Smart Power Switches for Automobile and Industrial Applications

Dr. Alfons Graf, Infineon Technologies AG, Munich

INTRODUCTION

Semiconductors are changing the world, and this includes automobile and industrial applications. An increasing number of functions are now controlled and monitored by electronic algorithms. To this end, menu-driven inputs are detected, sensors are evaluated and data is exchanged with other systems via wirelink and wireless communication interfaces. Ultimately, however, the electrical actuator provided, a motor, magnet, valve or lamp, is activated by a power switch. The emerging long-term objective, particularly in automobile applications, is that anything that in any way moves, slides, rotates, pumps, blows, heats, cools or vibrates will be selectively activated by power semiconductors as required.

POWER SEMICONDUCTORS MAKE IDEAL SWITCHES

Smart power switches perform the above tasks in an exemplary manner. This applies not only to the switching operation per se, which could also be implemented e.g. by a relay or manually actuated switch, but also to performing fuse functions, such as protecting lines against short-circuits, sensing the current flowing at any given time, load diagnostics as well as load control tailored to requirements by means of pulse width modulation (PWM).

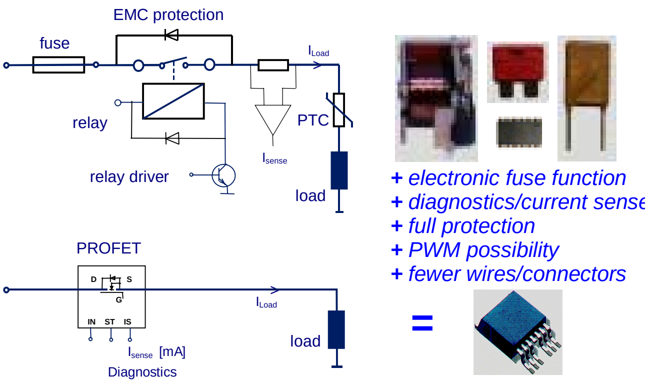


Fig. 1: Application and functionality of a smart power switch compared to the discrete solution

The necessary suppression of electromagnetic interference (EMC) during the switching process should also not be forgotten.

Fig. 1 shows a comparison of a circuit arrangement for inductive load switching, protection and diagnostics comprising, on the one hand, conventional components and, on the other, designed around a smart power switch. This article will now focus in somewhat greater detail on the functions that a smart power switch can provide in addition to the purely switching function.

application	*supply*	V_{AZ}
12V automotive el. power net power switching	generator	>45/60V
42V automotive el. power net starter/generator, power switching	generator	>60/70V
24V truck el. power net power switching	generator	>65V
80V e.g. local high voltage fuel direct injection	DC/DC conv.	>80V
60-80V active zener clamp fast inductance de-excitation	--	>60/80V
12/24/48V industry application power switching	power supply	>65V

Fig. 2: Different dielectric strength requirements (minimum active Zener clamping) of semiconductor switches

Fig. 2 shows typical dielectric strength requirements placed on power semiconductors in automobile and industrial applications. Although low-voltage electronics of less than 100V are generally involved, when using CMOS-related technologies these are also commonly referred to as "high-voltage technologies". As a rule, voltages of 12, 24, 42 or 48VDC are present. However, the type of voltage generation and storage means that the power semiconductors used must have a significantly higher dielectric strength. These devices are therefore mainly equipped with overvoltage protection functions, such as active Zener clamping, in order to limit transient inductive voltage peaks. For the permitted dynamic overshoot of the voltage limit values, the energy content of the spikes is critical, whereas under steady-state conditions the limit values must never be exceeded.

In the case of switches for 12V applications, this overvoltage protection is normally at around 45V. In the case of 24V and 42V systems, as well as in industrial applications, the overvoltage protection is 60V or more. Special applications such as rapid opening and closing of e.g. injection valves require an even higher dielectric strength of approx. 80V.

DESIGN DETERMINES PRICE

Power semiconductors are available in a wide variety of designs. For higher currents, vertical DMOS technology or CDMOS and BCDMOS technologies with logic capability (designated OptiMOS, Smart5 and SPT5 at Infineon) are primarily used nowadays. The state-of-the-art approach is a monolithic solution which integrates the power transistor and the control and diagnostic electronics on a single chip. This saves costs compared to using discrete components, and also has clear advantages in terms of reliability, system security and footprint.

