Technical Article

Power Tips: Design Considerations of High-voltage Converters in a Cascode MOSFET

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As I mentioned in my last blog, a cascode MOSFET configuration provides a low-cost alternative for high-voltage applications such as smart meters and motor drives. To further understand how a cascode MOSFET configuration works in high-voltage converters, Figure 1 shows a MOSFET modeled by a switch in parallel with a diode and a capacitor,. In addition to the switch, diode and paralleled capacitor, you must also consider the gate-to-source capacitance, C_g, of the top-side MOSFET.

In this blog post, I will discuss two possible operational conditions when using a cascode MOSFET configuration: $V_{in} < V_{Zc}$ and $V_{in} \geq V_{Zc}$, where V_{Zc} is the clamping voltage of the Zener diode Z_C.

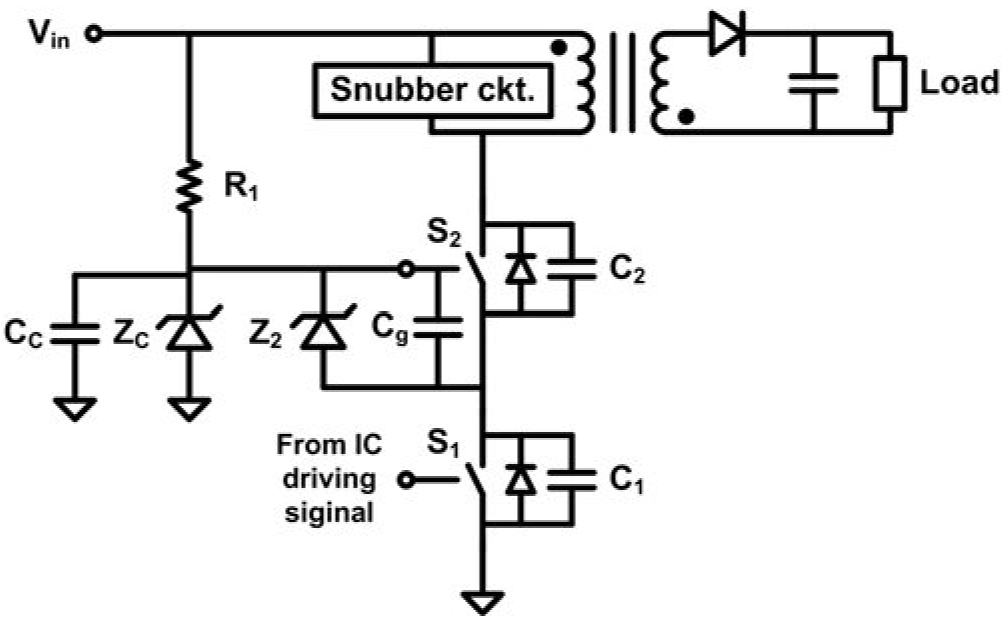

Figure 1. Flyback Converter in a Cascode MOSFET Configuration

$V_{in} < V_{Zc}$

When the converter first powers up, capacitor C_C will be charged to V_{in} through R_1. Once the controller bias voltage is charged above the undervoltage lockout (UVLO) threshold, switch S_1 turns on. As shown in Figure 2, when S_1 turns on, the energy in C_C transfers to C_g and leads to voltage increases on C_g. In order to turn on S_2, the clamping voltage of Z_2 needs to be set higher than the gate-to-source threshold voltage ($V_{gs(th)}$) of the top-side MOSFET. It is important to have enough energy in C_g to keep the top-side MOSFET turned on during the entire on state after the bottom-side MOSFET turns on. In other words, C_C can’t be too small. Sometimes, the parasitic capacitance of Z_C might not be enough and will require an external capacitor in parallel with Z_C.

