Switching Regulator Series

Snubber Circuit for Buck Converter IC

In buck converter ICs, many high-frequency noises are generated at switch nodes. A snubber circuit provides one way of eliminating such harmonic noise. This application note explains how to set up the RC snubber circuits.

RC snubber circuit

Figure 1 shows the circuit of buck switching converter. In an actual circuit, there exist a number of parasitic inductors L_P and parasitic capacitances C_P as shown in Figure 2. When the high-side switch is turned ON or OFF, the energy that is accumulated in the parasitic inductors causes resonance in the input loop. Very small values for parasitic elements render resonance frequencies over several hundred MHz, causing the deterioration of EMI (electromagnetic interference) properties (Figure 3).

RC snubber circuits are commonly employed to eliminate such high-frequency noise. The reduction of high-frequency noise can be achieved by adding a simple RC network to the switch node, as shown in Figure 4.

Figure 5 shows the operation of the snubber circuit. The energy that is accumulated in the parasitic inductors while the high-side switch is turned ON is stored as electrostatic energy in the snubber capacitor C_{SNB}. Since the potential of the switch node increases to the input voltage V_{IN}, the energy of $1/2 \times C_{SNB} \times V_{IN}^2$ is stored in the capacitor when charged up to V_{IN}. Then, the generated resistance loss $1/2 \times C_{SNB} \times V_{IN}^2$ is equal to the energy that is charged in the snubber resistor R_{SNB}. As the potential of the switch node decreases to ground, with the low-side switch being turned ON, the energy that is stored in the snubber capacitor C_{SNB} is discharged via the snubber (damping) resistor. Again, the energy of $1/2 \times C_{SNB} \times V_{IN}^2$ is consumed at the snubber resistor R_{SNB}. As a further explanation on this equation, the electric charge Q of the capacitor after charging is $C_{SNB} \times V_{IN}$ and the power supplied from the power source is $V_{IN} \times Q = C_{SNB} \times V_{IN}^2$. The energy that is stored in or released from the capacitor is determined only by the capacitance and voltage of the capacitor if the period of the charge-discharge cycle is sufficiently longer than the CR time constant. When charging, half of the energy from the power source is converted to Joule heat at the resistor, and the other half is stored in the capacitor as electrostatic energy. When discharging, half of the stored electrostatic energy is converted to heat at the resistor. Only the time necessary for charging or discharging depends on the resistor value, while this ratio remains constant.

Since the total loss of $C_{SNB} \times V_{IN}^2$ is generated at the resistor in each cycle of switching, a loss of $C_{SNB} \times V_{IN}^2 \times f_{SW}$ is generated. The loss is generated in the snubber circuit even without any load, as long as the switching operation is being performed, resulting in lower efficiency.

