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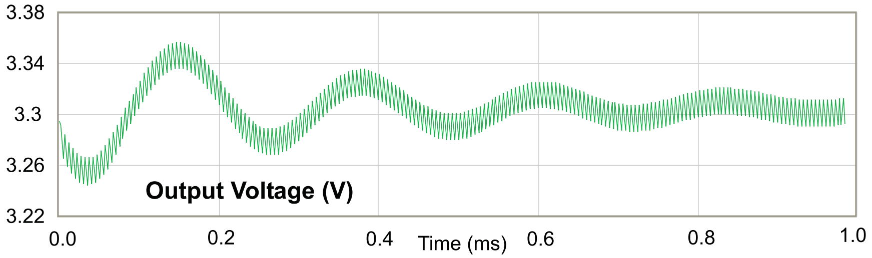
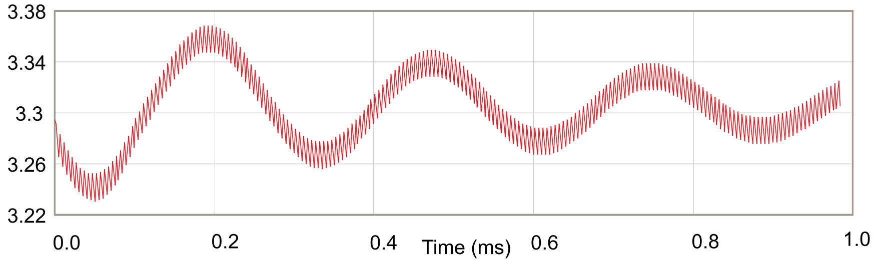
6.7.3 Buck Converter Transient Response – too Little Gain

Fig. 6.30(a) shows a step-load transient response for a buck converter with voltage-mode control. The converter has a 4 kHz oscillatory response, indicating insufficient phase margin.

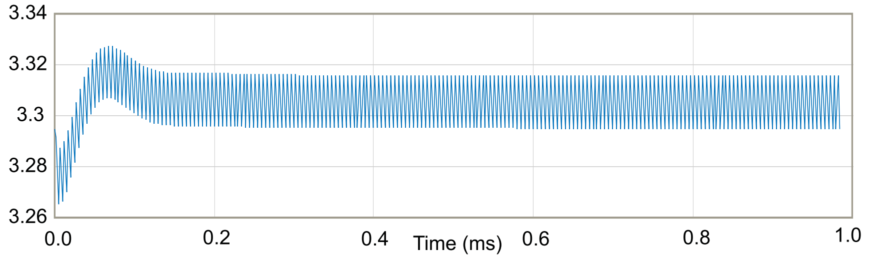
In the previous section, reduction of loop gain was the proper solution to improve the response. However, in the buck converter case shown here, ***reducing the gain*** makes the stability problem ***worse.*** The step load response is even more undamped, as shown in Fig. 6.30b.



(a) Original Transient



(b) Reduced Gain



(c) Increased Gain

Figure 6.30: Transient load response of buck converter (a) before (b) after gain reduction and (c) after gain increase.

The proper solution in this case is to ***increase*** the gain of the feedback loop, resulting in the response of Fig. 6.30(c).

Looking at the loop gains of Fig. 6.31 gives us insight into what is happening. The green curve shows the original gain, the red curve shows the decreased gain, and the blue curve shows increased gain. The phase margins at the crossover frequencies give us the characteristic transient response. For the red curve, we can see that the loop crossover has dropped close to the LC filter resonant frequency, resulting in only 10 degrees phase margin.

For the blue curve, the crossover is moved to a much higher frequency, away from the LC filter resonance, where the phase delay is much less. This results in a stable system with 60 degrees phase margin. Further changes can be made to stop the phase dropping down close to -180 degrees, and the loop gain information provides clear information on how to proceed.

For the buck converter with voltage-mode control, just above the filter resonance, the phase improves as the frequency increases. This information is available from the loop gain, but not from the step-load response.

