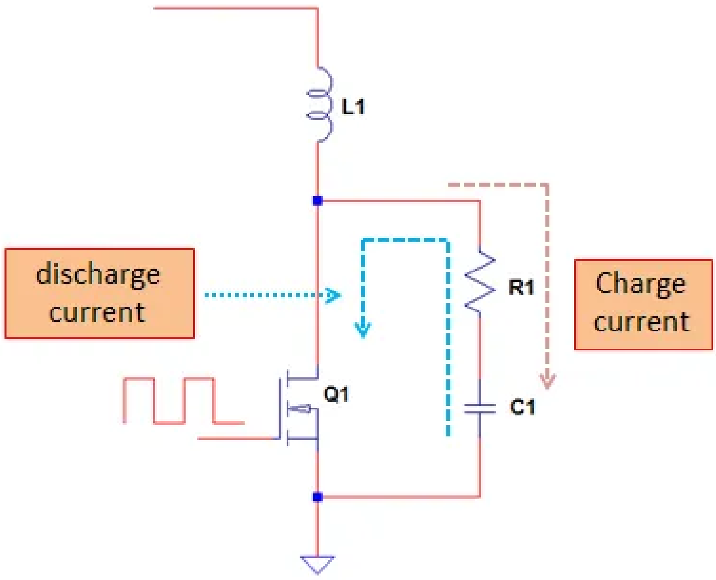

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Snubber Circuit Design Analysis

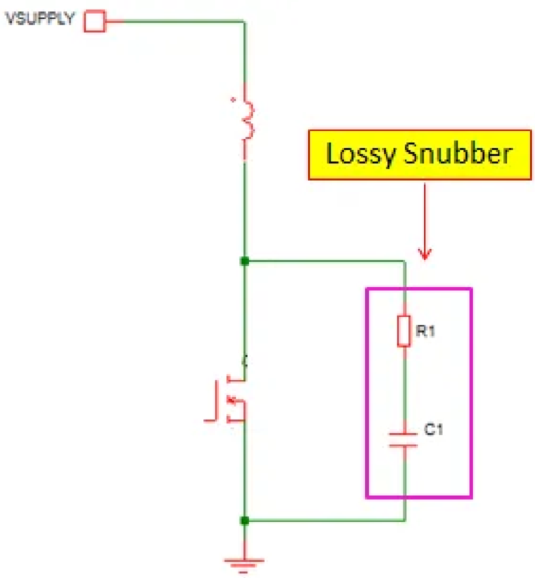
What is a Snubber?

Snubber is a form of circuit protection against voltage spikes, ringing and oscillation effects. Snubber works by either clamping voltage spikes but not altering the ringing frequency or does the same function. Snubber circuit design is one of the complex tasks in circuit design. It needs a deep knowledge on circuit's foundations to design a good snubber circuit. However, after reading this, you can design your own snubber circuit.

General Classifications of Snubber

Lossy or Dissipative

Lossy snubber circuit is the one that draws or consume power. In terms of system efficiency, using this is a disadvantage especially to power supplies that aims for very high efficiency requirement. However, this is less complex and easier to design. Dissipative snubber uses resistor and sometimes diode as dissipating elements.



Non-lossy or Non-dissipative

Non-lossy snubber circuit is the one that will not consume power. This is a complex solution most of the times and also expensive. This is preferred for high efficiency application. Non-dissipative snubber uses inductors and capacitors.

Lossy and Non-lossy Snubber Power Loss Comparison

Lossy Snubber losses depend on the selection of the snubber devices. The device selection is dependent to the level of voltage spike to suppress and the ringing frequency. For most applications, dissipative snubber losses are minimized and tolerable thus designers always use it for quick and easy design life.

