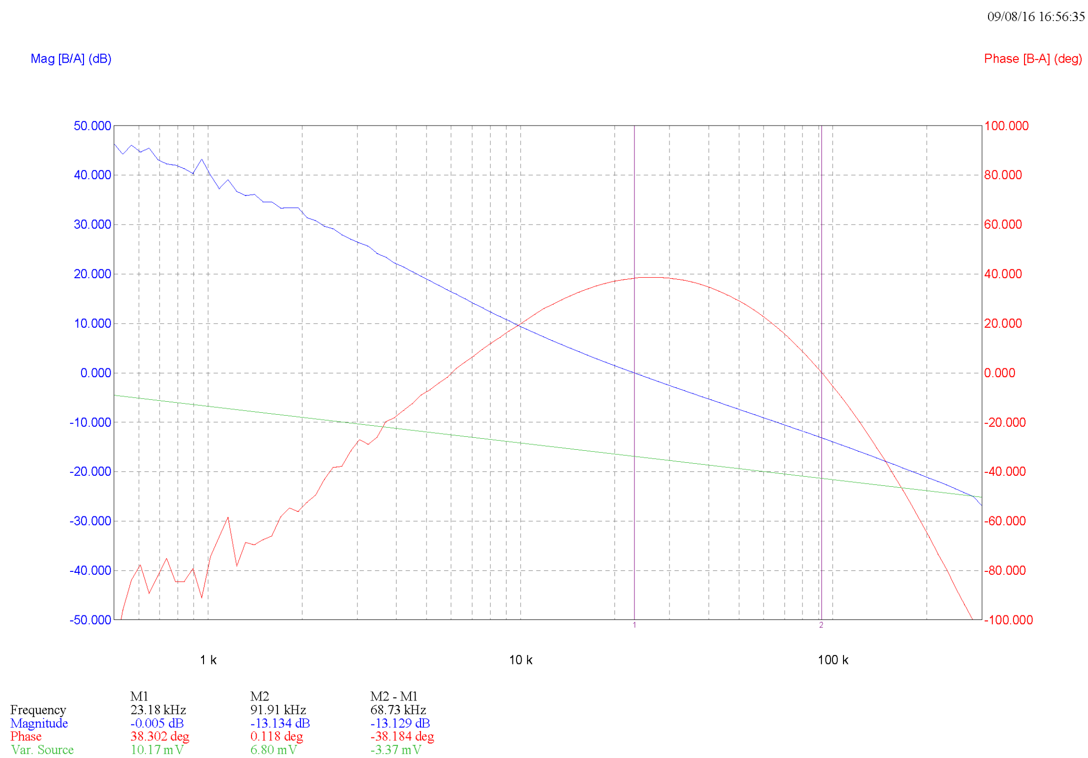

Figure 3. Loop Bode Plot of the TPS61021A Boost Converter Without C_{ff}

The most accurate way to measure the crossover frequency of a dc-dc converter is by using the network analyzer. When such an equipment is available, the crossover frequency can be quickly measured. Figure 3 shows the loop bode plot of the TPS61021A boost converter in Figure 2 using the network analyzer AP300. The phase margin of the boost converter is 38°, the crossover frequency f_{c_noCff} is around 23 kHz without the feedforward capacitor.

If the target phase margin is 60°, then there is a 22° gap between the tested value and the target value. Putting a zero at around 2 × f_{c_noCff} (refer to Table 1) can meet this design target. So we can get:

$$f_z = \frac{1}{2\pi \times R1 \times Cff} = 2 \times f_{c\_noCff}$$
$$Cff = \frac{1}{2\pi \times R1 \times 2 f_{c\_noCff}} \approx 10 \text{ pF} \tag{3}$$

where

- f_{c_noCff} = 23.18 kHz
- R1 = 316 kΩ (4)

Table 1. Phase Boost of a Single Real Zero f_z

Frequency	(1/10) × f_z	(1/8) × f_z	(¼) × f_z	(½) × f_z	f_z	2 × f_z	4 × f_z	8 × f_z	10 × f_z
Phase Boost	5.7°	7.1°	14°	26.5°	45°	63.4°	75.9°	82.8°	84.3°

Figure 4 shows the loop bode plot of the TPS61021A boost converter with 10-pF feedforward capacitor. The new crossover frequency is 28.8 kHz, close to the original crossover frequency. The new phase margin is 61°, about 23° higher than the original value, which is the same as previously estimated.

