RC Snubber Design in EZBUCK Circuit

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The AOZ101x EZBuck family IC are peak current-mode controlled step down regulators with integrated high-side P-channel MOSFET. A Schottky diode is used as low-side freewheeling device. It operates from a 4.5V to 16V input voltage range and supplies up to 5A of load current. It comes in SO-8 and thermally enhanced DFN-8 package.

1. Introduction of RC Snubber

The circuit parasitic inductance in the AOZ101x EZBuck is unavoidable; especially for AOZ1013 and AOZ1014 which use external Schottky diodes - parasitic inductance in PCB could cause severe voltage spike during switch transient. As shown in Figure 1 below, a simple RC snubber across the Schottky diode is strongly recommended for damping the parasitic resonance in the EZBuck regulator circuit when external Schottky is used. The simple RC snubber can 1) Reduce the voltage/current spike; 2) Shift the power dissipation from the semiconductor device to a snubber resistor; and 3) Reduce the noise. The major shortcoming is the RC snubber absorbs energy during each voltage transition and can reduce the overall efficiency of EZBuck.

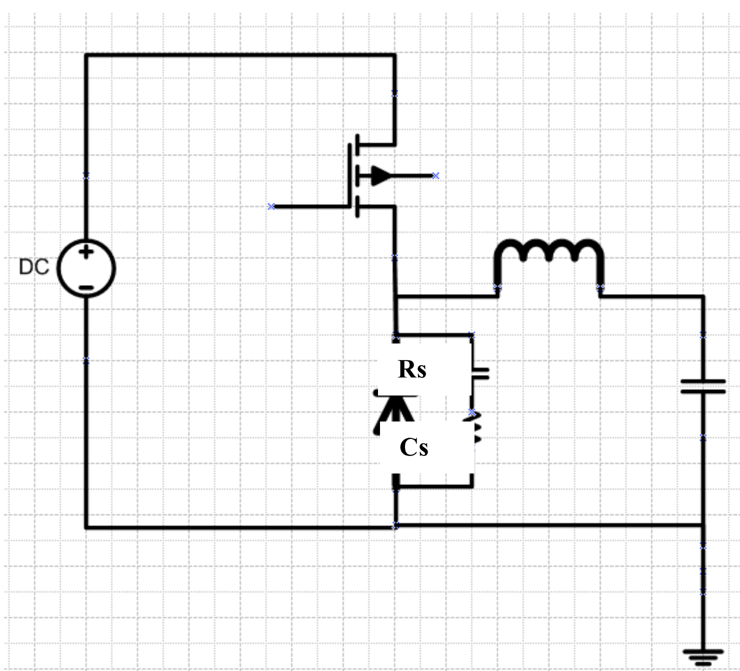

Figure 1: RC snubber in EZBuck circuit

The snubber capacitor can reduce the damping frequency and thus be helpful for voltage spike and noise reduction. The capacitor stores energy. It is charged when high-side switch turns on and discharged when high-side switch turns off. The amount of energy stored in each charge and discharge cycle will be dissipated in the snubber resistor. The power dissipation is independent of the snubber resistor. It may be calculated base on snubber capacitance, charging voltage and switching frequency. The equation is below:

$$P = 2 \cdot f \cdot (\frac{1}{2} \cdot C \cdot V^2) = f \cdot C \cdot V^2$$

Where f is the buck circuit switching frequency;
C is the snubber capacitance;
V is approximated equal to the input voltage;

The snubber resistor selection is the trickiest part of whole snubber design. The optimization of the resistor not only depends on the value of parasitic inductor, capacitor, reverse recovery of diode and etc; also depends on the distribution of parastics.

The simplified model shown in Figure 2 may be helpful for us to understand why LX rings; but it is far from enough to use it for design.

