Quick Tips to Diagnose and Stabilize an Unstable Switching Power Supply

By Amir Ranjbar, Sr. Field Applications Engineer at MPS

Introduction

An unstable power supply can cause severe system issues, such as audible noise from the passive components, unexpected jittering in the switching frequency, extreme oscillations on the output voltage during load transient events, and failures in the semiconductor switches. While there are various reasons for instability, an un-tuned compensation network accounts for majority of instability issues in switching power supplies. This article provides guidance on how to find out whether or not the source of instability is an un-tuned compensation network, and offers quick tips to improve the stability of unstable power supplies.

Transient Response: A Measure of Power Supply Stability

Transient performance of a switching power supply is characterized by two main criteria: the bandwidth (BW) and phase margin (PM). A higher BW results in a faster transient response. A higher PM, on the other hand, means better stability. To obtain an acceptable transient performance, a high BW and high PM are required. There is, however, a tradeoff between BW and PM. Techniques that increase BW generally reduce PM, and vice versa.

Figure 1 shows a typical transient response of a power supply with a high BW and low PM. When a load transition occurs, the output voltage goes through several oscillations before settling at the regulated voltage. The number of oscillations on the output voltage during a load transition is a good measure for the stability of a power supply. The number of oscillations is directly related to the PM, and therefore stability of a power supply.

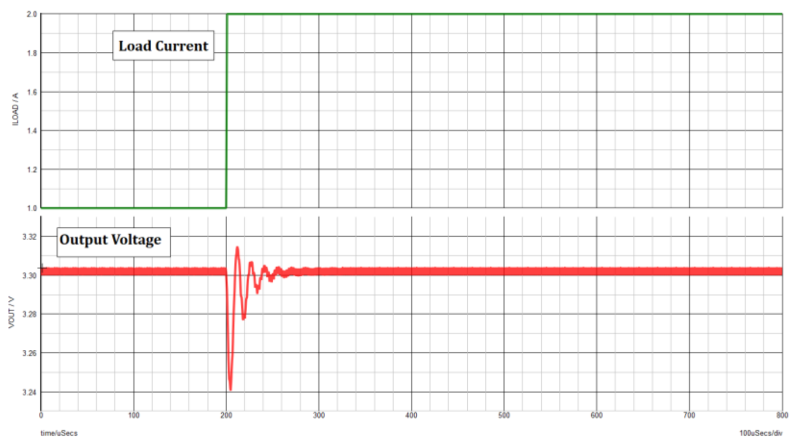


Figure 1: Typical Transient Response of a Power Supply

Compensation Networks in Switching Regulators

There are generally two types of compensation networks widely used for switching regulators: Type-II and Type-III. Type-II compensation networks employ a zero-pole set to achieve the desired BW and PM. To further improve a regulator's transient response, a Type-III compensation network is employed. Type-III compensation networks add an additional zero-pole set, which helps achieve higher BW and/or higher PM. Figure 2 shows a Type-III compensation network schematic.

