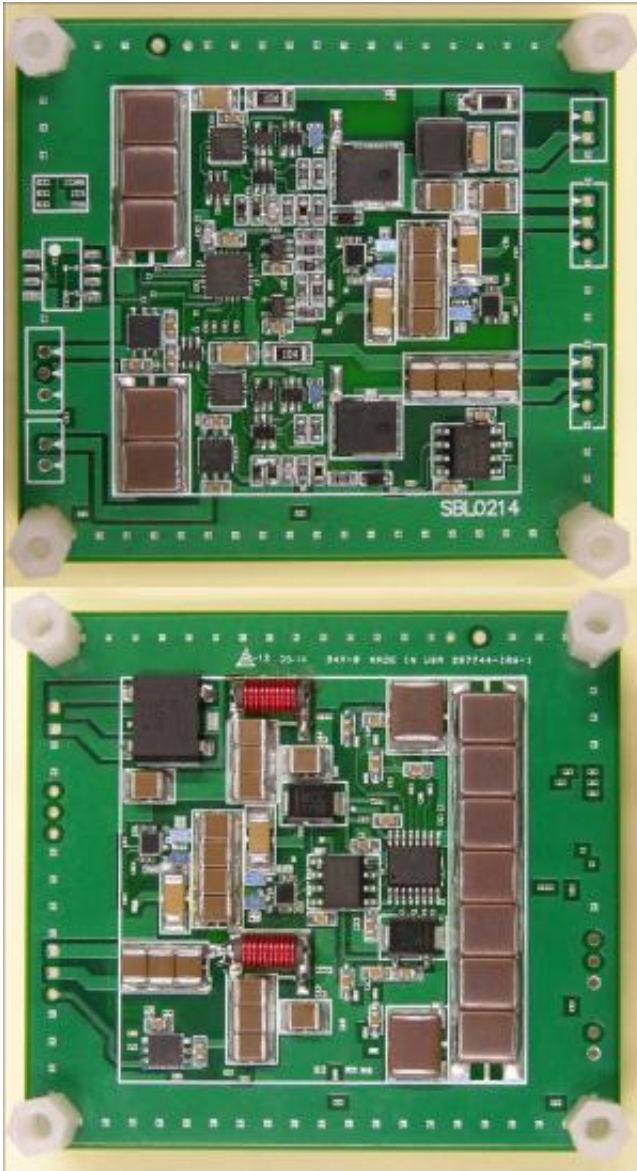


# Pushing the envelope in power electronics

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The front (top) and back (bottom) of a prototype 30W LED driver. Credit: Courtesy of David Perreault

U.S. electrical consumption is expected to climb about 1 percent a year through 2030, and the share of electricity that goes through power electronics is expected to climb to 80 percent during the same period. Global electrical consumption is rising more than twice as quickly, and this enormous market offers ever-widening opportunities for innovative power electronic circuitry that delivers new functionality, improves performance and efficiency, and boosts reliability while reducing footprints, says David Perreault, an MIT professor of electrical engineering and head of the Power Electronics Research Group.

"We have a set of interrelated technologies that enable size reductions and efficiency improvements in a broad range of applications, and the techniques we've developed can be applied, or modified and improved for use, in a wide range of other applications," Perreault says. "We often use highly specialized circuit techniques, because we can make the application so much smaller and higher-performance."

Much of Perreault's group's work focuses on ultrahigh-frequency conversion and ultraminiaturized converters. Its recent work also includes ways to eliminate [electrolytic capacitors](#) in [power](#) supplies, including those that convert between single-phase alternating current (AC) power and direct current (DC) devices.

## **Driving from the AC grid to DC devices**

A prototype LED lamp driver gives an example of three of the Perreault group's closely aligned research initiatives in AC/DC power conversion.

"When you buy a cheap fluorescent lamp and it dies, usually it's the power electronics that have failed," he says. "They may have failed because people have tried to do it very cheaply, so they've combined components in a manner that is not particularly good, and they may have failed because the components used aren't particularly good."

The most likely suspects among inadequate components are electrolytic capacitors—passive components that help to buffer energy between single-phase AC wall outlets and the LED lamp.

