Automated Tools Improve Frequency Response In Switching Regulators

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For system designers who are not power supply experts, the topic of switching regulator stability may be daunting. The easiest way to ensure regulator stability is to use a converter that is inherently stable, like hysteretic converters. With their varying switching frequency, however, that can lead to other problems related to filtering their switching noise. Another option is to choose internally-compensated regulators. These are appropriate for many designs, but usually do not support load currents much above 6 A (for stepdown regulators.) When a more sophisticated supply is needed, regulators with external compensation are needed.

Fortunately, many power supply design tools such as TI's WEBENCH Power Designer[1] include selection of compensation components. A few also include information to help assess a regulator's stability, like estimated phase margin and/or electrical simulations showing Bode plot and/or transient response.

What happens, though, if key schematic components have to be changed? How does the compensation change to match? Again, this varies by design tool. WEBENCH Power Designer includes a new Compensation Designer that makes it easy to update the compensation, and even improve it to gain faster response or better phase margin. This article will present a design example that demonstrates how to use Compensation Designer and the different options it offers for obtaining the desired transient response and stability.

As our example, let's create a power supply design with the LM21215A-1[2] using WEBENCH Power Designer. The input voltage is 3 V to 5V, and the output voltage is 1 V at 12 A. When the design is presented, the operating values show a phase margin of 45.1° at a crossover frequency of 33.1 kHz. A phase margin around 45° is good, indicating a balance of fast response and minimal overshoot in the transient response (Figs. 1 and 2.)
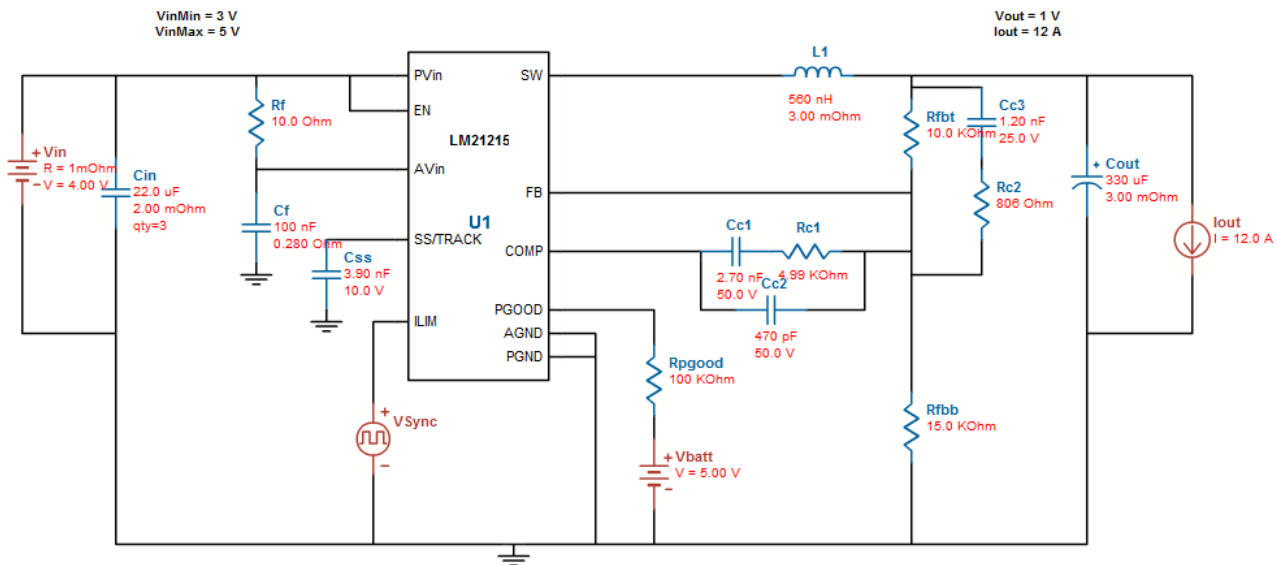

Fig. 1. Example stepdown switching regulator with external compensation network comprised of Cc1, Rc1, and Cc2.

