

Power Tip 51: Be aware of capacitor parasitics

By Robert Kollman, Texas Instruments

Power supply ripple and transient specifications establish the requirements for the amount of capacitance you will need. They also set limits on the capacitors' parasitic components. **Figure 1** shows a capacitor's basic parasitic components, which consist of the equivalent series resistance (ESR) and equivalent series inductance (ESL). It also graphs the impedance of three capacitor styles (ceramic, aluminum electrolytic and aluminum polymer), versus frequency. **Table 1** shows the values used to generate the curves. These are typical values you might find in a low-voltage (1V – 2.5V), medium current (5A) sync-buck power supply.

Capacitor Style	Capacitance (uF)	ESR (m-Ohm)	ESL (nH)
Ceramic	22	2	2
Aluminum Electrolytic	1000	20	5
Aluminum Polymer	220	10	5

Table 1: Comparing three capacitor styles, each has its strength.

At low frequencies, all three capacitors show no signs of parasitic components as the impedance is clearly a function of the capacitance alone. However, the aluminum electrolytic capacitor impedance stops diminishing and begins to look resistive at a relatively low frequency. This resistive characteristic continues to a relatively high frequency where the capacitor turns inductive. The aluminum polymer capacitor is the next capacitor to deviate from ideal. Interestingly, it has a low ESR and the ESL becomes apparent. The ceramic capacitor also has a low ESR, but since it has a smaller case size, its ESL is less than that of the aluminum polymer and aluminum electrolytic capacitors.

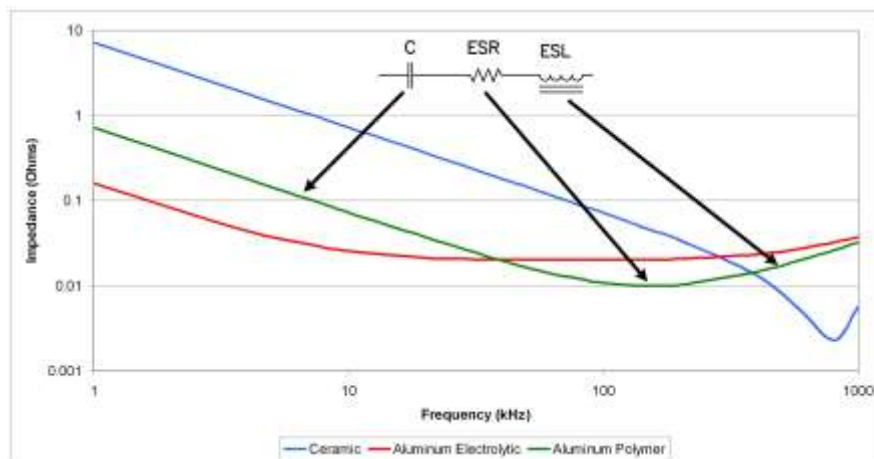


Figure 1: Parasitics alter the impedance of ceramic, aluminum, and aluminum polymer capacitors differently.

Figure 2 presents the power supply output capacitor waveforms from a continuous sync-buck regulator simulation operating at 500 kHz. It uses the dominant impedances of the

three capacitors in **Figure 1**: capacitance for the ceramic; ESR for the aluminum; and ESL for the aluminum polymer.

The red trace is the aluminum electrolytic capacitor, which is dominated by the ESR. Consequently, the ripple voltage is directly related to the inductor ripple current. The blue trace represents the ripple voltage across the ceramic capacitor, which has small ESL and ESR. The ripple voltage in this case is the integral of the ripple current in the output inductor. Since the ripple current is linear, this results in a series of time-squared sections and appears sinusoidal in shape.

Finally, the green trace represents the ripple voltage where the capacitor impedance is dominated by its ESL, such as an aluminum polymer. In this case, there is a voltage divider formed by the output filter inductor and ESL. The relative phasing of these waveforms is as expected. With the ESL dominating, the ripple voltage leads the output filter inductor current. With ESR dominating, the ripple is in phase with the current, and with capacitance dominating, it is lagging. In reality, the output ripple voltage does not comprise a voltage from only one of these elements. Instead, it is a sum of all three. So expect to see some of each in the ripple voltage waveform.