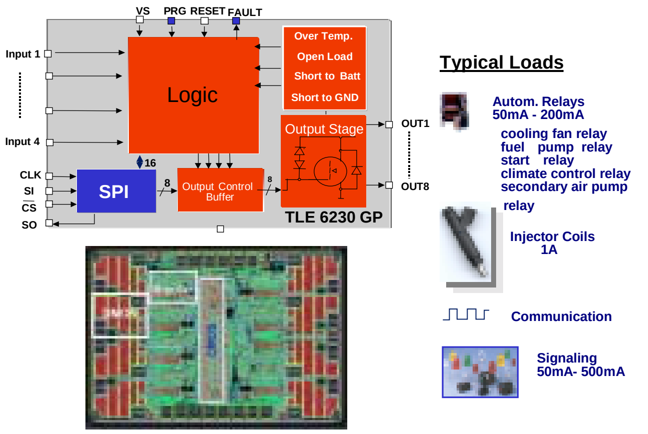


Fig. 3: Automobile application: monolithically integrated 8-channel switch with full protection, full diagnostics and SPI interface

Fig. 3 shows an example of a fully integrated smart multichannel switch for automobile applications. The outputs are capable of driving typical loads in engine management, such as relays, injection valves and signal lamps, or even of being misused as communication drivers for longer lines. In addition to every conceivable protection function, the device offers parallel and serial interfaces (known as SPI) both for input signals and for diagnostic outputs. The eight channels and the logic section are clearly visible on the chip photo. Both bipolar, CMOS and DMOS components are used on the semiconductor for the various tasks.

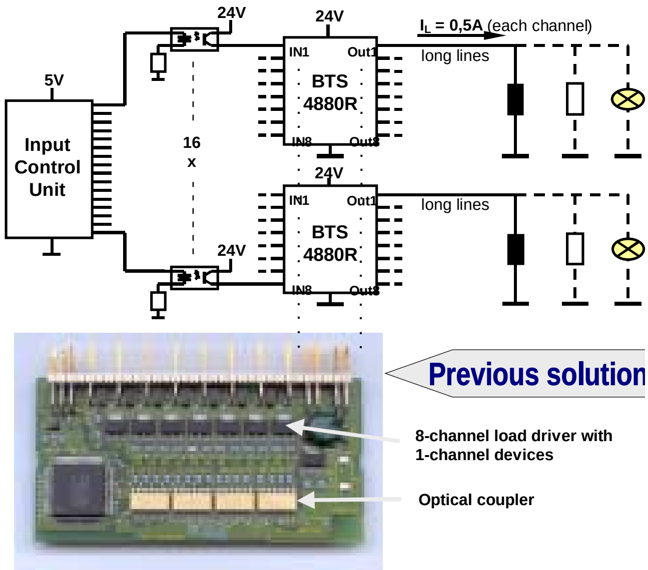


Fig. 4: Industrial application: monolithically integrated 8-channel switch with full protection

Another example in Fig. 4 likewise shows an 8-channel switch, optimized for industrial applications. Apart from the different voltage requirements and different noise levels, the power switches for industrial applications differ little from those used in automobile applications. The common feature of many industrial applications is that they have electrical isolation, generally in the form of an optocoupler, at the input and are generally required to switch an unknown load (resistive, inductive, capacitive) via, in some cases, very long lines at the output. The advantage of using an 8- or 16-channel switch can be assessed from the board with single-channel switches illustrated. In the long term, the input-side electrical isolation (nowadays optocoupler) can also be incorporated in the smart multichannel switch.

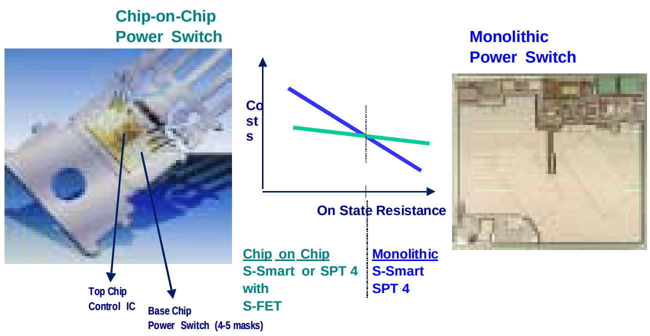


Fig. 5: Distinguishing between the preferred designs of monolithic and chip-on-chip power switches

This monolithic technology has become established and proved its worth for single and multiple switches up to approx. 5A continuous current. The higher the currents, the larger the power switch and its surface area need to be compared to the logic portion. Fig. 5 shows, on the right-hand side, a typical, still “healthy” area ratio of this kind. Here, the entire switch has to be manufactured in complex smart technology using a large number of masks, which invariably means high costs. In order nevertheless to implement affordable solutions for high-performance, low-resistance switches, an obvious approach is to realize the power section in inexpensive OptiMOS technology and the logic portion in more complex Smart5 technology, either adjacently (chip-by-chip) or vertically (chip-on-chip). Although this means slightly higher assembly costs, this disadvantage is soon more than compensated by the lower silicon costs. The crossover point is of course greatly technology-dependent, and is constantly being driven down further as each new technology emerges. It is currently at around 20mΩ or less. Mounting the chips vertically additionally provides chip area advantages, allowing high-performance switches to be implemented in smaller and therefore more cost-effective semiconductor packages. This again reduces the production costs and increases their attractiveness.

