Special Subject Book Nov. 1999

TRILITHIC™
High Current Motor Driver

Meet the
Second Generation

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Power Semiconductors

Infineon technologies

Never stop thinking

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Contents

Introduction

New Components for DC Motor Control are Capturing the Market

The steady growth of electronics into the automotive sector, and into virtually every aspect of everyday life, is giving Power Integrated Circuits (PICs) ever greater importance for system optimization. New technologies are providing semiconductor replacements for an increasing number of electromechanical components such as switches or relays, and the trend towards higher current values has prompted the development of new driver devices.

A group of such devices may be used in reversible DC motor drives. For this application, it is essential that the supply voltage be able to be applied to the motor in both directions. As shown in **Figure 1**, this requires four switches: one switch to ground and one switch to the supply voltage for each motor terminal. Switches between the motor terminal and ground work as Low-Side Switches (LSS) and the switches between the motor terminal and supply voltage work as High-Side Switches (HSS).

Freewheeling diodes are connected in parallel with the switching transistors for active motor braking as well as for commutation of inductive loads. This arrangement is known as a Full-bridge or an H-bridge because of its topology, one branch of this circuit being known as a Half-bridge. Innovative technologies are making the solid-state H-bridges more prevalent in high-current applications and they are increasingly replacing relays on Printed Circuit Boards (PCBs).

The TrilithIC™ [1] Idea

The ideal bridge consists of four switches and four freewheeling diodes without internal resistance which can be actuated without power and without turn-on delays.

In practical applications, the following parameters are therefore of critical importance:

- The ON-state resistance of the switches; generally bipolar or power-MOS transistors.
- The peak current rating of the switches; DC motors are effectively large capacitive loads in their start-up phase because of their inertia.
- The quiescent current of the device; must be as low as possible.

The bridge must also have “diagnostic” capabilities: a status output (flag) must be able to signal or indicate the status of the motor drive to the drive system (microcontroller). Also, it is desirable for the outputs to have short-circuit and overtemperature protection. Individual switches configurable as required (as a bridge, half-bridge or individual high-side or low-side switch), and connectable in parallel, are expanding the application possibilities of the device and increasing the volume requirements. Consequently, expanding production is bringing down manufacturing costs while the functional parameters provide reduced power dissipation, lower assembly costs, and overall lower system costs.

Particular attention has been paid to reducing power dissipation because low on-state resistance values are essential for semiconductors in small, inexpensive standard packages. For PICs, this means preferably an SMD plastic package such as the **P-DSO-28**. This can reduce system costs in several respects. As no heatsinks or even screw- or clamp-connections are required, assembly costs are considerably lower. Less space is taken up on the PCB and a lower profile is achieved. In addition, SMDs can be mounted on both sides of the board.

Thanks to the newest generation of semiconductors, loss of electrical energy as heat is virtually eliminated from the PCB. Consequently, the package design for the electronics can be small and light. Moreover, as the power required for the drives can be supplied almost without energy loss, the entire power budget is more favorable. As a direct consequence, the DC generator in a vehicle can in turn be made smaller and lighter, and therefore, be produced more cheaply.

This weight-saving will help lower the fuel consumption of more advanced automobiles. All these considerations have prompted **Infineon Technologies** to present the slogan:

“Silicon Instead of Heatsink”

The section **Technical Background** describes how the adoption of this concept by DC motor control applications led to the creation of the **TrilithIC™** idea and to the development of the **TrilithIC™** Family.

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[1] **Tri|lith** [*gr.*; “Stone Triangle”] Prehistoric Stone Monument (Bronze Age and Early Stone Age)

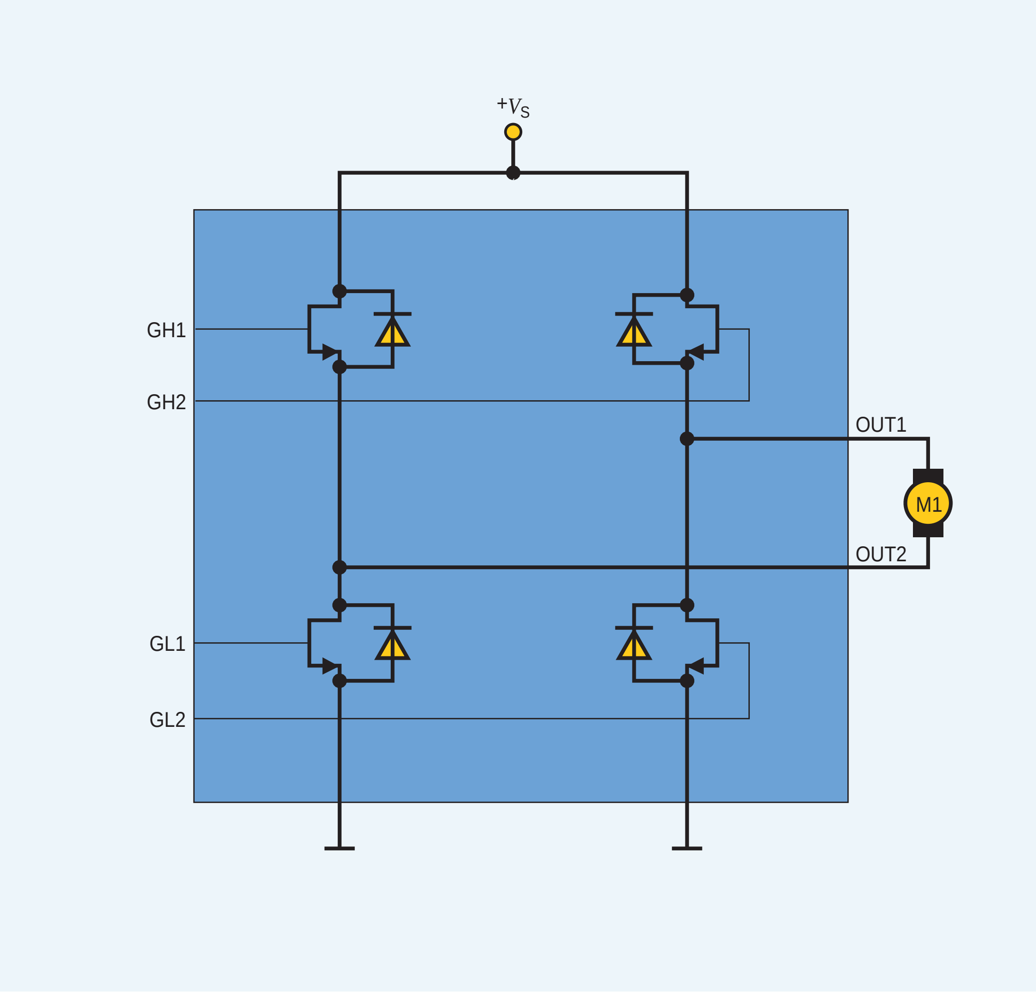
TRILITHIC^{TM} History

The story began with the invention of the **TRILITHICs™** in 1996, and launch of the first devices, the high-current H-bridges **BTS 770** and **BTS 771**. This was followed by the introduction of the fully protected versions **BTS 774** and **BTS 775** in 1998. In 1999, after selling more than ten million devices throughout the world, **Infineon Technologies** now presents the second generation **TRILITHICs™**, the family **BTS 77x0**. Experience gained from the first generation and expertise in the latest in wafer- and packaging-technology have been incorporated to improve the feature list and key parameters of the devices. The product range has been enlarged and we can now offer our customers even more choices and more cost-effective DC motor drive solutions.