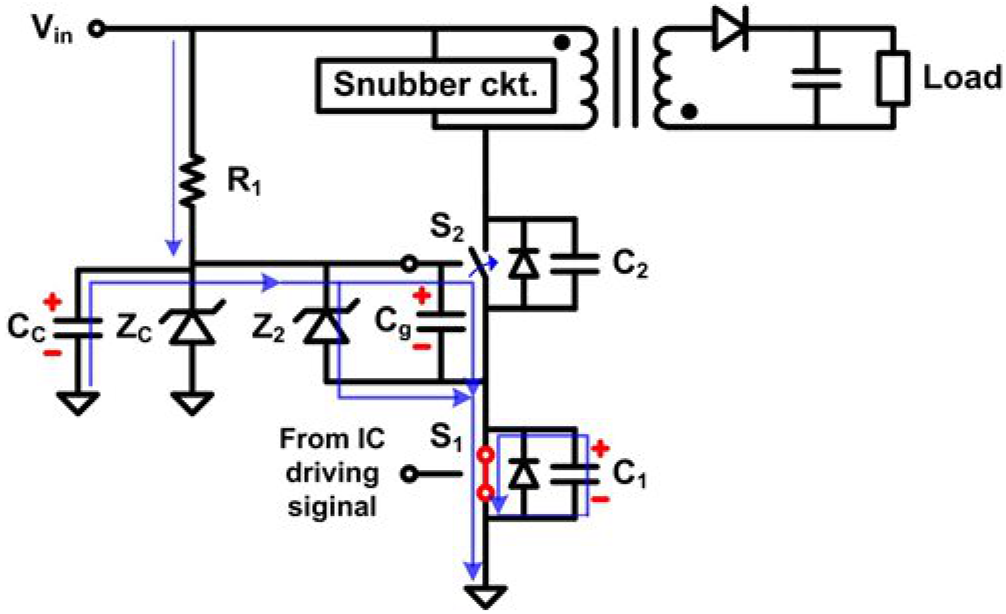

Figure 2. MOSFET Turned-on Transient

When the MOSFET on the bottom side turns off (Figure 3), the current from the transformer quickly charges C_1. C_g discharges and energy goes back to C_C again. Once C_g discharges to a voltage level lower than $V_{gs(th)}$, S_2 turns off and C_2 charges up.

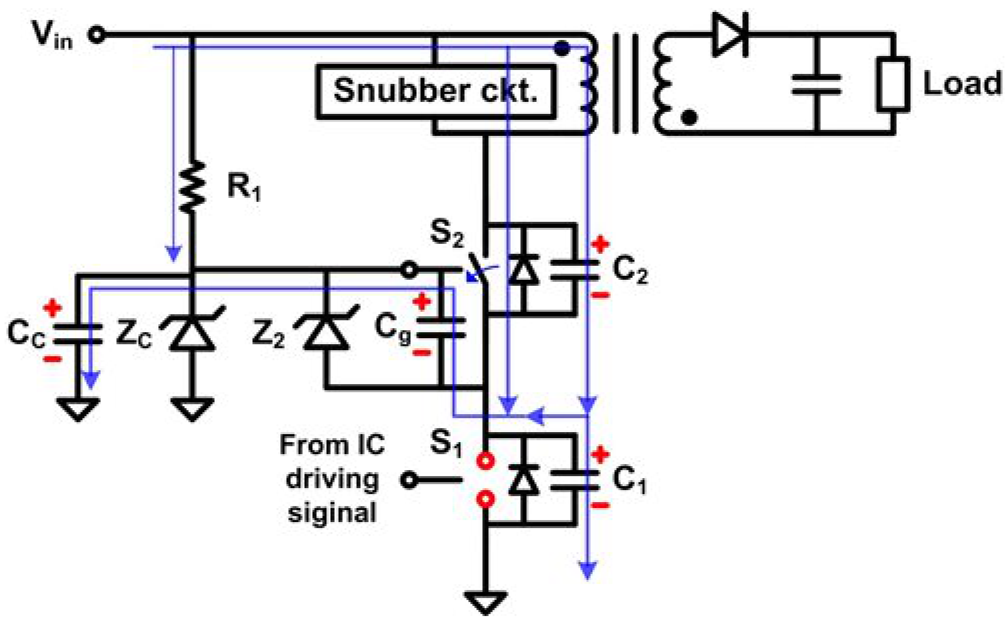

Figure 3. MOSFET Turned-off Transient ($v_{in} < V_{Zc}$)

$V_{in} \geq V_{Zc}$

The current-flow directions during the low-side MOSFET turned-on transient when $V_{in} \geq V_{Zc}$ are exactly the same as when $V_{in} < V_{Zc}$. During low-side MOSFET turned-off transient, transformer current discharges C_g and then flows through C_C and Z_C, as shown in Figure 4. In this transient, Z_C acts as a snubber and clamps the low-side MOSFET voltage to $V_{Zc} + V_{F\_Z2}$, where V_{F_Z2} is the Zener forward voltage drop of Z_2.