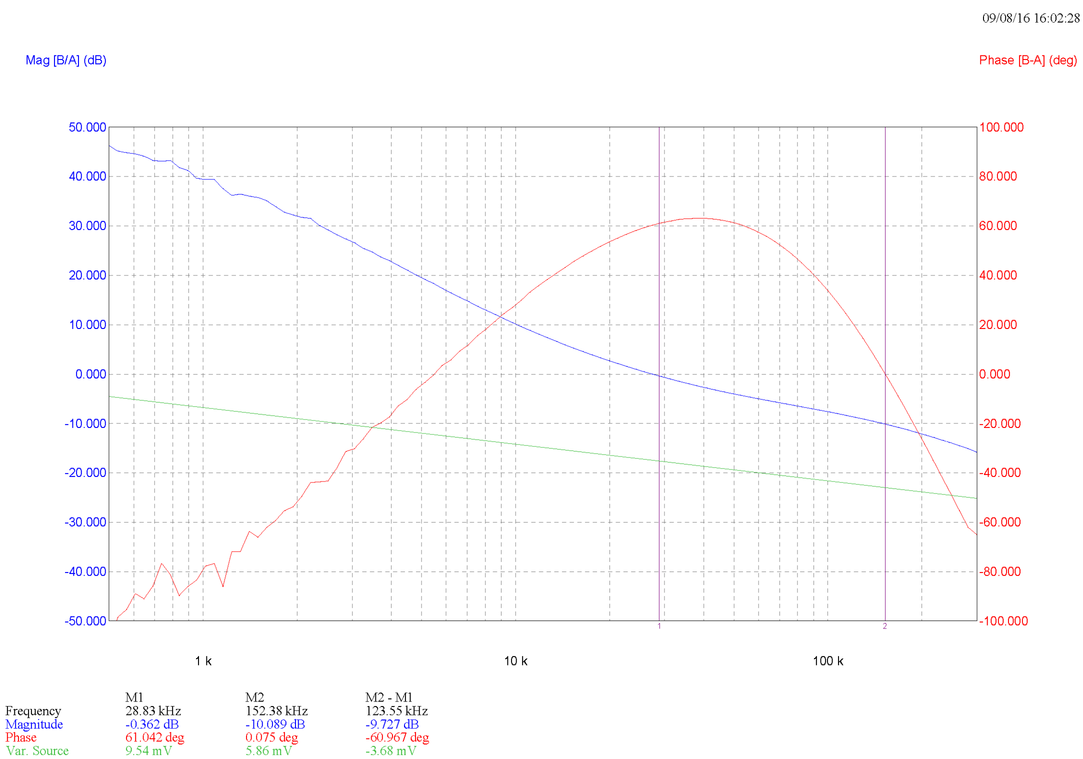

Figure 4. Loop Bode Plot of the TPS61021A Boost Converter with Cff = 10 pF

Figure 5 shows the load transient comparison with and without the 10-pF feedforward capacitor. The output voltage deviation during the load transient is 240 mV without the feedforward capacitor. With a 10-pF feedforward capacitor, the output voltage deviation can be reduced to 195 mV.