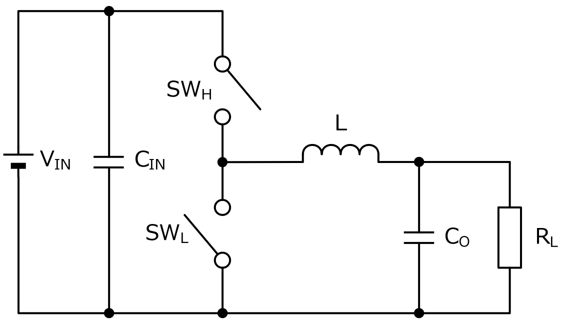

Figure 1. Buck switching converter circuit

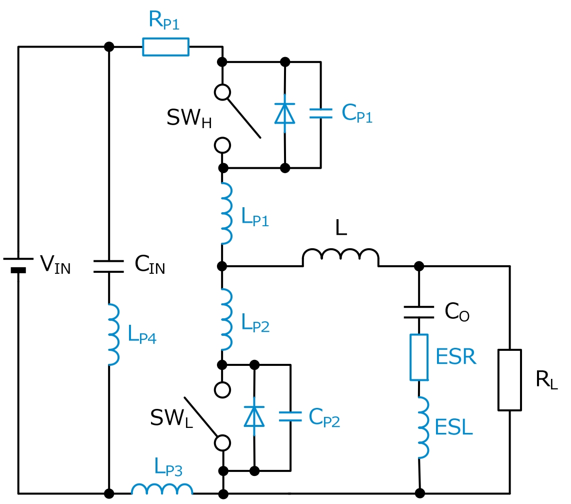

Figure 2. Circuit taking parasitic elements into consideration

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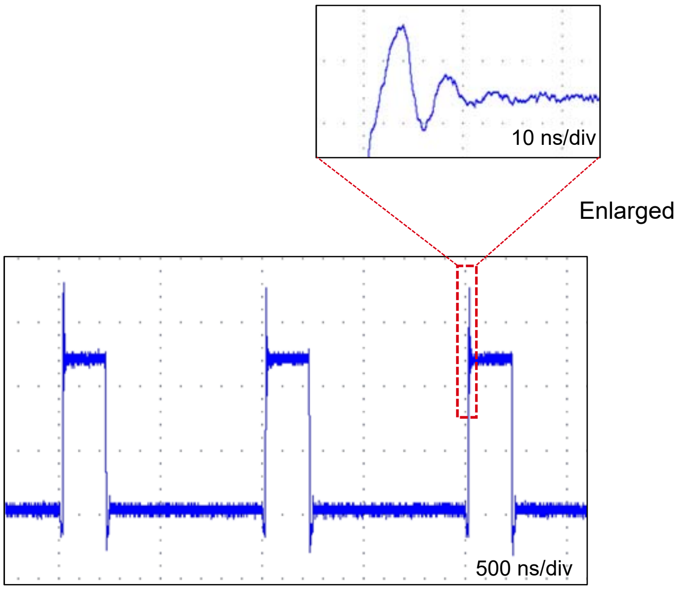

Figure 3. Ringing waveform of switch node

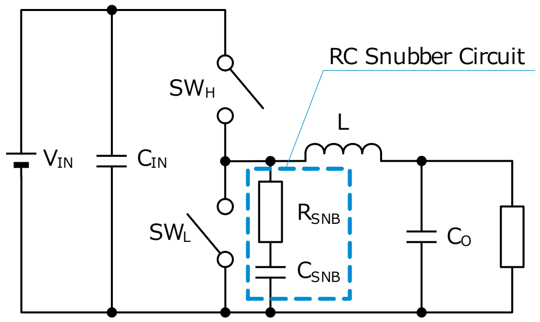

Figure 4. RC snubber circuit

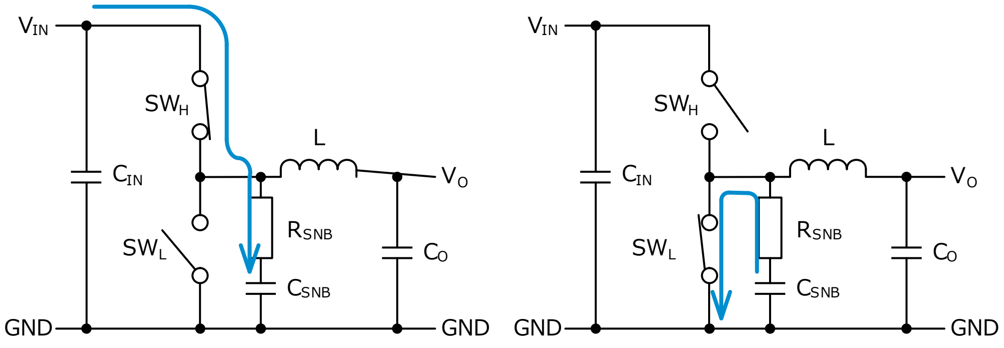

Figure 5. Operation of snubber circuit

Calculation of RC value

According to K. Harada, T. Ninomiya, and M. Kohno, “Optimum Design of RC snubbers for Switching Regulators” (in IEEE Transactions of Aerospace and Electronics Systems, Vol. AES-15, No. 2, March 1979), the RC value of a snubber circuit at which the ringing disappears is given by the following two equations:

$$R_{SNB} = 0.65 \times \sqrt{\frac{L_P}{C_{P2}}} \tag{1}$$

$$C_{SNB} = 8 \times C_{P2} \tag{2}$$

However, L_P and C_{P2} are parasitic elements, and their values are not disclosed by their manufacturers or in some cases are too small to be used for extracting the constants. Here, a method is described for calculating the constants by monitoring the waveforms on the actual equipment. The calculation procedures are given briefly in the next section.

Calculation procedures of RC value

1. Measure the ringing frequency f_r with an oscilloscope.

2. Connect the capacitor C_{P0} between the switch node and ground, and determine the capacitance value at which the ringing frequency is decreased by a factor of 2.