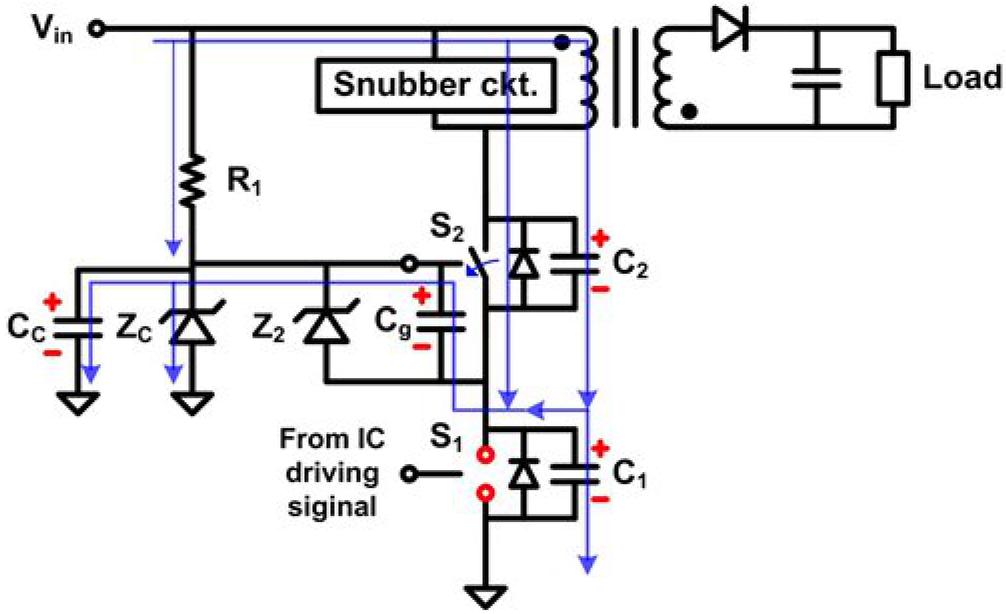

Figure 4. MOSFET Turned-off Transient ($v_{in} \geq V_{ZC}$)

The longer turn-off delay time S_2 has after S_1 has already turned off, the higher current flows through S_2 to Z_C, which might lead to a thermal issue for Z_C. Figure 5 below shows a turn-off transient example. As you can see, S_2 is starting to turn off after S_1 is fully turned off. In the transient, S_1 is already off and S_2 is turning on. A surge current flows through Z_C and this causes a thermal issue with Zener diode Z_C.