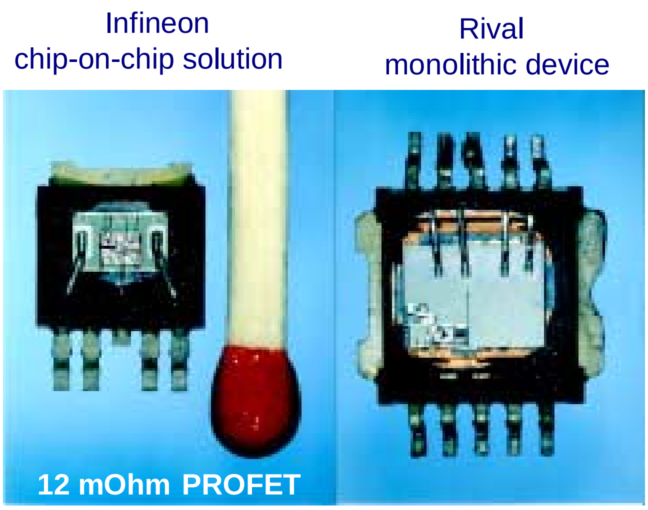


Fig. 6: Chip area and package comparison of a chip-on-chip product with a comparable monolithic product

Fig. 6 shows these advantages to good effect in the case of an actual product with 12mΩ compared to a monolithic rival product with virtually identical electrical characteristics.

Fig. 7 impressively demonstrates how this technology has enabled package size and on-state resistance as well as the costs of a smart power switch to be reduced over the last 10 years. In 1990, a smart 12mΩ semiconductor switch in a Dpak package was inconceivable, but today it is reality.

To the question of the reliability of a chip-on-chip device, my reply would be as follows: Some 15 years' experience and several hundred million components sold for automobile applications, one of the severest tests of all, speak for themselves. Nor is chip supply in any way ruled out by this assembly technology. Customers can just as easily use the chipset employed for a chip-on-chip device on their hybrid modules, mounted adjacently for the simplest.

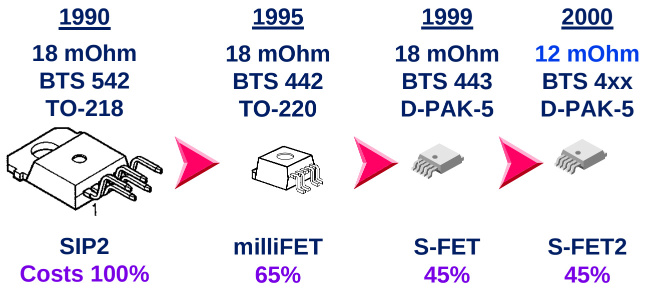


Fig. 7: Evolution of chip-on-chip high-current switches

Figs. 8 to 10 show other variations on this assembly technology. Fig. 8 illustrates a smart IGBT optimized for a vehicle ignition system. The unit consists of a 400V or 600V IGBT optimized for this application and, mounted on top of it, a control and diagnostic chip manufactured using 90V SPT4 technology. The resulting highly compact smart device with full overtemperature and short-circuit protection and controllable by means of logic levels will even react automatically to faults in the ignition circuit and also report them.

Fig. 9 shows the chip photo of the smart ignition IGBT in chip-on-chip technology

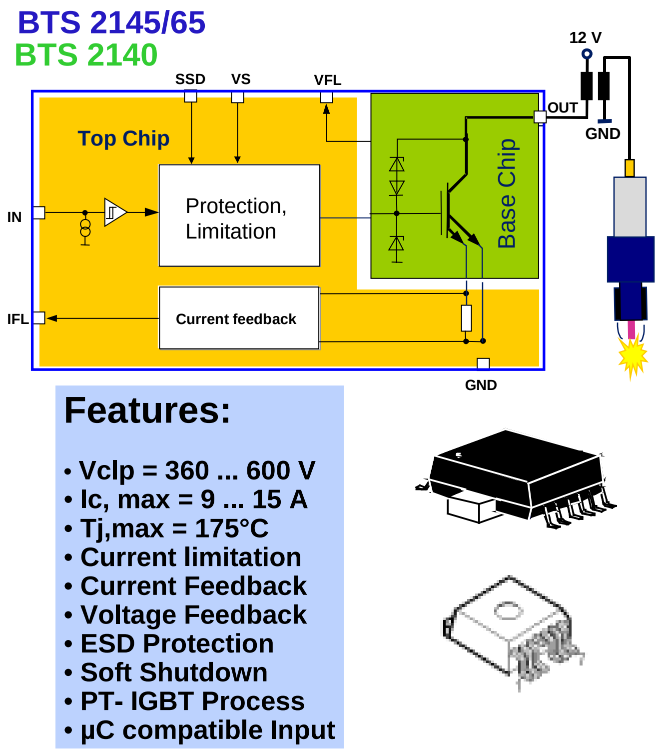


Fig. 8: Smart ignition IGBT with full protection and diagnostics, realized in chip-on-chip technology

