# Optimising Power Design Through MOSFET Efficiency and Integration

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## Choosing advanced MOSFET technologies for enhanced efficiency through improved performance of intrinsic Diode

MOSFETs and fast recovery diodes are fundamental elements of power switching applications ranging from photovoltaic inverters to HID lamp ballasts and power supplies for telecoms and servers. Designers of these applications are under pressure to continually improve performance at the same time as reducing board real estate and ensuring reliable operation.

Take, for example, photovoltaic cells used in solar panels. As this market grows and matures there is an increasing demand for more compact and more efficient electronics so that every possible milliWatt of energy harvested from the sun reaches the load. Inverters are an essential part of every solar energy generation system. Photovoltaic inverters convert the DC current produced by an array of photovoltaic cells to AC at local line voltage and frequency, ready to be fed into the grid or used to power an off-grid network. Micro-inverters that connect to just one panel each are also available – ensuring that reduced output from any panel (perhaps because of shade or snow) doesn't disproportionately affect the output of the total array. Inverter designers often face the seemingly conflicting requirements of improving performance and minimising losses whilst compacting form factor and ensuring reliability. Careful selection of the appropriate MOSFET technologies can deliver significant advantages in all these areas. MOSFETs and recovery diodes are also important for telecom and server power supplies with full bridge or zero voltage switching/phase shift topologies; full bridge motor control systems; uninterruptible power supplies; and ballasts for high intensity discharge (HID) lamps.

## Power switches

Power MOSFETs are typically the preferred switching technology for all of these designs because they offer a simple-to-drive option that can be switched efficiently at high voltages and at high frequencies. And in most of these applications a rating of 600V is typically used to ensure enough 'headroom' for the safe handling of high voltage transients.

MOSFETs can contribute to overall efficiency by minimising losses, broadly split into conduction losses and switching losses. A low MOSFET on-resistance (RDS(ON)) minimises conduction losses. On-resistance-area (RDS(ON)*A) is one of the figures of merit for MOSFETs; if RDS(ON)*A can be reduced, it means a smaller RDS(ON) device can be fitted into the same package size, improving efficiency. A MOSFET's switching losses are mainly related to its parasitic capacitances, so minimising these will make switching more efficient. Even small increases in overall efficiency may mean a smaller inverter can be selected for a given application.

Another important factor to consider is the MOSFET's gate charge, QG, which indicates the energy required to switch the device. If QG is low, higher switching frequencies can be used, minimising the size of some of the external filtering components. Losses are also reduced in the gate-driver circuitry. However, low QG devices tend to have higher RDS(ON); for this reason, the figure of merit RDS(ON)*QG is often quoted.

MOSFET reliability is also a very important consideration in a system that is expected to last for much longer than the typical lifetime of a consumer product. Photovoltaic inverters or industrial motor control systems, for example, may be expected to last for 10, 15, or 20 years (or more). Furthermore, there may be requirements for the devices to maintain good performance at extreme temperatures – for example in harsh industrial environments or to address the need to maintain a stable output in all weather conditions.

## Companion devices

One thing that the applications mentioned above have in common is the need for companion diodes to be used in conjunction with the MOSFET. Each power MOSFET in an inverter, for example, requires a diode to protect it from being damaged by the reverse current from an inductive load. Because the MOSFETs switch at high frequency, fast recovery diodes (FRDs) are used; their properties can also help increase efficiency. Faster FRD reverse recovery times (trr) help to minimise switching losses. In addition, choosing devices in which the FRD is integrated into the body of the MOSFET can help to reduce component count, save space, simplify design and streamline inventory.

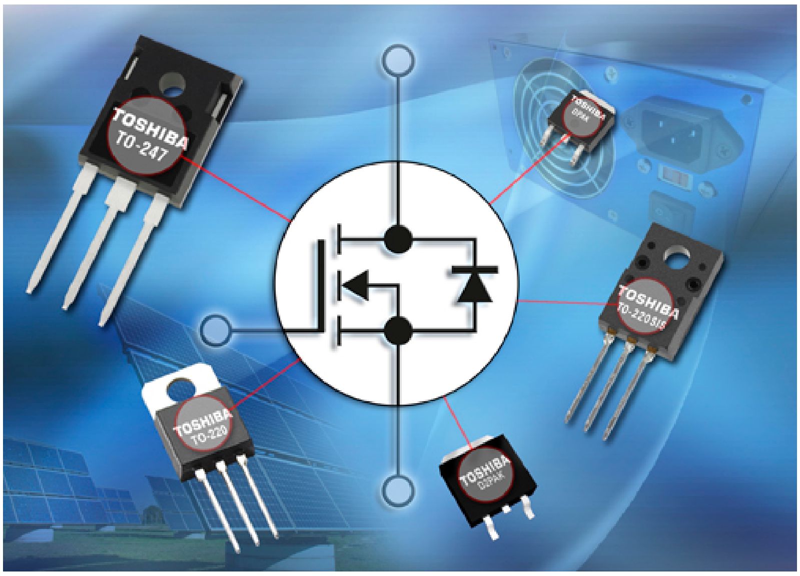


Figure 1 – MOSFET package options using FRD

A variety of MOSFETs with integrated FRDs are now available, in a range of different package options (Figure 1). As an example, Toshiba's TK16A60W5 15.8A-rated power MOSFET integrates MOSFET and FRD in a TO-220SIS package. The trr of the device is just 100ns (compared to 280ns of a standard version) and RDS(ON) is just 0.23Ω. Other examples include the high current TK31N60W5 and TK39N60W5 MOSFETs in TO-247 packaging. These are rated for maximum currents of 30.8A and 38.8A respectively. Maximum respective RDS(ON) ratings (at VGS = 10V) are 0.099Ω and 0.074Ω, with trr characteristics of 135ns and 150ns.

