Application Report
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How to Compensate With the TPS6510x and the TPS6514x

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ABSTRACT

The boost converters in the TPS6510x (TPS65100, TPS65101, TPS65105) and the TPS6514x (TPS65140, TPS65141, TPS65145) series use external loop compensation providing high flexibility in LCD supply design. If designing a typical application scheme, use the recommended components from the TPS6510x datasheet (SLVS496) and the TPS6514x datasheet (SLVS497). This application note gives a deeper understanding on how to select the external components and how they can influence the performance.

General Description of the Boost Converter

The boost converter as it is implemented in the mentioned devices is a voltage-mode regulator. Figure 1 shows a high-level circuit description of the power stage and the control loop. The following section explains how this works.

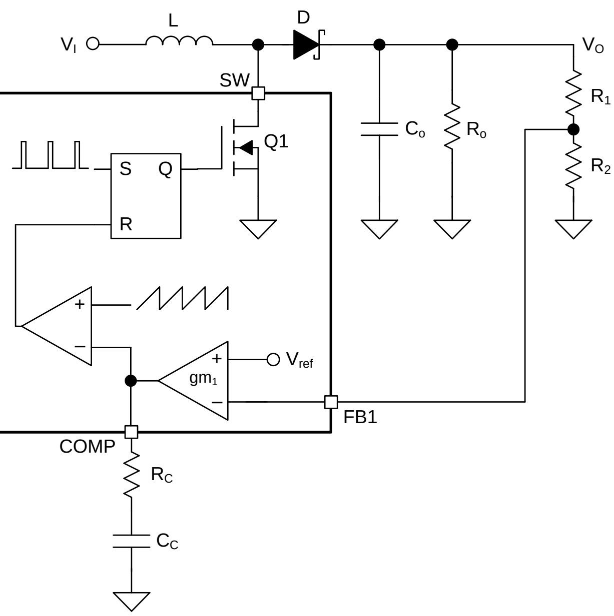


Figure 1. High-level Scheme Voltage-Mode Control

The output voltage from the feedback-divider is compared to a reference voltage Vref. The error between the two voltages is amplified by the compensated error amplifier (gm_1). This signal goes into the duty cycle modulator (gm_2) which drives the gate of the power switch. The compensation components are connected to the COMP pin which is the output of the internal error amplifier gm_1.

Compensating the right-half-plane zero (RHPZ) is the main complex problem that must be solved. This is due to the nature of every boost converter. When the main switch Q1 is turned on, the inductor is disconnected from the load for a longer period of time and this causes the output voltage to drop initially.

Although the control signal is trying to increase the initial response of the output, it will react in a decrease. Only after the time delay that corresponds to the RHPZ has passed will the output follow the control signal. To limit the time delay, and therefore limit the RHPZ effect, the compensation circuit limits the bandwidth of the LC filter and stabilizes the system.

The frequency of the RHPZ in a boost converter in continuous-conduction mode is defined as:

$$f_{RHPZ} = \frac{V_O (1 - D)^2}{I_O (2\pi \times L)}$$

where

- V_o is the output voltage
- I_o is the output current
- D is the duty cycle of a boost converter $\left(\frac{V_O - V_I}{V_O}\right)$
- L is the inductance. (1)

This formula shows that the RHPZ is dependent of the output power and the input voltage.

Note that the RHPZ decreases with higher output current and lower input voltage. For best performance, calculate the worst-case scenario which means the highest output load and lowest input voltage.

