An Innovative Approach to Input Bridges

Power management is increasingly important in all areas of electronic engineering; from the distribution of high voltage supplies to the effective monitoring of very low core voltages in digital devices. Through the efficiency benefits of replacing conventional input rectification with a self-driven synchronous rectification technique called Active Bridge concept, the challenge of delivering better power management solutions will be met. **Davide Giacomini, European Director of SMPS Applications and Luigi Chiné, SMPS Application Engineer, International Rectifier**

Today, there is much talk about low power solutions, with a specific focus on portable, battery operated devices. In general, semiconductors that operate from ever-lower voltages allow these 'high profile' devices, such as mobile phones and media players, to operate for longer between charges, and it represents an important element of the overall direction of the industry. With this focus on portability, however, it is easy to overlook the equally important need to operate other, less portable devices more power-efficiently. Environmental issues and the rising price of utilities give this its own emphasis and there is now an increased appreciation for the need to consider overall power requirements in the kind of electrical devices we use everyday, such as home appliances, labour saving devices and even automated manufacturing.

Although we tend to think in terms of low voltages, the majority of electronic devices in operation are, in fact, powered through the nationally distributed high voltage power supply, in one way or another; either directly or through an adapter for rechargeable devices. Distributing power across large geographical distances is most efficiently achieved at very high voltages, but at the point of use these voltage levels are clearly too high and must be stepped down, a process that is inherently inefficient. Maximising the efficiency of converting large AC voltages to more useable DC voltages, particularly for appliances connected directly to the main AC power supply, is an area with scope for improvement.

Low efficient diode bridge

One of the most basic elements in this area of power electronics is the diode bridge, used extensively to provide full-wave rectification of an AC voltage to something that begins to resemble a DC supply. Further smoothing and filtering using resistor, capacitor and inductor networks normally follows.

Diodes are technically active devices, which are created through forming a P-N junction in a semiconductor material. However, they miss the control element found in other, more sophisticated active devices such as silicon controller rectifiers or even simple transistors. Standard diodes exhibit a forward bias voltage drop of around 0.7V all the time they are conducting, which in the configuration of a full-wave rectifier represents inefficiency. It also represents a form of power dissipation and, in high current applications, that can become significant, in terms of the heat dissipated and power used. Another characteristic of the venerable full-wave input bridge is that there are always two diodes conducting at any time, effectively exacerbating the power dissipation issue.

Despite its inherent weaknesses, in low load applications this topology still offers a cost-effective solution. It is also used extensively in high power applications and is probably on the increase. For instance, AC induction motors are now being replaced with DC motors and they will likely implement a diode bridge to provide the voltage conversion. In this case, the power penalties are clearer.

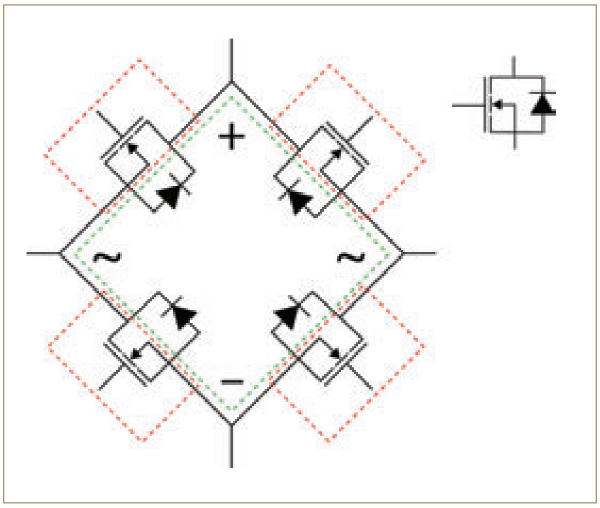

Figure 1: **A bridge structure using four FETs instead of diodes reduces power dissipation significantly**

More efficient synchronous rectification

Using the parasitic diode present in all MOSFETs, this problem can be addressed more efficiently. By creating a bridge structure using four FETs instead of diodes, as shown in Figure 1, the power dissipation exhibited using diodes can be avoided.

The synchronous rectification technique works by reducing the amount of time during any half-cycle that the body diodes in the transistors are conducting, by turning the transistor on for the majority of the half-cycle. When the transistor is on, the body diode is bypassed, drastically reducing the power that would be lost if it were conducting for the entire half-cycle.

In operation, as current starts to flow through the FET's body-diode during the start of a half-cycle in the AC supply, a negative voltage is generated across the transistor's drain and source terminals. By detecting this voltage drop the control circuit can turn on the FET, thereby reducing the power dissipated in the