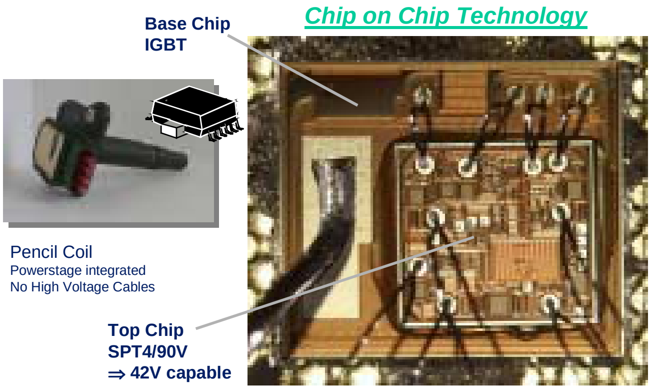


Fig. 9: Chip photo of the smart ignition IGBT in chip-on-chip technology

Fig. 10 shows a further development of multichip assembly technology in which e.g. four chips of different semiconductor technologies are mounted side by side on electrically isolated islands to form a semiconductor full-bridge for bidirectional control of a DC motor. Here too, despite complex assembly, a clear cost and surface area advantage over a monolithic solution is obtained by using technologies optimized to suit requirements. In this case, standard transistors in OptiMOS technology are employed for the lowside transistors and smart power transistors in Smart5 technology for the highside transistors. These can then also simultaneously provide the control, protection and diagnostic functions for the bridge as a whole. Electrical isolation of the individual components need not be provided at great cost in the silicon, but simply and inexpensively by the mutually isolated metal islands.

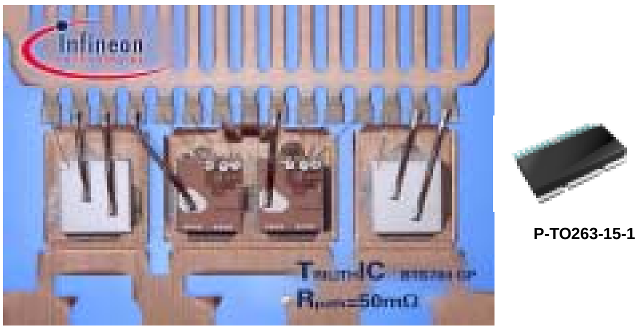


Fig. 10: Smart semiconductor full-bridge with full protection and diagnostics, realized in chip-by-chip technology

This example once again impressively demonstrates that the costs of a device are determined not only by the silicon itself, but also to a large extent by the assembly technology and the partitioning. Full integration in silicon is an elegant and future-oriented technology, although not always the most cost-effective in many applications. Multichip mounting will continue to be attractive in the future. To enable unusual requirements also to be incorporated in a package, Infineon even uses multichip assembly technologies such as chip-on-chip-on-chip (three chips, one on top of the other) or chip-on-chip-by-chip (two chips side-by-side and another chip on top).

SMART POWER SWITCHES CAN DO MORE THAN JUST SWITCH

As mentioned at the outset, although load switching is certainly the main function of smart power switches, they also have to perform protection and diagnostic functions. However, they are above all the enablers when it comes to modifying systems in order to increase functionality and even reduce costs.

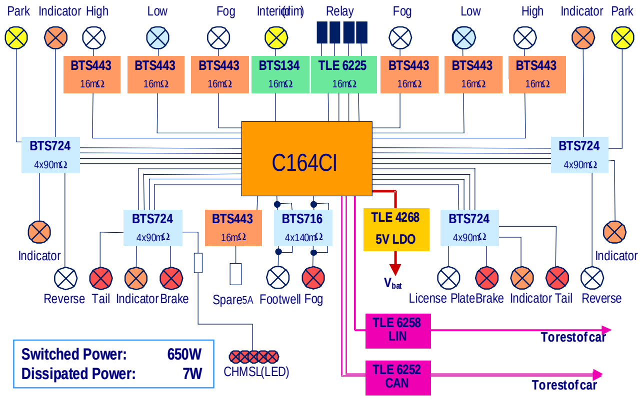


Fig. 11: Innovative vehicle light module

As an example, Fig. 11 shows an innovative light module for switching and monitoring all the external lamps in an automobile. The switching commands are issued by a central microcontroller which is linked to the main vehicle computer via communication devices. The single- and multichannel power switches have been dimensioned so that the module can be constructed using standard FR4 circuit board material and accommodated in a plastic package. To allow the module to be mounted in the dashboard, power dissipation likewise had to be minimized, thereby saving cooling costs and simplifying the wiring. On the other hand, the power semiconductors were generously dimensioned to achieve this minimal dissipation. We call this strategy, which has now been successfully implemented by OEMs and suppliers, “silicon instead of heatsink”.