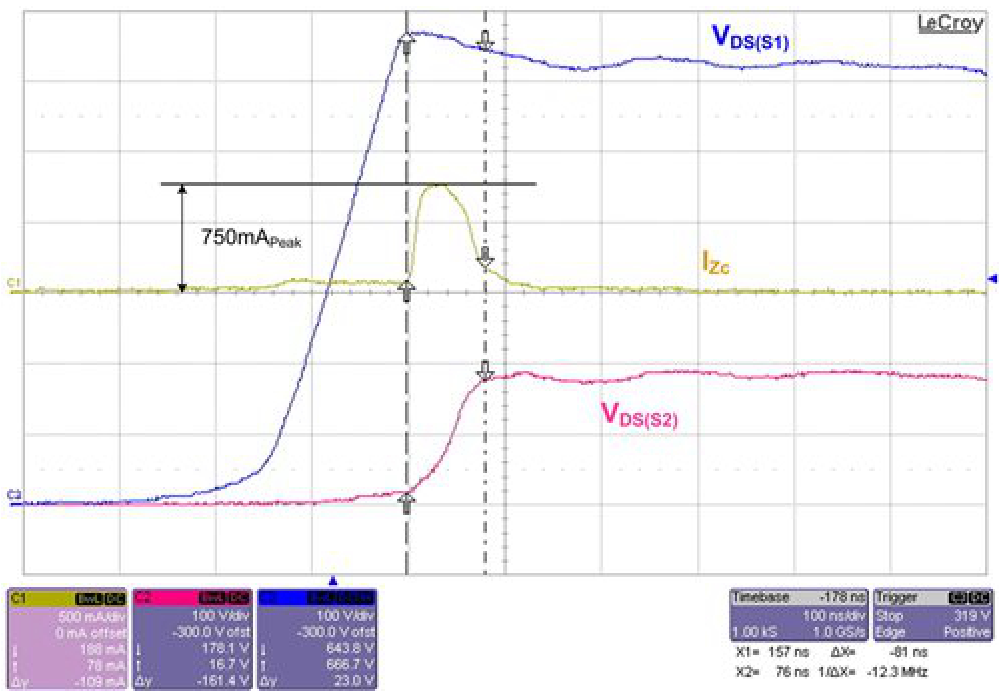

Figure 5. Waveforms During MOSFET Turned-off Transient with a Longer Turn-off Delay Time ($v_{in} \geq V_{ZC}$)

If the turn-off delay time between S_1 and S_2 can be minimized by using MOSFETs with better transient characteristics (like the example in Figure 6), the current going to Z_C can also be minimized, and reducing the temperature rise of Z_C.

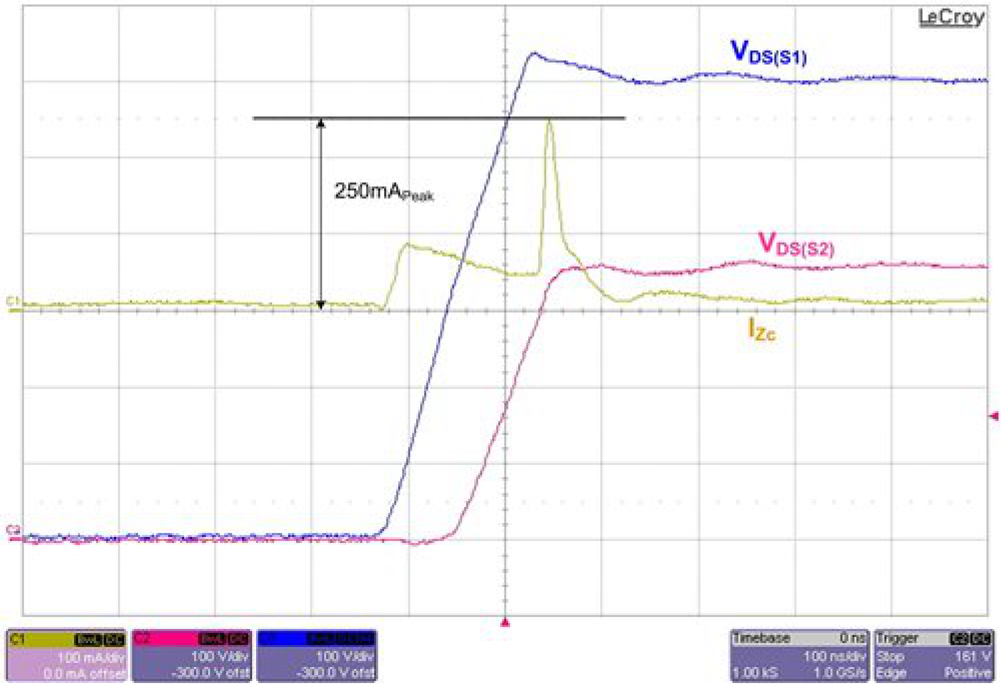

Figure 6. Waveforms During Low-side MOSFET Turned-off Transient with a Shorter Turn-off Delay Time ($v_{in} \geq V_{Zc}$)

Many components go into designing high voltage converters with a cascode MOSFET configuration, but mastering the key operations with carefully circuit parameter selection allows for a low cost alternative for high-voltage applications.

Additional Resources

- Discover TI's Power Tips blog series on Power House.
- Check out the following TI Designs reference design, which use a cascode MOSFET configuration
  - 400V to 690V AC Input, 50W Flyback Isolated Power Supply Reference Design for Motor Drives