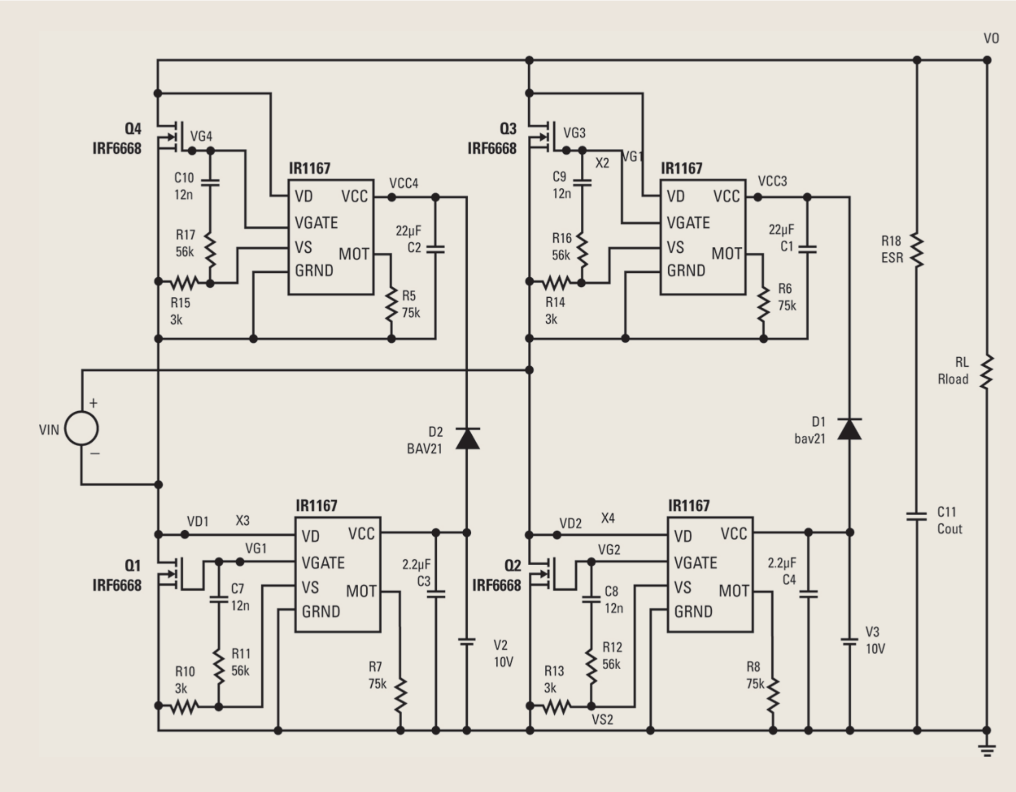

Figure 2: Discrete solution to implement synchronous rectification up to a maximum of 200V

device. The lower the $R_{DS(on)}$ of the transistors, the more effective the solution.

Up to 600V

The effectiveness of the technique depends largely on two elements; the FETs used and the accuracy of the control circuit. International Rectifier's synchronous rectification devices, the IRF1166 and IRF1167, were developed to provide a simple, discrete solution to implementing this control up to a maximum of 200V, as shown in Figure 2. This is a similar configuration to using four FETs to drive a brushless DC motor and, as in that application, it is important to ensure that the FETs switch on and off at the right time to avoid short-circuits. This is a factor of how effectively the control circuit senses the negative voltage generated across the FET as the current starts to flow through it, which happens as the AC voltage increases from 0V.

Another challenge in this implementation is ensuring the comparator in the control IC is capable of withstanding the high supply voltages, while still detecting the small reverse bias voltage across the body-diode. This has been achieved through Gen 5 HVIC technology, which integrates precision low voltage functions in a high voltage device using isolation barriers.

For maximum benefit, the FET must continue conducting until the half-cycle voltage returns to 0V or as close as possible without crossover. The danger here is that the relatively slow changes in voltage/current could cause the control circuit to misinterpret those small changes as the trailing or leading edge of the current or next cycle respectively. Until the current is high enough to cause a definite and detectable voltage drop, the circuit could repeatedly turn the FET on and off for a short time during crossover. This is most likely to occur in a circuit with a resistive load, where the rate of change in current is slower than, for example, a capacitive load.

The solution to this is to include an RC network, bootstrap capacitors and two bootstrap diodes in the control circuit. This injects additional current during the 0V range to ensure the threshold voltage is effectively breached long enough for the voltage drop across the body diode to pass through the uncertainty range.

