Title: Power Tips: Calculating an R-C Snubber
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Date: 03/01/2016, Power House

Tags: power tips, snubber, damping, ringing, flyback, 7 steps, R-C, RC

Most power supply designers have seen ringing in switch-mode converters. This ringing can generate radiated and conducted noise, cause circuit jitter, over-stress components and create excessive dissipation. This is often a major concern in applications such as audio, processor power, and any design that requires EMI qualification. Often adding a simple resistor–capacitor (R-C) snubber to damp out the ringing is all that's required to tame the circuit. But all too often guess work is used when selecting values, resulting in less than optimal performance. Wouldn't it be better if this trial-and-error approach could be replaced with a simple step-by-step process?

Figure 1 shows two common locations in a flyback converter where excessive ringing occurs. In both places, component lead, PCB, and transformer leakage inductance ring with non-linear component and inter-winding transformer capacitances. This L-C tank rings at a frequency and amplitude that is generally unknown until the circuit is tested. In many instances the ring amplitude and duration is significant and must be reduced. One solution is to damp or "snub" the oscillation with a series R-C circuit, typically placed across the rectifier or the FET.

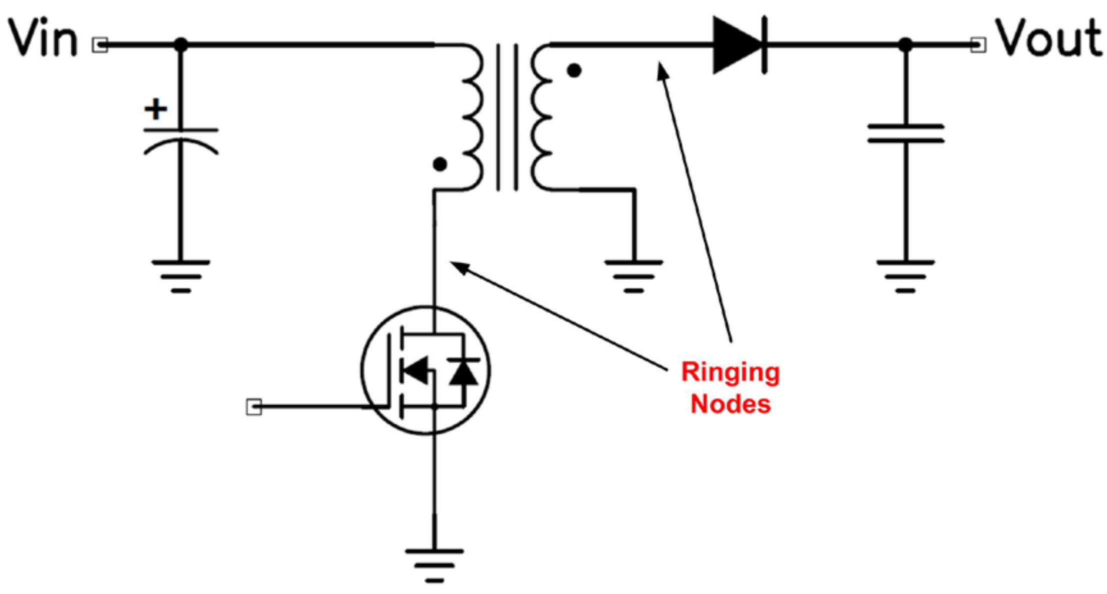

Figure 1: Leakage inductance and component capacitances create ringing in converters, such as a flyback.

The 7-step procedure below uses a common methodology that shifts the resonant frequency of the ringing to calculate the circuit's parasitic inductance (L) and capacitance (C_o). Once these are known, the snubber capacitor (C_{snub}) and resistor (R_{snub}) are calculated which provide a reasonable starting set of values for the R-C snubber. The example waveforms in the figures below were taken for an R-C snubber placed in parallel with the rectifier.