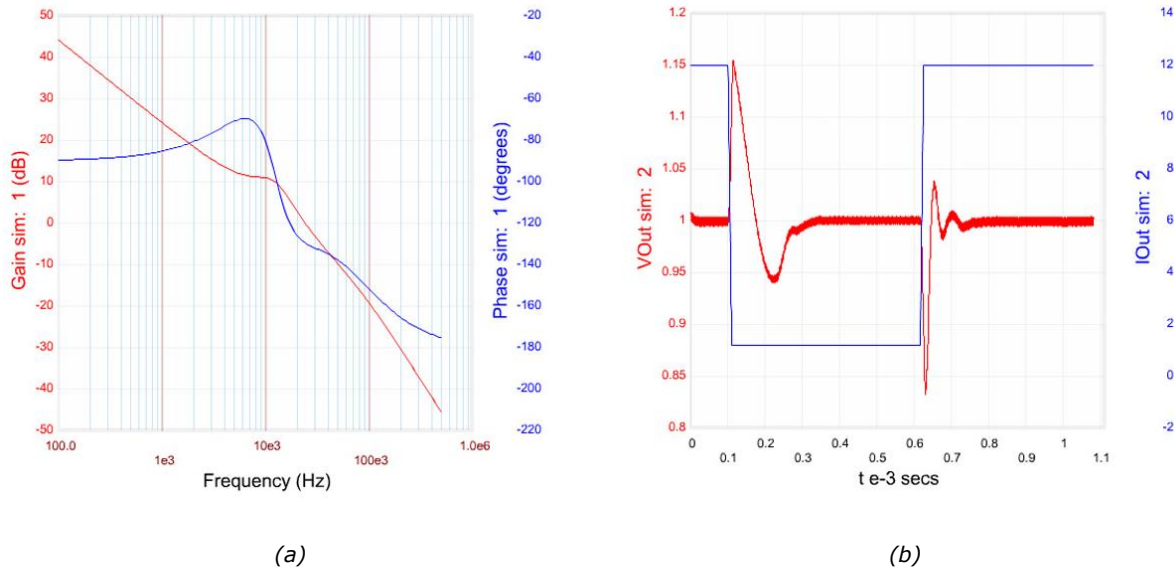(a)   (b)

*Fig. 2. Frequency response (a) of the switching regulator of Fig. 1 and load transient response (b)
for the same switching regulator.*

Changing Key Components Can Compromise Regulator Stability

Sometimes we have to change components that impact the frequency response. This is often due to the need to use certain components in several designs, so that inventory can be simplified. If we change the inductor from the suggested 560 nH to 1.2 µH (still within the recommended range for this design), the phase margin is reduced to about 37°. This is lower than our target of 45°. The transient response shows that the output voltage rings a lot more now, demonstrating less stability (Fig. 3.)
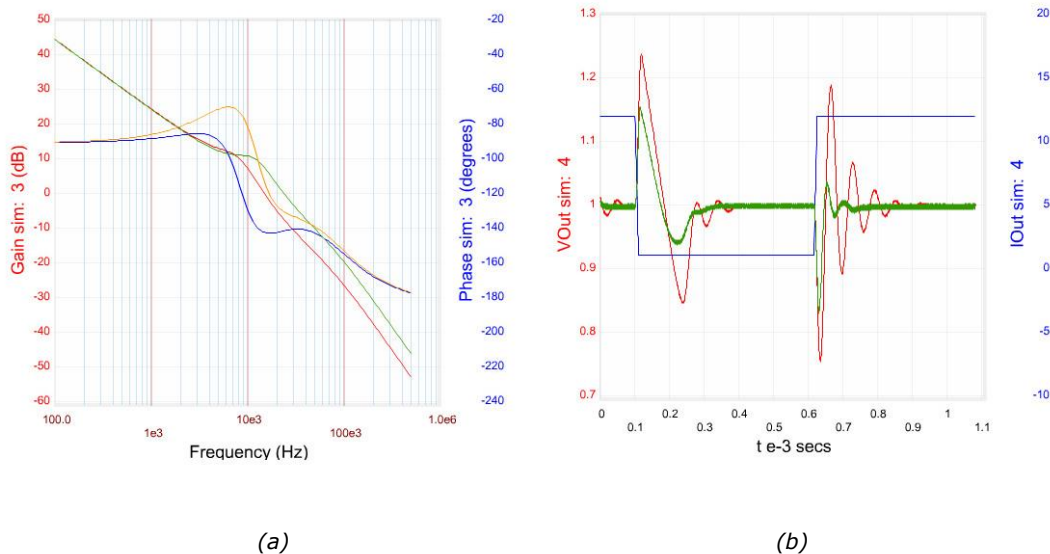

(a)   (b)

*Fig. 3. Frequency response of the circuit of Fig. 1 (a) with the original 560-nH inductor (green
gain plot, orange phase plot) and with a 1.2-µH inductor (red gain plot, blue phase plot). Load
transient response (b) for the same two design variations show lower stability for the 1.2-µH
inductor case. The output voltage with the original 560-µH inductor is the green trace; output
voltage with the 1.2-µH inductor is the red trace; the 12-A to 1.2-A to 12-A load step is the blue
trace.*

Improving Regulator Stability

Now, how do we improve the phase margin and, thus, the stability? We have several possible approaches:

- Change the compensation network or other key components individually, and test the results;

- Use WEBENCH Compensation Designer, targeting a specific phase margin;

- Using WEBENCH Compensation Designer, change the poles/zeroes of the frequency response directly;

- Using WEBENCH Compensation Designer, change compensation components and test the results before applying them to the design.