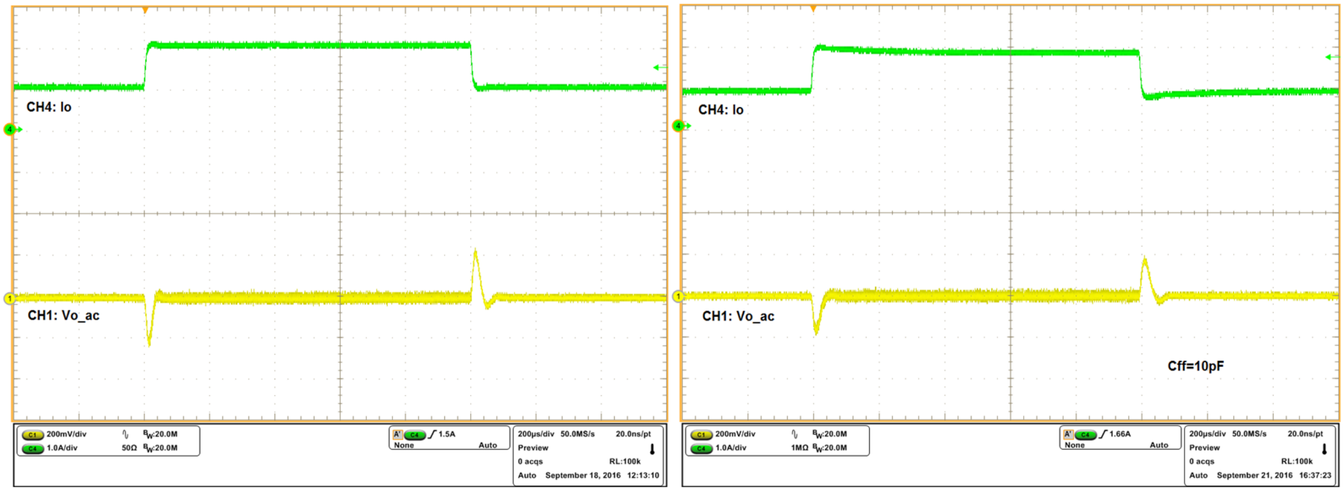

Figure 5. Load Transient Comparison With and Without C_{ff} = 10 pF (V_{IN} = 2.4 V, I_O = 1 A to 2 A)

3.2 Calculating the Feedforward Capacitor for Faster Loop Response With C6 = 100 µF

In some applications, the customer will add electrolytic capacitors or tantalum capacitors at the output side to sustain the big pulsed load current and avoid the output voltage from dropping too much. Figure 6 shows the schematic of the TPS61021A boost converter with an extra 100-µF tantalum capacitor (C6) at the output side.

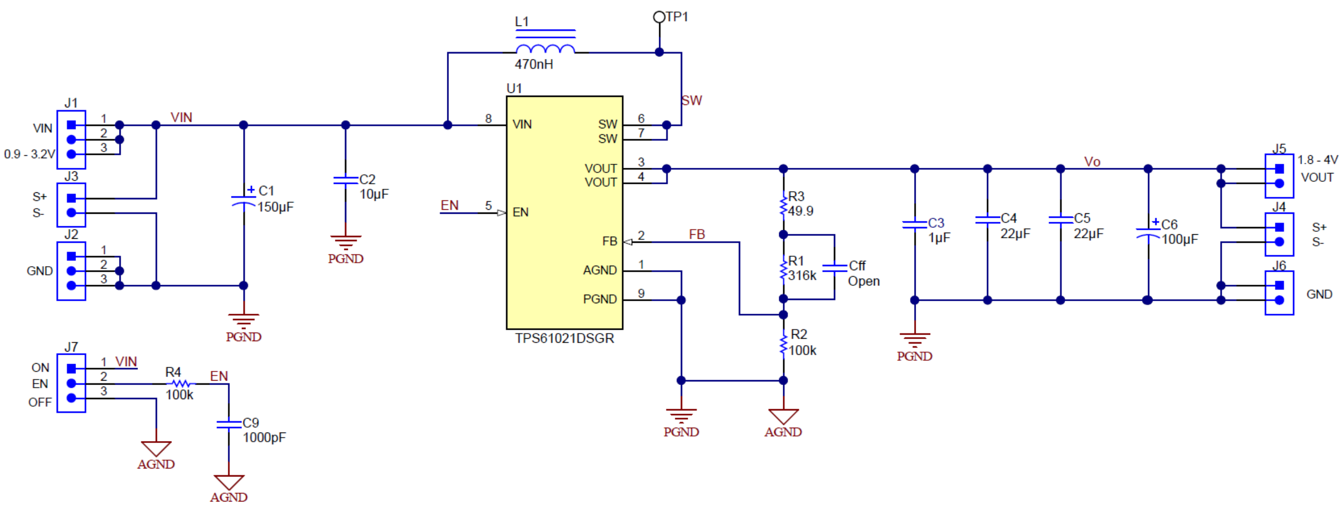

Figure 6. TPS61021A Boost Converter With C6 = 100 µF (no C_{ff})

Figure 7 shows the loop bode plot of the TPS61021A boost converter in Figure 6. With an extra 100–µF tantalum capacitor C6 at the output side, the crossover frequency f_{c_noCff} decreases to 9 kHz.