This special subject book provides an overview of the **TRILITHIC™** product line. It highlights the enhancements of the second generation devices and includes detailed application information to enable our customers to optimize their products through the use of our Power Integrated Circuits.

This book is organized as follows: After this introduction, the basic elements of the **TRILITHIC™** concept and the most important features are explained in the section **Technical Background**. In the section **TRILITHIC™ Product Range**, the products are presented. The section **Thermal Characteristics** presents results of thermal analysis and explains the consequences for typical applications. Finally, the section **Applications** describes how the **TRILITHICs™** work in practice with some application examples.

Figure 1
Principle of an H-Bridge Circuit



Technical Background

Choice of Technologies: Lateral or Vertical?

To build an H-bridge with minimal switch ON-state resistances, it is necessary to compare the technologies employing Lateral and Vertical Power-MOS structures.

Figure 2 shows a **Lateral** Power-MOS structure in cross-section. The current flows from the drain lead of the package via the bond wire to the drain of the MOS structure, through the n-channel to the source, via the second bond wire, to the package's source contact.

Advantages of Lateral Power-MOS:

- Both power connections can be brought out in isolated form (monolithic integration of an H-bridge is possible)
- Only one cooling surface at ground potential is required

Disadvantages of Lateral Power-MOS:

- Large lateral spread of the power MOS structure
- Current flow via two relatively high-resistance bond contacts

The monolithic H-bridges **TLE 5205-2** and **TLE 5206-2** are typical representatives of these PICs (see the chip photo in **Figure 3**). These products consist of an H-bridge with a branch resistance of 400 mΩ (typical) and deliver peak currents of up to 6 A. Full short-circuit protection and diagnostic circuitry are also integrated. The technology required for producing this device enables bipolar, C-MOS and D-MOS structures to be implemented on the same chip. This is known as **Smart Power Technology** (SPT). If moderate output currents, a high level of logic complexity (such as a Serial Peripheral Interface) and precise analog performance are required, SPT is the technology of choice for semiconductor H-bridges.

In contrast to this, the basic design for a **Vertical** technology is shown in **Figure 4**. Here, the current flows from the drain contact, which in this case is always on the backside of the chip; that is, from the heatsink through the chip to the source contact (vertically). From there, the current flows via a single bond wire to the package source lead. The ON-state resistance is, therefore, much lower than with the Lateral structure.

Advantages of Vertical Power-MOS:

- Very low specific ON-state resistance (approximately two times lower than in Vertical technology)
- The technology has fewer mask-steps than SPT (thus, is more cost effective)

Disadvantage of Vertical Power-MOS:

- As the chip backside builds the drain of the power MOS, the drains of all power stages on one chip are inseparably connected to each other (monolithic integration of H-bridge is not possible)

The **BTS 724** as a typical representative of this technology is shown in the chip photo in **Figure 5**. This device contains two High-Side Switches (HSS) whose source contacts have been brought out. The drain leads are connected to the leadframe (heat slug) and, thus, to the chip backside. It is fabricated in **Infineon's S-Smart** Technology with complete on-chip drive and diagnostic circuitry. If only the "naked" MOS-FET, without any drive and diagnostic functionality is required, **S-FET** technology, optimized for lowest ON-state resistance, is used.

Figure 2
Lateral Power-MOS Structure

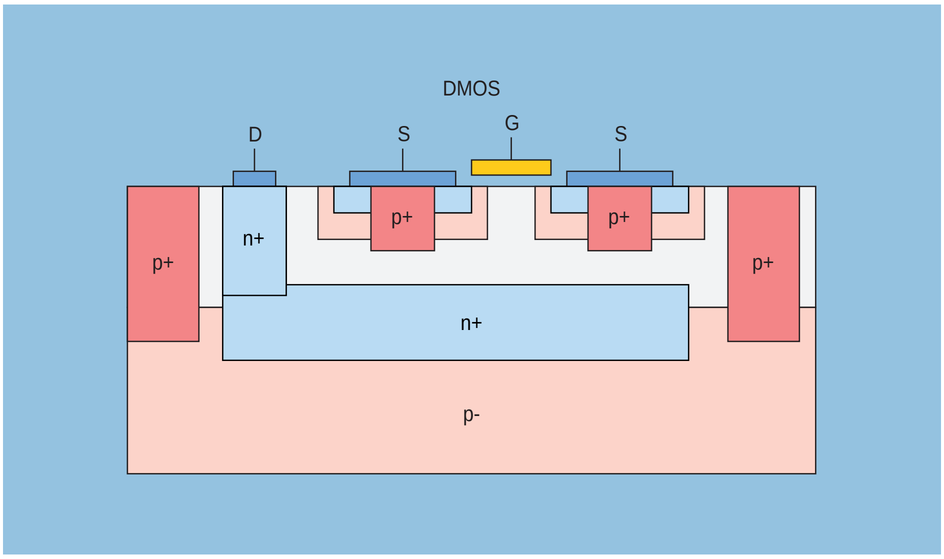


Figure 3
Chip Photo of the TLE 5205-2

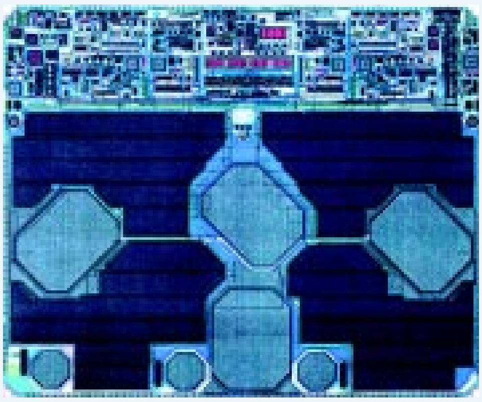


Figure 4
Vertical Power-MOS Structure

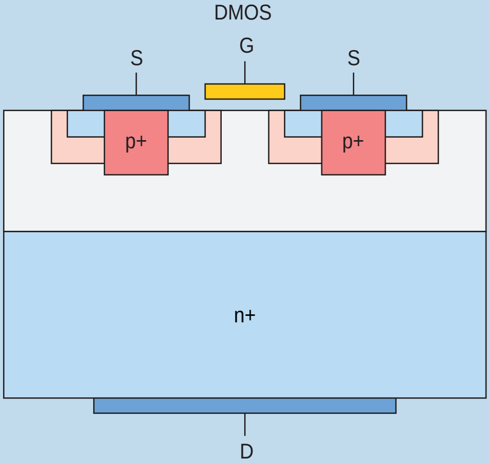
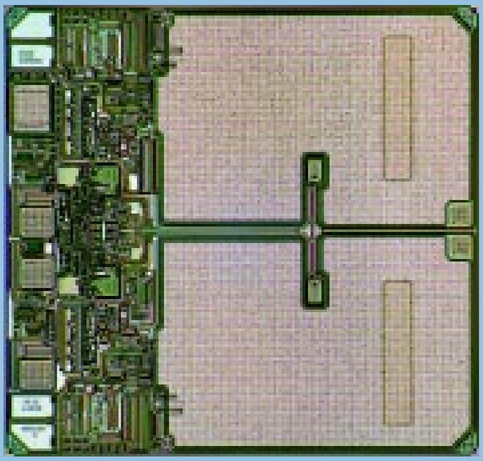


Figure 5
Chip Photo of the BTS 724



The TrilithIC™

In a comparison of the ON-state resistances per unit area, the result is as follows:

An H-bridge circuit comprising Vertical chips can be fabricated with considerably lower ON-state resistance than using Lateral structures with the same chip surface area. However, as the drain contact of a Vertical MOS-FET is inseparably connected to the backside of the chip and the leadframe, the full-bridge topology cannot be realized monolithically. Therefore, it is not implemented as a monolithic, but as a **TrilithIC™**.