WEBENCH Compensation Designer is a new tool within WEBENCH Power Designer. It makes it much easier to adjust the frequency response of a regulator, quickly testing the result of possible changes to identify a good solution.

We will not follow the first approach, as that's too time-consuming. Let's check out the results with the other three approaches.

1) Target a specific phase margin.

In the WEBENCH design, we click the Re-Comp button to open Compensation Designer. Initially, the original design performance is shown (Fig. 4 at left), with a phase margin of 36.8°. The suggested target phase margin is 47° and target crossover frequency is 50 kHz. Both values are good targets.

We move the Optimization Tuning toward "Robustness," to emphasize phase margin over frequency response. Next click "Auto Compensate." The resulting phase margin is now 47° with a crossover frequency of 49 kHz (Fig. 4 at right.) This meets our targets! We then click the button "Apply Changes to Design." Checking the Bode plot and the transient response simulations confirms that the stability is now good (Fig 5.)

(a)   (b)

Fig. 4. WEBENCH Compensation Designer allows the user to review existing compensation and stability, and adjust compensation design to new targets. Using the design of Fig. 1 and the larger 1.2-uH inductor, the original frequency response summary and compensation components are shown in green type, next to the default targets and ranges (a). With Optimization Tuning slider toward "Robustness," click the button "Apply changes to design." The updated frequency response summary and compensation component values are shown in green type (b).
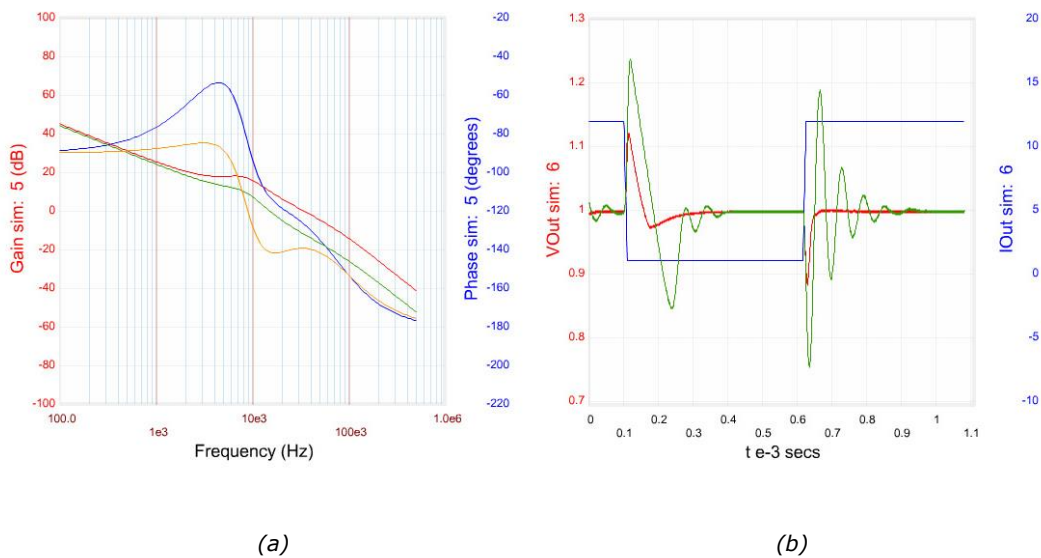

(a)   (b)

Fig. 5. Based on Fig. 1, the frequency response of the circuit with 1.2-µH inductor, with the original compensation (green gain plot, orange phase plot), and with the improved compensation (red gain plot, blue phase plot) (a). Load transient response for the same two design variations, showing improved stability for the new compensation (b). The output voltage with the original compensation is the green trace; output voltage with the updated compensation is the red trace; the 12-A to 1.2-A to 12-A load step is the blue trace.

2) Change frequency response poles and zeroes.

Option 2 is a more challenging technique and requires some control theory expertise. Opening Compensation Designer, we go to the Manual tab (instead of Auto), and click the button to "Edit Poles/zeroes." The frequencies of the poles and zeroes in the frequency response are shown (Fig. 6.)