In addition to lamp switching per se, the module has the following functions:

- Providing flasher operation
- End-of-tape and factory programming for country variants (daytime driving light) and customer requirements (interior lighting dim time)
- Switching and diagnostics for optional equipment: headlamp bulb or ballast for Xenon lamps
- Protecting load lines against overload and short circuit

- Reducing fuses and fuse holders at their exposed mounting locations
- Reducing cables and connectors
- Failure diagnostics for lamps and checking their correct power ratings
- Extended service life through power regulation and lamp pre-heating using PWM
- Fault management by activating other available lamps with required brightness
- Reducing electromagnetic radiation by means of optimized switching edges and time-staggered switching
- System security by means of hard-wired fallback levels in the event of software and communication problems (limp home) and also by means of duplicated and crosslinked supply concept.
- Interface to an optional trailer lamp module

Finally, using power semiconductors also reduces the weight of these modules, often with lower system costs. One thing is certain, however: with this system the end customer will no longer have to suffer the annoyance of a flat battery due to a light having been accidentally left on. In addition, he can also enjoy slightly reduced fuel consumption due to the power dissipation having been reduced by 15W compared to the previous model.

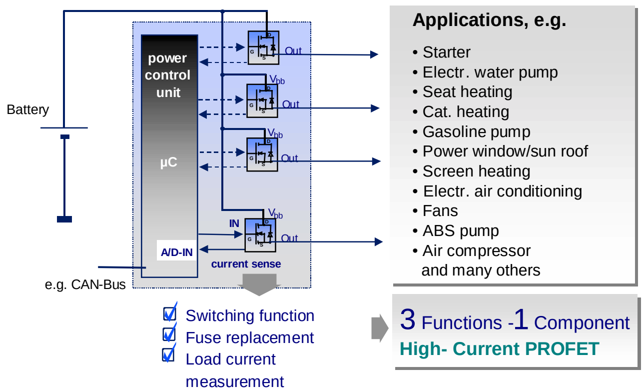


Fig. 12: Intelligent switching and power distribution unit incorporating smart power switches

As a result of the increased performance of the new semiconductor technologies, smart power switches are increasingly making inroads into high-current areas which have hitherto been served by relays or else not implemented because no technical solutions were available. Such applications include the switching and control of electric heaters, large motors or electrical protection and distribution units. For example, Fig. 12 shows a switching and distribution unit of this kind which can also simultaneously perform a power management function for optimum distribution of limited power and energy in the vehicle.

Semiconductors have also successfully carved themselves a niche in extreme high-current applications. The so-called smart battery terminal is the best example of this. This constitutes a switching and protection element between the battery and the rest of the vehicle electrical system, handling starter or load currents of between 100A and 200A as well as starter peak currents of more than 1000A.

Also in the next example, although switching is the basic function, other system advantages flow from the additional possibilities of smart power semiconductors.

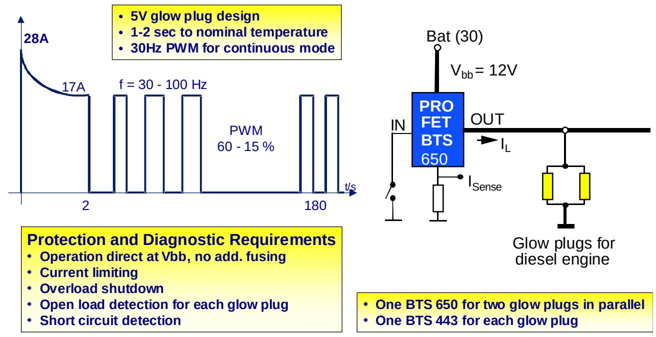


Fig. 13: Rapid heating and temperature control of diesel glow plugs using PWM

Modern diesel glow plugs are not only switched on and off. Due to the dimensioning of the glow plug to handle higher currents with simultaneously reduced thermal capacity, the plug heats up very quickly in approx. 1-2 seconds. In order to avoid burnout, the temperature response is determined by measuring the current response and power reduction is performed using PWM (Fig. 13). The elegant solution of switching high currents and then performing power reduction by PWM is the only way of achieving the system advantage of a very short starting operation. Other proposed solutions using a switching relay and self-regulating glow plug look very expensive in comparison.

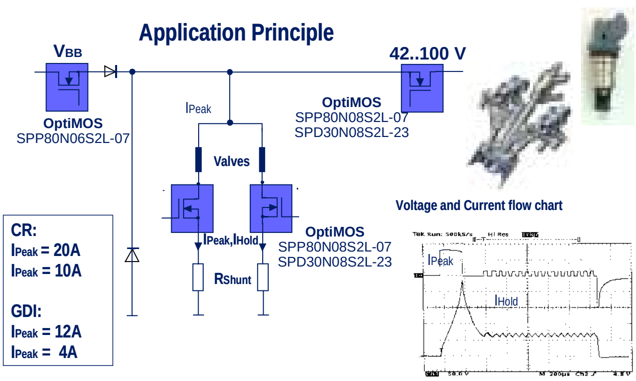


Fig. 14: Peak-and-hold control for electromagnetically actuated direct injection valves

A similar concept is also used for peak-and-hold control of electromagnetically actuated direct injection valves (see Fig. 14). Once again, in order to achieve highly dynamic valve opening operations, a high voltage or high current is initially applied to the valve to open it quickly. Then, to hold the valve open, the transition to a lower current value is performed by PWM.

