

# DESIGN NOTES

## Capacitor and EMI Considerations for New High Frequency Switching Regulators – Design Note 95

Carl Nelson and Bob Essaff

The LT<sup>®</sup>1372 family of boost and flyback converters and the LT1376 buck converter form a new line of high frequency switching regulators offered by Linear Technology. Up to 10 times faster (250kHz to 1MHz) than older devices, these new converters are actually more efficient than older designs. Several design considerations for high frequency switchers are discussed here.

### Capacitor Technology Considerations

At lower frequencies, magnetics dominates the size of DC-to-DC converters, but at frequencies above 200kHz the largest component is typically the input and output bypass capacitors. This makes it important to pick the right capacitor technology in critical size applications. The most important parameter in choosing the capacitor is cost versus size and impedance. The input and output capacitors must have low impedance at the switching frequency to limit voltage ripple and power dissipation.

It is also desirable to have low impedance at much higher frequencies because high amplitude narrow spikes are created if the capacitor has even a few nH of inductance. The amplitude of these spikes is determined by the rate-of-rise of current ( $di/dt$ ) fed to the capacitor. For a high speed converter,  $di/dt$  may be as high as 0.5A/ns. Even 3nH of capacitor lead inductance will create  $(0.5 \text{ e}^9) (3 \text{ e}^{-9}) = 1.5\text{V}$  spikes. The second part of this Design Note shows how to attenuate these spikes using parasitic PC board elements.

Figure 1 details the impedance characteristics of the most popular switching regulator capacitors. These are aluminum electrolytic, solid tantalum, OS-CON, and ceramic. Within one technology, impedance at lower frequencies tends to closely track physical volume of the capacitor, with larger volume giving lower impedance.

**Aluminum electrolytics** perform poorly and are rarely used at frequencies above 100kHz, but their low cost and higher voltage capability may cause them to be used for input bypass applications.

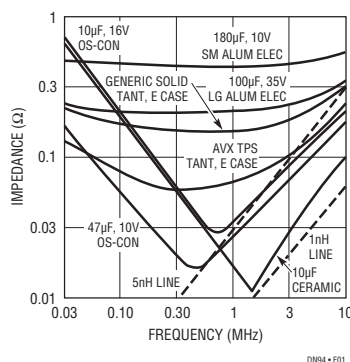


Figure 1. Capacitor Impedance

**Solid tantalum** capacitors offer small size, low impedance, and low Q (to prevent loop stability problems). The down side of tantalum is limited voltage, typically 50V maximum, and a tendency for a small percentage of units to self-destruct when subjected to very high turn-on surge currents. AVX addresses the problem with their TPS line which features more rugged construction and special surge testing. Even TPS units must be voltage derated by 2:1 if high turn-on surges are expected, limiting practical operating voltage to 25V. Even with their shortcomings, solid tantalum seems to be the technology of choice for medium to high frequency DC-to-DC converters.

**OS-CON** capacitors from Sanyo and Marcon are made with a semiconductor-like dielectric that gives very low impedance per unit volume. They greatly outperform aluminum units, but have a few pitfalls of their own. Maximum voltage is 25V, height is significantly greater than solid tantalum, and most units are not surface mount. The very low ESR (effective series resistance) of OS-CON capacitors can also cause a problem with loop stability in switching regulators.

**Ceramic** capacitors offer the lowest impedance at 500kHz and beyond, but they suffer from high cost,

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large footprint, and limited temperature range. They are probably best suited for input bypassing at higher voltages, and very high frequency ( $\geq 1\text{MHz}$ ) applications.

Note that at high frequencies, most of the capacitors approach an inductive line of about 1nH to 5nH. Smaller units in parallel will reduce effective inductance, but cost goes up.

### Controlling EMI: Conducted and Radiated

EMI strikes terror into system designers because its causes and cures are not well understood. There are two separate issues involved; meeting external FCC standards and avoiding internal system malfunctions. Higher frequency switching regulators would seem to make the whole problem much worse, but there are several mitigating circumstances that have allowed nearly all systems to use high frequency converters with few problems.

