

Loop Control: Hand Calculations or Automation?

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Loop control is an important part in the design of a switching power supply, however for various reasons, it is often considered at the very end of the project, when the main components have already been selected and are populating the prototype. Through simple trial and error it is sometimes possible to get the impression that a design delivering an acceptable transient response on the oscilloscope is ready for production, but this is a very unwise (and potentially costly) policy.

Stray and parasitic elements often remain hidden during these prototype tests. In the factory, the dispersions of these parameters, combined with silicon lot-to-lot variations, can make converters fail in quantity at the final test. To avoid such stressful situations, design engineers should spend time analyzing the loop in detail. This article details how use of automated design tools could be a path worth exploring.

Stabilizing CCM Flyback Converters

Popular in the notebook adapters market, the flyback converter operated in current-mode control lends itself very well to low-cost but rugged system designs. A typical application of such a converter appears in Fig. 1.

The controller in this particular case is ON Semiconductor’s NCP1271, which operates in fixed-frequency current-mode control and includes a number of useful features. These include timer-based short-circuit protection, frequency modulation for an EMI-friendly signature and a skip-cycle function that operates in soft mode to meet new standby power requirements while generating no acoustic noise.

Usually, these converters are designed to operate in continuous conduction mode (CCM) at low line to reduce conduction losses, but they will naturally transition to the discontinuous conduction mode (DCM) of operation at high line. In this example, we will assume that the hardware design is done, implying the selection of the transformer primary inductance L_p , the turns ratio N of the transformer and the rest of the elements—only the TL431 needs to be addressed.

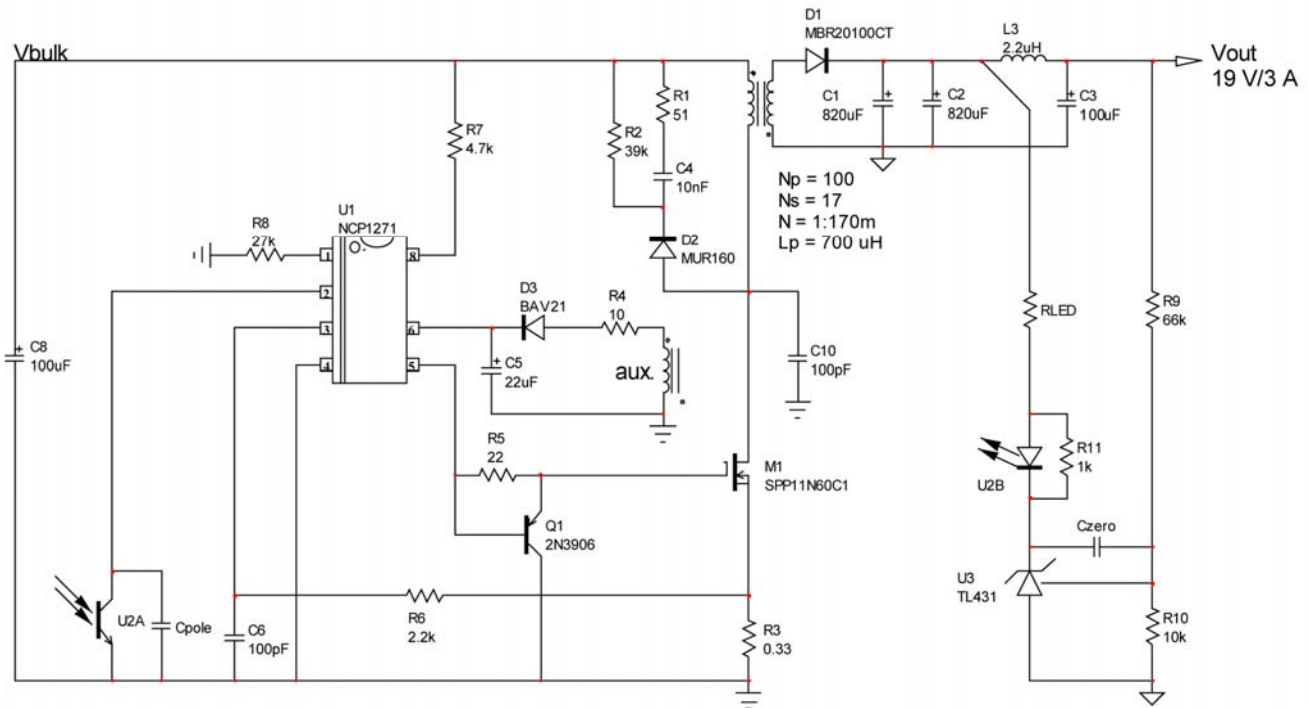


Fig. 1. A typical flyback converter design using an NCP1271 controller, which features a frequency-jittered oscillator.