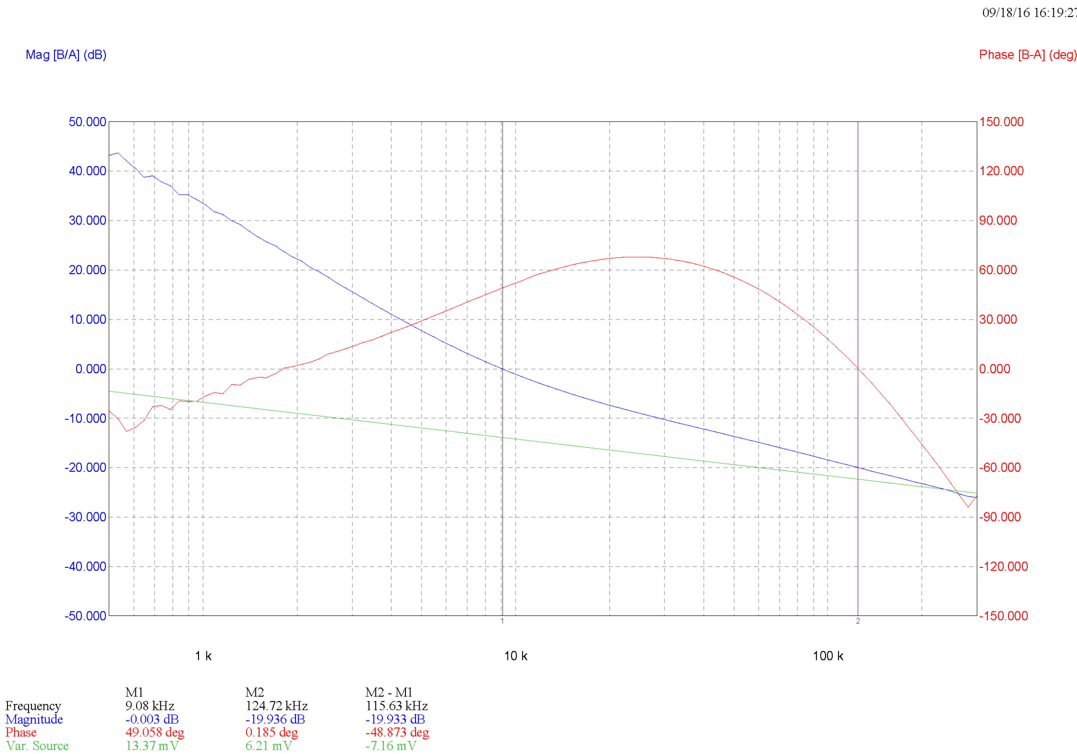

Figure 7. Loop Bode Plot of the TPS61021A Boost Converter in Figure 6 (V_{IN} = 2.4 V, I_O = 2 A)

Figure 8 shows the load transient response of the TPS61021A boost converter in Figure 6. The output voltage deviation during the load transient is 400 mV.

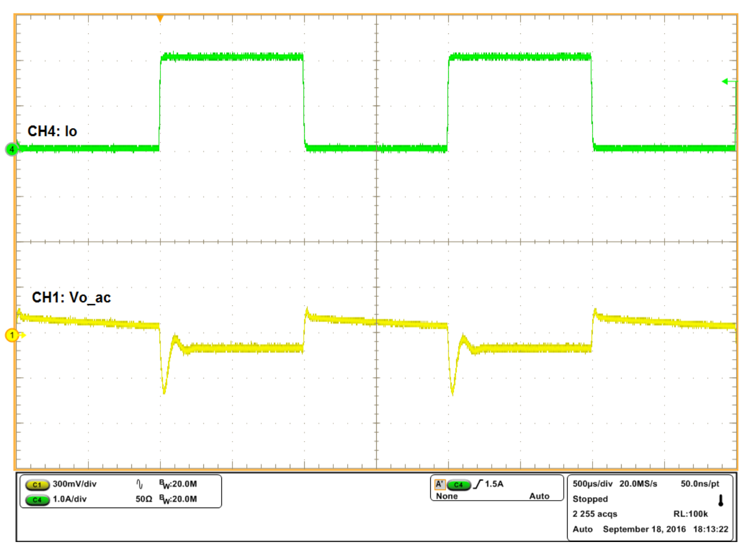

Figure 8. Load Transient Response in Figure 6 (V_{IN} = 2.4 V, I_O = 0 A to 2 A)