Another typical application of PWM is direct operation of 12V components at a higher voltage, e.g. 42V. This requirement exists because driving many loads at a lower voltage has advantages, e.g. glow plugs have a longer service life, and also many components are difficult to convert to a higher voltage (winding procedure in the case of small motors). Due to this kind of operation, voltage conversion or power matching is therefore performed directly by the switching element, this obviating the need for a separate step-down converter.

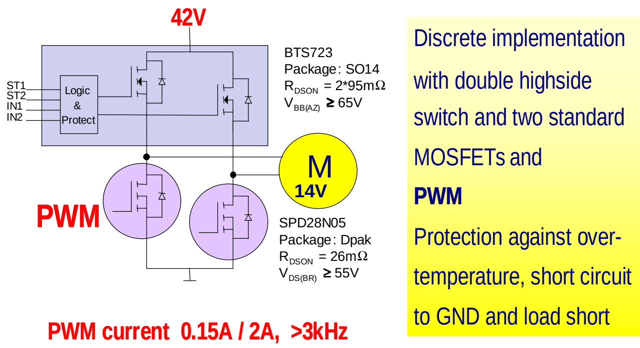


Fig. 15: Operation of a 12V door lock motor directly at 42V using PWM

Fig. 15 shows a small 12V DC motor, in this case a vehicle door lock motor, operated directly at 42V. For this purpose, the semiconductor bridge responsible for motor direction reversal must be beefed up for switching higher frequencies of e.g. 20kHz. The door lock motor and the locking mechanism can be used without modification, and even the dynamic behavior of the lock is virtually unchanged. The filter complexity for reducing the electromagnetic emissions is not fundamentally more difficult or costly than is necessary in any case for steady-state operation of this brush motor and nowadays provided as standard in the motor. In addition, elimination of the thermal cutout and overvoltage limiting in the motor can also be considered, as this function should be performed by the semiconductor.

Another very important additional function of smart power semiconductors is to protect lines against short circuit and overload. Once again, this is not merely a question of assuming the present fuse function alone. Power semiconductors can take this in their stride, as evidenced by innumerable examples of applications that have stood the test of time.

As well as this purely switching function, semiconductor switches are also capable of providing other electrically variable fuse characteristics. Built-in current sensing allows the user initially to set virtually any fuse characteristic and also adapt the timing to suit changing conditions. For example, higher peak currents can be permitted for switching on a load, but must then no longer occur after a certain operating time. Alternatively, the characteristic can be such that a slow-blowing fuse behavior can be set for the rated current or a transient overload (starting current), whereas a very fast-acting response can be provided in the event of a short circuit. An intelligent cutout of this kind can then even be used by several loads in parallel, with the fuse characteristic adapted to suit the number of currently active loads.

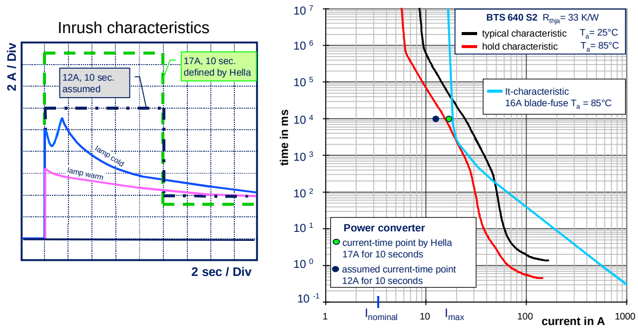


Fig. 16: Switching and fuse protection of an electronic ballast for Xenon lamps

Fig. 16 illustrates the use of a smart power switch as a switch and fuse cutout for the electronic ballast of a Xenon lamp. It can be seen that a 16A slow-blow fuse is required for the inrush currents specified by the manufacturer, although the continuous current is only approx. 3A. The fuse used therefore has quite significant weaknesses in the event of overload currents in the range 10-15A, and it also acts very slowly if a short circuit occurs. An intelligent 30mΩ power switch can provide a virtually perfect solution to this problem. On the one hand, it can handle the required inrush peaks by virtue of its slow-acting response in this range, and, on the other, it is capable of selectively disconnecting static overloads above 6-8A, and with current sensing is even more sensitive. Even in the event of a short circuit with very high currents, this integrated cutout reacts one to two powers of ten quicker than the fuse, which in turn has a very positive effect on the stress placed on lines, conductor tracks and connectors.