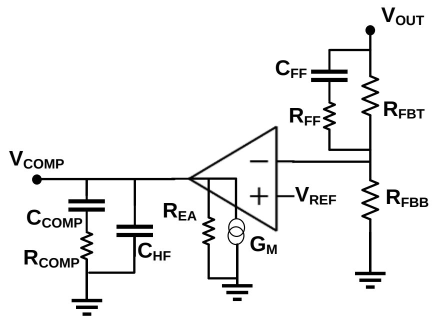
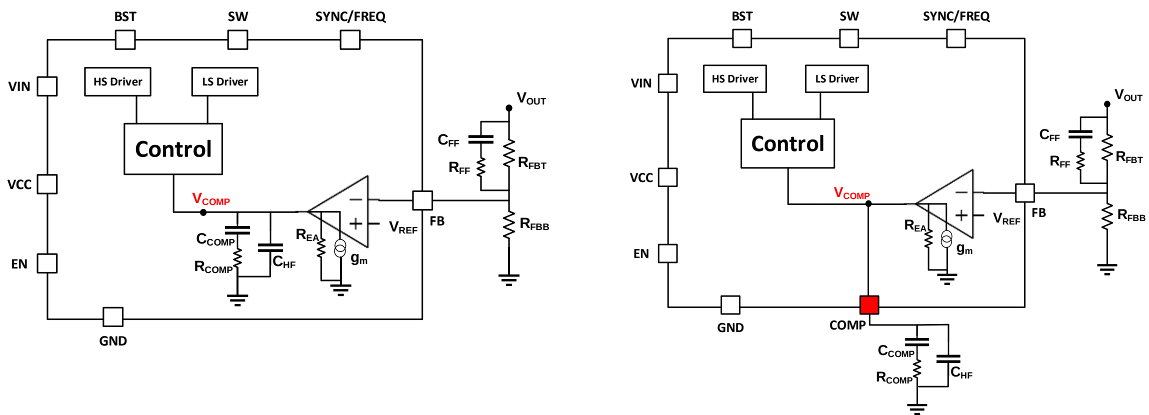


Figure 2: Type-III Compensation Network

The goal of this article is to show how simple techniques can be used to stabilize an unstable power supply. Note that the proposed techniques will only be effective if the source of instability is an un-tuned compensation network.

The two types of switching regulators, described below, are from a compensation network implementation point of view. These two types are: switching regulators with an external compensation network, and switching regulators with an internal compensation network. Figure 3 shows the typical application circuits for these two power supply types.



a) Internal Compensation Network **b) External Compensation Network**

Figure 3: Two Types of Compensation Networks in Power Supplies

Available Knobs to Stabilize an Unstable Power Supply

As discussed earlier, the instability in a switching regulator can be verified by looking at its transient response to a load change.

Figure 1 showed an example of an unstable power supply, which exhibited several oscillations on the output voltage when a load transition occurred. Figure 4 shows the bode plot for the power supply in Figure 1. In this example, the BW is 65kHz while the PM is only 16°. To have a power supply with an acceptable transient performance, a BW of no more than 10% of the switching frequency and a PM of >60° is recommended. The switching frequency in Figure 1's power supply was 400kHz. This limits the allowable BW to <40kHz. In Figure 4, the high 65kHz BW leads to a small PM (only 16°).

Note that in noise-sensitive applications, the BW must be further limited to less than 5% of the switching frequency.

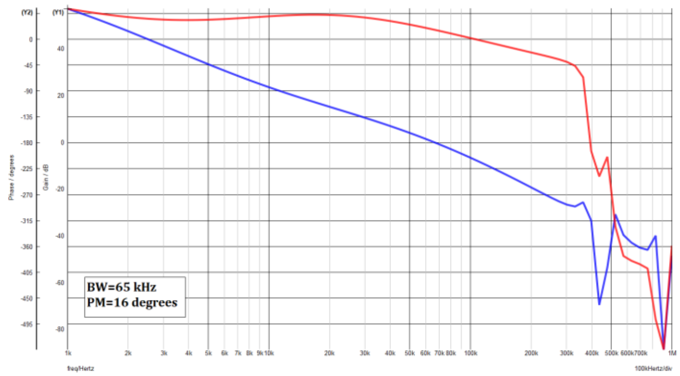


Figure 4: Bode Plot for the Power Supply in Figure 1

Figure 4 shows that the magnitude curve (in blue) reaches 0dB when the phase curve (in red) is already descending. For a proper PM and good stability, the 0dB point on the magnitude curve must occur before the phase curve starts descending.

The techniques presented below will allow readers to quickly fix unstable switching power supplies, while offering methods to see if reducing BW can improve stability. If the stability is improved as the BW is significantly reduced, that's confirmation that the source of instability was an un-tuned compensation network.

Note that BW reduction does two things to improve the stability. First, it makes the control loop slower. The slower control loop prevents or limits sharp spikes and/or oscillations on the output. Second, reducing the BW can increase the PM, which in turns improves the stability.