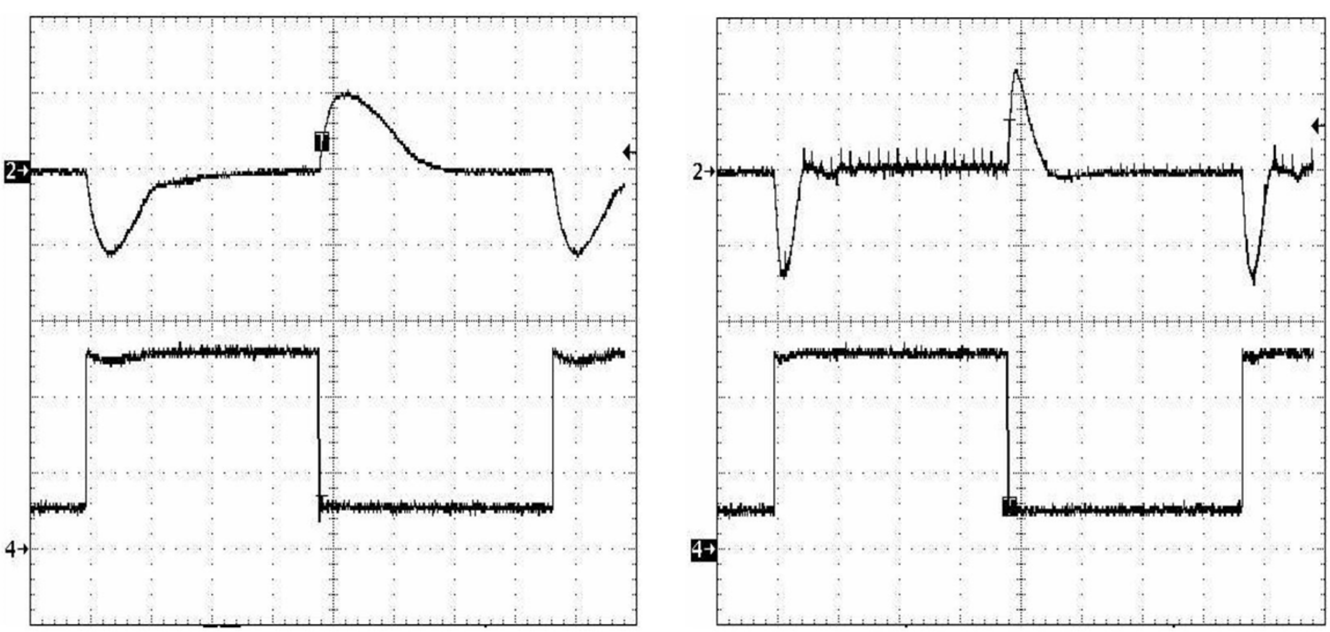
The next step is to set the crossover frequency (f_Z) that needs to be set by the RC components of the compensation network. A reasonable approximation commonly used is:

$$f_Z \ll \frac{f_{RHPZ}}{10} \quad (2)$$

A good start is to set C_C = 1 nF for a 3.3-V input or C_C = 2.2 nF for a 5-V input. Lower input voltages require a higher gain; therefore, a lower compensation capacitor value.

To test the converters performance it is the best to apply a load step to the converters output. The images in Figure 2 show the effect of different compensation components on the performance.

A larger compensation capacitor, such as 4.7 nF, corresponds to a slower response and a smaller compensation capacitor corresponds to a faster response but lower gain.



C_C = 4.7 nF C_C = 1 nF

Figure 2. Load Transient Big-Small Comp Cap (Load Step: 50 mA – 150 mA – 50 mA)

NOTE: If the device operates over the entire input voltage range from 2.7 V to 5.8 V, a large compensation capacitor, up to 10 nF, is recommended.

Lastly the compensation resistor must be calculated. The formula can be derived from the crossover frequency of an R-C- filter:

$$f_Z = \frac{1}{2\pi C_C R_C} \quad (3)$$

Reshaping this formula to get R_C is:

$$R_C = \frac{1}{2\pi C_C f_Z} \quad (4)$$

Figure 3 and Figure 4 show how the load transient looks if you select incorrect R_C components and Figure 5 gives an example for an ideal selection.