The first thing that must be done is to obtain the control-to-output transfer function of the current-mode flyback converter, also known as the open-loop 'plant' transfer function. There are four ways that this can be achieved:

1. By analytically deriving the small-signal model of the converter in question and using an automated mathematical tool to extract the magnitude and phase of the power-stage response. Details on the factors relating to the magnitude of CCM current-mode flyback appear in Reference 1 and are described below in Equation 1. The various poles and zeros are seen here but also the double subharmonic poles located at half the switching frequency f_n and affected by a quality coefficient Q_p :

$$|H(f)| = 20 \log_{10} \left[G_0 \frac{\sqrt{1 + \left(\frac{f}{f_{z1}}\right)^2} \sqrt{1 + \left(\frac{f}{f_{z2}}\right)^2} \sqrt{1 + \left(\frac{f}{f_{z3}}\right)^2}}{\sqrt{1 + \left(\frac{f}{f_{p1}}\right)^2}} \frac{1}{\sqrt{\left(1 - \left(\frac{f}{f_n}\right)^2\right)^2 + \left(\frac{f}{f_n Q_p}\right)^2}} \right] \quad (\text{Eqn. 1})$$

The phase also needs to be separately calculated to make sure a complete Bode plot is generated. The negative sign on the second term of Equation 2 shows that f_{z2} is actually a right half-plane zero (RHPZ):

$$\arg H(f) = \tan^{-1} \left(\frac{f}{f_{z1}} \right) - \tan^{-1} \left(\frac{f}{f_{z2}} \right) + \tan^{-1} \left(\frac{f}{f_{z3}} \right) - \tan^{-1} \left(\frac{f}{f_{p1}} \right) - \tan^{-1} \left(\frac{f}{f_n Q_p} \frac{1}{1 - \left(\frac{f}{f_n}\right)^2} \right) \quad (\text{Eqn. 2})$$

These formulas imply the separate calculation of each of their elements and require great care in computing and plotting of the final results. Also, they are only valid for CCM. If the converter transitions to DCM, these expressions will need to be updated with new ones, further lengthening the study. If we assume that an understanding of the technique needed to derive these results is required, then a practical implementation of these formulas will be restricted to someone at ease with complex mathematical analysis.

2. The second option makes use of a SPICE large- or small-signal averaged model. This does not shield the design engineer from needing to know what might hide behind the model, but they will no longer have to manipulate tedious equations. First, a SPICE model automatically computes the operating point and tells the engineer whether the converter operates in CCM or in DCM. It then selects the appropriate equation arrangement for the mode of operation. At that point, the engineer simply presses the start button and the Spice tool generates an ac plot in little more than a second.

3. Automated software is another possibility. ON Semiconductor has released an automated spreadsheet that handles all these details for the engineer. By populating the component values for L_p , N , input voltage, etc, and then updating the spreadsheet, the required information can be quickly obtained. This approach will be covered in more detail later.

4. The last option is to build a prototype and try to extract the ac response of the power stage via a network analyzer. This operation is relatively easy when testing a power supply whose loop is already stabilized and the engineer simply wants to confirm his calculations by a bench measurement. But in cases where the power supply is not stabilized, or is barely stable, the task gets far more complicated. However, a combination of option 4 with one of the previously discussed options will ensure that engineers build a rugged and stable prototype in the smallest amount of time.

A New Automated Tool

As already made clear, compensating a flyback converter requires a reasonable degree of knowledge of control loop theory. Engineers are often tempted to circumvent this requirement by just going to the laboratory and playing with the resistor and capacitor values until the step response looks good. On several visits that I personally made to customers sites in the past, I saw this kind of approach being taken. Despite the warnings I expressed, the boards went into full production, and only a few months later, the manufacturing lines had to be stopped due to unexpected instabilities at the final test stage.