Contrary to popular misconceptions, older switching regulators rarely were a major contributor to overall system noise problems if the system contained reasonable amounts of logic chips. The noise created by a microprocessor, databusses, clock drivers, etc. usually swamps out switcher noise. This can be seen very simply by connecting a linear regulator temporarily in place of the switcher. Radiated noise using standard FCC methods, and supply line noise often show almost no change when the switcher is turned off.

The second reason for reduced high frequency switcher noise problems is that the components used are physically smaller. Radiated noise is proportional to radiating line length, so smaller, tightly packed components radiate significantly less.

Conducted EMI usually makes its appearance as ripple current fed back into the input supply, or as ripple voltage at the regulator output. Figure 2 shows how both of these effects can be virtually eliminated by using parasitic inductance in input or output lines. At 500kHz each inch of board trace represents nearly  $0.1\Omega$  of reactance, and for the higher harmonics the impedance is much higher. This impedance can be used in combination with existing capacitors to create “free” filter action.

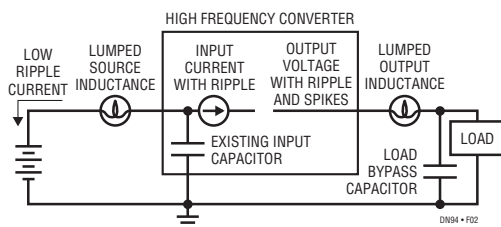


Figure 2. Free High Frequency Filters Using Parasitics

At the input, as shown in Figure 3, the switching ripple current will all disappear into the input bypass capacitor if the reactance in the input lines is large compared to the capacitor impedance. For instance, an OS-CON 33 $\mu\text{F}$ , 20V capacitor has an impedance of about  $0.02\Omega$  at 500kHz. If the supply lines have an effective length of six inches (input plus return), the line reactance will be about  $0.6\Omega$  at 500kHz. The fundamental of the ripple current will be attenuated by the ratio of line impedance to capacitor impedance =  $0.6/0.02 = 30:1$ . Higher harmonics will virtually disappear.

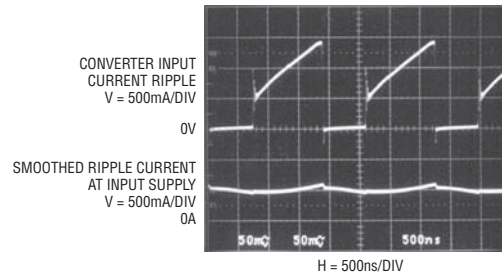


Figure 3

Output ripple can be filtered by utilizing the reactance of output lines in conjunction with load bypass capacitors as shown in Figure 4. With two inches of output trace ( $0.16\Omega$  at 500kHz) and  $0.15\Omega$  capacitor impedance, fundamental ripple will be attenuated by two-to-one and output noise spikes virtually eliminated. The Fourier components of these spikes start above 25MHz where line reactance is  $4\Omega$  per inch.

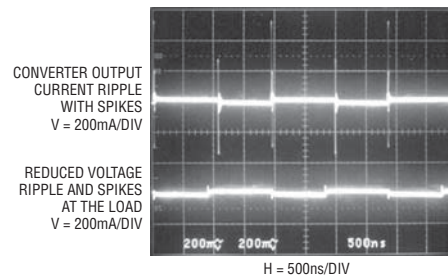


Figure 4

A common cause of radiated noise is the use of “open core” magnetics. The lowest cost high frequency inductors are wound on ferrite rods or barrels, which do not have a closed magnetic field path. This generates large local B fields that can play havoc with sensitive low level circuitry such as disk drives, A-to-D converters, and IF strips. Each application needs to be evaluated separately, but in situations where low signal levels exist in close proximity to the converter, closed core magnetics such as toroids or E cores should be used until extensive system level testing has proved out a cheaper solution.