3. A third of the capacitor value C_{P0} is the value of the parasitic capacitance C_{P2}.

$$C_{P2} = \frac{C_{P0}}{3} \quad [F] \tag{3}$$

4. Calculate the parasitic inductance L_P from the parasitic capacitance C_{P2}.

$$L_P = \frac{1}{(2\pi f_r)^2 \times C_{P2}} \quad [H] \tag{4}$$

5. Calculate the characteristic impedance of the resonance.

$$Z = \sqrt{\frac{L_P}{C_{P2}}} \quad [\Omega] \tag{5}$$

6. Set the snubber resistance R_{SNB} to the equivalent value to the characteristic impedance Z.

$$R_{SNB} \geq Z \quad [\Omega] \tag{6}$$

7. Choose a snubber capacitance C_{SNB} larger than the parasitic capacitance C_{P2} by a factor of 1 to 4.

$$C_{SNB} = (1 \; to \; 4) \times C_{P2} \quad [F] \tag{7}$$

8. Calculate the consumption power of the snubber resistance R_{SNB}.

$$P_{RSNB} = C_{SNB} \times V_{IN}^2 \times f_{SW} \quad [W] \tag{8}$$

Use a resistor with rated power that is larger than the consumption power by a factor of 2.

Calculation example of RC value

This section outlines the procedure for calculating RC values while performing actual measurements.

1. Measure the ringing frequency with an oscilloscope. Be sure to use a probe for the switch node at the measurement point. To reduce the additional capacitance on the switch node, remove the hook tip that is attached at the end of the probe and directly contact the probe pin with the switch node. Remove the ground lead since it adds an inductor component. Attach a ground lead adapter instead and minimize the ground length (Figure 6).

   Enlarge the ringing waveform to measure the frequency (Figure 7). In this example, we see a frequency of 217.4 MHz.

Figure 6. Probe setup

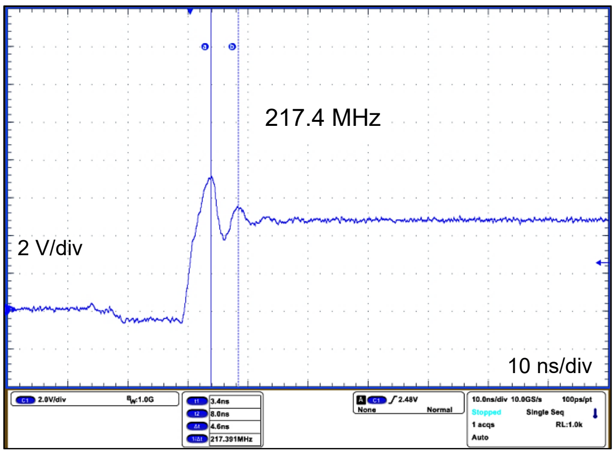

Figure 7. Measuring the ringing frequency

2. Connect the capacitor C_{P0} between the switch node and ground as shown in Figure 8, and determine the capacitance value at which the ringing frequency is decreased by a factor of 2. In this example, aim for a frequency of 108.7 MHz, which is a half of 217.4 MHz. As an experimental result, an additional capacitance of 680 pF was observed to bring the ringing frequency to about 108.7 MHz (Figure 9).