For those who do not have the time needed to derive the equations, it is worth considering an automated tool that can do all the math. This was the reasoning behind ON Semiconductor’s development of its automated Excel-based spreadsheet, which features several separated tabs, starting from the component values up to the final bill-of-materials. The user simply enters the component values for the converter section and presses OK. The user then sees the power-stage response, as illustrated in Fig. 2 (right side), confirming the peaking and the CCM operation. In this example, the duty-cycle is 55% and the gain flattens to 19.6 dB at dc.

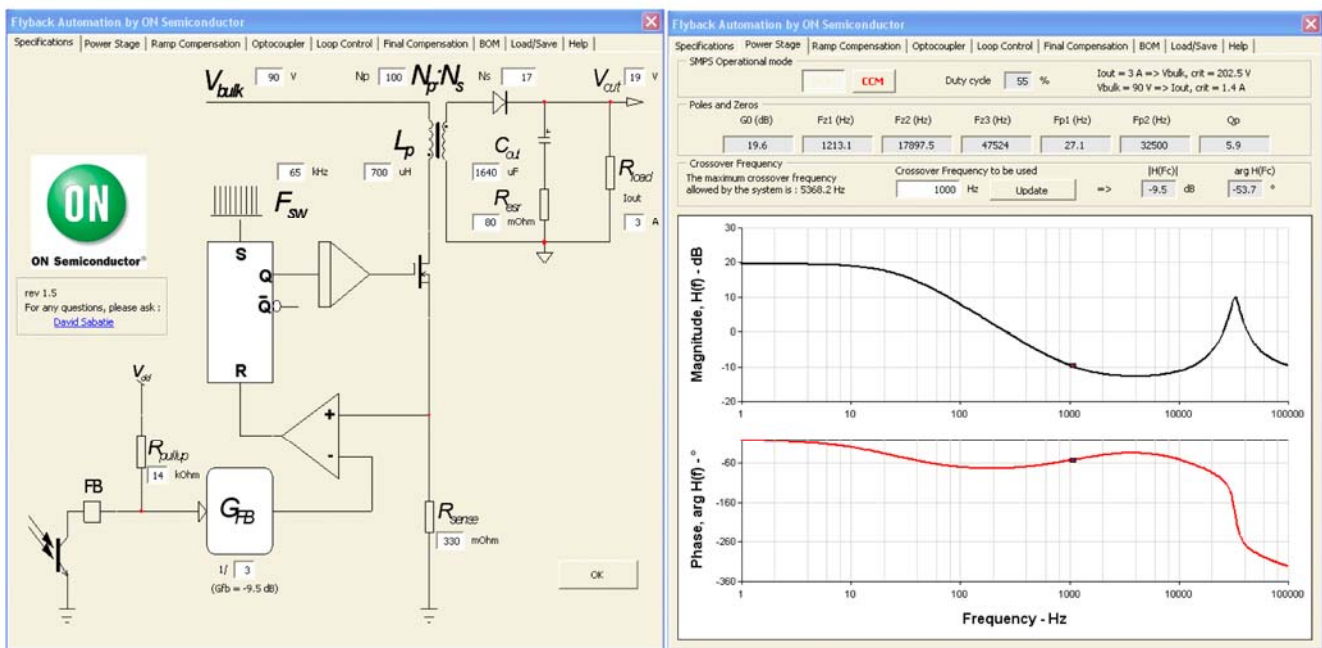


Fig. 2: ON Semiconductor automated spreadsheet tool - The left-side opening screen invites the user to fill up the component values calculated. Once OK is pressed, the power stage tab appears and unveils the power stage ac response (shown on right).

The software then damps the subharmonic poles by selecting the right amount of compensation ramp (Figure 3). The spreadsheet calculates the equivalent quality coefficient, Q_p , and checks how much ramp compensation is necessary to reduce it below 1. In theory, it reduces the risk of overcompensation given by the other calculation methods, which solely rely on the inductor down slope and consider a duty-cycle excursion of up to 100%.