To further reduce the output voltage deviation, a feedforward capacitor can be added to increase the crossover frequency. An effective way of increasing the bandwidth is to put the zero f_Z at a frequency equal to or lower than the crossover frequency f_{c_noCff}. So we can get:

$$f_Z = \frac{1}{2\pi \times R1 \times Cff} \leq f_{c\_noCff}$$ (5)

$$Cff = \frac{1}{2\pi \times R1 \times f_{c\_noCff}} \geq 56 \text{ pF}$$

where

- f_{c_noCff} = 9.08 kHz (6)

A large Cff will shift the crossover frequency to a very high frequency while moving the maximum phase boost point to a lower frequency. So there is an upper limit for the Cff selection. If the minimum phase margin requirement is 45°, then the value of the feedforward capacitor should be lower than the value corresponding to the 45° phase margin. This corresponding Cff value can be determined by testing. Generally, it is not recommended to increase the Cff to a value which is much greater than the value calculated using Equation 6. So Cff = 68 pF is chosen in this design example.

Figure 9 shows the loop bode plot of the TPS61021A boost converter with a 68-pF feedforward capacitor. The new crossover frequency is 20.9 kHz, more than twice the original bandwidth. The new phase margin is 104°, also much greater than the original phase margin.

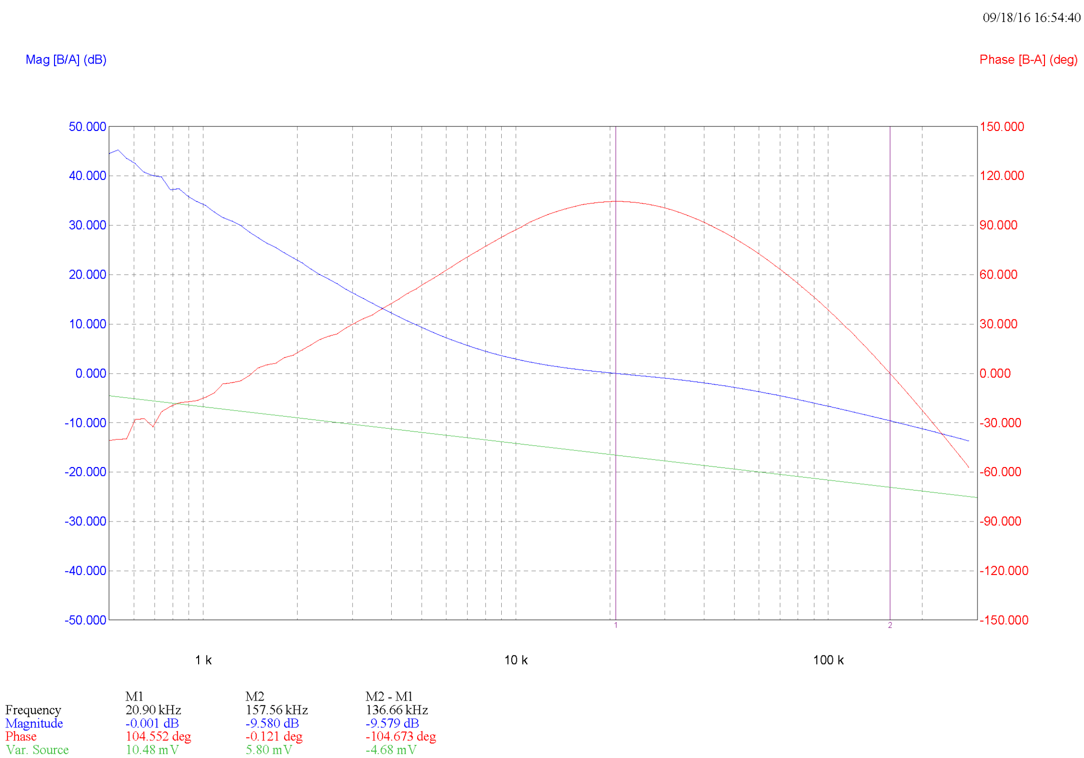

Figure 9. Loop Bode Plot of the TPS61021A Boost Converter With Cff = 68 pF (V_{IN} = 2.4 V, I_O = 2 A)

Figure 10 shows the load transient response of the TPS61021A boost converter with a 68-pF feedforward capacitor. The output voltage deviation during the load transient is reduced to 250 mV, which is about 150 mV lower than that of the no Cff condition.