Regulators with External Compensation Networks

In power supplies with external compensation networks, the compensation network is placed at the COMP pin. In that scenario, a quick way to see if the oscillations on the output are caused by an un-tuned compensation network would be to place a large capacitor at the COMP pin. The large capacitor at the COMP pin introduces a low frequency pole to the control loop, which limits the BW significantly. The bigger this capacitor is, the lower the BW. Figure 5 shows the effect of adding a large capacitor at the COMP pin. A typical range for the capacitor at the COMP pin would be between 100nF and 1µF.

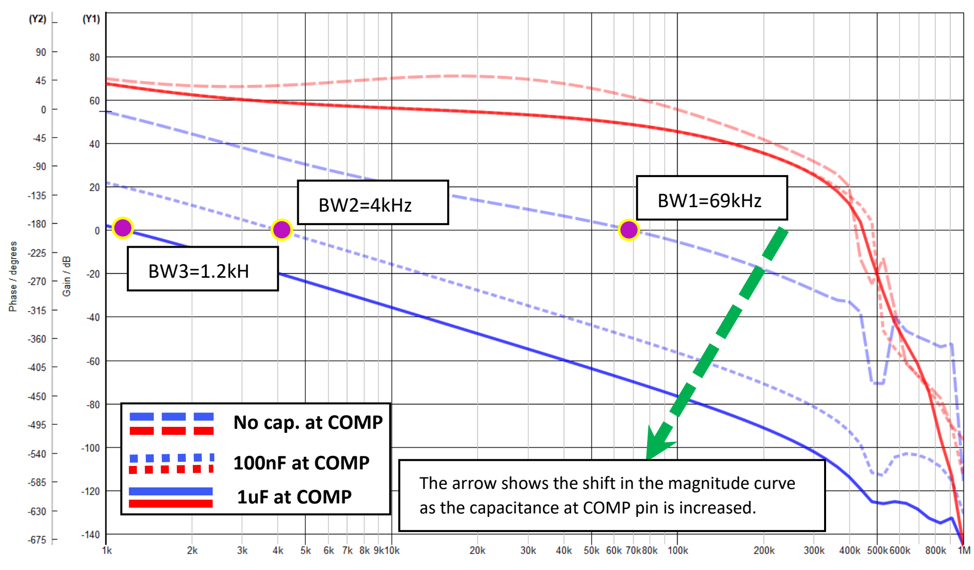


Figure 5: Effect of Adding a Big Capacitor to the COMP Pin

Regulators with an Internal Compensation Network

For regulators with an internal compensation network, the COMP pin is not available. Therefore, external knobs must be used to reduce the BW and improve stability. The most effective method to limit the BW of a switching regulator with an internal compensation network is using a resistor in series with the feedback pin (called a FB-series resistor).

Figure 6 shows the impact of adding a FB-series resistor. This resistor shifts the magnitude curve down with a minor impact on the phase curve. Therefore, it effectively limits the BW and increases the stability of the power supply. The bigger the FB-series resistor, the greater the BW reduction. Typical FB-series resistors should range between 5kΩ and 100kΩ.