Next, the user is required to enter the optocoupler characteristics, consisting of a current transfer ratio (CTR) and a pole whose position depends on the pull-up or pull-down resistor. In the given example, the CTR is 30% and the pole is found to be at 4 kHz. A tutorial available with the software package details how to characterize the optocoupler and its role must be well understood when designing the power supply.

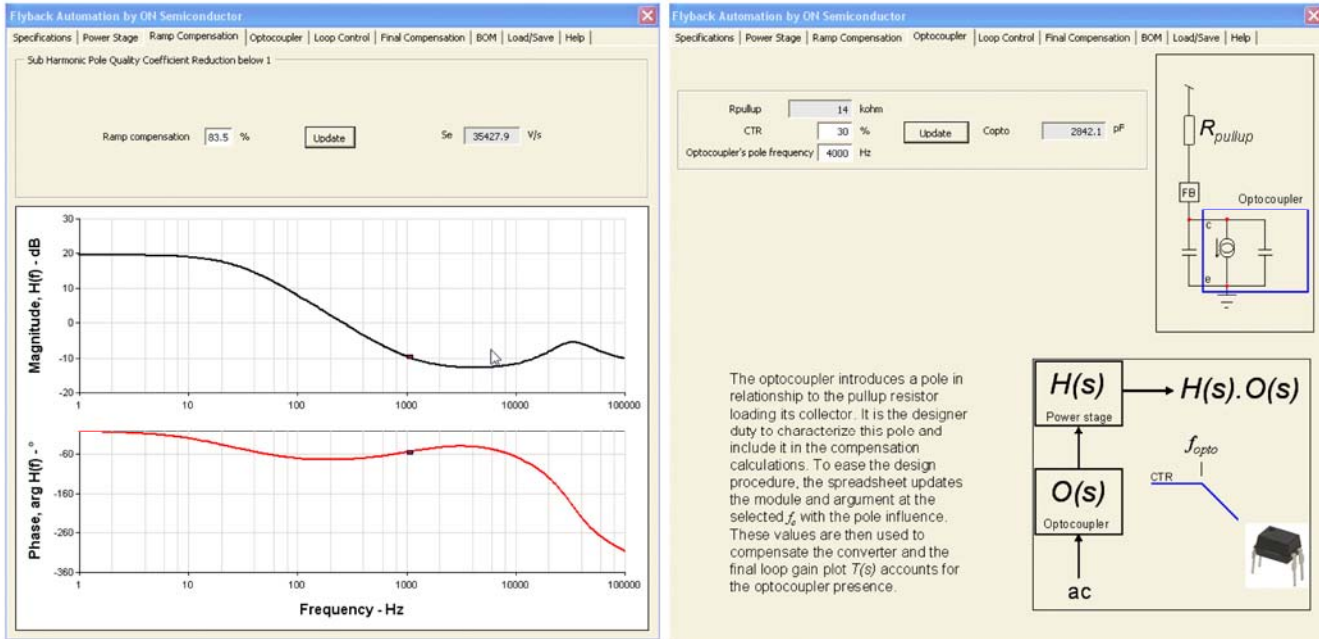


Figure 3: Once the power stage ac response has been obtained, the next step is to evaluate the necessary amount of ramp compensation and its effect on the power-stage response. Then, the optocoupler tab will appear and let the user enter the measured pole.

As Figure 4 depicts, the type 2 compensator offers the needed 25° boost by placing a zero at 635 Hz and a pole at 1.5 kHz (left). The software implements the k factor technique, which places the crossover frequency in the geometric mean of the selected pole and zero. Finally, as confirmed by Figure 4 right side, the loop gain exhibits a crossover point close to 1 kHz with an adequate phase margin.