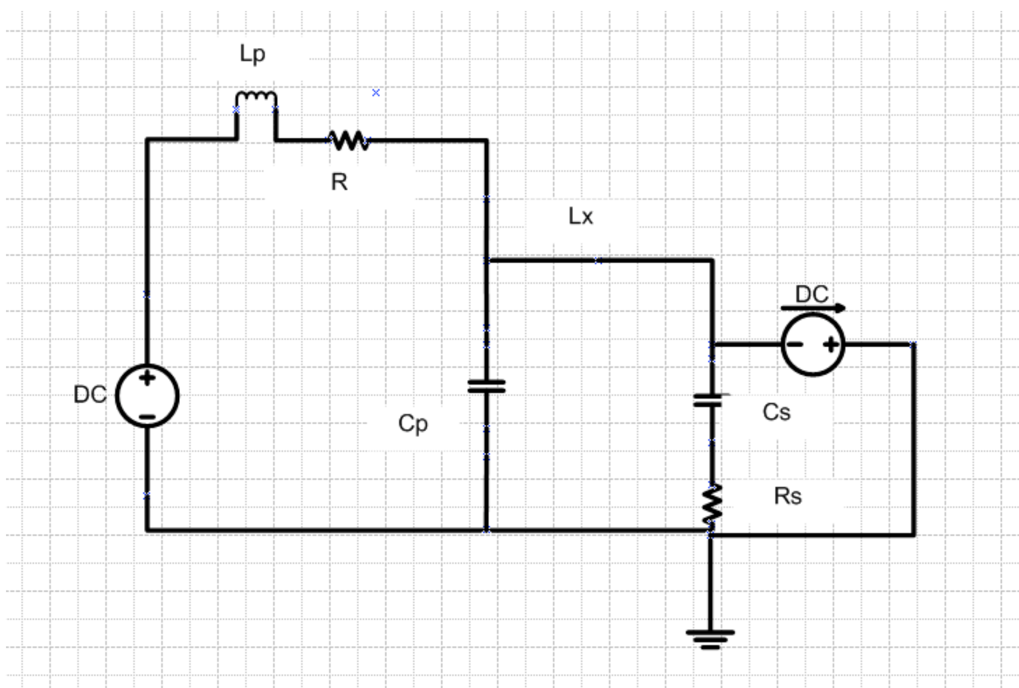

Figure 2: Over simplified model for PMOS turns on transient of buck converter

Lp is the parasitic loop inductance which formed by input capacitor, PMOS, Schottky diode; R is the $R_{DS(ON)}$ of PMOS plus the trace resistor; C is the parasitic capacitor. DC current source represents the main inductor current.

A more detailed model is shown in Figure 3. Using this model, the measured results can match well with the simulation and mathematical analysis. But, this model is too complicated and also is not realistic to identify the distribution of parasitic. In the following diagram, a simple design rule is introduced as a guideline for RC snubber design. Due to the nature of low resistance oscillation system, the oscillation frequency is similar regardless of the simplified model, detailed model or real application; although the amplitude and phase may be different. Based on that, a design guidance is presented as following.