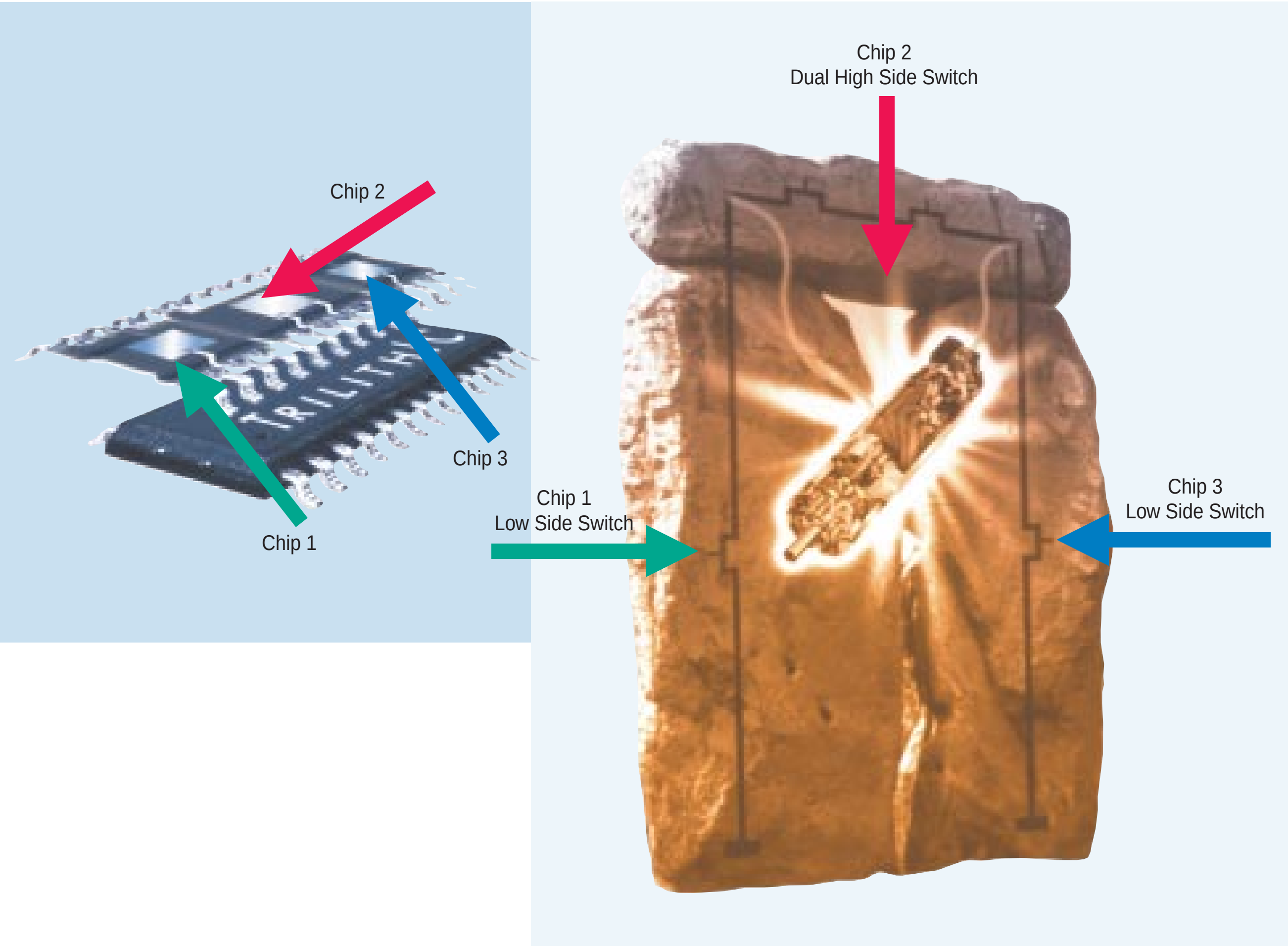
The device consists of one chip for the two High-Side Switches with the drain lead connected to the supply voltage, and two other chips for the Low-Side Switches (LSS). The insulation of the low- and high-side drains is achieved by a package with three electrically isolated leadframes. This results in a "**TrilithIC™** IC" or **TrilithIC™** as shown in **Figure 6**.

The Packages

Two packages types are available for **TrilithIC™** chips. For medium current loads or for applications with only limited duty cycles, the **P-DSO-28** is the optimum choice. Its internal layout is shown schematically in **Figure 7**. The double High-Side Switch is in the center, with the two Low-Side Switches above and below.

The power bond contacts required for the four source leads are implemented using Al-wedge technology with 250 µm thick Aluminum wires. This is an improvement over the multiple gold-bonding used in the first

Figure 6
Principle of the TrilithIC™



generation package. The bond wire resistance is further reduced, and the Al-wedge technology, leading to identical materials of bond pad and wire, produces even more robust packaging to support higher chip temperatures.

The enhanced-power concept is applied to improve the thermal performance of the package by reducing the thermal resistance. This means that each of the three leadframe-islands has a direct metallic connection to four pins of the standard package:

- Leadframe of LSS1 to the pins 1, 3, 25, and 28
- Leadframe of LSS2 to the pins 12, 14, 15, and 18
- Leadframe of the double HSS to the pins 5, 10, 19, and 24

These connections ensure efficient transfer of heat from the chip to these pins and, thus, to the PCB, where cooling areas can be used to further reduce the overall thermal resistance. See section **Thermal Characteristics** for a more detailed description.

If the application requires high continuous currents and, thus, a large amount of continuously dissipated power, it is desirable to use a package with even lower thermal resistance. For that purpose, a second **TRILITHIC™** package has been developed: the **PowerPak P-TO263-15**, as shown schematically in **Figure 8**.

In contrast with the **P-DSO-28**, the **PowerPak** has full-size heat-slugs, similar to a standard **P-TO220** package, for each of the three leadframe-islands. In the section **Thermal Characteristics**, the thermal performance of this package and how it can be cooled with external heatsinks is described in more detail.