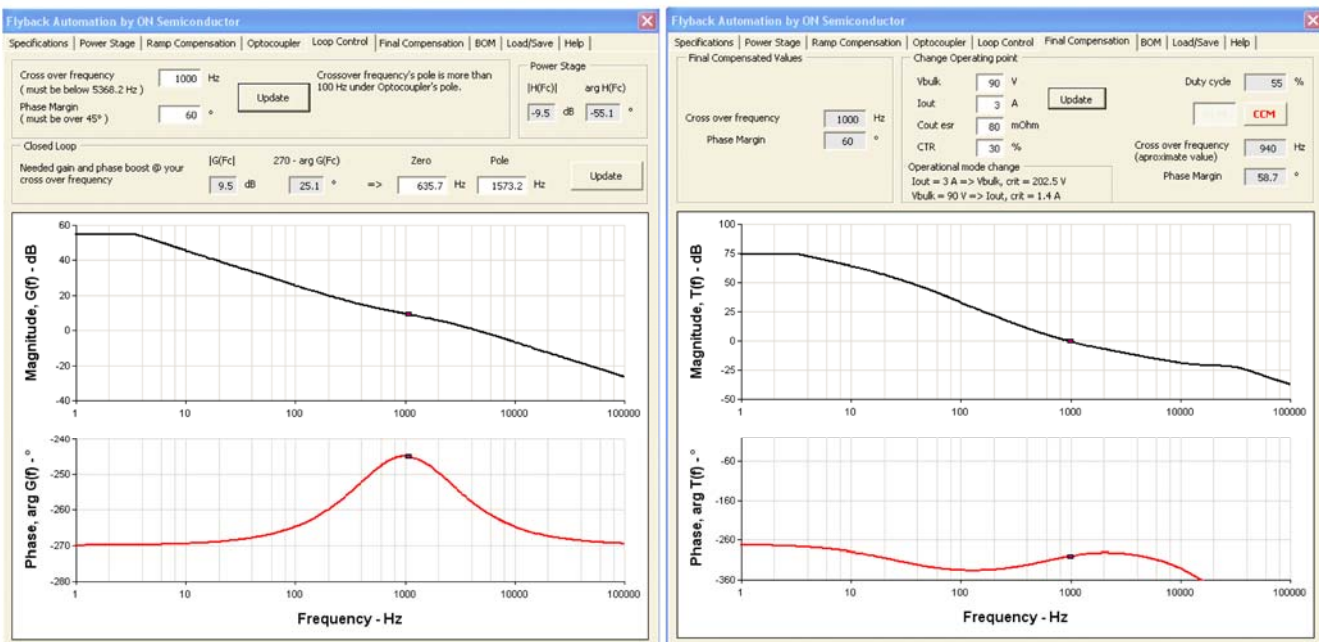


Figure 4: The proposed compensator for a 60° phase margin on the left shows a boost of 25°, very close to what was originally calculated. Once compensated, the resulting phase margin corresponds to the exact figure (shown on the right).

A button in the upper right corner lets the user change the operating points (in particular the input voltage and the output current). When the update button is pressed, the software recomputes the power-stage characteristics, keeping the compensator parameters constant. It then displays the loop gain, accounting for the changes you requested. The user can then quickly check if the power supply remains stable when it transitions from CCM to DCM, for example. Output capacitor equivalent series resistance (ESR) and optocoupler CTR are among the parameters that can also be swept.

At the end, Fig. 5 offers a view of the TL431 and all its calculated values. The right panel indicates ways to practically implement ramp compensation. As an NCP1271 was selected, the insertion of a simple resistor from the sensing element to the current-sense pin does the job instantaneously. To improve overall noise immunity and avoid noise pick up by long copper traces, it is recommended that a small capacitor of at least 100 pF be placed in parallel with the optocoupler. This capacitor should be located very close to the controller.