We can improve the phase margin by changing the Zero frequencies to be closer to the double-pole created by the inductor and output capacitor $(1/(2\pi \ast sqrt(L \ast Cout)))$. In this case, the double-pole is at about 8 kHz. If we target Zero 1 at 4 kHz (half of 8 kHz), and Zero 2 at 8 kHz, the resulting phase margin is 49°, with a crossover frequency of about 59 kHz. This is much better than the previous values of 37° and 20 kHz (Fig. 7.)

⊙ Edit Poles/zeroes	Input	Calculated		⊙ Edit Poles/zeroes	Input	Calculated
Name				Name		
Gain (dB):	89.98	89.98		Gain (dB):	89.98	89.24
Zero 1 (kHz):	11.81	11.81		Zero 1 (kHz):	4.00	3.63
Zero 2 (kHz):	12.27	12.27		Zero 2 (kHz):	8.00	6.88
Pole 1 (Hz):	0.00	0.00		Pole 1 (Hz):	0.00	0.00
Pole 2 (kHz):	79.67	79.67		Pole 2 (kHz):	79.67	83.40
Pole 3 (kHz):	164.55	164.55		Pole 3 (kHz):	164.55	141.57

(a)   (b)

Fig. 6. Calculated poles and zeroes are in green type, for the example design with 1.2 uH inductor (a). Calculated poles and zeroes after changing Zero 1 target to 4 kHz, and Zero 2 target to 8 kHz (b).
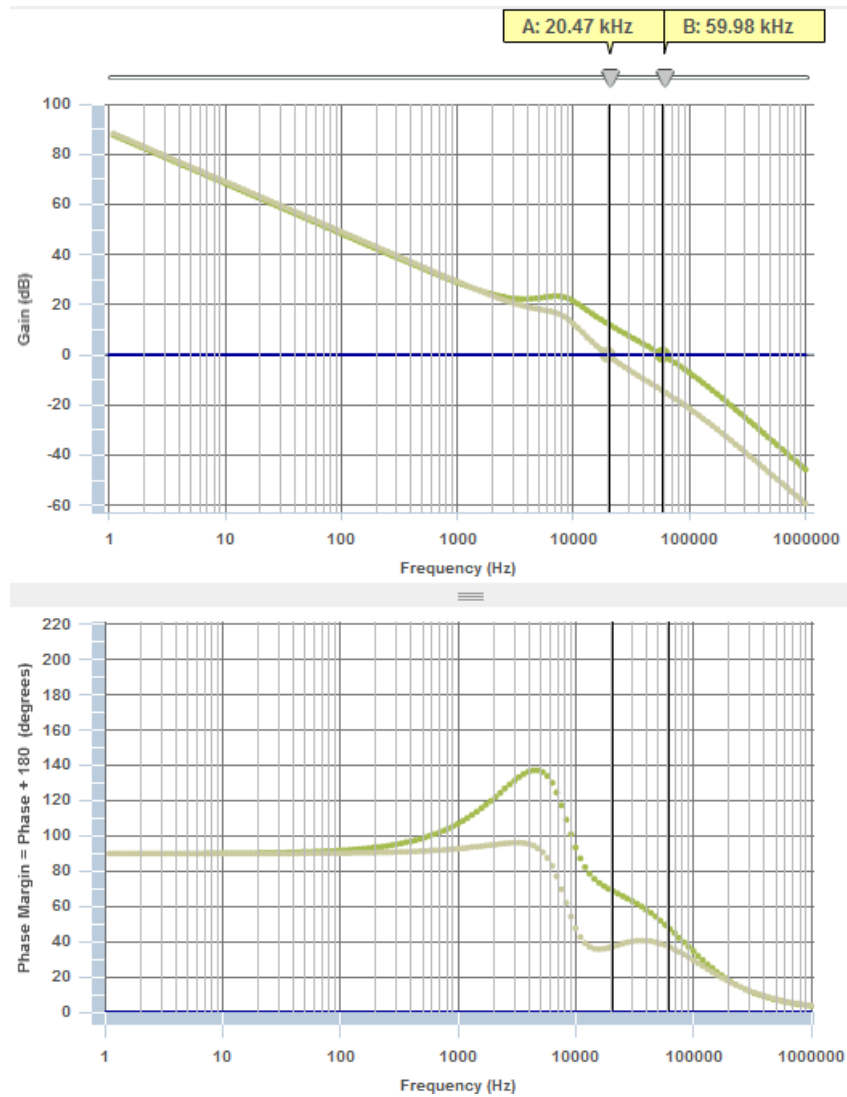
Fig. 7. Bode plot before (gray line, marker A) and after (green line, marker B) changing the target frequencies for Zero 1 and Zero 2.