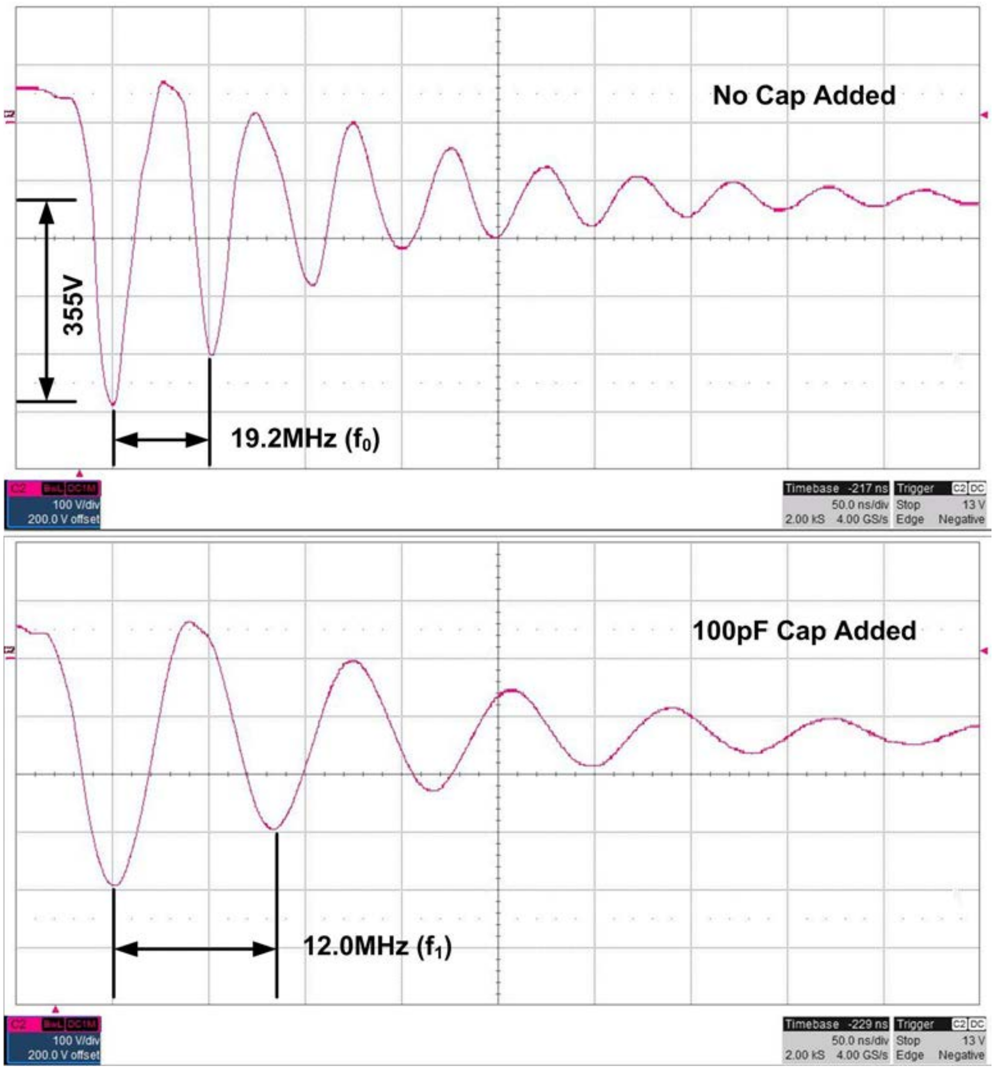

Figure 2: Un-snubbed rectifier ringing (top) and frequency shifted ring (bottom)

7 steps to calculate a snubber:

1) Measure the circuit's oscillation frequency (f_0). See figure 2 (top).

2) Add a capacitor (C_1) in parallel with the rectifier or FET and measure the shifted oscillation frequency (f_1). Select a C_1 value that is several time larger than the rectifier's typical capacitance at full reverse voltage in the datasheet. In this example, the rectifiers reverse capacitance was 22pF, so 100pF was chosen for C_1. A frequency shift of at least 50% is reasonable. See figure 2 (bottom).

3) Calculate the frequency shift ratio; $m = \frac{f_0}{f_1}$

4) Calculate the circuit's parasitic capacitance; $C_0 = \frac{C_1}{(m^2-1)}$

5) Calculate the circuit's parasitic inductance; $L = \frac{(m^2-1)}{(2\pi f_0)^2 C_1}$

6) Calculate the starting snubber capacitor value; $C_{snub} = 3 * C_0$.

7) Calculate the starting snubber resistor value; $R_{snub} = \sqrt{\frac{L}{C_0}}$.

The spike reduction and damping effect of the calculated values are shown in figure 3. Larger values for C_{snub} will reduce the voltage spike amplitude further, but also will increase power loss in R_{snub}. The designer must now weigh the tradeoff between acceptable voltage ring amplitude and R_{snub} losses.