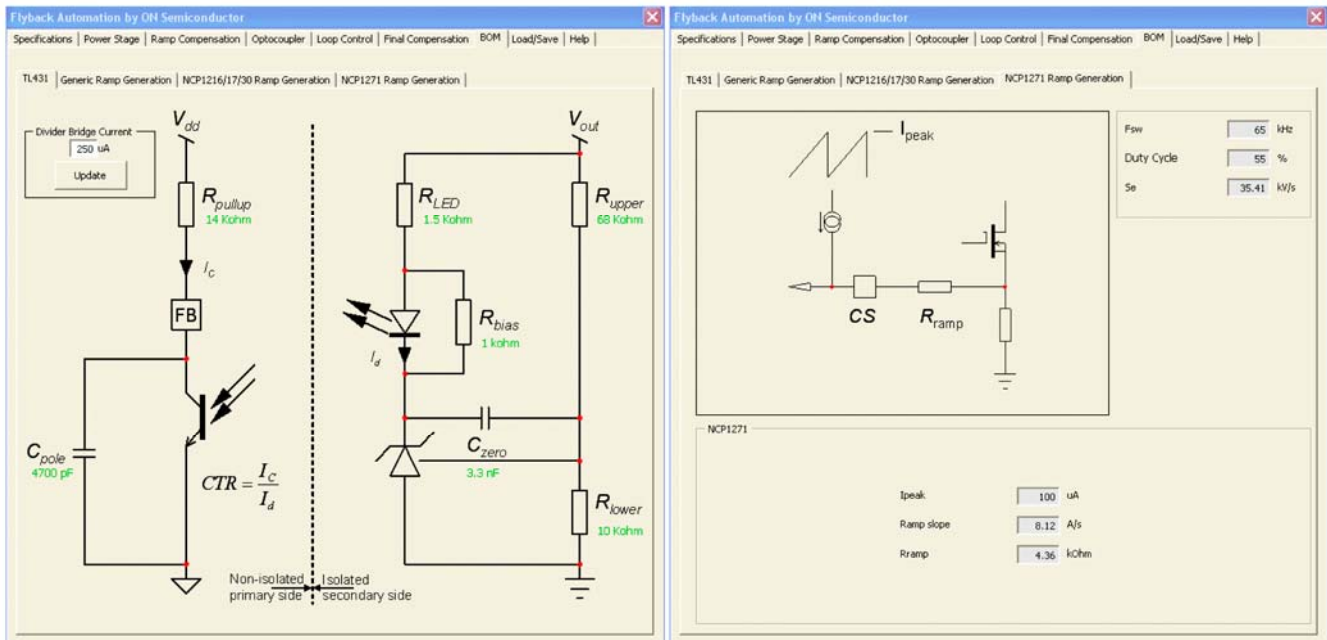


Fig. 5: Finally, the software shows the required TL431 configuration with its associated components (left). It also explains how to implement ramp compensation either generically or by using the internal NCP1271 circuitry (right).

Several experiments have been carried out to check the validity of the compensation strategy adopted in the spreadsheet. Experience shows that the final results collected on the bench with a network analyzer are very close to the final goal. Most of the discrepancies come from capacitor ESR or the optocoupler characteristics. It is important to pay close attention to those factors before running the software and loop control. The spreadsheet can be downloaded from the Internet (see Reference 2).

Conclusion

This article describes several possible solutions that can be applied to stabilize the loop in power supply projects. Whatever solution is chosen, it is important to understand the parameters involved in the design of a TL431-based compensator. If design software or simulation tools can quickly suggest a working circuit, it is in the design engineer's interest to understand the analytical steps behind the compensator calculations. This knowledge allows engineers to challenge the delivered results and detect a flaw in their approach. But it also enables them to improve the final result by placing emphasis on a particular parameter whose importance is greatest in their eyes.

References

1. C. Basso, "Switch Mode Power Supplies: SPICE Simulations and Practical Designs", McGraw-Hill, 2008.
2. Details can be found at <http://www.onsemi.com/pub/Collateral/FLYBACK%20DWS.XLS.ZIP>

About the Author



Christophe Basso is an application engineering director at ON Semiconductor in Toulouse, France. He has originated numerous integrated circuits among which the NCP120X series has set new standards for low standby power converters. SPICE simulation is also one of his favorite subjects and he has authored his second book on the subject, "Switch-Mode Power Supplies: SPICE Simulations and Practical Designs", published by McGraw-Hill in 2008. His work was positively reviewed in several magazines and in a recent PELS newsletter. Christophe holds a BSEE-equivalent from the Montpellier University, France and an MSEE from the Institut National Polytechnique de Toulouse, France. He holds 7 patents on power conversion and often publishes papers in conferences and trade magazines. He will conduct a new tutorial on loop compensators at the next APEC 2010 conference.

For further reading on loop compensation, see the How2Power Design Guide, search the Design Area category and select Control Methods as the subcategory. To narrow your search, try entering keywords such as "control loop," "stability," or "compensation."