Figure 7
Pin Assignment and Internal Layout of the TRILITHIC™ P-DSO-28

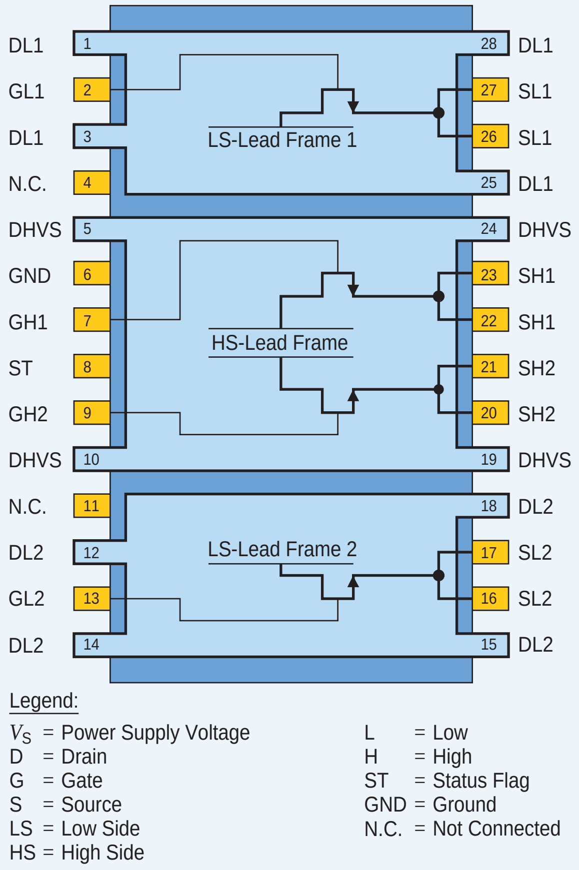
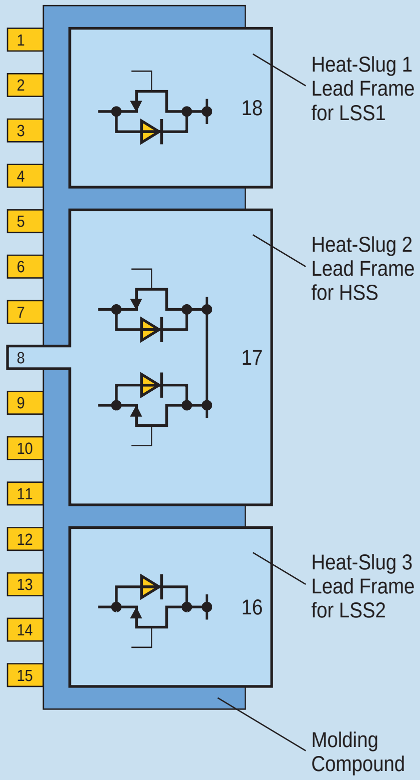


Figure 8
Internal Layout of the TRILITHIC™ P-TO-263-15 (PowerPak)



TrilithIC™ Feature List

Requirements for the bridge circuit - such as overload and short circuit protection, diagnostics capability, inputs with TTL/CMOS compatibility, overtemperature protection, etc. - make it necessary to implement at least the High-Side Switches in **S-Smart** Technology, as the charge pump and diagnostic circuit require a higher degree of manufacturing complexity. In the case of the **BTS 724** shown in **Figure 5**, 30 percent of the chip area is taken up with these functions.

If protection against short circuit to the supply voltage is not required, then the economical **S-FET** Technology, optimized for minimum ON-state resistance, can be employed for the Low-Side Switches. **S-FET** requires only about half as many mask steps for chip production as **S-Smart** Technology. However, if protected Low-Side Switches are required, **S-Smart** Technology is also preferred here.

The various features of the **TrilithIC™** are explained in detail in the following paragraphs.

Input Interface

The control Inputs of the High-Side Switches consist of TTL/CMOS compatible Schmitt-triggers with hysteresis. Buffer amplifiers are driven by these stages and generate the signals necessary to drive the power stages. The inputs of the unprotected Low-Side Switches are connected to the gates of N-channel logic-level MOS-FETs. In the case of protected Low-Side Switches, an additional gate driver is present. The most important feature is that all inputs can be driven directly by a microcontroller, no predriver is necessary for switching the **TrilithICs™** (as it is needed for a relay).

Short Circuit to Ground Protection

In the event of a short circuit to ground of the HSS source output, the protection circuitry integrated on the High-Side chip protects the device by an internal current limitation. This current limitation is achieved by an OP-amplifier which monitors the drain-source voltage drop and compares it to an internal reference voltage. If this reference level is reached, the output current is reduced. The resulting current limit is specified as the initial short circuit current and determines the maximum peak current that can be supplied by the device.

Overtemperature Shutdown

In addition to this current limitation (which prevents the short circuit current from instantaneously destroying the chip or the bond-wire), an overtemperature shutdown is also implemented. The temperature of the power stage is measured by an integrated temperature sensor. If the shutdown-temperature is reached, the power stages are turned off. As soon as the temperature has decreased by the hysteresis distance, the chip is restarted. The minimum shut-down temperature is set to 150 °C. This determines the maximum chip temperature during operation that will be used in the thermal considerations described in the section **Thermal Characteristics**.

Overload Protection

To achieve overload protection of the active path of the bridge, the Low-Side Switches are designed to have a lower ON-resistance than the associated High-Side Switches. This leads to the following protection concept: In the event of short circuit to ground, the smart High-Side Switch protects itself because of its internal current limitation and overtemperature shutdown. In the event of an overload or a shorted load, the smart High-Side Switch protects the entire bridge by virtue of its relatively higher ON-state resistance (because the HSS will always dissipate more power and will thus have a higher temperature). This protection concept is utilized in these **TrilithIC™** devices: **BTS 7700 G**, **BTS 7710 G** and **GP**, **BTS 7760 G**, **BTS 7770 G** and **BTS 780 GP**.

Short Circuit to Supply Voltage

If further protection against short circuit to the supply voltage is required, the unprotected Low-Side MOS-FETs must be replaced by protected Low-Side Switches. These **TrilithICs™** are fully short circuit proof, that is, they withstand shorts of the outputs to ground and supply voltage as well as overload and shorted load. This protection concept is employed in all the **TrilithIC™** products except those specifically listed in the previous paragraph.

Diagnosis

In typical power drive systems, more is required than for the power stage just to protect itself against various fault conditions as described above; it is also necessary to give the control unit (typically a microcontroller) feedback on such errors. The **TrilithICs™** are equipped with an error flag that is set if either overload or short circuit to ground is detected. The only exceptions are the econo-types **BTS 7760 G** and **BTS 7770 G**, which do not have status output.

