Technical Article

Power Tips: A Simple Circuit to Implement Smooth Soft Start for an Isolated Converter

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Most DC/DC converters require a soft-start circuit to limit the in-rush current at startup. Although a smooth soft start is required for systems with power-on reset (POR), this is difficult for an isolated converter with a controller on the primary side and a limited duty cycle or current.

Figure 1 shows the soft start of a forward converter with a duty-cycle soft start from the primary side. The steady-state output of the converter is 12V. A 50% load current is applied at 10V, the POR threshold of the system. As soon as a load is applied, the output drops and triggers system shutdown, causing the system power cycle several times. At the end of soft start, the output overshoots 10%, which is not desirable.

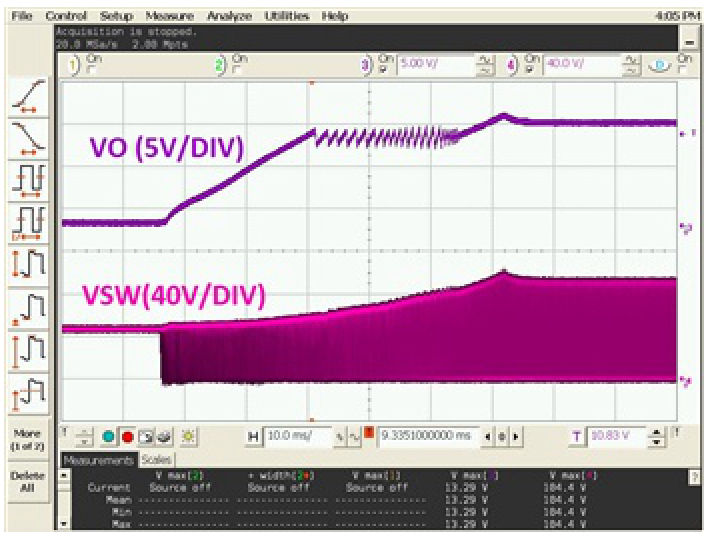

Figure 1. Output of a Forward Converter During Startup with a Load Applied at 10V

In this post, I will use a simple circuit to achieve a smooth soft start for an isolated converter. The circuit is applied to an active-clamp forward converter with the LM5025 as the controller. Figure 2 shows the concept of secondary-side soft start.

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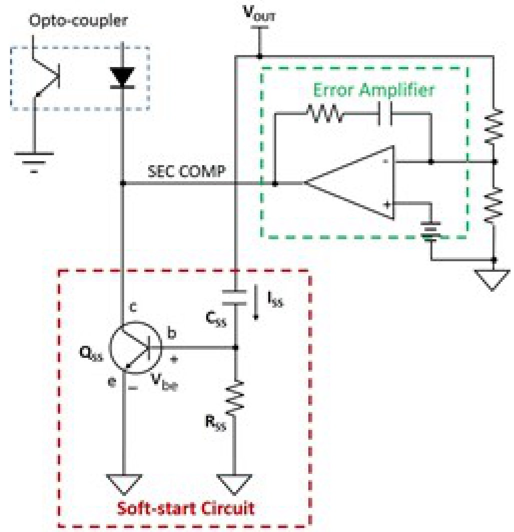

Figure 2. Secondary-side Soft-start Circuit for an Isolated Converter

When first applying the input, the converter output (V_{OUT}) starts to rise. The capacitor (C_{SS}) is charging up. The C_{SS} charging current (I_{SS}) flows through the resistor (R_{SS}). When I_{SS} is high, then $V_{BE(on)}/R_{SS}$. Q_{SS} turns on and starts to pull current from the secondary-side comp node (SEC COMP), thus reducing the duty cycle. During soft start, the error amplifier saturates and the soft-start circuit dominates the feedback loop. The converter, C_{SS}, R_{SS}, Q_{SS} and optocoupler form a closed loop. When the output rises to regulation, the error amplifier starts to regulate and I_{SS} reduces. Q_{SS} turns off.

Equation 1 shows the transfer function from V_{OUT} to the optocoupler current:

$$G_{SS}(s) = \frac{i_D(s)}{v_{OUT}(s)} = \beta \cdot C_{SS} \cdot s \tag{1}$$

While being effective, this simple circuit might not be stable because the Q_{SS} forward gain (β) is high and varies dramatically from part to part. To stabilize this circuit, insert a gain-reducing resistor (R_E) between the emitter of Q_{SS} and ground, as shown in Figure 3. Increasing R_E can reduce the feedback-loop gain during startup.

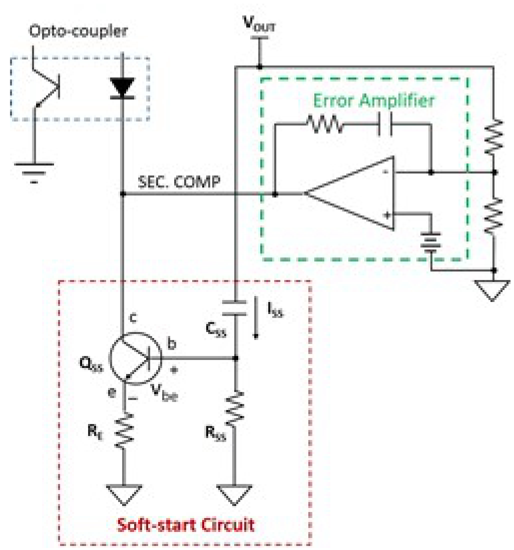

Figure 3. Adding R_E To Stabilize the Soft-start Circuit

Equation 2 shows the soft-start circuit transfer function with R_E:

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$$G_{SS}(s) = \frac{\beta \cdot R_{SS} \cdot C_{SS} \cdot s}{(R_{SS} + \beta \cdot R_E) \cdot (1 + \frac{\beta \cdot R_E \cdot R_{SS} \cdot C_{SS} \cdot s}{R_{SS} + \beta \cdot R_E})} \quad (2)$$

At high frequencies, use Equation 3 as an approximation of Equation 2:

$$G_{SS}(s) \approx \frac{1}{R_E} \quad (3)$$

I added the soft-start circuit to the converter with these parameters:

- C_{SS} = 0.1µF.
- R_{SS} = 100kΩ.
- R_E = 1.18kΩ.

