# RC Snubber Resonant Design

An RC snubber is just a resistor and capacitor in series that damps out the oscillations occurring when a switched inductive circuit turns off.

How this is supposed to work is that the snubber capacitance forms a resonant tank circuit with the inductance, the resistor absorbs the tank's energy, and the oscillations damp out quickly.

In practice, snubber circuits tend to be ill-designed, simply because it seems there's no good way to measure the actual inductance and stray capacitance at the switch. Folks tend to apply a 100-ohm resistor and a 100 nF capacitor and hope for the best. Sometimes that works. Most of the time it's suboptimal.

You can do better than that.
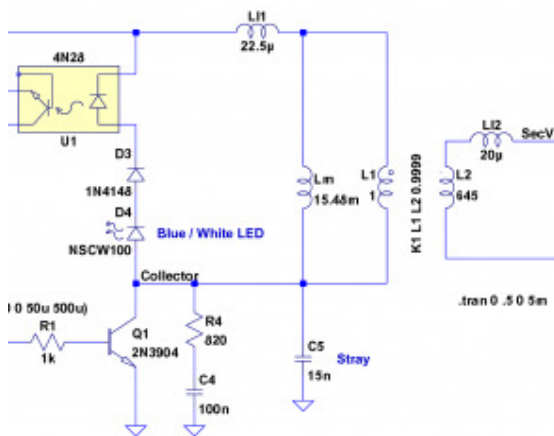
Forward converter switch, transformer, and snubber

Here's the key chunk of simple-minded forward converter I'm doing for a Circuit Cellar column. It's an LTSpice IV model, not an actual schematic, but the hardware is pretty close to what you see here. The "Stray" capacitance at C5 represents a measured value, not an actual component. The transformer parameters come from my measurements there.

A microcontroller drives the transistor switch, which draws current through the transformer primary and transfers power to the secondary winding; the turns ratio is 1:25, so a 6 V input becomes a 150 V output. When the microcontroller shuts off the switch, the collector voltage pops

up to about 11 V, at which point the stack of diodes turns on and the inductor begins to discharge. The diode forward-bias characteristics keep a more-or-less constant voltage until the current becomes essentially zero, so the collector voltage declines only slightly as the current drops.

When the current drops enough that the diodes don't conduct very much, the collector node is in a peculiar condition: there's no place for the remaining energy to go!
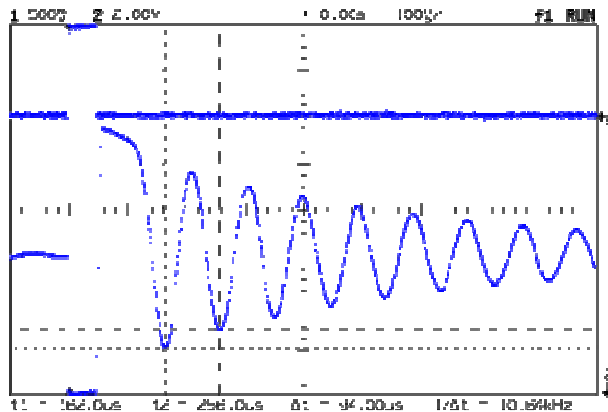
Undamped collector ringing

This scope shot shows the result. The drive pulse (top trace) pulls the collector voltage (bottom trace) to zero, it snaps up to 11.5 V, and then declines to about 10 V before the diodes switch off. At that point the collector voltage rings like a bell: 8 V peak-to-peak at 10 kHz. That's a very low frequency because the primary reflects the fairly substantial stray capacitance in the zillion-turn secondary winding.

In order to form a resonant circuit, you need some idea of the existing inductance and capacitance. You can't just clip a meter in there to measure them, because their values depend on the frequency, layout, and actual hardware.

One good experimental technique is pretty well summarized in Maxim's AN-3835, which deals with Cold-Cathode Fluorescent Lamp drivers. Pay no attention to the CCFL stuff, as snubber fundamentals are the same wherever you go.

Basically, you add a test capacitance across the transistor (from collector to ground, similar to C5 in the schematic) and measure the new ringing frequency. Fiddle with the test capacitance until the frequency is half of what it started at. Use reasonably short lead lengths,

particularly for applications that don't involve actual transformers or inductors; surface-mount capacitors are your friends.

What you're doing is fiddling with this equation:

$$F = 1 / (2 \pi \, sqrt \, (L \, C))$$

Because of the square root around LC, when you increase the capacitance by a factor of 4, the frequency decreases by a factor of 2. So the test capacitance required to cut the frequency in half is three times the original stray capacitance. Got that?

Knowing the original stray capacitance, which is 1/3 the test capacitor value, and the original ringing frequency, you can figure out the actual inductance:

$$L = 1 / ((2 \pi \, F)^2 \, C)$$

Now the magic happens…

You know the inductance and capacitance of the tank circuit *and* its resonant frequency. At that frequency, the inductive and capacitive reactances are equal:

$$X_L = 2 \pi \, F \, L$$
$$X_C = 1 / (2 \pi \, F \, C)$$

In fact, they're also equal to what's called the characteristic impedance of the circuit:

$$Z = sqrt(L / C)$$

The resonant frequency is about 10 kHz and an additional 60-some-odd nF dropped the frequency to about 5 kHz. Fairly obviously, your stock of caps will affect the precision of the results. Let's suppose the stray capacitance, shown as C5, is about

$$C5 = 60 / 3 = 20 \text{ nF.}$$

The inductor is then:

$$L = 13 \text{ mH}$$

The characteristic impedance works out to:

$$Z = 800 \text{ ohms}$$

Take those numbers with a grain of salt, but twiddling the scope cursors will get you pretty close in your own circuit.

In order to swamp any variations in the stray capacitance (during the production run or whatever), pick the snubber capacitance to be at least four times the stray capacitance, rounded up to the next standard value. In this case, that works out to the traditional 100 nF, but that need not be the case.
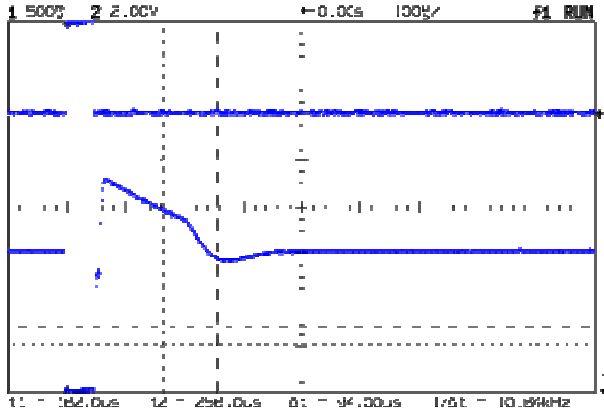
Snubbed ringing

You want to kill the ringing stone cold dead, so pick the snubber resistance equal to the characteristic impedance. That makes it a tank circuit with:

Q = R sqrt(C / L) = 1

Which is a pretty low Q, all things considered.

The scope shot shows the result with an 820 Ω resistor and a 100 nF capacitor: *wham*, no ringing!

Notice that the collector voltage is slightly lower immediately after the transistor switches off, as compared to the undamped case, because there's now some juice going into the RC snubber. The overall converter efficiency will drop and you can trade off Q for efficiency for resistor dissipation in the usual manner.

Pretty slick, huh?

Update: you might want to put the snubber directly across the winding in higher-powered systems, to keep the snubber current out of the power supply. In this case it doesn't matter all that much.