After the zeroes have been changed, we find the phase margin much improved, increasing from 37° to 49°. The crossover frequency is also increased, from 35 kHz to 60 kHz. There are other techniques that can achieve good phase margin at higher crossover frequency, such as those used by the Automatic recompensation, but those are the topic of another article!

3) Change the compensation components.

The external compensation components determine the poles and zeroes that we discussed in Option 2. In the case of our example using the LM21215A-1 (Fig. 8), the datasheet gives equations and information about their relationship (Equation 1.)

$$f_{Z1} = \frac{f_{LC}}{2} = \frac{1}{2\pi R_{C1}C_{C1}}$$

$$f_{Z2} = f_{LC} = \frac{1}{2\pi(R_{C1} + R_{FB1})C_{C3}}$$

$$f_{P1} = f_{ESR} = \frac{1}{2\pi R_{C2}C_{C3}}$$

$$f_{P2} = \frac{f_{sw}}{2} = \frac{C_{C1} + C_{C2}}{2\pi R_{C1} C_{C1}C_{C2}}$$
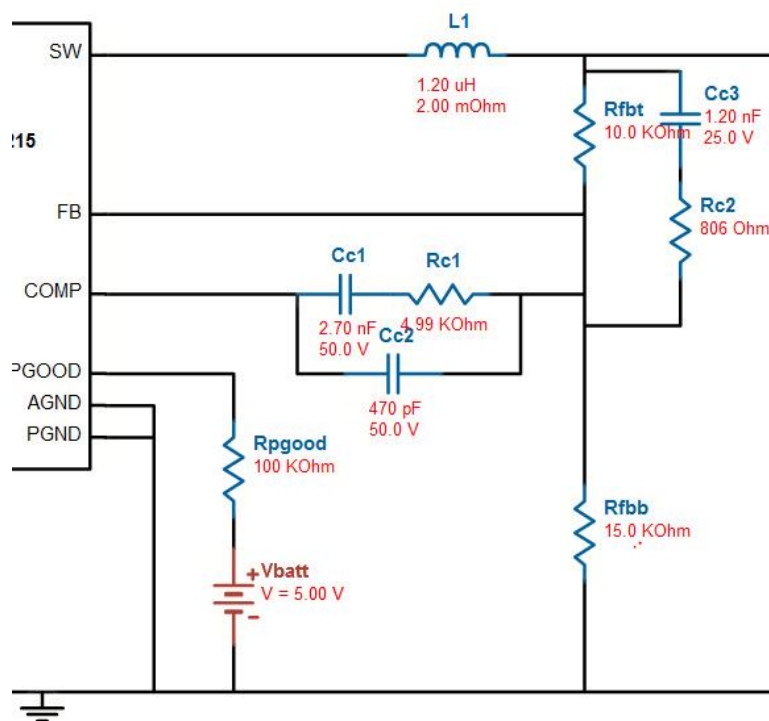
(1)

Fig. 8. LM21215A-1 design schematic section showing compensation components Rc1, Rc2, Cc1, Cc2, and Cc3.

We may want to adjust the compensation components individually, if some of the values do not match what we have in stock. Or we may want to attempt to improve the frequency response.

Taking the first case, and using our original 570-nH inductor in the working example, we see Rc2 is 806 Ω. If our closest stocked 1% resistor is 750 Ω, phase margin is decreased from 45° to about 44°, and crossover frequency is reduced from 33 kHz to 30 kHz (Fig. 9). We need to decide whether the changes are significant and pose a problem.

(a)   (b)

Fig. 9. The starting values for the compensation components are shown in the box on the top left, and the resulting frequency response is shown just below in the box for Design Operating values (a). The result of changing Rc2 from 806 Ω to 750 Ω is shown in the box for Design Operating values on the bottom right (b). Notice Cc3 was automatically changed to 1 nF, to partially counter the result of Rc2's change.

Another way to manage the compensation component values is to go back to the "Auto" tab on the Compensation Designer. There is a section that sets a range for the component values. We can adjust the range on any of the components (Fig. 10.)

Fig. 10. WEBENCH Compensation Designer allows the user to limit the range of values used for the compensation components.

Conclusion

When a power supply design's compensation needs to be reviewed, adjusted, or optimized, tools like WEBENCH Compensation Designer offer as much or as little automated guidance as you like.

References

1. WEBENCH Power Designer
2. LM21215A-1 datasheet

About The Author

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For further reading on transient response, see the How2Power Design Guide's Advanced Search page, go to Search by Design Guide Category and select "Transient Response" in the Design Area category. Also, try selecting "Control Methods" and "Stability" as these tabs will also point to related articles.