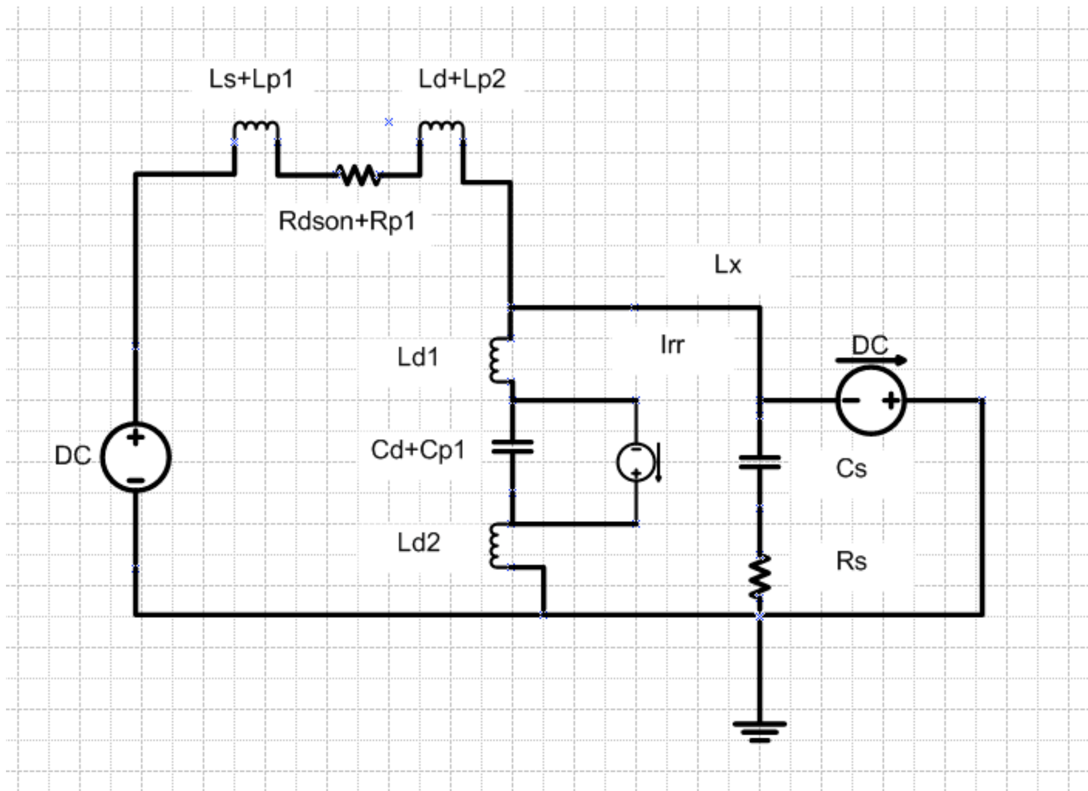

Figure 3: Complete model for PMOS turns on transient of buck converter

Ls is the source inductor of PMOS and Lp1 is the corresponding parasitic inductor; $R_{DS(ON)}$ is the $R_{DS(ON)}$ of PMOS and Rp1 is the trace inductor corresponded; Ld is the drain inductor of PMOS and Lp2 is the corresponding parasitic inductor.

Ld1 is the inductor of diode anode; Cd is the output capacitor of diode and Cp1 is the parasitic capacitor corresponded; Ld2 is the inductor of diode cathode; Irr is the nonlinear reverse current of diode.

2. RC Snubber Design Guidance

Without adding RC snubbers, the voltage of LX during PMOS turns on transition can be measured as Figure 4. The oscillation frequency can be obtained, in this case is about 90 MHz. Due to the nature of low resistor system; the oscillation frequency $f_o = \frac{1}{2*3.14*\sqrt{Lp*Cp}}$, where Lp is the parasitic inductor for the oscillation loop and Cp can be approximated as junction capacitor (Ct) of diode. Check the datasheet of Schottky diode and find the Ct at applied voltage. One example is shown in Figure 5. For 12V application, the Ct is about 330 pF. The Lp can be calculated as:

$$Lp = \frac{1}{(f_o*2*3.14)^2*Cp}$$, this case is about 10 nH.