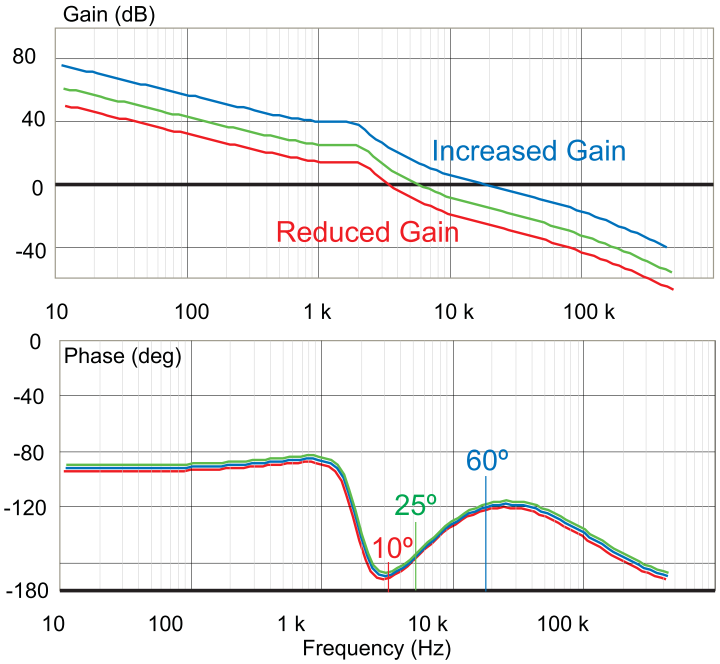


Figure 6.31: Loop gain and phase of the buck converter.

7.1 Designing with the TL431

Power supply designers are constantly striving to reduce cost. Prices have been driven down to very low levels, and compromises must often be made to meet both performance and cost goals. One of the targets for cost reduction is always the control loop. Designers are typically so focused on power processing that control design is often an afterthought, and not viewed as crucial to performance. Only later in the design process does the importance of a good controller become apparent.

One of the ways to reduce the cost of the feedback loop is to utilize the TL431 controller. While not offering as good a gain-bandwidth product as a standalone amplifier, this three-terminal part includes a reference. It also takes up little board space, and has become widespread in the industry as a way to achieve reasonable performance at a reduced cost.

In this section, we'll look at the complications involved in using the TL431, especially when it is configured with an optocoupler to provide isolation in the feedback loop.

7.1.1 Operational Amplifier Feedback

For the best performance, the preferred approach to feedback control compensation is an error amplifier and a precision reference. For nonisolated converters, the amplifier and reference may be included in the PWM control chip. They are usually of sufficient quality to meet demanding performance standards.

Current-mode control is the best way to control converters, and is used by most power supply designers. For this type of control, the optimal compensation network is a type II amplifier, an example of which is shown in Figure 7.1. In this configuration, a conventional operational amplifier is used to amplify the difference between the output voltage of the power supply and a fixed reference voltage.

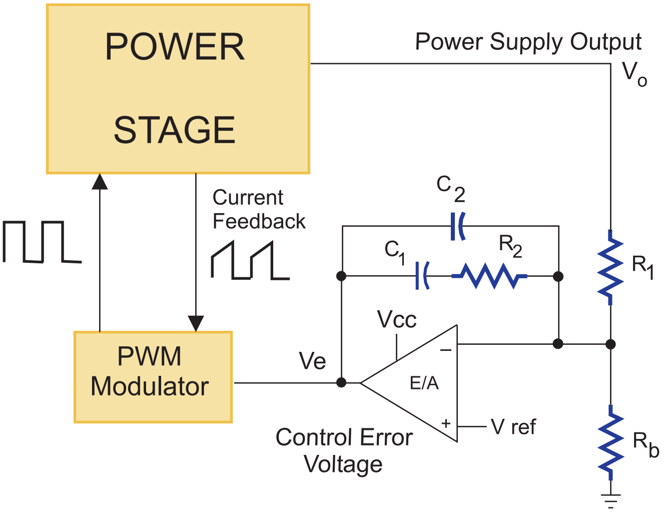


Figure 7.1: Type II compensation feedback

The amplifier is supplied by a separate V_{cc}, and the operation is not affected by variations in the supply voltage due to a good power supply rejection ratio.

Figure 7.2 shows the typical compensation curve for a type II amplifier. At low frequencies, the circuit acts like an integrator, utilizing components C_1 and R_1 to provide high gain. Resistor R_b provides the correct dc regulation level, but due to the virtual ground at the input of the error amplifier, it does not appear in any of the gain equations.