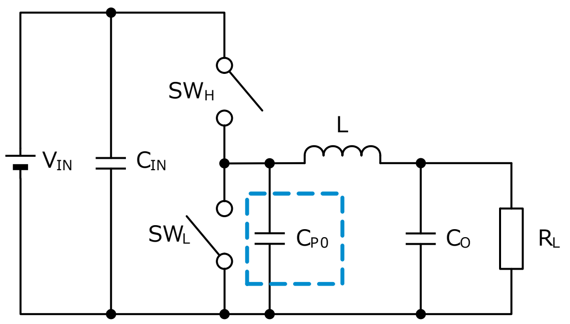

Figure 8. Addition of C_{P0}

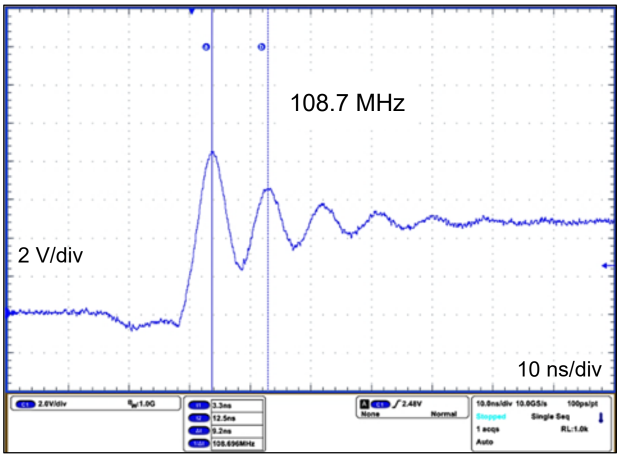

Figure 9. Ringing frequency with a capacitance of 680 pF added to C_{P0}

3. Since the resonance frequency of ringing is determined by $f_r = \frac{1}{2\pi\sqrt{L_P \cdot (C_{P2}+C_{P0})}}$, the frequency is decreased by half when the capacitance value is increased by a factor of 4. Therefore, the parasitic capacitance C_{P2} is estimated to be a third of the added capacitance C_{P0}. Since C_{P0} is 680 pF, the parasitic capacitance C_{P2} is calculated as follows:

$$C_{P2} = \frac{C_{P0}}{3} = \frac{680\ \text{pF}}{3} = 227\ \text{pF}$$

4. Now that the parasitic capacitance C_{P2} is known, calculate the parasitic inductance L_P by transforming the equation for the resonance frequency $f_r = \frac{1}{2\pi\sqrt{L_P \cdot C_{P2}}}$. From the ringing frequency f_r of 217.4 MHz and the parasitic capacitance C_{P2} of 227 pF,

$$L_P = \frac{1}{(2\pi f_r)^2 \times C_{P2}} = \frac{1}{(2\pi \times 217.4\ \text{MHz})^2 \times 227\ \text{pF}} = 2.36\ \text{nH}$$

5. Calculate the characteristic impedance of the resonance. To simplify the calculation, do not consider any loss of transmission line; just use ideal actual values.

$$Z = \sqrt{\frac{L_P}{C_{P2}}} = \sqrt{\frac{2.36\ \text{nH}}{227\ \text{pF}}} = 3.22\Omega$$

6. To attenuate the ringing, it is necessary to set the snubber resistance R_{SNB} to be equivalent to the characteristic impedance of resonance Z.

$$R_{SNB} \geq Z \quad [\Omega]$$

In this example, the value of 3.3Ω is chosen.

7. Choose a snubber capacitance C_{SNB} larger than the parasitic capacitance C_{P2} by a factor of 1 to 4.

$$C_{SNB} = (1\ to\ 4) \times C_{P2} \quad [F]$$

Since the calculation gives the values of 227 pF, 454 pF, 681 pF, and 908 pF, actual capacitors of 220 pF, 470 pF, 680 pF, and 1,000 pF are used. Measure the ringing waveform while switching these capacitors in order. As shown in Figures 10 to 14, the result suggests that the ringing disappears and a good waveform is obtained with the capacitance at 680 pF. If the ringing remains, measure the waveform while further increasing the capacitance to a value larger than the parasitic capacitance by a factor of about 10. However, note that increasing the capacitance leads to greater power loss and results in lower efficiency.

8. Calculate the consumption power of the snubber resistance R_{SNB} with the following equation: In this example, the input voltage V_{IN} of 5 V and the switching frequency f_{SW} of 1 MHz give

$$P_{RSNB} = C_{SNB} \times V_{IN}^2 \times f_{SW} = 680\ \text{pF} \times 5^2 \times 1\ \text{MHz} = 17\ \text{mW}$$

a loss of 17 mW is generated at the snubber resistor. The loss is small in this example, but it can become larger with a higher input voltage. To avoid burning out the snubber resistor, it is therefore necessary to pay attention to the rated power of the resistor. It is recommended to use a snubber resistor of which rated power is larger than the consumption power by a factor of 2.

For example, when the input voltage V_{IN} is 24 V and the switching frequency f_{SW} is 1 MHz,

$$P_{RSNB} = 680\ \text{pF} \times 24^2 \times 1\ \text{MHz} = 0.39\ \text{W}$$

the generated consumption power of 0.39 W requires a 6432 size resistor (2512 in inches) with a rated power of 1 W.