OUTLOOK

Today's smart power switches provide the optimum solution for use in the voltage range between 5V and 60V. The main drawback currently is that the often very high overvoltage withstand capability compared to the rated voltage and the operating requirements for polarity reversal result in higher costs than would arise from switching at rated voltage on its own. Efforts to specify the new 42V automobile electrical system such that the max. 58V overvoltage withstand capability has been limited to what is technically necessary is therefore a very welcome development. Also, the -2V polarity reversal protection with a maximum duration of 100ms offers optimum conditions for using power semiconductors. It can generally be stated that the silicon employed particularly for the power switches designed for 42V is optimally used, and this must necessarily result in lower costs from this side. It is also very welcome that the new voltage requirements in the 42V range coincide very closely with the voltage requirements for industrial applications and 24V truck applications (compare also Fig. 2). By gearing the semiconductor devices to all three fields of application, quantities can be satisfactorily increased.

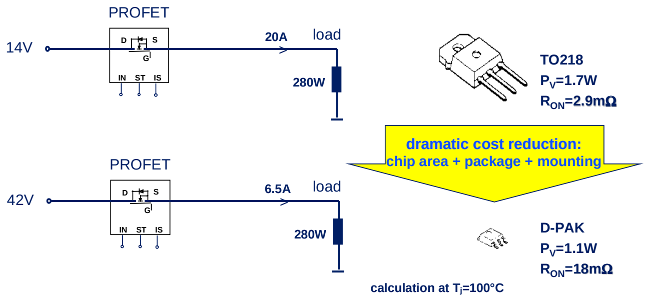


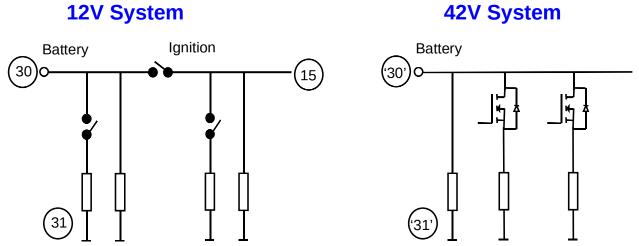
Fig. 17: Effects of a lower current at 42V on the size of power switches.

In addition, the higher the voltage, the lower the current to be switched, which means that the on-state characteristics of a semiconductor switch can be designed to provide a much higher resistance. For the transition from 14V to 42V, it can be shown that, assuming the same silicon size, i.e. approximate cost neutrality, the power dissipation can be reduced by a factor of 5-6 or that, assuming unchanged power dissipation, the necessary silicon area will shrink by the same factor of 5-6. Optimizations in the intervening period are of course highly probable, depending on whether the system costs can be reduced by lower semiconductor costs or lower costs for cooling measures.

If this smaller silicon area is then also housed in a smaller semiconductor package, this provides a further significant cost reduction for the finished power semiconductor. Fig. 17 shows two possible switch versions operating at 14V and 42V for a 280W load, e.g. a heated rear window. Whereas at 14V a relatively expensive switch with e.g. 2.9mΩ in a TO218 package is necessary, at 42V the same switching operation can be performed by a relatively inexpensive semiconductor switch with e.g. 18mΩ in a Dpak package and with simultaneously reduced power dissipation.

If these dramatic cost reductions are not always so clearly perceived at present, this is purely and simply because of the different volume scenarios between 12V and 42V components. All I can do here is urge greater courage in looking to the future and self-confidence in achieving one's objectives.

In conclusion, I would like to highlight a challenge posed by electrification of a battery-operated system, specifically at 42V.



Battery terminal designations	30 + 15 and 31	"30" and "31"
Battery size Wh e.g.	800 Wh	800 Wh
Battery V, Ah e.g.	12V, 66 Ah	36V, 22 Ah
Quiescent current per car	18 mA	6 mA
Quiescent current per module	300 µA	100 µA

Fig. 18: Change in architecture and associated increase in quiescent current requirements

Fig. 18 schematically illustrates a present-day 12V vehicle electrical system. We can see a main ignition switch with switched and unswitched loads on both sides of the ignition switch. Everything which is still connected to the battery (terminal 30) in the off state has a disadvantageous effect on the quiescent current.

Future predictions show that an increasing number, if not the overwhelming majority, of loads will be controlled by their own semiconductors. If this is the case, the switching contact of the ignition lock becomes increasingly irrelevant and can be simulated by a purely software function, i.e. the switches are informed whether the ignition is active or inactive at any given moment. However, this means that, even in the parked vehicle, a large number of potential quiescent current loads are connected to terminal 30, i.e. the number of quiescent current loads will rise dramatically compared to today.

At 42V there is now the added problem that, assuming the same size and therefore unchanged energy content, a 12V battery with e.g. 66Ah will only provide 22Ah at 42V. In order to preserve the vehicle's starting capability for a number of weeks, a permitted quiescent current of 5-8mA at 42V is therefore calculated for the entire vehicle. In other words, this means that the nowadays often specified quiescent current requirements of 300µA for each electronic module in the 12V vehicle will have to be lowered to 100µA per module when changing over to 42V. And this, it must be said, for considerably more loads. The semiconductor industry will have to meet this challenge.