Current Sense

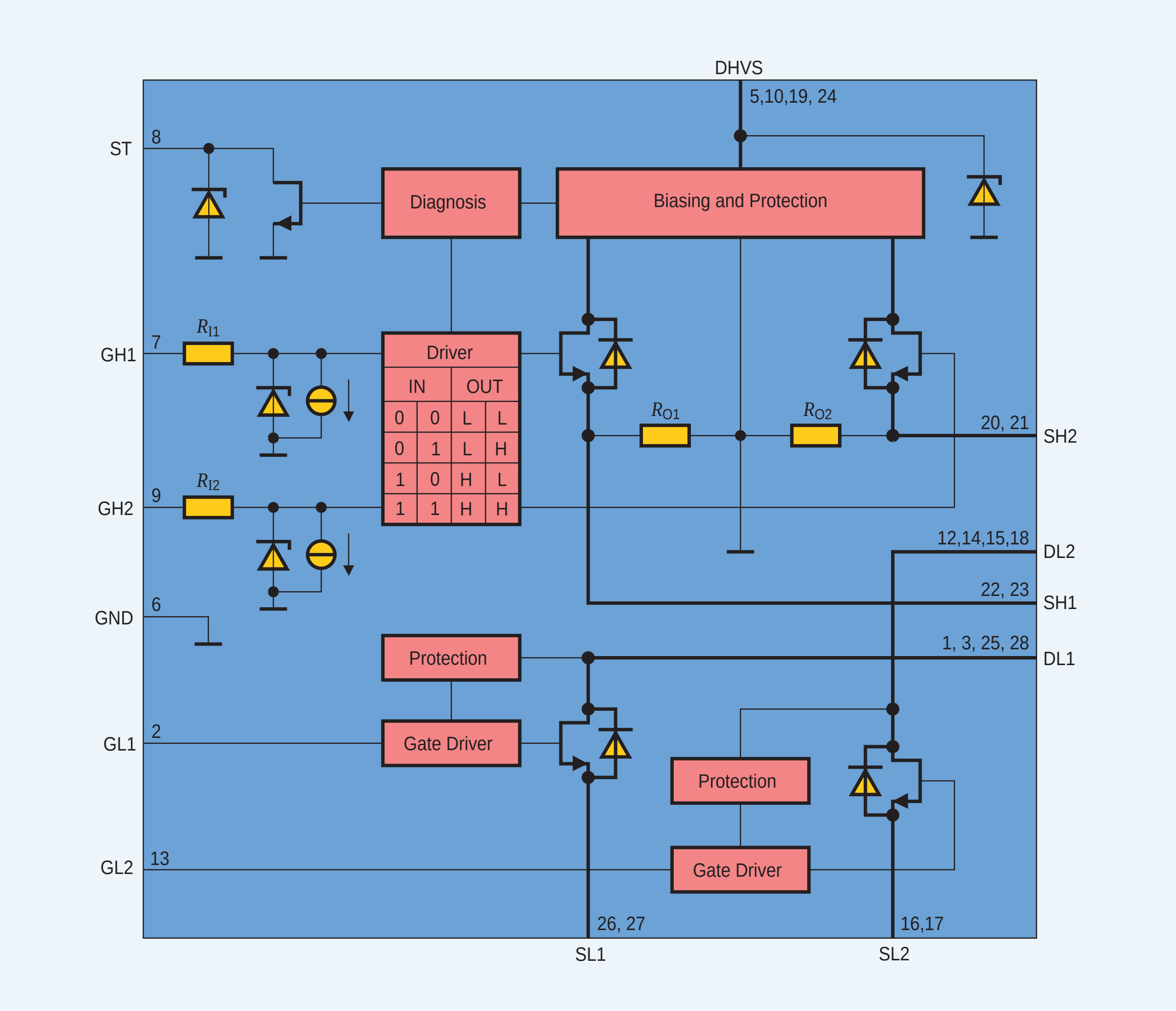
The **BTS 7780 G**, **BTS 7790 G** and **K**, **BTS 7990 K** and **BTS 7980 K** types not only have a status output, but have a combined status/current sense output. In normal operation, a current source is connected to the output, delivering a current proportional to the current flowing through the High-Side Switch. An external resistor is used to generate a voltage signal that can be read out. If an error is detected, the output is set to 5 V. This current sensing feature can be used to detect motor block, for example, and makes external shunt resistors and OP-amps obsolete.

Current Consumption

For battery-driven stand-alone applications, such as automotive body modules, the current consumption in OFF-state (the quiescent current) must be as low as possible. In the design of the **TrilithICs™**, the quiescent current was minimized, leading to values as low as 5 µA for the second generation **BTS 77x0** types.

The **BTS 7750 G** is an example of a fully-protected **TrilithIC™**. Its block diagram is provided in **Figure 9** to illustrate the functional blocks which implement the features just described.

Figure 9
Block Diagram of BTS 7750 G



IN		OUT	
0	0	L	L
0	1	L	H
1	0	H	L
1	1	H	H

TRILITHIC™ Product Range

A broad range of products has been developed from the original **TRILITHIC™** idea and its first representatives, the **BTS 770** and **771**. **Figure 10** gives an overview of the entire family. In the vertical direction, the products are arranged according to the output current that can be handled. In the horizontal direction, they are arranged according to their feature list. The path resistances are typical values at room temperature. For reference, the products of the first generation are also shown next to their successors.

The two rows at the bottom of **Figure 10** show the products in the **P-DSO-28** package with the typical path resistances of 220 mΩ and 120 mΩ, respectively. In terms of features, the range starts with the **BTS 7760 G** and **BTS 7770 G**, having protected HSS only and no status output. These products are intended to be used as simple relay replacements with microcontroller compatible inputs.

Feature list enhancements continue with the **BTS 7700 G** and **BTS 7710 G** with status output and fast, but unprotected, LSS. If full protection is required and switching frequencies below 1 kHz are sufficient, the **BTS 7740 G** and **BTS 7750 G** fully-protected devices are the right choices. Finally, the high-end types, **BTS 7780 G** and **BTS 7790 G**, combine full protection and fast Low-Side Switches which allow for PWM applications above 25 kHz. Additionally, these products have a combined status/current-sense output to permit easy current measurement without the use of external shunt resistors and OP amps.

Three of the products just described, the **BTS 7710 GP**, **BTS 7750 G**, and **BTS 7790 G** are also offered in the **PowerPak P-TO263-15**. They have a "**GP**", "**K**", respectively, instead of the "**G**" in their part number. This package has a very small thermal resistance and thus permits driving higher continuous currents with the same chips.

Three additional products for even higher currents are offered in the **PowerPak**. The **BTS 780 GP** with only 50 mΩ path-resistance has fast Low-Side Switches and a protected High-Side Switch. For even lower ON-state resistances, the Chip-on-Chip technology is employed for our top-of-the-line product, the **BTS 7990 K**, with a path resistance of 20 mΩ. While the **BTS 780 GP** has fast but unprotected Low-Side Switches, the **BTS 7990 K** offers full protection and integrated driving units for powerless control of all four switches. The **BTS 7990 K** also has the combined current sense/status output. Finally, the **BTS 7980 K** is the fully protected successor of the **BTS 780 GP**.

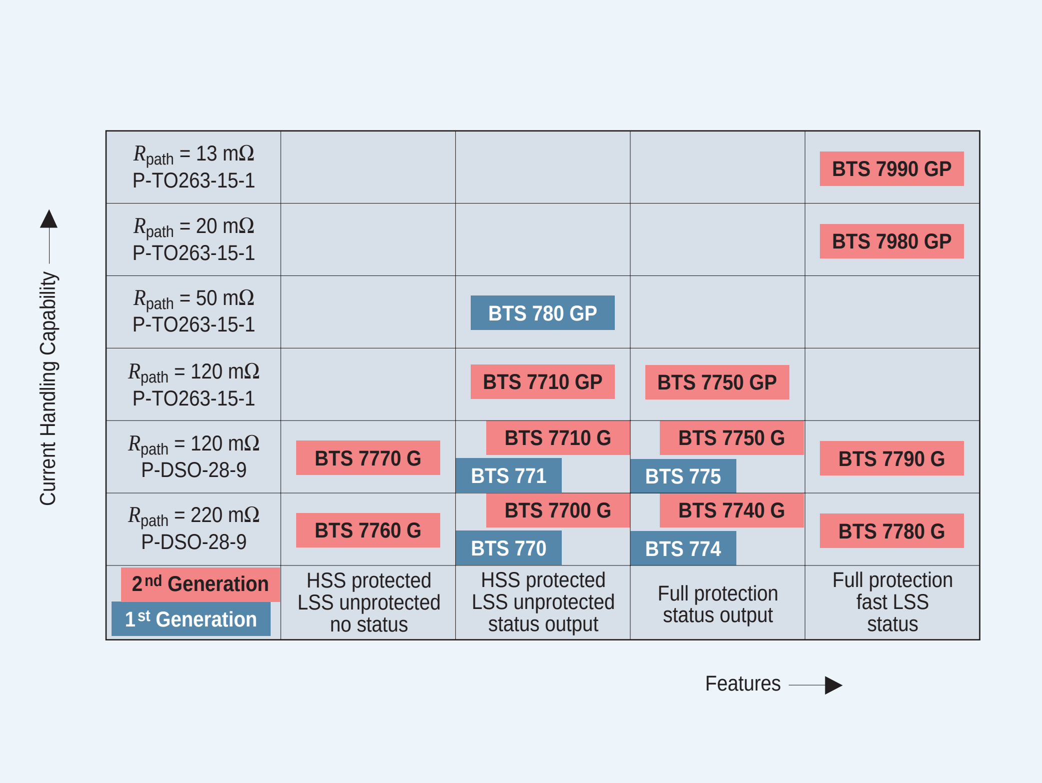
Table 1 lists the key parameters of the entire **TRILITHIC™** family. Two columns give the **path resistance** (that is, $R_{\text{on,path}} = R_{\text{DS ON H}} + R_{\text{DS ON L}}$). One column gives the typical value at room temperature, and the other gives the maximum limit at 150 °C. Three current values are given for each device: The **peak current** is determined by the internal current limitation that protects the device. The typical value at ambient temperature is given in the table. The **continuous output current** is the maximum permissible current that can be driven continuously for the device on our reference PCB at an ambient temperature of 85 °C. The 1s pulse current is the maximum current that can be driven for 1 second, again for the device on the reference PCB at 85 °C ambient temperature. For details on how to determine the maximum current in a specific application, please refer to the section **Thermal Characteristics**.