Figure 4 shows the soft-start waveform with these circuit parameters. When the system starts pulling current, the soft-start circuit stops drawing current from the COMP and the duty cycle increases quickly. The converter continues to soft start, after a minor dip caused by the load transient.

Figure 4. Soft-start Waveform of the Soft-start Circuit Shown in Figure 3

Figure 4 also shows that after the load is applied, the converter switching node (VSW) has an additional voltage spike. Figure 5 shows the zoomed-in waveform. It is obvious that the system oscillates at 9.5kHz.

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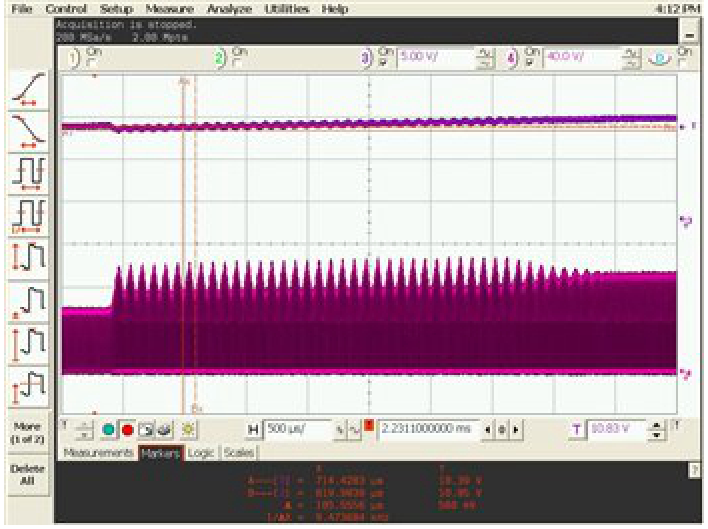

Figure 5. Zoomed-in Soft-start Waveform with Soft-start Circuit

The controller in this design is a voltage-mode controller. The power stage has 180 degrees of phase drop because of the double poles. It is necessary to add a zero to improve stability; you can do this by adding a capacitor (C_E), in parallel to R_E. In order to add 45 degrees to the phase margin, I placed a zero at 9.5kHz, the measured oscillation frequency. With R_E = 1.18kΩ, I added a 15nF capacitor.

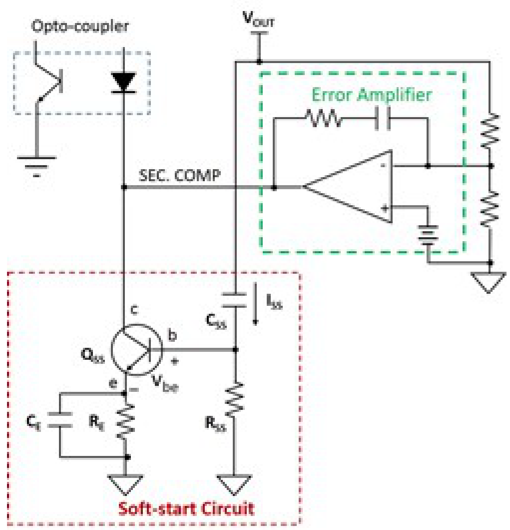

Figure 6. Soft-start Circuit with Improved Stability

Figure 7 shows the startup waveform with C_E = 15nF. The oscillation is eliminated. The total soft-start time is 50ms.

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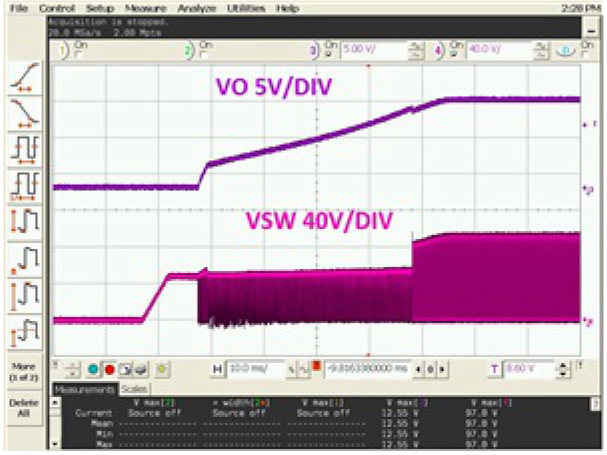

Figure 7. Soft-start Waveform with C_E = 15nF

During soft start, the typical optocoupler diode current (I_{opto_D}) is from 1.2mA to 0.8mA. This is determined by the LM5025 and the optocoupler forward gain. With R_E = 1.18kΩ, the voltage across R_{SS} is $V_{BE(ON)}$ + R_E × 0.8mA = 1.644V. VBE(on) = 0.7V. Thus, you can calculate I_{SS} as I_{SS} = ($V_{BE(ON)}$ + R_E × I_{opto_D})/R_{SS}. I_{SS}/C_{SS} sets the output V_{OUT}, dv/dt. To ensured the effectiveness of the secondary-side soft-start, the primiary-side soft-start should be set much faster than the secondary-side soft-start as well.

Test results show the effectiveness of this simple soft-start circuit to achieve a smooth soft start for an isolated converter.

Additional Resources

- Read more Power Tips blogs.
- Watch Power Tips videos.
- Download the LM5025 data sheet.

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