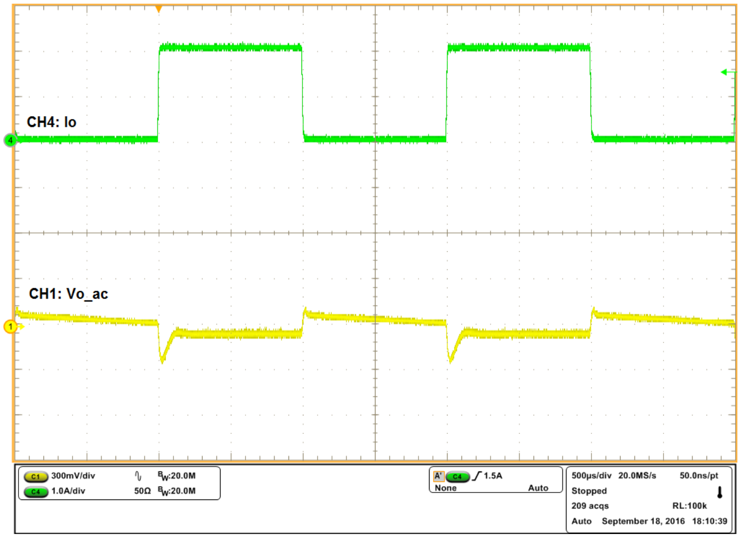

Figure 10. Load Transient Response in Figure 6 With C*ff* = 68 pF (V_{IN} = 2.4 V, I_O = 0 A to 2 A)

3.3 *Determining the Crossover Frequency and Phase Margin by Oscilloscope*

In the lack of a network analyzer condition, the crossover frequency and phase margin of the converter can be estimated through the load step waveforms tested by the oscilloscope. The article *Evaluation and Performance Optimization of Fully Integrated DC/DC Converters* (Topic 7 of the 2006 Portable Power Design Seminar) described the relationship of the load step waveform with the crossover frequency and the phase margin. The output voltage load step response of the converter gives the information of the loop stability (refer to Figure 11).

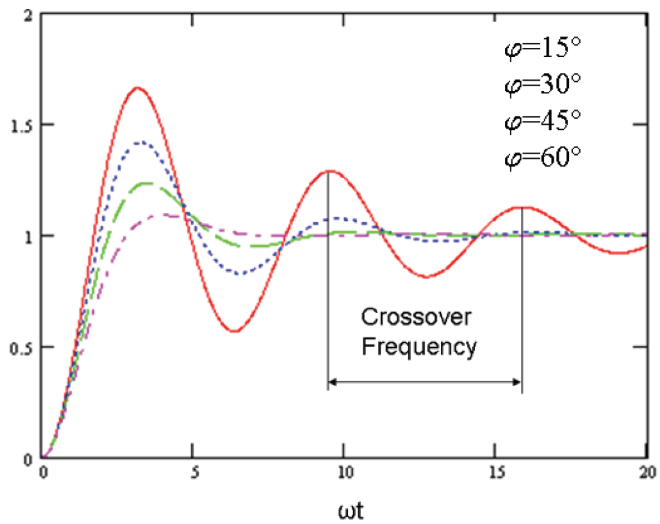

Figure 11. Output Load Step Response vs Loop Phase Margin

4 Conclusion

The feedforward capacitor used in the feedback network improves the performance of the internally-compensated boost converters. With the measured loop bode plot by the network analyzer, the value of the feedforward capacitor can be properly calculated to improve the phase margin or increase the bandwidth. In the lack of the network analyzer condition, the crossover frequency and phase margin of the converter can be determined by the load step waveforms.

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