1. Introduction

MARK DAVIS-MARSH: Hi. I'm Mark Davis-Marsh, and I'm going to be talk about capacitor selection. This is going to be an overview of capacitor selection, and it's part of switching power supply component selection. So when you're selecting capacitors for DC/DC converters, there's a lot of things you're already going to know. And these are going to be determined by the needs of your design. You're probably already going to know your input voltage range, your output voltage range. And that automatically is going to determine your duty cycle. You're also probably going to know, at least in the right range, how much output current your design's going to use. And this will generally allow you to design an inductor that keeps your ripple current in the 30% to 40% divide of I out range. Knowing all of this, that's going to allow us to use these parameters to design our output capacitor selection.

2. Selection Process Summary Electrical Specifications

So if we look at the general process for selecting the output capacitors, there's a couple things you have to look for. First thing you want to look for is the RMS current rating of the capacitor. This is basically what we're going to be talking about in the rest of this presentation. We also need to look at the applied voltage at the capacitor. And you're going to want to de-rate the capacitor based on the chemistry. We're going to talk about that in another upcoming section. You're also going to want to size the bulk capacitance based upon your voltage deviation requirements. So this is going to be your transient response, and it's going to be based on how much capacitance you need in order to supply current to your load and not go out of your specified upper voltage range. We'll talk about that also in another segment. And you're going to want to check that the output capacitor meets the stability requirements of your controller or regulator. That's a whole topic unto itself, and we won't be talking about that in this segment.

3. Selection Process Summary

So when you're looking at the selection process, you're also going to want to look at what combinations of capacitors work best for your solution. In general, you're going to want to use tantalums or aluminum electrolytics for bulk capacitance. This is for having enough capacitance to supply load transience, or to dampen an LC filter. You're going to want to use ceramic capacitors for decoupling and bypass of high-frequency switching. So on a DC/DC converter design, you're going to want to use ceramics very close to your input and very close your output in order to get rid of high-frequency noise. You're also going to look at different mechanical challenges. Vibration—ceramic capacitors of the larger case sizes don't do well with a lot of vibration. You're going to look at temperature. Aluminum electrolytics don't do well at cold or hot temperatures. At cold temperatures, they have an ESR that becomes too high, and also that sometimes makes them unusable for switching power supplies. And at hot temperatures, the internal electrolyte will dry up and they can have failures. So you're going to want to look at those mechanical challenges. You're also going to want to look at lifetime. So, the ceramics and polymer capacitors have improved lifetime over electrolytic and tantalum. But the larger ceramics
can crack, so you want to take a look at these different things. There's always a trade-off between the cost and the performance.

4. Selection Process Summary

When you're doing your selection, you're going to want to de-rate the capacitors. And you're going to want to look at what parameters they have that need to be met. So one of the key ones, like I said, was RMS currency. You need to make sure that that capacitor can meet the RMS currents that you have for the design. It should meet the peak voltages. You can't have a capacitor selected that's too close to the peak voltages; it'll seem. This is just not a way that we'd like to design. We want to have some margin of error in there. And then just remember that to do this, you're probably going to de-rate all of the chemistries of the capacitor by at least 20% on voltage. And for tantalum, you're going to want to de-rate it 50%. Tantalum tends to have high failures above 50% of the rated voltage. So you're going to definitely want to de-rate these for reliability reasons. Not for reliability reasons, but for other reasons, you're going to want to de-rate a lot of class 2 ceramic capacitors to about 50%. So what happens? Basically for a class 2 ceramic capacitor, as it goes closer to its rated voltage, the capacitance will actually decrease. So that 10 microfarad capacitor that you thought you had is now maybe a 6.8 or a 4.7, depending on the type of ceramic. And you're definitely going to want to stay away from the Y5V capacitors. These are just not useful in any switch mode power supply design.

5. Selection Process Summary

So like I said, you want to look at how the capacitors can work well together. And if one type works well for one thing and another for another, you might want to parallel them together. Use the polymer and electrolytic and tantalums for bulk capacitance, and use the ceramics for decoupling.

6. Capacitor RMS Current

So let's talk about the RMS current. This is kind of the first feature that you're going to look at when you're looking at the parameters of your capacitor. The RMS current entering the capacitor is basically going to heat the capacitor. So the rating of RMS current for the capacitor is basically a self-heating limit on that capacitor. You don't want to heat the capacitor to the point where it could cause failure. So in order to know what RMS current rating we need, we need to look at the different topologies, and the RMS currents for these topologies. And that's going to give us a number that we can use to get the right kind of capacitor for our solution.

7. Common Topologies: BUCK
Let's take a look at a buck converter. So, buck converter standard topology, it takes a higher input voltage and bucks it down to a lower output voltage. How does it do that? Basically, it chops the input voltage waveform into a pulse. And the average of that pulse is an average through and LC filter, and that gives you your output voltage. So when we turn on the high-side FET—and that's shown in the current loop in red—the current is going to flow through the inductor, and then bypass from the output capacitor. You then turn off the high-side MOSFET. You're going to turn on the low-side MOSFET. This is shown in more of a magenta pinkish color. And that current is now going to flow through the low-side FET through the inductor, and bypassed through the output capacitor. Now, where these two loops overlap, that current is basically a low-frequency current. It's a nice regular triangular-shaped current, for the most part. But where those two currents don't overlap, you have a pulsed current. This is a very high-frequency pulse current that's being supplied by the input capacitor. So what that means is the RMS current on the input capacitor is much higher than the RMS current on the output capacitor. And all of your switching current that is most needfully to bypass is on the input side.

8. Common Topologies: BUCK

If we look at the equations for this, you can see that the input capacitor RMS current is much more complex than the output capacitor RMS curve for a buck regulator. And that basically comes down to these pulse currents that are coming on the input capacitor.

9. Common Topologies: BOOST

If we look at a boost converter, a boost converter is basically a buck converter laid out backwards. So now, where we had a lot of pulse currents on the input capacitor of a buck regulator, we now have pulse currents on the output capacitor of a boost. So we can look at the general lay of the current transition. But basically the critical path is from the low-side FET, through the diode, and to the output capacitor. And this is where you're going to get the pulsed currents.

10. Common Topologies: BOOST

If we look at the equations for the boost converter, basically you can see they're the reverse for the buck converter, with the pulse converter pulse currents on the capacitor RMS current, and the very smooth triangular currents on the input capacitor.

11. Common Topologies: BUCK BOOST

If we look at a buck boost converter, it's basically the worst of a buck and a boost in terms of RMS current. It has pulsing currents on the input capacitor, and on the output
So if we take a look at the on transition, the current flows in this path. In the off transition, the current flows in this path. And you can see that we don't have good alignment of where these two currents overlap, so we have large pulsed currents on both the input and output capacitors.

12. Common Topologies

So, if we look at the equations for RMS current for a non-inverting case, you could see that when it's in a buck mode, the input capacitor has large pulse RMS currents. And then when it switches to boost mode, the output capacitor has large RMS currents. So basically, it has higher RMS currents on the input and output capacitors than either a buck or a boost standalone converter.

13. Additional Topologies

If you want to take a look at other topologies—SEPIC, flyback, forward—these all have their own limits for RMS current. And they have different voltage ratings necessary for the capacitor. If you take a look at the app note SLUW001A, this has a large chart that shows all of the general topologies that are useful, and it will give you the ratings that you need to design your capacitor.

14. Thank you!

So thank you for watching this capacitor overview. Have a good day.