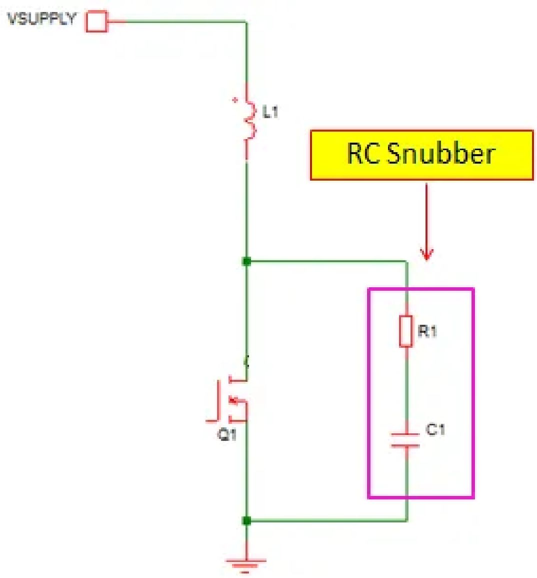
Non-lossy snubber is ideally lossless or will not consume power. However, there is no such thing as ideal so it has small losses on it. In the past several snubber circuit design I did (speaking of a dissipative snubber), I manage to set the power loss to less than 1W for a 500W or even higher power. This corresponds to 0.2% of the output power which is negligible for the efficiency.

Commonly Used Snubbers in Practical Applications

Despite of

many snubber variations, snubber circuit design is often times concentrate only into two commonly used configurations.

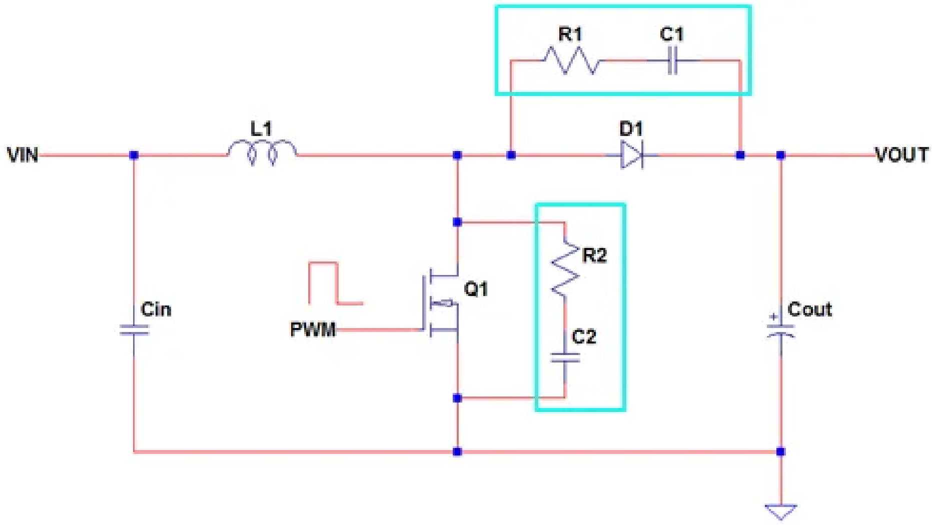
1. RC Snubber



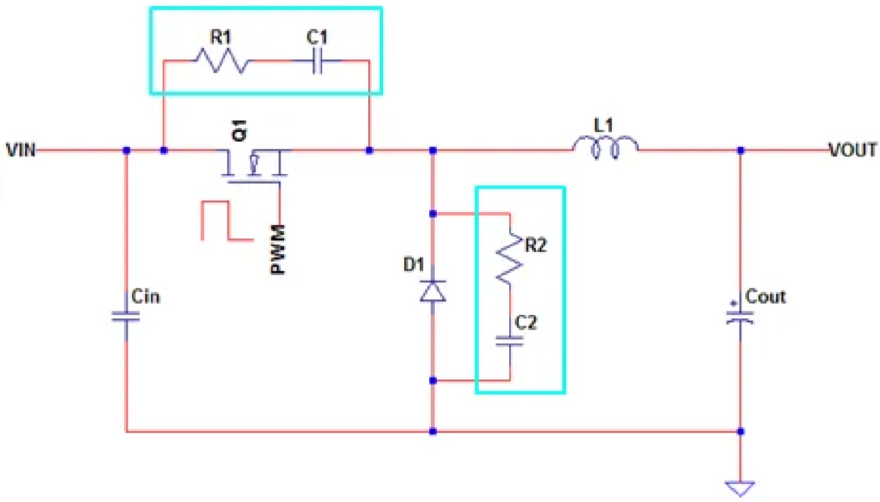
From the name itself, it is uses resistor and capacitor to form a snubber circuit. This is commonly used snubbers for switching MOSFETs.