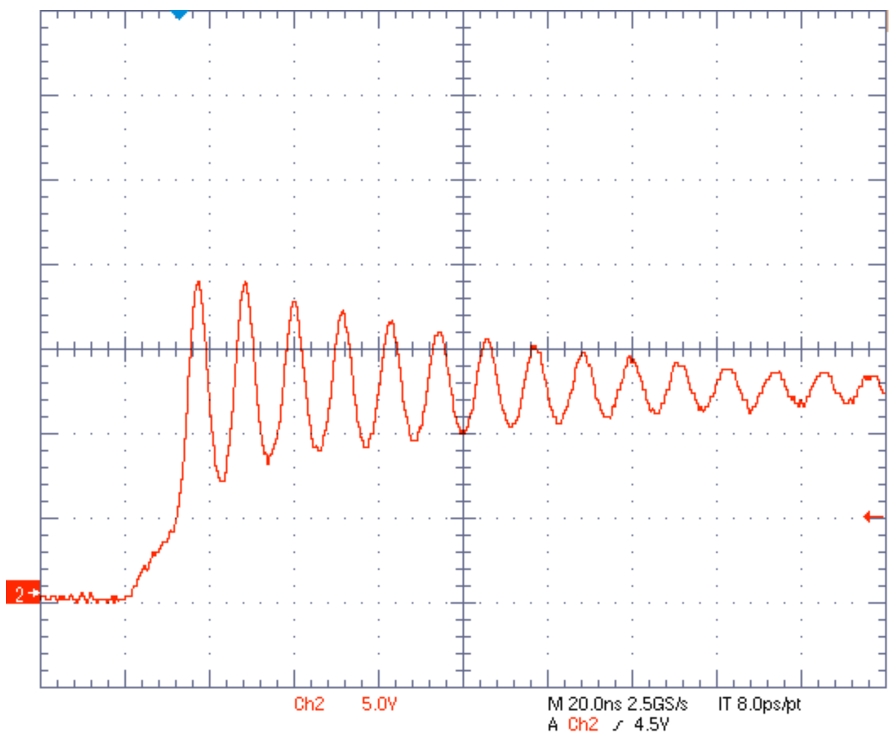

Figure 4: The voltage of LX during PMOS turns on transition

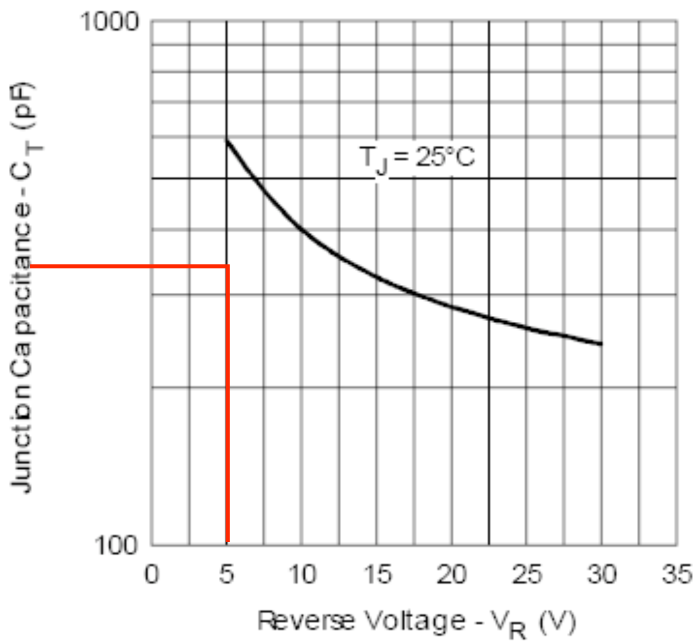

Figure 5: Junction capacitor of Schottky diode

The selected snubber capacitor Cs should be 3 times of Ct (Cs=3*Ct), in this case is 1n pF. Choose snubber resistor Rs equals to two times of inductive impedance at the measured oscillation frequency. In this case, Rs=2*3.14*fo*Lp, equals to about 12 ohm. We can choose 10 ohm to 20 ohm resistors. The power consumption can be calculated using $P = 2 \cdot f \cdot (\frac{1}{2} \cdot C \cdot V^2) = f \cdot C \cdot V^2$, in this case is 72mW. The temperature rise vs. power dissipation of resistor is shown in Figure 6. We can choose 0805 package to control the temperature rise below 40^{o}C; and 1206 for even lower temperature rise.

It is always a good practice to put the estimated RC values and optimize it experimentally.

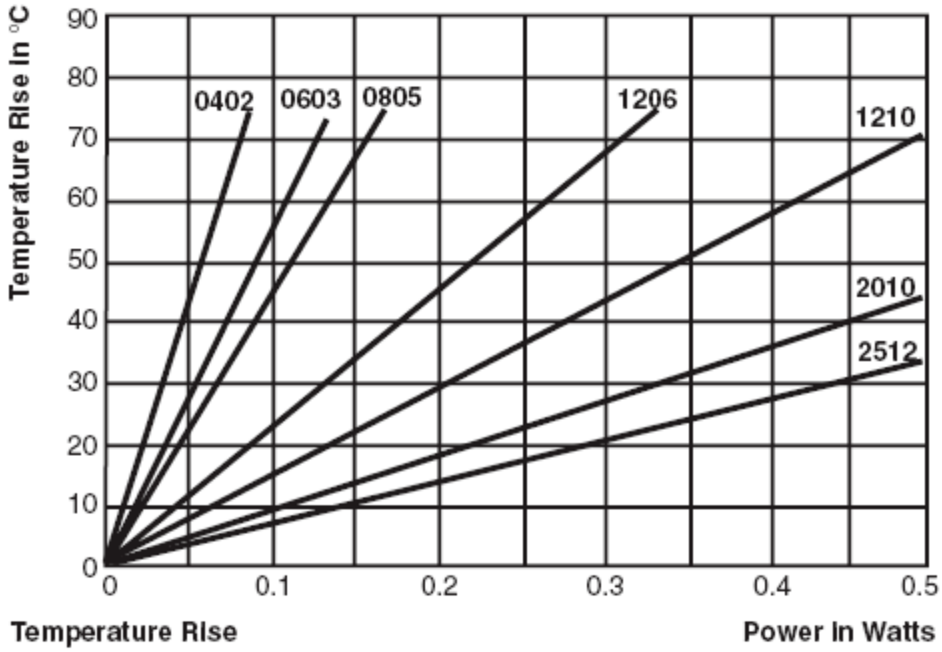

Figure 6: Temperature rise vs. power dissipation

Surface mount components are recommended to eliminate the lead inductance. Place them as close as possible to the diode to minimize the trace inductance.

3. Summary

The simplified model of RC snubber can be used to understand why snubber is needed, but it is not very helpful for design. The simulation results using detailed model can match the measurement results, but it is too complicated to locate the distribution of parasitic inductance. Based on the nature of oscillation frequency, the simple design guidance is given:

Cs=3*Ct, Rs=2*(2*3.14*Lp*fs) (fs=500kHz) and $Lp = \frac{1}{(f_o*2*3.14)^2*C_t}$. The package of snubber resistor should meet the thermal requirement, the power dissipation of resistor equals to $P = 2 \cdot f_s \cdot (\frac{1}{2} \cdot C \cdot V^2) = f_s \cdot C \cdot V^2$, where the C is the snubber capacitor (Cs) and V is the applied voltage.