Table 1 **TRILITHIC™ Product Range - Key Parameters**

Type	$R_{\text{on, path}}$, typ (mΩ)	$R_{\text{on, path}}$, max (mΩ)	Peak Current (A)
BTS 7790 GP	120	tbd	12
BTS 7790 G	120	tbd	12
BTS 7780 G	220	tbd	8
BTS 7750 GP	120	285	12
BTS 7750 G	120	285	12
BTS 7740 G	220	500	8
BTS 7710 GP	120	260	15
BTS 7710 G	120	260	15
BTS 7700 G	220	480	9
BTS 7770 G	120	260	15
BTS 7760 G	220	480	9
BTS 780 GP	50	110	44
BTS 7980 K	20	50	tbd
BTS 7990 K	13	35	tbd

Figure 10

TRILITHIC™ Product Range - Overview



R_{path} = 13 mΩ P-TO263-15-1				BTS 7990 GP
R_{path} = 20 mΩ P-TO263-15-1				BTS 7980 GP
R_{path} = 50 mΩ P-TO263-15-1		BTS 780 GP		
R_{path} = 120 mΩ P-TO263-15-1		BTS 7710 GP	BTS 7750 GP	
R_{path} = 120 mΩ P-DSO-28-9	BTS 7770 G	BTS 7710 G BTS 771	BTS 7750 G BTS 775	BTS 7790 G
R_{path} = 220 mΩ P-DSO-28-9	BTS 7760 G	BTS 7700 G BTS 770	BTS 7740 G BTS 774	BTS 7780 G
2nd Generation 1st Generation	HSS protected LSS unprotected no status	HSS protected LSS unprotected status output	Full protection status output	Full protection fast LSS status

Continuous Output Current [1] (A)	1s Pulse Current [1] (A)	Short Circuit Protection	Max. LSS Switching Frequency	Diagnostic Interface	Package	Remark
3.0	13.0	Full	50 kHz	Status & Current Sense	P-TO263-15	NEW !! Fast and Full Protection
2.4	4.2	Full			P-DSO-28	
1.8	3.2	Full			P-DSO-28	
3.0	13.0	Full	2 kHz	Status Flag	P-TO263-15	Full Protection
2.4	4.2	Full			P-DSO-28	
1.8	3.2	Full			P-DSO-28	
3.1	14.0	Load + GND	100 kHz	Status Flag	P-TO263-15	Fast LSS
2.5	4.4	Load + GND			P-DSO-28	
1.8	3.2	Load + GND			P-DSO-28	
2.5	4.4	Load + GND	100 kHz	No Status	P-DSO-28	Simple Relay Replacement
1.8	3.2	Load + GND			P-DSO-28	
5.0	24.0	Load + GND	100 kHz	Status Flag	P-TO263-15	Fast LSS
8.0	36.0	Full	30 kHz	Status & Current Sense	P-TO263-15	NEW !! Chip-on-Chip in PowerPack. Fast and Full Protection
9.5	43.0	Full			P-TO263-15	

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[1] For device on reference PCB at 85 °C ambient tempereture

Thermal Characteristics

Customers interested in our **TRILITHIC™** products often ask a question like *"O.K., nice product, but how much current can it deliver?"* In principle, the answer is simple: *"so much that the chip temperature does not exceed 15 0°C"*. But, what this means in terms of current depends on many parameters; such as the ON-state resistance of the switches, the thermal resistance of the package, and the ambient temperature. The amount of current which can be delivered also depends on customer-specific factors like the PCB layout and the duty cycle. This section provides the information necessary to determine performance of the device in applications.

Finite Element Modeling

Finite Element Method (FEM) simulation was used to determine the thermal behavior. The model set-up for the **P-DSO-28** package is shown in **Figure 11a**. The molding compound encapsulating the device is omitted in the figure to reveal details of the internal design, but was taken into account in the simulations.

For the application, the thermal behavior of the device soldered to a PCB is important. For this reason, a reference standard PCB (see **Figure 12**) was designed, made from 1.5 mm thick FR4 material and clad on one side with a 70 µm Cu coating. Clearly visible are the "cooling surfaces" whose areas were made proportional to the ON-state resistance of the switch being cooled and, thus, to the power produced. Simulations of the **TRILITHIC™** on this reference PCB were performed; **Figure 11b** shows the corresponding FEM model.

Bridge operation is considered in the simulation. This means that power is dissipated in one High- and one Low-Side Switch and distribution of power over the two switches is proportional to the ON-state resistances: The total dissipated power, $P_{\mathrm{tot}} = P_{\mathrm{LS}} + P_{\mathrm{HS}}$, is subdivided such that $P_{\mathrm{HS}} / P_{\mathrm{LS}} = R_{\mathrm{ON,HS}} / R_{\mathrm{ON,LS}}$.

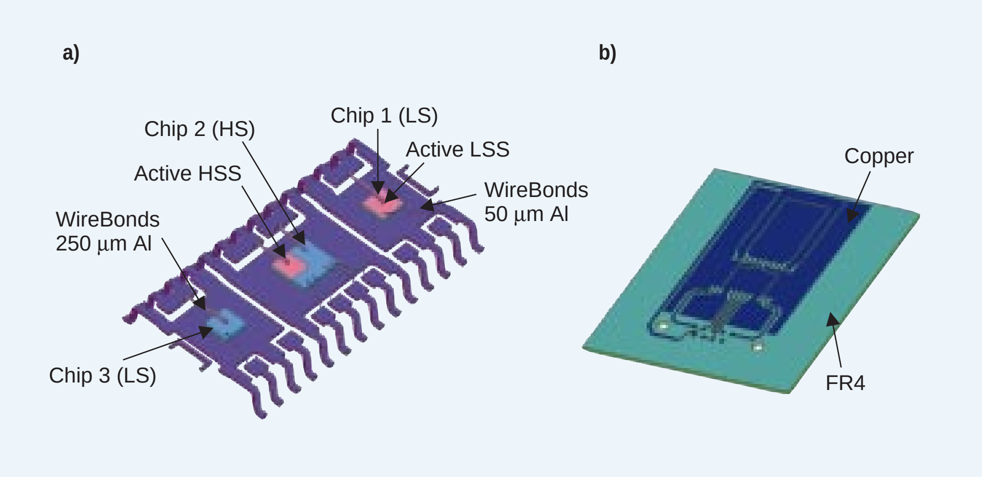


Figure 11
Set-up of the Finite-Element Model for Thermal Simulations (P-DSO-28)