Although the constants of 3.3Ω and 680 pF are chosen in this example, these are only valid for the ringing frequency that was initially measured. It must be considered that the situation may be different depending on the input voltage or the load current. It is necessary to determine in advance the condition in which the ringing will be attenuated at most as desired values.

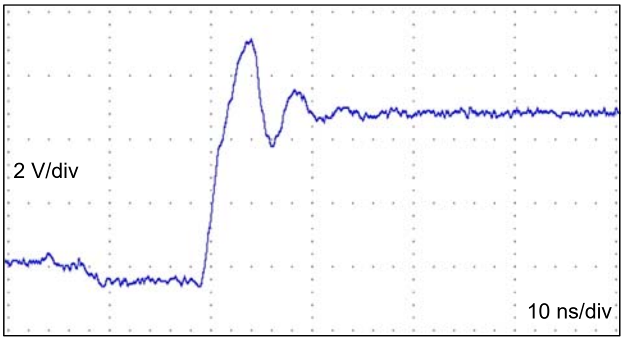

Figure 10. Without snubber circuit

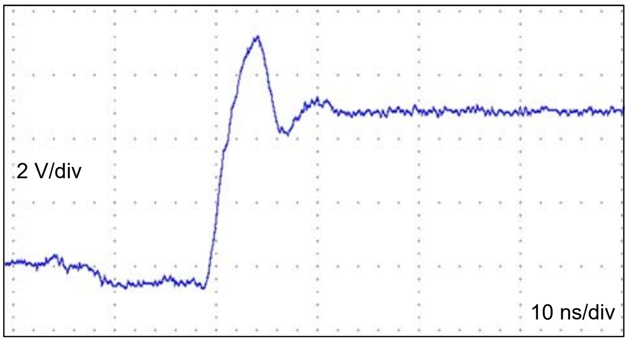

Figure 11. R_{SNB}=3.3Ω, C_{SNB}=220 pF

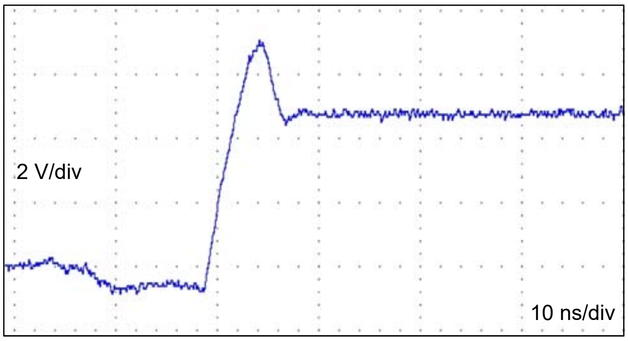

Figure 12. R_{SNB}=3.3Ω, C_{SNB}=470 pF

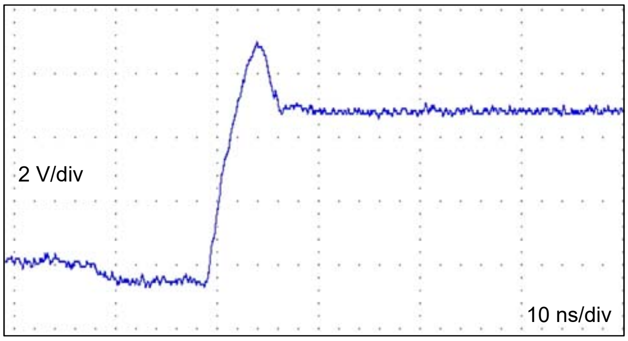

Figure 13. R_{SNB}=3.3Ω, C_{SNB}=680 pF

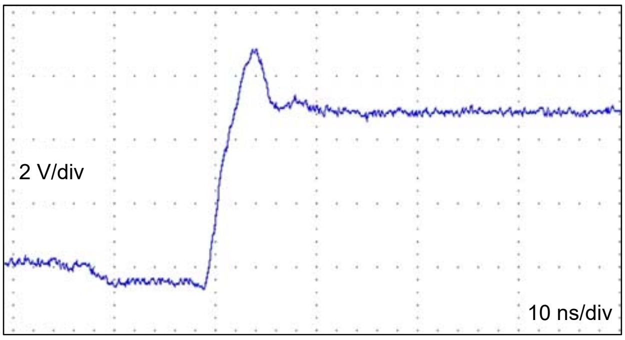

Figure 14. R_{SNB}=3.3Ω, C_{SNB}=1,000 pF

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