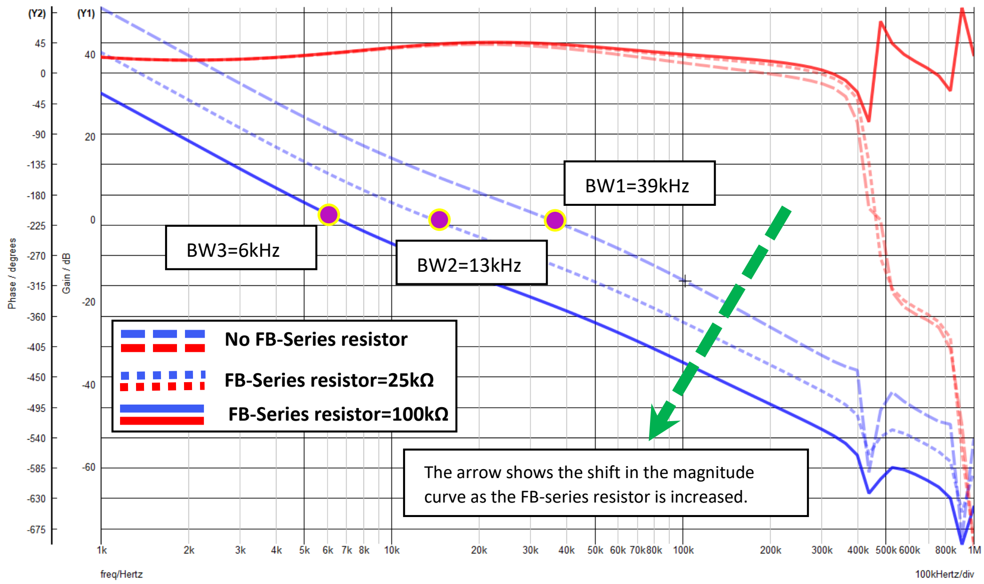
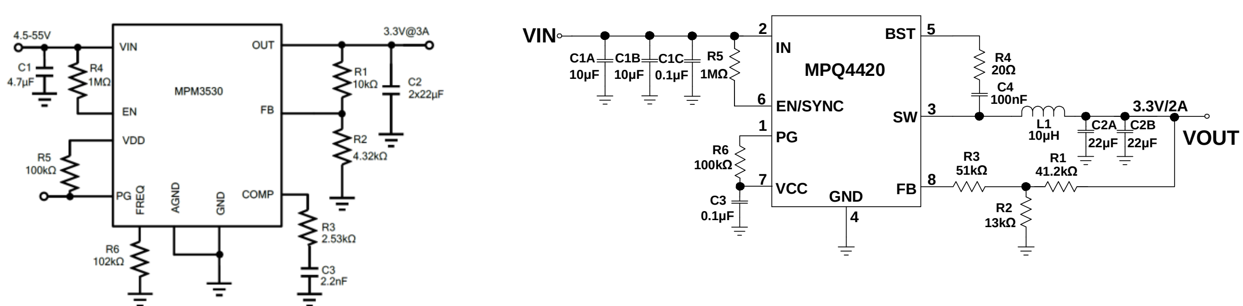


Figure 6: Effect of Adding a Resistor in Series with the FB Pin

Verification of Proposed Techniques for Troubleshooting an Unstable Power Supply

This article will use two parts in this example. The MPM3530 is a 55V/3A buck power module with an external compensation network from Monolithic Power Systems (MPS). Figure 7(a) shows the MPM3530's typical application schematic. Figure 7(b) shows the MPQ4420, a 36V/2A synchronous buck regulator from MPS with an internal compensation network.



a) MPM3530 Typical Application Schematic

b) MPQ4420 Typical Application Schematic

Figure 7: Example Typical Application Schematics

To show the effectiveness of adding a big capacitor at the COMP pin, consider the MPM3530. In this example, the compensation network components are chosen such that the regulator becomes unstable. This is done by increasing R3 in Figure 7(a) from 2.53kΩ to 16kΩ. Figure 8 shows the MPM3530's transient response and its bode plot. The high number of oscillations on the output represent the low stability. The small PM of only 2° on the bode plot confirms the low stability.