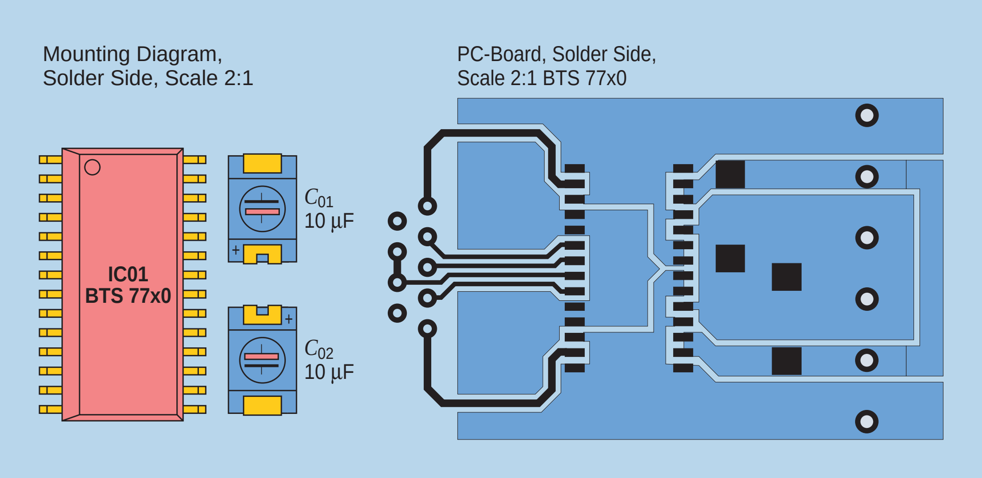


Figure 12
Outline of the Reference PCB for the Products in P-DSO-28

Simulation Results for the P-DSO-28

For the **P-DSO-28** package, two boundary conditions were simulated:

- First Boundary Condition:
  The solder points of the leads were kept at a constant temperature of 85 °C. This simulation gives the thermal resistance between the hottest point of the chip (the junction of the power stage) and the lead, $R_{\text{th,J-Lead}}$
- Second Boundary Condition:
  The PCB was kept in still air (that is, non-moving) and the ambient temperature was kept at 85 °C. This simulation gives the thermal resistance between junction and ambient for the reference PCB, $R_{\text{th,J-Amb}}$

The result of a simulation with the first boundary condition and a total dissipated power of 2 W is shown in **Figure 13** for the **BTS 7750 G**.

$R_{\text{th,J-Lead}}$ is calculated from the temperature difference between T_{ChipMax} and T_{Pinx} = 85 °C, divided by the power dissipated in the two switches P_{tot}. For the example in **Figure 13**, this leads to
$R_{\text{th,J-Lead}}$ = (388.4 K - 357 K) / 2 W = 15.7 K/W.

If the whole application is taken into account, the thermal resistance of the PC board to ambient is added to $R_{\text{th,J-Lead}}$. Although this value depends on the specific PCB layout in the particular application, it is determined for the reference PCB depicted in **Figure 11b** by applying the second boundary condition. **Figure 14** shows the result of such a simulation. The total thermal resistance from junction to ambient is determined by
$R_{\text{th,J-Amb}} = (T_{\text{ChipMax}} - T_{\text{ambient}}) / P_{\text{tot}}$, the result is 41 K/W.

For a given maximum ambient temperature, the maximum power that can be dissipated continuously in the device can now be calculated. For instance, an ambient temperature of 85 °C gives a temperature differ-

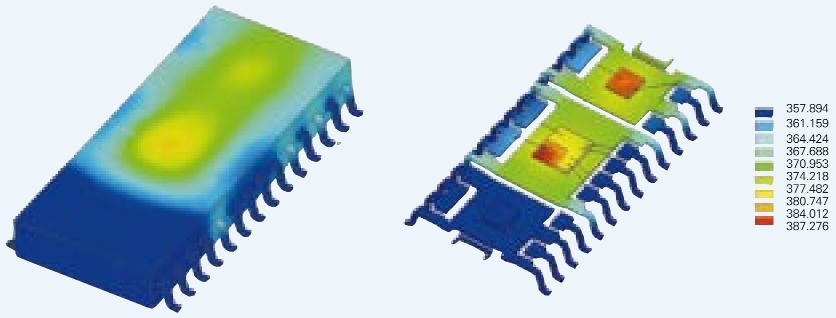


Figure 13
Steady-State Temperature Distribution for the BTS 7750 G at a Power-Dissipation of 2 W in Full-Bridge Operation

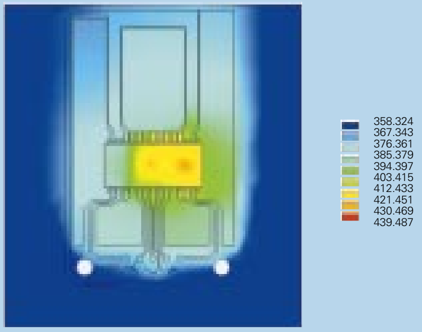


Figure 14
Steady-State Temperature Distribution for the BTS 7750 G on the Reference-PCB in Still Air

ence of ΔT = (150 °C - 85 °C) = 65 K because the maximum chip temperature allowed is 150 °C. Now, $\Delta T / R_{\text{th,J-Amb}}$ = 1.6 W is calculated, which means that at an ambient temperature of 85 °C, 1.6 W can be dissipated continuously in the device. **Table 2**, summarizes the results of the steady-state thermal simulations.

Now, it is known how much power can be dissipated, but the current is not yet known. To determine that, the path-resistance in bridge operation must be known, that is, the sum of ON-state resistances of the high- and Low-Side Switches,
$R_{\text{on,path}} = R_{\text{DS ON H}} + R_{\text{DS ON L}}$.

We must consider the maximum values at 150 °C, the maximum limit given in the data sheet. For the **BTS 7750 G**, this gives a maximum path-resistance of 285 mΩ. The maximum current can now be calculated.

So:

T_{jmax} = 150 °C (max. chip temperature),

$R_{\text{th,J-Amb}}$ = 41 K/W (thermal resistance junction to ambient)

and

T_{amax} = 85 °C (maximum ambient temperature).

Equating

$P_{\text{totmax}} = (T_{\text{jmax}} - T_{\text{amax}}) / R_{\text{thj-a}}$ (maximum dissipation)

and

$P_{\text{totmax}} = (I_{\text{out}})^2 \times R_{\text{on,path}}$,

yields the result of I_{max} = 2.4 A.

In **Figure 15** and **Figure 16**, the results of the above calculation are shown for other values of maximum ambient temperature and thermal resistance.