Some Circuits Where RC Snubber Circuit Used

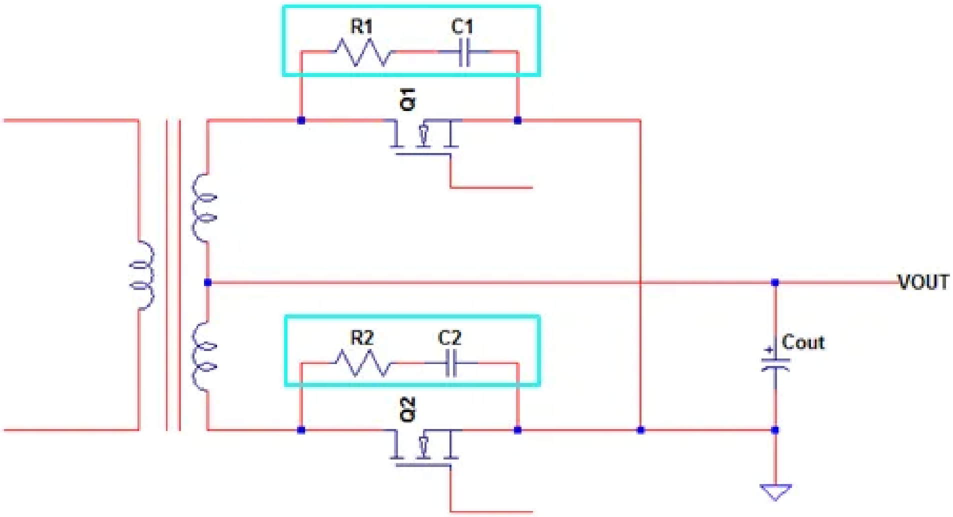
Boost Converter Topology



Buck Converter

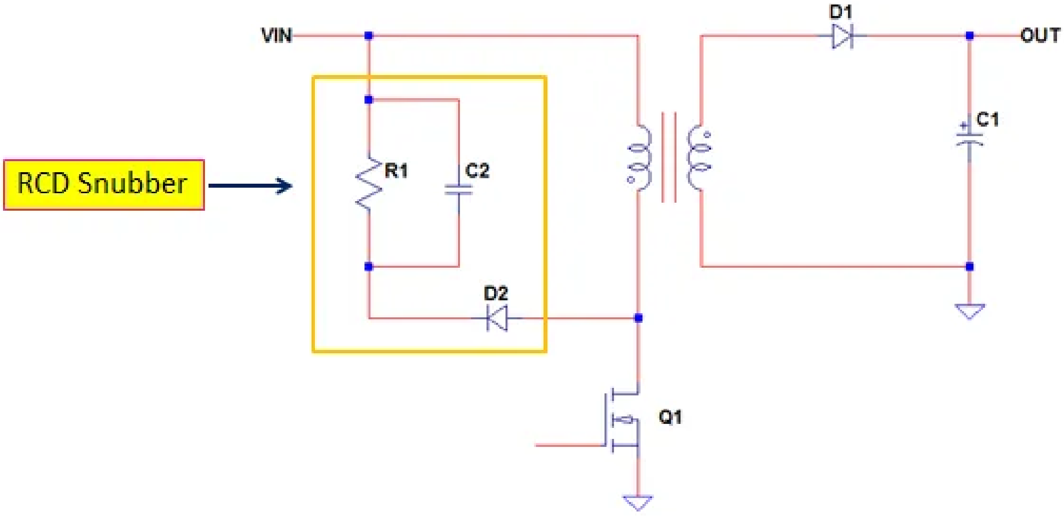


DCDC Synchronous Rectifier



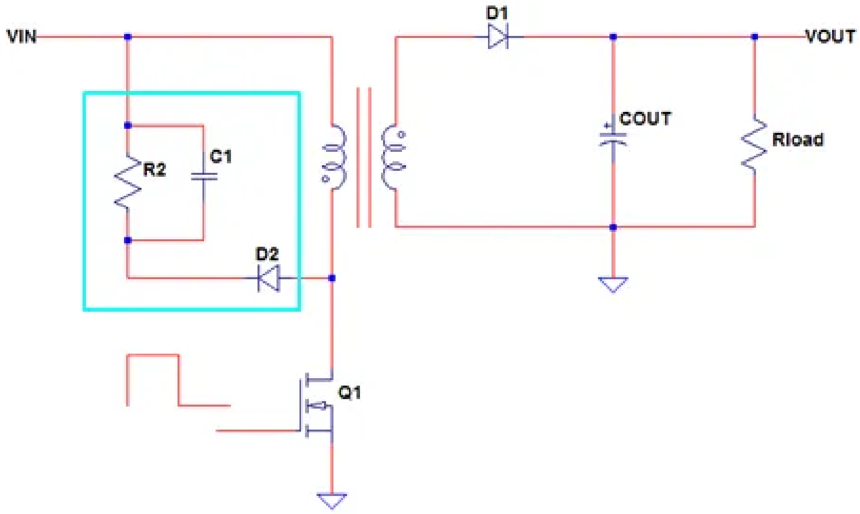
2. RCD Snubber

For some designers, they called this as RCD clamp more often that RCD snubber. It is because it will literally clamp the voltage spikes while not modifying the spike or ringing frequency. RCD snubber is consisting of resistor, capacitor and diode.