In addition to the improvements in conduction losses and switching losses, integration has also meant that the devices can maintain a good trr at high temperatures. Figure 2 shows test results for the TK16A60W5 device compared with a typical competing device with the same trr at a channel temperature of 25°C.

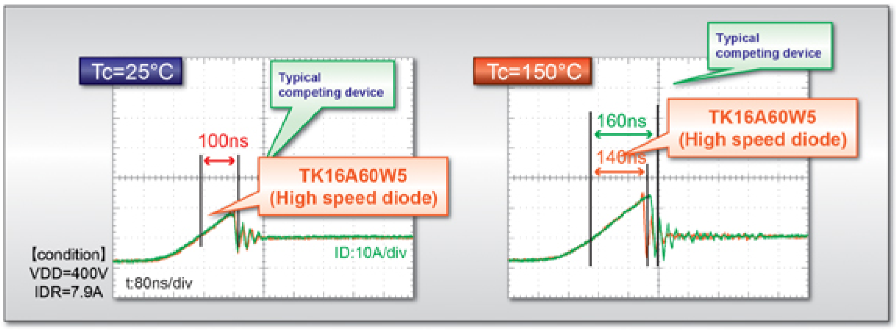


Figure 2 – Reverse recovery time versus temperature

At 150°C, trr for the TK16A60W5 increased by 40%, whereas trr for the competing device increased by 60%.

## Fourth generation

So, how has this integration been achieved, and why does this result in improved specifications?

The underlying technology used in these devices is DTMOS IV, Toshiba's fourth generation superjunction technology. In a superjunction MOSFET, the N-region is heavily doped so that its resistivity can be taken beyond the silicon limit. This N-region is bounded by two pillars of P-type material to allow a very high breakdown voltage, as shown in Figure 3.

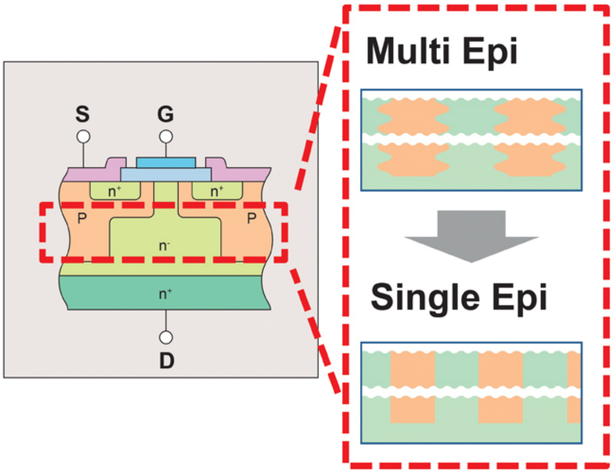


Figure 3 – DTMOS IV superjunction process

This combination of very low $R_{DS(ON)}$*A and high breakdown voltage makes the technology ideally suited to power MOSFETs since space savings can be implemented without power loss penalties.

DTMOS IV uses a process called deep trench filling, which allows the pitch of the columns to be narrowed and their aspect ratio to be increased. Further, deep trench filling allows the P-type material to be deposited into etched trenches in a single epitaxial process. Previously, multiple epitaxial layers were required to form pillars that were this tall and thin. Using just one epitaxial process can produce a better, more uniform pillar shape (as seen in Figure 3), shorten production lead times, save cost, and allow for easier geometry shrinking in the future. What's more, the more uniform pillar shape helps the device maintain its $R_{DS(ON)}$ and $t_{rr}$ characteristics at temperatures up to 150°C.

The narrow trench pitch produced by DTMOS IV reduces $R_{DS(ON)}$*A by 30% compared to DTMOS III. Devices with the same die area can therefore reduce their $R_{DS(ON)}$ by 30%. Alternatively, if similar $R_{DS(ON)}$ characteristics are acceptable, the MOSFET's die area can be reduced by 30%. A compromise between the two has seen $R_{DS(ON)}$ decrease while freeing up space for a fast recovery diode to be included in the same overall package size. Integrating the diode into the MOSFET package means the $t_{rr}$ of the MOSFET-diode combination device is reduced significantly.

Narrowing the pitch of the P-type pillars also reduces $Q_G$. Low $Q_G$ allows the devices to operate at high switching frequencies and reduces losses in the gate-drive circuitry. However, along with the $R_{DS(ON)}$ tradeoff mentioned above, if $Q_G$ is too low, very high $dV_{DS}/dt$ can encourage ringing, along with its undesirable side effect, electromagnetic interference (EMI). Toshiba's devices are therefore carefully optimised to maintain the same performance and $R_{DS(ON)}$*$Q_G$ figures as the previous generation of MOSFETs.

Reducing the physical size of the MOSFET die as outlined above has a positive effect on output capacitance ($C_{OSS}$), which helps reduce switching losses and maintain efficiency even in partial load situations. $C_{OSS}$ has actually been reduced by 12% in the latest family of devices. Again, this contributes to the devices' ability to be switched at high frequencies.

## Summary

Careful selection of power MOSFET technologies can make a big difference to the efficiency and the performance of a target system. The latest developments in semiconductor technology have allowed a fast recovery diode to be integrated into the body of the MOSFET, while maintaining the package size of the previous MOSFET, resulting in space savings and reduced component counts. The DTMOS IV process, based on deep trench filling technology, reduces the amount of process steps, saving cost and improving performance of the superjunction MOSFETs at the same time.

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