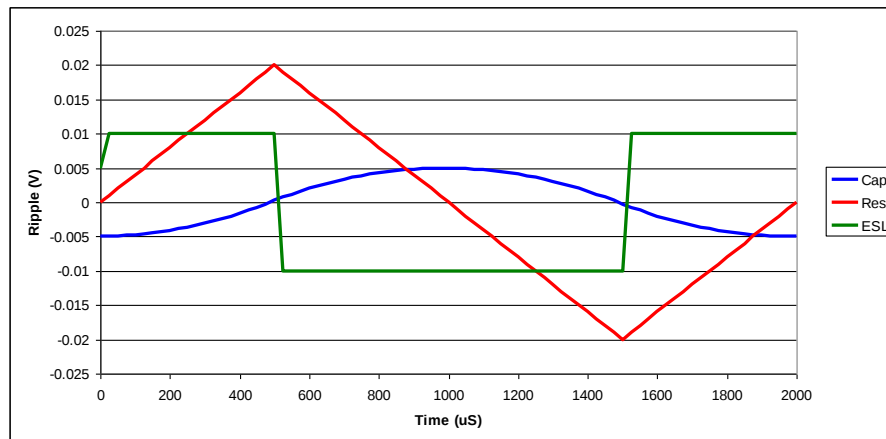


Figure 2: The capacitor and its parasitic elements create different ripple voltages in a continuous sync-buck.

Figure 3, shows the waveforms in a deeply continuous flyback or boost where the output capacitor current is both positive and negative with rapid state changes. This is apparent in the red trace, which is the voltage generated by this current times the ESR. The result is a square wave. The voltage on the capacitor element is simply the integral of a square wave. This results in a linear charge and discharge, shown by the blue triangle waveform. Finally, the voltage across the capacitor's ESL is only significant when the current changes during transition. This can be quite high, depending on the output current rise time. Note that in this case the green trace is divided by 10, which assumed a 25 nS current transition. These significant inductive spikes are one of the reasons you often see a two-stage filter in a flyback or boost power supply.

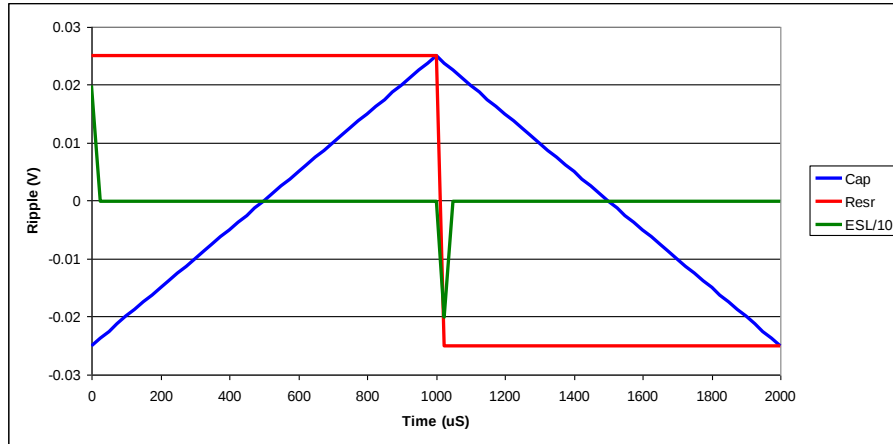


Figure 3: Waveforms change with continuous flyback or boost output current.

To summarize, the impedance of the output capacitor helps set ripple and transient performance. With power supply frequencies moving higher, the parasitics become important and cannot be ignored. Near 20 kHz, the aluminum electrolytic capacitor's ESR is large enough to dominate the capacitance impedance. At 100 kHz, some aluminum polymers turn inductive. Keep mindful of ESL in all three styles as power supplies move into mega-Hertz switching frequencies.

Please join us next month when we will examine a low-power, offline flyback converter.

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