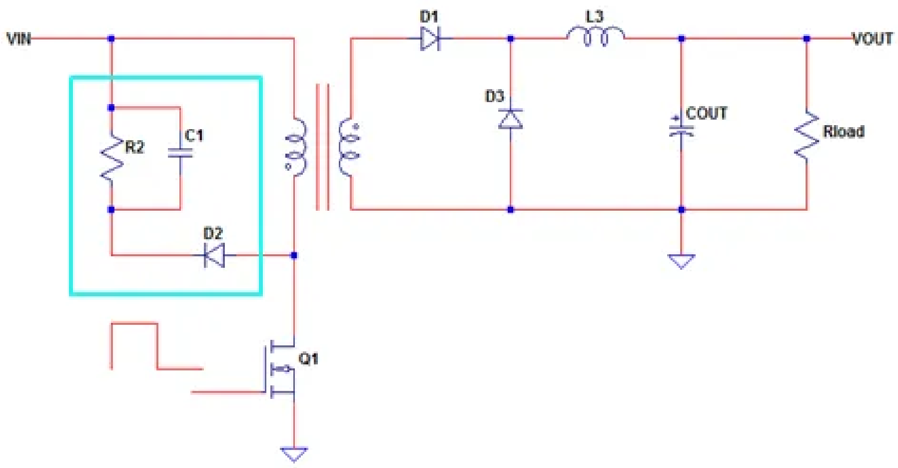


Some Circuits Where RCD Snubber is used

Flyback Converter

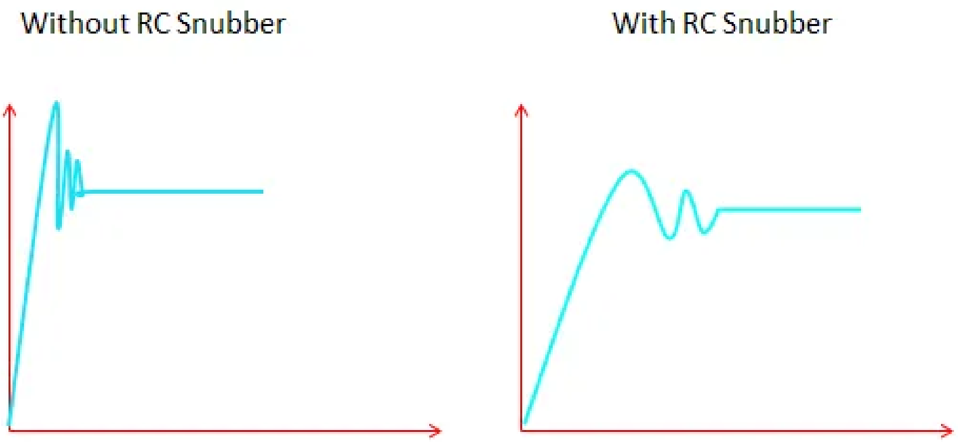


Forward Converter

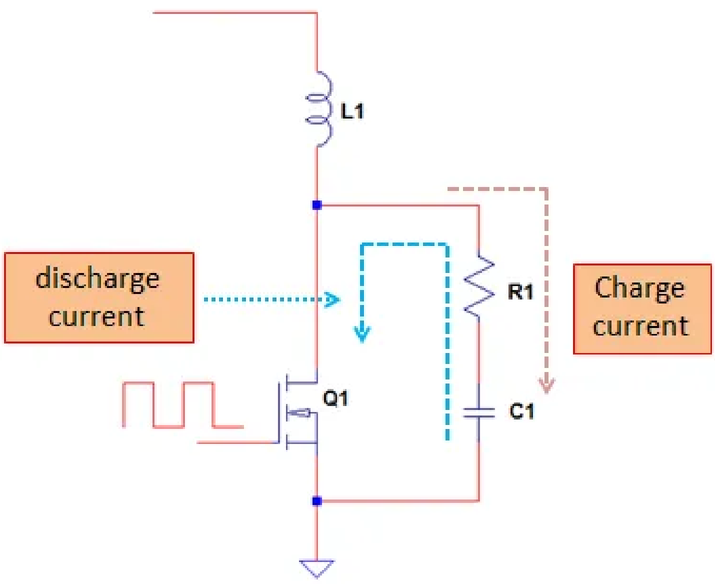


How RC Snubber Works

RC snubber is commonly used in switching converters to limit the voltage spike on the switching device into a safe level. Not just by simply clamping the voltage spike alone, but also modifying the spike frequency or ringing behavior to prevent further issue.



RC snubber works by modifying the ringing frequency as well as lowering the voltage spike level. The capacitor acts as charge storage and the resistor provides a discharge path. For instance in below circuit, the RC snubber R1 and C1 protects the MOSFET Q1 from voltage spike on the drain. When the MOSFET is OFF, the snubber capacitor will charge through R1. When the MOSFET turns ON, the capacitor will discharge through R1 to the MOSFET and to the circuit ground. The cycle will repeat with the capacitor is empty. The resistor is the one dissipates power. In a single switching cycle, there are two times where current flows to the resistor. Below illustration called the currents as charge and discharge currents.