In a single IC implementation, for voltages up to 600V, the bootstrap diodes

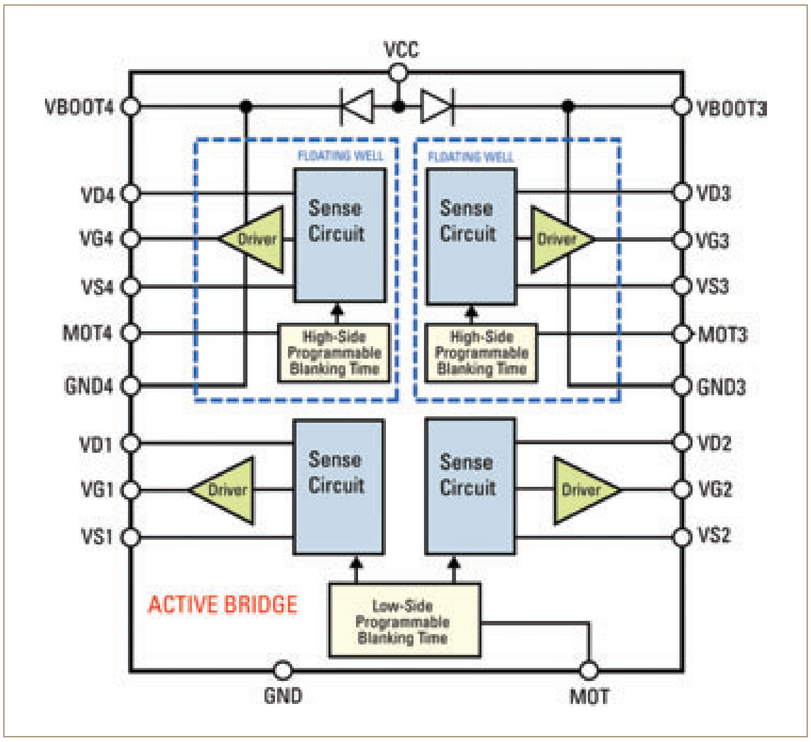

Figure 3: Integrated Active Bridge Controller for voltages up to 600V

could be integrated, while the RC network would likely be replaced with dedicated configurable blanking time blocks for each driver section, to allow different FETs to be accommodated. It is also possible to integrate the FETs, bootstrap capacitors and control functions in a single device, forming a direct replacement for existing diode based full-wave bridge rectifiers. This could provide not only significant power savings but also a substantial reduction in PCB space. Figure 3 shows how this integrated Active Bridge controller may be realised. Additionally a prototype using four IRAC-D2 daughter cards has been realised.

Great efficiency gains

To verify the effectiveness we compared two active bridge designs, at different input voltages of 100V and 40V and different output power, against standard schottky-diode bridge solutions. Figures 4 and 5 show the results obtained. For the 40V system we used 4x IRF6613 (DirectFet medium Can) compared with 4 x SS34 in SMC package; for the 100V instead we used 4x IRF6644 (DirectFet medium Can) against 4x MBR10H100 in TO263 package.

In the case of Figure 4, the amazing result is the 5.5% gain in efficiency at 20V input and about 50W output; the reason is the higher current flowing into the FETs showing much lower dropout than a diode.

At increasing input voltage and decreasing output current, the efficiency advantage drops to a still good 2 to 3%. The three curves are limited in power to limit the peak current into the devices to an acceptable operating level compared to their rated I_d and I_f. In Figure 5, the efficiency gain shows the same trend: at 60V and 250W output the current is much higher and the gain is exceeding 2%; at 100V this efficiency gain drops to about 1.1 to 1.3% depending on the load.

This last case seems to be less appealing in the balance of benefits and cost. We have to remember, however, that the four IRF6644s are much smaller than the comparing diodes in TO263: each DirectFet is about 80% smaller in area and 95% in volume than the diodes. This allows a much smaller solution and higher power density, often eliminating the need for a bulky heatsink.

Conclusion

Using SO8 FETs or better DirectFETs in an input active bridge configuration (with synchronous rectification control), is the way to increase efficiency and power density whilst reducing or eliminating the need for an heatsink. As shown from the graphs, efficiency improvement is quite noticeable and the benefits may be different according to the output power. If the output voltage is high, the efficiency increase may not be very important, especially if delivering kilowatts, but then the much lower power dissipation across the bridge allows for smaller and cooler solutions. If the output voltage is low, efficiency becomes the predominant difference, also for low current outputs.

Figure 4: Efficiency results at low voltage input

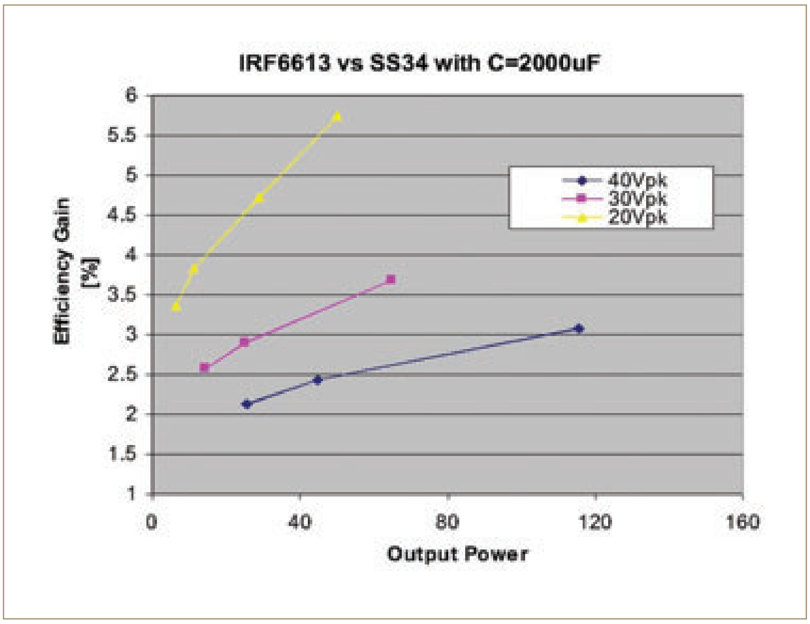

Figure 5: Efficiency results at medium voltage input