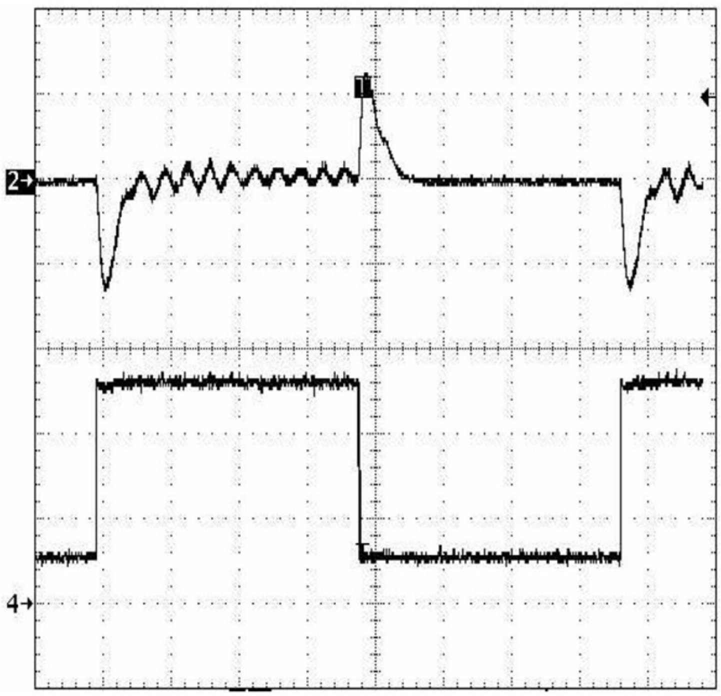


Figure 3. Overcompensated → R_C is Too Big

Figure 4. Undercompensated → R_C is Too Small

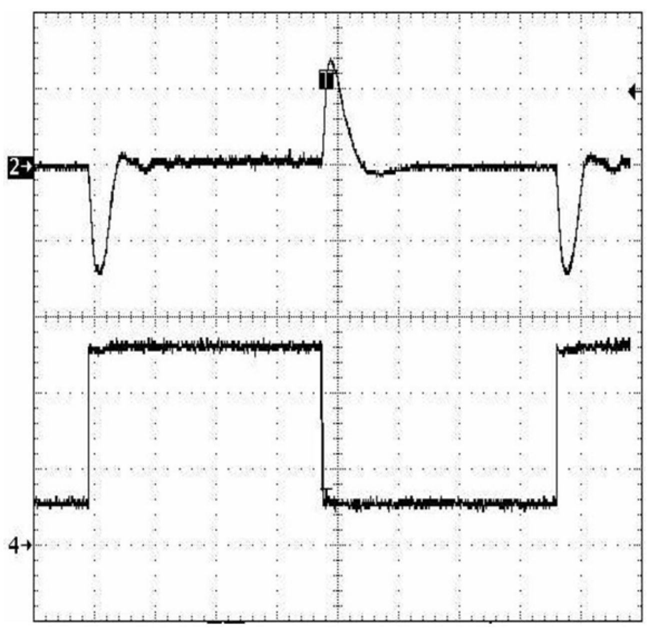


Figure 5. Ideal Selection of R_C

Example Calculation for Notebook Supply Applications

V_I = 2.7 V, V_O = 10 V, I_O = 300 mA, L = 3.3 µH, D = 0.73, C_c = 1 nF

1. **Calculate RHPZ**

$$f_{RHPZ} = \frac{10\ V\ (1 - 0.73)^2}{0.3\ A\ (2\pi \times 3.3\ \mu H)} = 118\ kHz$$

2. **Set crossover frequency:**

$$f_Z = 10\ kHz$$

3. **Calculate Rc:**

$$R_C = \frac{1}{2\pi \times 1\ nF \times 10\ kHz} = 15\ k\Omega$$

Example Calculation for Monitor Supply Applications

V_I = 5 V, V_O = 13.5 V, I_O = 400 mA, L = 4.7 µH, D = 0.63, C_c = 2.2 nF

1. **Calculate RHPZ**

$$f_{RHPZ} = \frac{13.5\ V\ (1 - 0.63)^2}{0.4\ A\ (2\pi \times 4.7\ \mu H)} = 160\ kHz$$

2. **Set crossover frequency:**

$$f_Z = 16\ kHz$$

3. **Calculate Rc:**

$$R_C = \frac{1}{2\pi \times 2.2\ nF \times 16\ kHz} = 4.5\ k\Omega$$