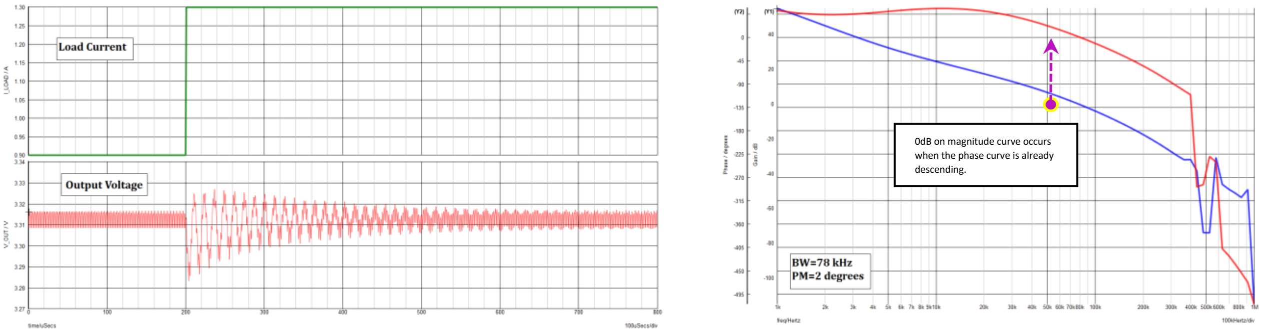


Figure 8: MPM3530 Transient Response and Bode Plot With Un-Tuned Compensation Network

Figure 9 shows what happens to the transient response once a 1µF capacitor is added to the COMP pin. The high oscillations on the output are damped, which means stability has improved. The bode plot shows that the BW has reduced significantly, as expected. The BW reduction results in a major PM increase, which then improves stability.

However, the improvement in stability is achieved at the expense of a slower response; the output voltage settling time has increased significantly, from 300µs to 2ms. Also note that due to a slower response to the load change, the maximum voltage undershoot is increased to 700mV, compared to 15mV in Figure 8.

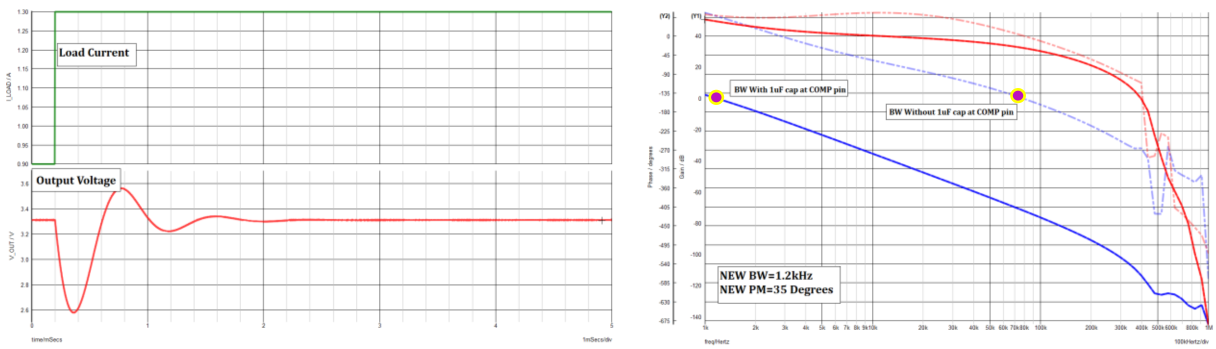


Figure 9: Stability Improvement Effect of a Big Capacitor at the MPM3530's COMP Pin

As shown in Figure 7(b), the COMP pin is not available in regulators with internal compensation networks, such as the MPQ4420. Figure 10 shows the transient response of the MPQ4420 without any FB-series resistor (e.g. R3 is set to 0Ω in Figure 7(a)). The high oscillation on the output voltage during load transition demonstrates low stability. Looking at the bode plot, the BW is 72kHz while the PM is only 11°. Since the MPQ4420's default switching frequency is 410kHz, the BW must be limited below 41kHz.