Finally, a few more comments about future changes in smart power switches: First it should be noted that smart power switches increasingly are being designed as multichannel switches and therefore are also being implemented in surface-mount packages, a trend which is also discernible for low-resistance single-channel switches. In addition, the trend is also towards even more independent functionality of the power switches. Thus it is conceivable that e.g. a PWM signal will no longer be implemented by the microcontroller, but smart power switches will perform this function independently. The aim is not only to relieve the load on the microcontroller, but also to transfer, to the analog world of the smart power switches, functions which can only be implemented expensively in the digital world of the microcontroller.

GENERAL NOTE

This information specifies technical characteristics but does not guarantee them.

CONTACT ADDRESS

Dr. Alfons Graf, Infineon Technologies AG, Automotive Power Innovation, Munich.

alfons.graf@infineon.com.

Dr. Alfons Graf studied general electrical engineering and electrophysics at Munich Technical University, where, from 1985-1990, he also pursued research leading to a PhD in the field of MOS breakdown and laser scanning. In 1990 he began working for Siemens AG on the design, layout and testing of CMOS ASICs. After moving to power semiconductors in 1993, he first took over the definition and application of power switches, eventually heading up Technical Marketing for power semiconductors. Dr. Graf is now head of innovation and EMC activities for automotive power switches at Infineon Technologies AG.

Since 1995, Dr. Graf has been a permanent member of various international bodies promoting the introduction of the 42V automotive electrical system and is also working on the 42V standardization committee in FAKRA/VDE and ISO. He organized the 1st and 2nd International Congress on 42V PowerNet in 1999 and 2001.

REFERENCES

1) PROFET, Functional Description & Application Notes http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/prod_ov.jsp?oid=13852&cat_oid=-8171

2) Silizium statt Kühlkörper (Silicon instead of Heatsink), Dr. Alfons Graf, 15th Congress 'Elektronik im Kraftfahrzeug' (Automotive Electronics), Essen, 31 May –1 June 95, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/prod_cat.jsp?oid=-8171

3) Sense Highside Switch in Smart Power Technology takes over Fuse Function, Dr. A. Graf, Dr. A. Blessing, P. Sommer, A. Koroncai, Dr. J. Tihanyi, 7th International Congress Elektronik im Kraftfahrzeug (Automotive Electronics), Baden-Baden, 12-13 September 96, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/prod_ov.jsp?oid=13853&cat_oid=-8171

4) Intelligente Leistungshalbleiter für zukünftige Kfz-Bordnetze (Intelligent Power Semiconductors for Future Automotive Electrical Systems), Dr. A. Graf et al., 17th Congress 'Elektronik im Kraftfahrzeug' (Automotive Electronics), Munich, 3-4 June 97, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/sol_cat.jsp?oid=-8259

5) 4mOhm Smart-Power Highside Schalter mit Strom-Sense (4mOhm Smart Power Highside Switch with Current Sense), Dr. C. Xu, Dr. M. März, R. Sander, Dr. A. Graf, 17th Congress 'Elektronik im Kraftfahrzeug' (Automotive Electronics), Munich, 3-4 June 97, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/prod_ov.jsp?oid=13853&cat_oid=-8171

6) Smart IGBT for Advanced Ignition System, Claus Preuschoff, SAE 2001 World Congress, Detroit, 5-8 March 2001

7) Automotive Electrical Systems – The Power Electronics Market of the Future, John G. Kassakian, APEC 2000, http://auto.mit.edu/consortium/

8) Jump Starting and Charging Batteries with the New 42V PowerNet, Paul Nicastri et al., 1st International Congress on 42V PowerNet, 28-29 September 1999, Villach, http://auto.mit.edu/consortium/

9) Semiconductor Technologies and Switches for New Automotive Electrical Systems, Dr. A. Graf, EAEC European Automotive Congress, Barcelona; 30 June – 2 July 99 http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/sol_cat.jsp?oid=-8259

10) Sicherungsersatz mit Smart Leistungsschaltern (Replacing Fuses by Smart Power Switches), Dr. .A. Graf, H. Estl, 8th International Congress Elektronik im Kraftfahrzeug (Automotive Electronics), Baden-Baden, 8-9. October 98, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/sol_cat.jsp?oid=-8259

11) 42V PowerNet in Door Application, Dr. A. Graf, A. Pechlaner SAE 2000 World Congress, Detroit, 6-9 March 2000, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/sol_cat.jsp?oid=-8259

12) Driving Small Motors at 42V PowerNet, Dr. F. Klotz, Dr. A. Graf, SAE 2001 World Congress, Detroit, 5-8 March 2001, http://www.infineon.com/cgi/ecrm.dll/ecrm/scripts/sol_cat.jsp?oid=-8259

13) The New Automotive 42V PowerNet: Preparing for Mass Production, Proceedings of 2nd International Congress 42V, Dr. A. Graf et al., Ludwigsburg, 24-25 April 2001, Expert Verlag, ISBN 3-8169-1992-8