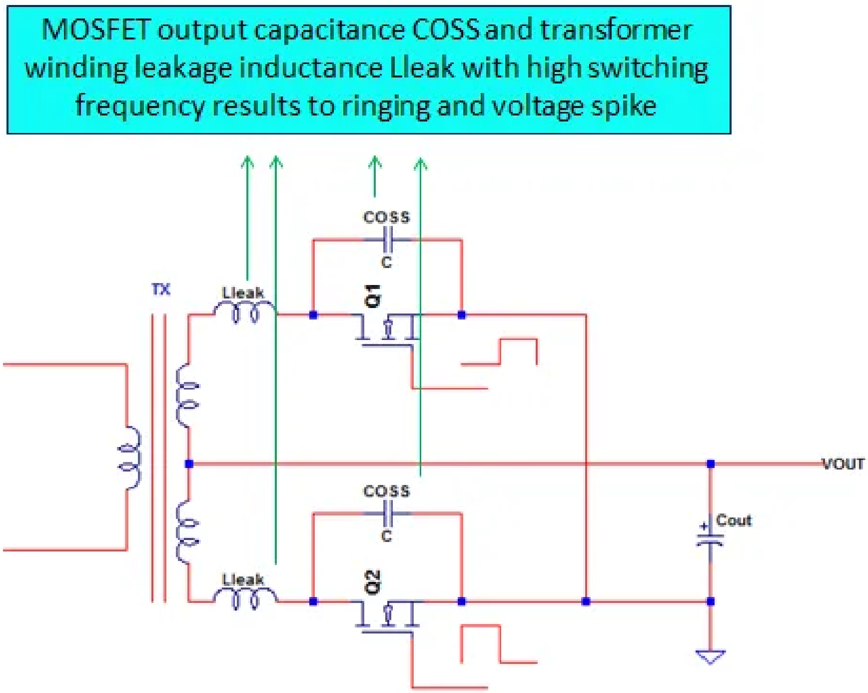


The fact that an RC snubber is capable of modifying the ringing frequency, it is instrumental in solving EMI related issues. In the past, I had solved several issues in EMI b using RC snubbers on switching MOSFET and diodes.

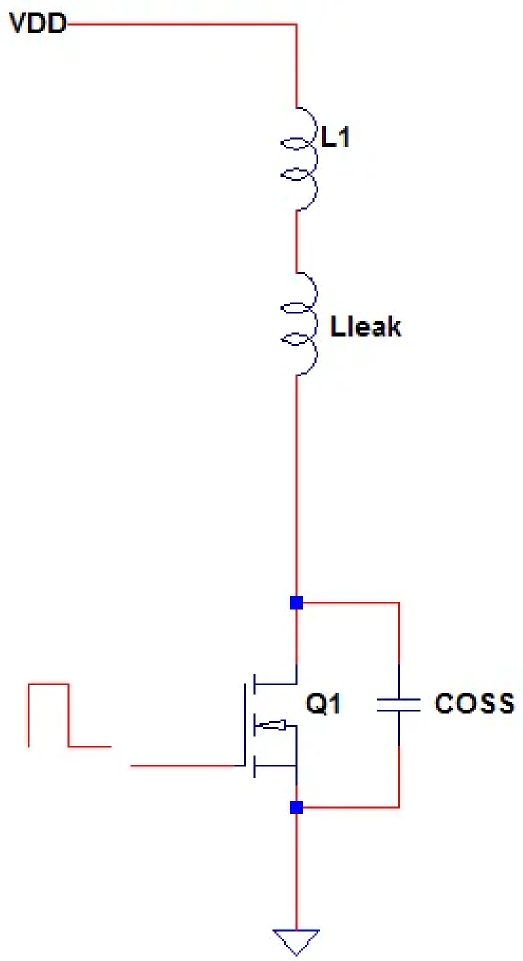
What Creates Ringing and Voltage Spikes in Switching MOSFET?

Ringing and voltage spike is caused by the interaction of leakage inductance and MOSFET output capacitance. It is the leakage inductance that will give voltage spike and not the desired inductance. The leakage inductance will store energy but this energy is not being transferred to the load or to a desired system and thus nowhere to go.

Below diagram is a common synchronous rectifier in center tap full bridge rectification. This circuit structure is common in DCDC section of an SMPS. The energy in the desired inductance will be transferred to the load (output side) but the leakage energy has nowhere to go.



Q1 and Q2 in the above diagram will not operate in the same time. When Q1 is ON, Q2 is OFF and vice versa. The circuit is can be simplified by taking only individual MOSFET as below.



The VDD level is just ideally twice the level of the output plus the spike.