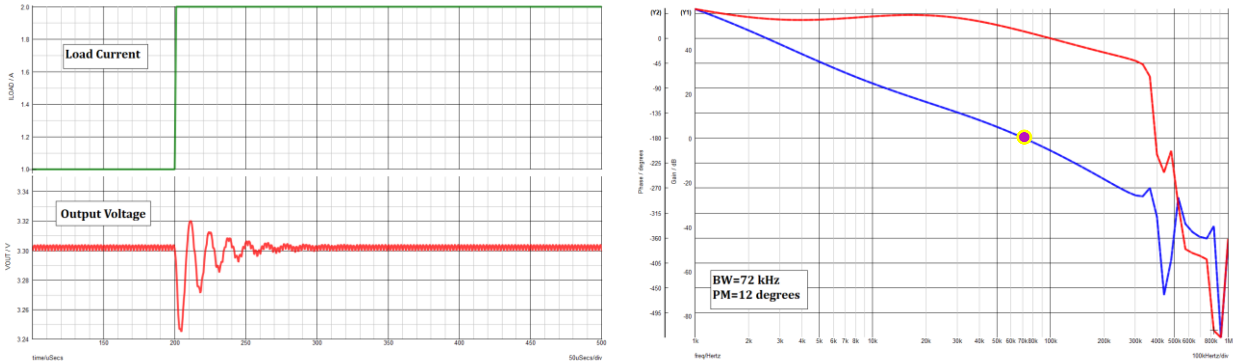


Figure 10: MPQ4420 Transient Response and Bode Plot Without FB-Series Resistor

Figure 11 shows how changing R3 from 0Ω to 51kΩ significantly reduces oscillations during transient response. As expected, introduction of the FB-series resistor shifted the magnitude curve down, which means a lower BW and higher PM. In this scenario, the new BW is 21kHz and the PM has improved from 11° to 43.5°.

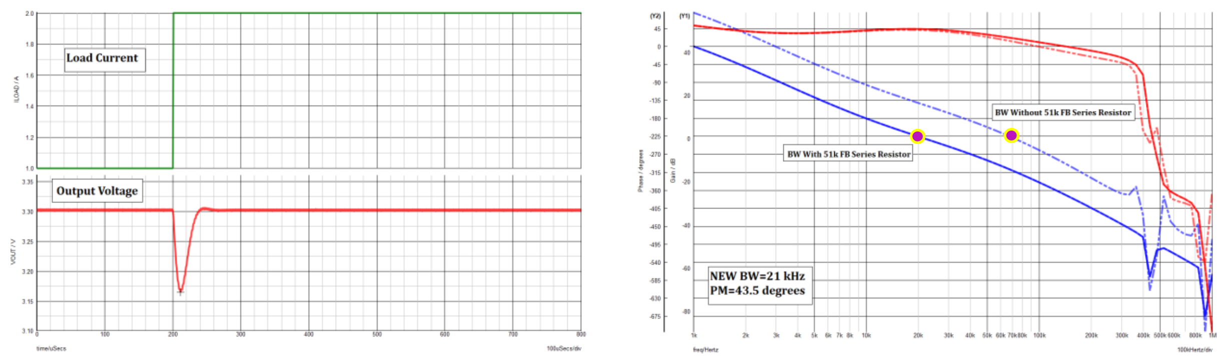


Figure 11: MPQ4420 Transient Response and Bode Plot with FB-Series Resistor

Further Improvement on Power Supply Transient Response

Despite the higher stability and fewer oscillations on the output shown in Figure 12, the PM is still below the 60° target. Further BW reduction will not provide any additional boost to the PM, and it further slows down the response time. As learned earlier, lower BW also increases the magnitude of voltage undershoot.

An additional knob can be used to improve the PM without making the regulator slower by sacrificing the BW. This solution is a feed-forward capacitor (C_{FF}).

Because this is a Type-II internal compensation network, it does not provide any phase boost. If phase boost is required, add C_{FF} on the feedback network (see Figure 12). C_{FF} adds another zero to the compensation network, which can boost the PM without reducing the BW. In fact, if the capacitor is selected properly, the PM can be improved and the BW can also be increased to achieve a faster transient response.