Manufacturers use electrolytic capacitors because they are cheap and can store the energy in a relatively small volume. "But they are inherently unreliable—they have a liquid electrolyte that dries out—and they have low temperature limits," Perreault says. "So one of our thrusts is developing energy-buffering techniques that let us eliminate the electrolytic capacitors while maintaining small size. In the LED lamp prototype design, the architecture is set up so that it can use ceramic capacitors to buffer the energy. The trick is to do this without making the device bigger or more expensive."

The LED driver exploits another closely related line of research, on very high-frequency (30 to 300 megahertz) switching that helps to miniaturize energy storage and filtering needs in the converter.

Perreault uses an analogy of transferring water in buckets to explain the approach. "A power converter scoops some energy from the input, transfers it, and then throws it to the output," he says. "Here the energy-source elements—inductors and capacitors—are my buckets for moving around energy. If I can run this converter much faster, I can use a smaller bucket and still transfer the same amount."

"That approach does a few things for you," he explains. "First, you can change your buckets for thimbles. Secondly, you can physically manufacture thimbles in ways that aren't practical for buckets, so you can do a better job of integrating the various pieces in a power supply. Third is bandwidth: If you want to suddenly change what you're doing, you're only stuck with a thimbleful of energy instead of a bucketful of energy that you've got to redirect, so you can get more speed by going to these frequencies."

Implementing this architecture, the prototype LED driver achieves a power factor (a measure of the waveform quality of the line currents) up around the rarely achieved EPA Energy Star recommendations for LED drivers. The driver also provides a power density five to 10 times that of current commercial systems.

Improved power density, in turn, allows minimizing the volume of the inductors and capacitors, which normally are the largest component in such a power supply, so the prototype is much smaller—another major research goal.

"If you can make that LED driver smaller, you can open up a lot more area for heat transfer, which makes the whole system run better," Perreault points out. "Additionally, all things being equal, making it smaller and more integrated ultimately makes it cheaper, which will help these expensive products."

The power conversion technologies developed in the Perreault lab are key ingredients for the world's smallest laptop power adapter supply, created by the MIT spinoff company [FINsix](#). Shipping this fall, FINsix's 65-watt Dart adapter weighs two ounces and is little bigger than an ordinary electrical plug. Other startups and established companies have also adopted and licensed technologies from his group to create innovative products.

Perreault and colleagues have achieved similar success in applying high-frequency switching techniques to greatly enhance the efficiency of radio-frequency power amplifiers. This work has led to the MIT spinoff company [Eta Devices](#), co-founded by Perreault and former MIT associate professor Joel Dawson, which is commercially developing the technology to reduce power consumption for cellular base stations and handsets.

## DC distribution in server farms

Some of the approaches used to achieve miniaturization can be adapted instead to achieve ultrahigh efficiencies that also bring major paybacks for many applications in DC/DC [power conversion](#), with computer server farms providing some examples.

As cloud-computing services mushroom, server farms are being built and operated on an immense scale worldwide, with more than 8 million servers sold annually, according to market research firm IDC, and with server farms consuming well in excess of 1 percent of overall electrical energy usage globally.

The energy delivery in state-of-the-art server farms from grid to computation presently incurs substantial loss. Reducing power consumption through higher-efficiency [power electronics](#) will chop down electrical bills for servers, storage and communications systems, and for the air conditioning they require.

Many server-farm operators are moving toward DC distribution of power, either at high voltages or low voltages, because of the opportunity to eliminate some conversion stages, Perreault says.

Power distribution in [server farms](#) typically begins with three-phase AC, goes through uninterruptible power supplies to battery storage, is converted again to three-phase AC, then converted to DC, then stepped down to final DC loads. An alternative architecture that begins with 380V DC upfront can be more efficient, he explains.

This setup calls for very high efficiency DC/DC power converters, and Perreault's group has worked on subsystems at several levels, including some that convert from 380V down to 12V, and others in the telecom voltage range of 48V.

These converters employ "soft-switching" techniques that are targeted at very high efficiencies of 97 percent and above by trying to minimize the energy loss in every transition. The so-called resonant soft-switched converters explored in the Power Electronics Research Group are further architected to operate efficiently under different ranges of voltage and power—like a bicycle that can shift gears to match its local terrain.

"If systems only had to operate at one voltage, or one power level, it would be relatively straightforward to get very high efficiency and density," Perreault explains. "But when either the voltage or power vary over a very wide range, it suddenly becomes very tricky to do that. We've developed a number of techniques aimed at maintaining high efficiency under these conditions."

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