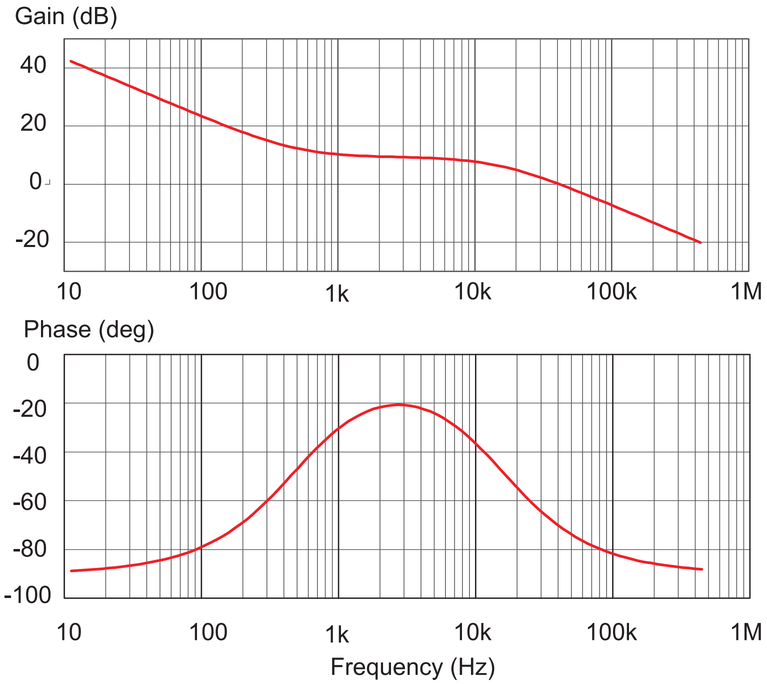


Figure 7.2: Type II compensation bode plot

At a frequency typically several times less that the loop gain crossover, a zero is introduced in the transfer function and the midband gain of the compensator is a simple expression given by the ratio of R_2 and R_1. At a higher frequency, selected according to the power stage characteristics, the circuit again forms an integrator, the gain determined by R_1 and C_2. Further details about the choice of these compensation parameters are given in chapter 5 of this book.

7.1.1 Using the TL431 as a Type II Amplifier

Although the TL431 is advertised as a transconductance amplifier, and is unusual in its configuration in a 3-pin package, it can be used as a standard Type II error amplifier if connected properly.

Figure 7.3 shows the required circuit connection for the TL431 to be used as a standard error amplifier. There are three differences found when using this part versus a standard operational amplifier:

1. A pullup resistor must be used on the output. The value of this resistor must be chosen to provide sufficient bias current to the device under all circuit conditions. Furthermore, the output of the amplifier must be kept above a minimum value required to provide the bias.
2. The reference is included in the part. It is a very good reference for the price.
3. The open loop gain, and drive capability are less than that of a good op amp. However, if you keep the impedances around the amplifier high, it will work well.

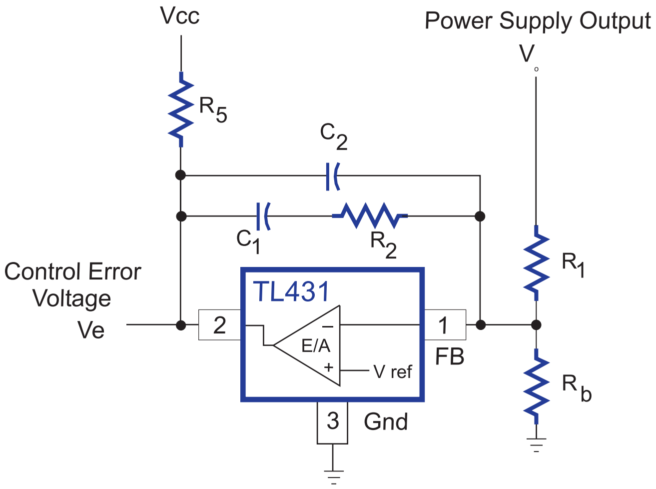


Figure 7.3: TL431 used as a type II amplifier

If the TL431 is configured as shown in Figure 7.3, and the rules above are obeyed, the design procedure is exactly the same as for a standard type II amplifier. Notice that the pullup resistor for the output of the TL431 is biased with a ***regulated voltage,*** and ***not connected directly*** to the output voltage.

7.1.2 Solution with Isolation

While the circuit shown in Fig. 7.3 is easy to design with and very predictable, it is not usually used in industry in this manner. The circuit that has become very widespread is where the TL431 is used in conjunction with an optocoupler to provide feedback loop isolation, as shown in Figure 7.4.

In this circuit, the output of the TL431 is powered through the resistor R_5 and the optocoupler diode, connected in series with the power supply output. This apparently subtle change has a big effect on the way the circuit works.