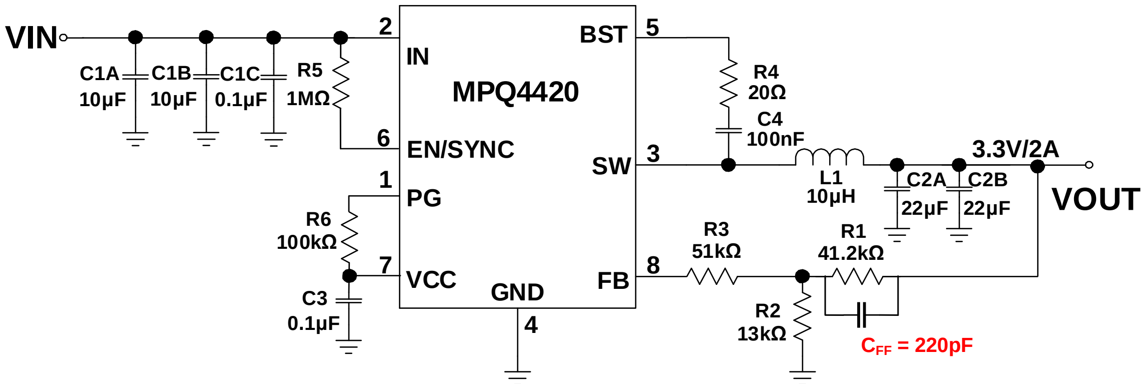


Figure 12: MPQ4420 Schematic with Feed-Forward Capacitor

Figure 13 shows the transient response and the bode plot for the MPQ4420 with a 19kΩ FB-series resistor and a 220pF C_{FF}. As shown here, the BW has increased to 40kHz, which is exactly 10% of the switching frequency, and the PM has reached 78°, which is in line with the target PM of >60°.

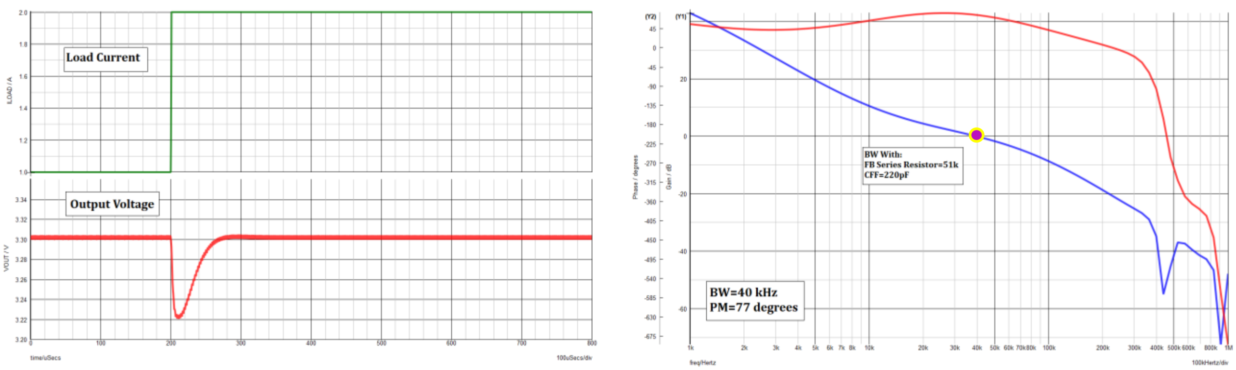


Figure 13: MPQ4420 Transient Performance with FB-Series Resistor and C_{FF}

Figure 13 shows that there is only one undershoot on the output voltage, which confirms that the device has good stability. The response time has also been reduced to about 60µs, and the undershoot voltage has been reduced to only 8mV.

Conclusion

This article explored several quick tips to diagnose and solve instability problems in switching power supplies. Separate techniques were proposed for stabilizing regulators with an external compensation network vs. regulators with an external compensation network. The effectiveness of the proposed techniques were verified by applying them to the MPM3530 and MPQ4420 from MPS, and this article demonstrated how a feed-forward capacitor can further improve a switching regulator's transient response.