RC Snubber Circuit Design and Analysis

There is no perfect method to use in selecting RC snubber components. However, there are techniques that are proven working well in actual design. One of the documents that I also refer to is the application note of NXP semiconductor, AN11160 which is entitled Designing RC snubbers. http://www.mikrocontroller.net/attachment/202527

/AN11160_Designing_RC_Snubbers__NXP.pdf

This is a good theoretical and practical approach to select RC snubbers starting values.

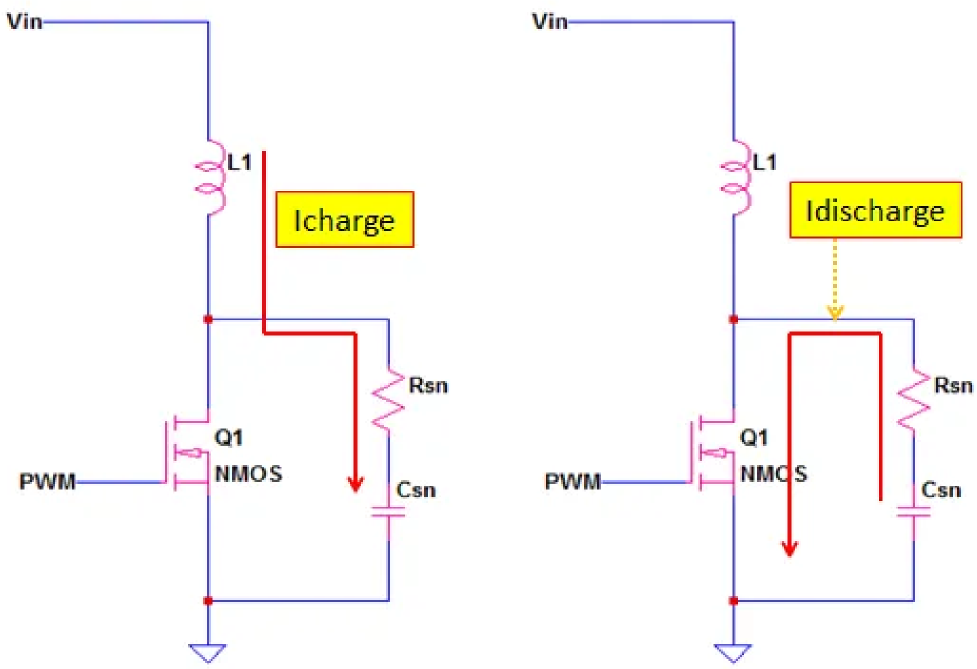
The critical parameters to consider for the selected parts are voltage and power dissipation of the snubber resistor. The voltage rating of the capacitor and resistor must be higher than the voltage spike.

