Question:
How do you increase the efficiency of a power converter with high voltage input and low voltage output?

Answer:
There are different solutions for applications that require conversion from a high input voltage down to a very low output voltage. One interesting example is the conversion from 48 V down to 3.3 V. Such a specification is not only common in server applications for the information technology market, but in telecommunications as well.

If a step-down converter (buck) is used for this single conversion step, as shown in Figure 1, the problem of small duty cycles emerges. The duty cycle is the relationship between the on-time (when the main switch is turned on) and the off-time (when the main switch is turned off). A buck converter has a duty cycle, which is defined by the following formula:

\[
\text{Duty Cycle} = \frac{\text{Output Voltage}}{\text{Input Voltage}}
\]

With an input voltage of 48 V and an output voltage of 3.3 V, the duty cycle is approximately 7%.

This means that at a switching frequency of 1 MHz (1000 ns per switching period), the Q1 switch is turned on for only 70 ns. Then, the Q1 switch is turned off for 930 ns and Q2 is turned on. For such a circuit, a switching regulator has to be chosen that allows for a minimum on-time of 70 ns or less. If such a component is selected, there is another challenge. Usually the very high power conversion efficiency of a buck regulator is reduced when operating at very short duty cycles. This is because there is only a very short time available to store energy in the inductor. The inductor needs to provide power for a long period during the off-time. This typically leads to very high peak currents in the circuit. To lower these currents, the inductance of L1 needs to be relatively large. This is due to the fact that during the on-time, a large voltage difference is applied across L1 in Figure 1.

In the example, we see about 44.7 V across the inductor during the on-time, 48 V on the switch-node side, and 3.3 V on the output side. The inductor current is calculated by the following formula:

\[
i_L = \frac{1}{L} \int u_L dt
\]

If there is a high voltage across the inductor, the current rises during a fixed time period and at a fixed inductance. To reduce inductor peak currents, a higher inductance value needs to be selected. However, a higher value inductor adds to increased power losses. Under these voltage conditions, an efficient LTM8027 μModule® regulator from Analog Devices achieves power efficiency of only 80% at 4 A output current.

Figure 1. Conversion of a voltage from 48 V down to 3.3 V in one single conversion step.
Today, a very common and more efficient circuit solution to increase the power efficiency is the generation of an intermediate voltage. A cascaded setup with two highly efficient step-down (buck) regulators is shown in Figure 2. In the first step, the voltage of 48 V is converted to 12 V. This voltage is then converted down to 3.3 V in a second conversion step. The LTM8027 µModule regulator has a total conversion efficiency of more than 92% when going from 48 V down to 12 V. The second conversion step from 12 V down to 3.3 V, performed with a LTM4624, has a conversion efficiency of 90%. This yields a total power conversion efficiency of 83%. This is 3% higher than the direct conversion in Figure 1.

This can be quite surprising since all the power on the 3.3 V output needed to run through two individual switching regulator circuits. The efficiency of the circuit in Figure 1 is lower due to the short duty cycle and the resulting high inductor peak currents.

When comparing single step down architectures with intermediate bus architectures, there are many more aspects to consider besides power efficiency. However, this article is only intended to look at the important aspects of power conversion efficiency. One other solution to this basic problem is the new LTC7821, hybrid step-down controller. It combines charge pump action with a step-down buck regulation. This enables the duty cycle to be $2 \times \frac{V_{IN}}{V_{OUT}}$ and, thus, very high step down ratios can be achieved at very high power conversion efficiencies.

The generation of an intermediate voltage can be quite useful to increase the total conversion efficiency of a specific power supply. A lot of development is being done to increase the conversion efficiency in Figure 1 with such short duty cycles. For example, very fast GaN switches can be used, which reduce the switching losses and, as a result, increase the power conversion efficiency. However, such solutions are currently more costly than a cascaded solution, such as in Figure 2.

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**Figure 2. Voltage conversion from 48 V down to 3.3 V in two steps, including a 12 V intermediate voltage.**