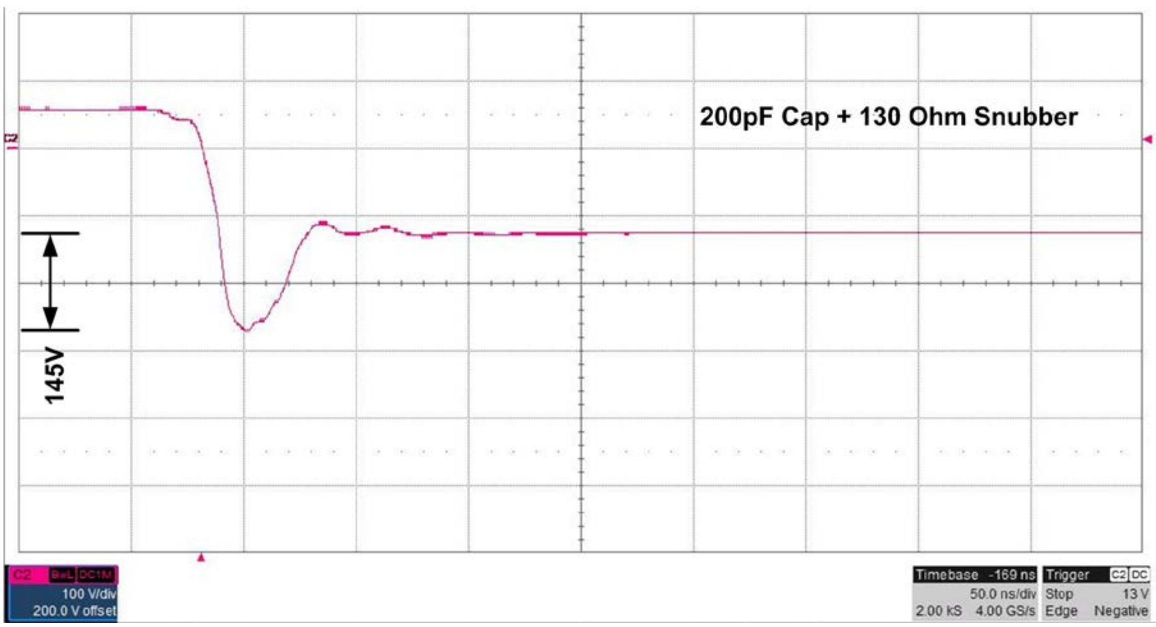

Figure 3: An optimized snubber reduces ring amplitude and damps the oscillation.

Figure 4 is a normalized plot of the voltage ring amplitude and snubber resistor losses versus R_{snub} $(normalized\ to\ R_{snub} = \sqrt{\frac{L}{C_0}} = 1)$. As R_{snub} moves away from the circuit's characteristic impedance of $\sqrt{\frac{L}{C_0}}$, ring amplitude and duration increase. Snubber power dissipation is near its maximum when $R_{snub} = \sqrt{\frac{L}{C_0}}$. If it is desired to reduce losses or adjust the ring amplitude, its best change the value of C_{snub}, a smaller value for less loss, but more ringing or a larger value for less ringing, but more losses. Using a value of R_{snub} between ½X to 2X of the calculated value, in most cases, this will maintain excellent damping.

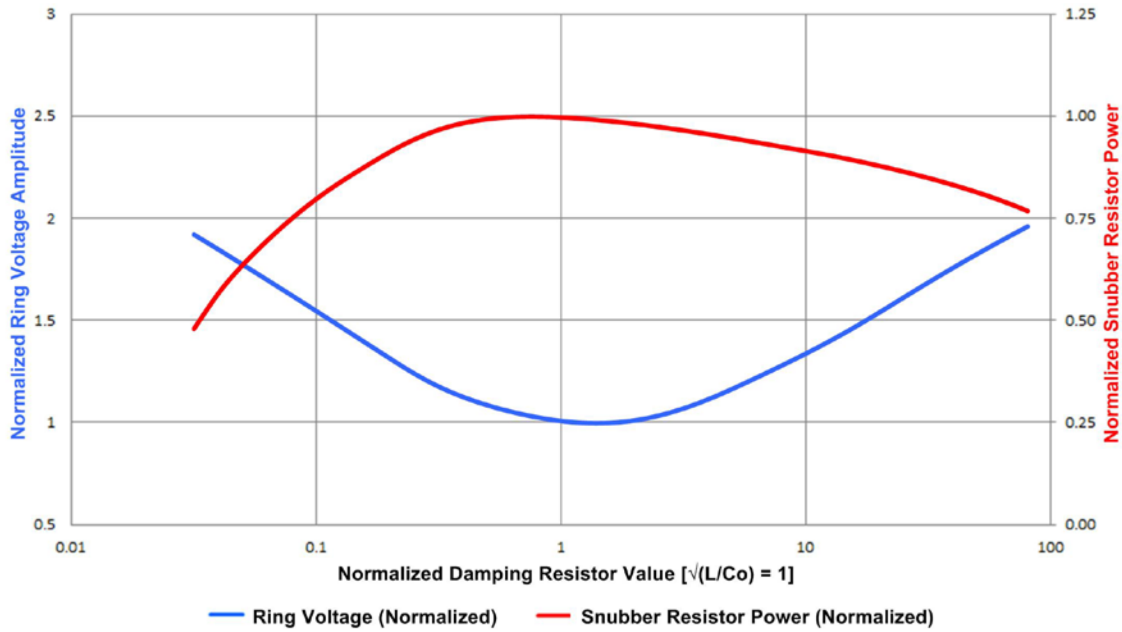

Figure 4: A snubber resistor value equal to the circuit's characteristic impedance minimizes ringing, but at maximum power loss.

Undamped ringing in switching converters can create excessive EMI and overstress components. An R-C snubber that is properly calculated can be instrumental in taming these issues. The 7 step procedure detailed above is simple to follow and provides a good starting point to help the designer "damp the ringing".

Check out TI's Power Tips blog series on Power House.