Power Loss in RC Snubber

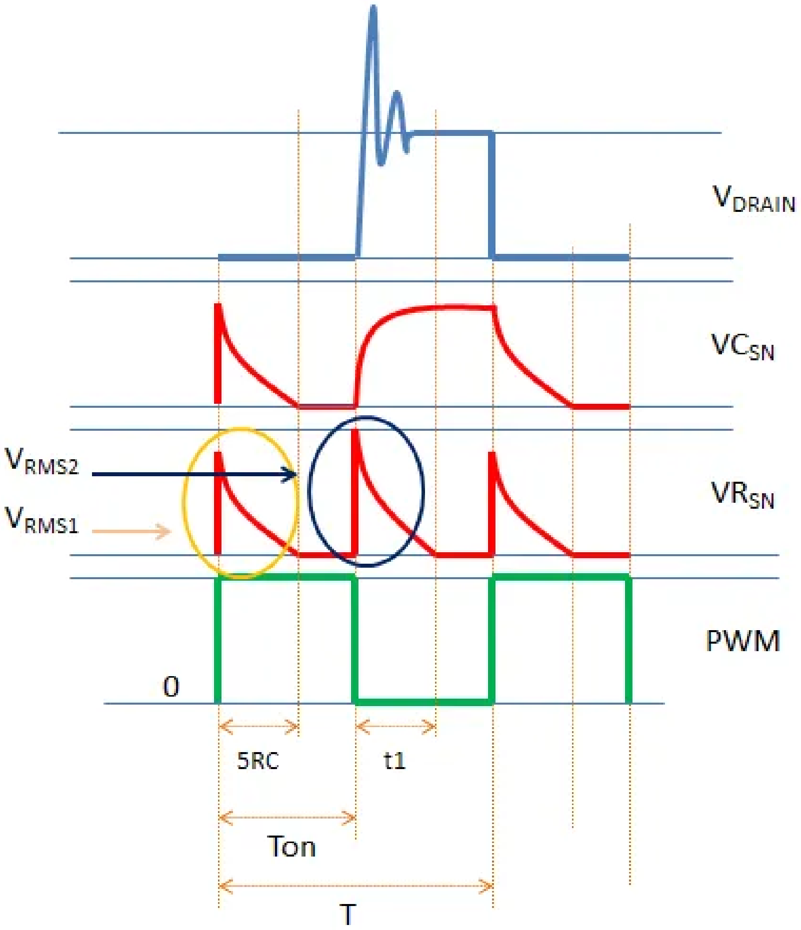
The contributor of power loss in RC snubber is the resistor. The right resistor size must be selected in terms of power loss and snubber effectiveness. Too high resistance has lower power loss but might deliver not effective snubber. On the other hand, lower resistance most likely can deliver an effective snubber but the efficiency of the system will suffer due to higher power loss in RC snubber.

How to Calculate Power Loss in RC Snubber Resistor

In below circuit, Rsn and Csn comprise the RC snubber network. When Q1 is turning on, the charge on the snubber capacitor will pass through Rsn to discharge. By the moment Q1 turns off, the capacitor Csn will charge through Rsn. Therefore, in a single switching cycle, the current will pass through the resistor twice.



Below are the important waveforms for the analysis. The total RMS power dissipation on the resistor is dependent to the VRMS1 and VRMS2. Actually, the RMS1 waveform is on the negative y-axis because it is happening when the capacitor discharges. However, since we are going to get the RMS value we draw the waveform in the positive y-axis. For RMS derivation, it will not matter.



Definitions:

V_{RMS1} – RMS value of the resistor voltage waveform when the capacitor is discharging

V_{RMS2} – RMS value of the resistor voltage waveform when the capacitor is charging

V_{DRAIN} – Drain voltage of Q1

VC_{SN} – Snubber capacitor voltage

VR_{SN} – Snubber resistor voltage

PWM – pulse width modulated signal on the gate of Q1 to turn it on and off

T – One switching period

Ton – the time that Q1 is on or the PWM is high

5RC – simply 5 tau or 5 time constants

t1 – the time the voltage on the resistor become zero after Q1 turns off

Note: on below derivations, the area under the curve is considered as triangular for easier integration. Thus the computed result is may be a bit higher than the actual test result.

Derivations:

t1

When Q1 is off, the snubber capacitor will charge and its voltage will rise exponentially while the snubber resistor will see very high voltage initially but decay exponentially, Thus

$$VDS = VDS_{MAX} \cdot e^{\frac{-t1}{R_{SN} \cdot C_{SN}}} \text{ solve}, t1 \rightarrow -C_{SN} \cdot R_{SN} \cdot \ln\left(\frac{VDS}{VDS_{MAX}}\right)$$

$$t1 = -C_{SN} \cdot R_{SN} \cdot \ln\left(\frac{VDS}{VDS_{MAX}}\right)$$

Where;

VDS – steady state of the drain voltage of Q1 (without the spike)

VDS_{MAX} – is the peak drain voltage (with the spike)

V_{RMS1}

V_{RMS1} is present from time zero to full discharge state of the capacitor which happening at 5 time constants.