Figure 15
Maximum Permissible Continuous Current for the BTS 7700, BTS 7760 (solid lines) and BTS 7740 (dashed lines) as a Function of Ambient Temperature and Junction-to-Ambient Thermal Resistance

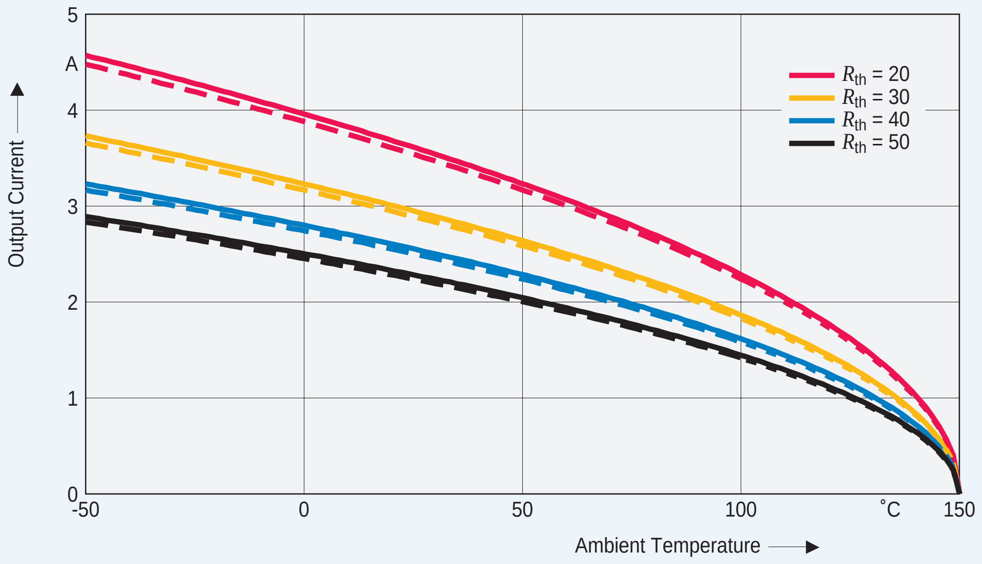
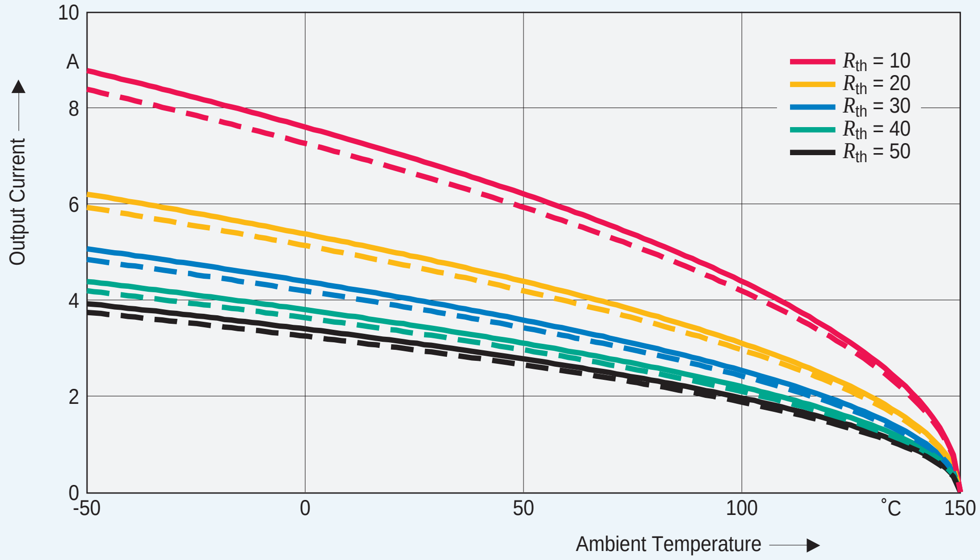


Table 2 **Results of Steady-State Thermal Simulations**

Type	Package	$R_{th,J-Lead}$ (K/W)	$R_{th,J-Amb}$ (K/W)	$R_{th,J-H}$ (K/W)
BTS 7700 G **BTS 7740 G** **BTS 7760 G**	P-DSO-28	15	40	–
BTS 7710 G **BTS 7750 G** **BTS 7770 G**	P-DSO-28	16	41	–
BTS 7710 GP **BTS 7750 GP**	P-TO263-15	1	26	2.9
BTS 780 GP	P-TO263-15	0.4	23	2.6

Figure 16
Maximum Permissible Continuous Current for the BTS 7710, BTS 7770 (solid lines) and BTS 7750 (dashed lines) as a Function of Ambient Temperature and Junction-to-Ambient Thermal Resistance. The Figures Apply for the P-DSO-28 Versions (G) as well as for the PowerPak Versions (GP)



Transient Thermal Resistance of the TRILITHIC™

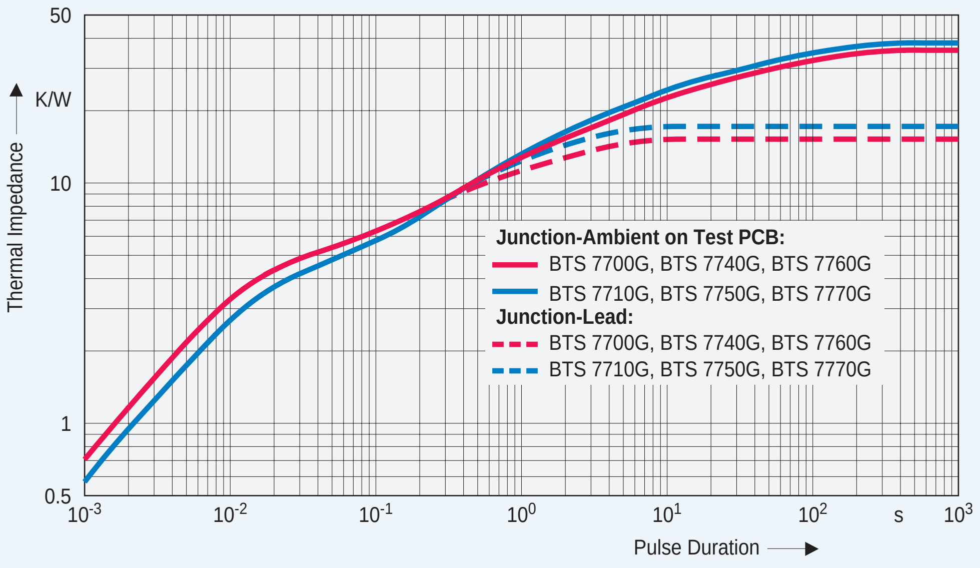
So far, only steady state conditions have been considered in this discussion. This gave us a value for the maximum continuous output current. The possible dissipations under transient conditions for times in the range of seconds are, however, much higher. The majority of DC motor drives with average load inertia come up to the rated speed in a few 100 ms, and in many applications (for example, automobile doorlock), only short load sequences in the seconds range must be delivered. For that reason, the response of the system in this time range is of critical importance and will now be examined in detail.

The transient thermal behavior is described in general by the thermal impedance Z_{th}, which gives the temperature rise per unit of dissipated power as a function of the time the power is applied. It is again determined by FEM simulations. In **Figure 17**, the thermal impedance of the **P-DSO-28 TrilithICs™** is shown for the case of a constant temperature at the leads ($Z_{\text{th,J-Lead}}$) and for the device on the reference PCB in still air ($Z_{\text{th,J-Amb}}$). At the beginning of the dissipation pulse, the heat capacity of the device absorbs most of the power, so the thermal impedance starts at very low values and increases with time, reaching saturation at the limit of the static value, that is, at the thermal resistances given in **Table 2**.

The most important result of the transient analysis is that the time constant is in the upper seconds range, for the simulation on the PCB even in the minutes range: It takes more than three minutes to reach steady state conditions!

To consider the example of the **BTS 7750 G** and a current pulse of 500 ms at an ambient temperature of 85 °C, for this pulse duration,
$Z_{\text{th,J-Abm}}$ (500 ms) = 10 K/W gives a maximum permissible power dissipation of
(150 °C - 85 °C) / 10 K/W = 6.5 W or a maximum current of 4.8 A.

Figure 17
Thermal Impedances of the TRILITHICs™
in the P-DSO-28 Package



Pulsed Operation

A practical application, however, most likely will not have a single pulse, but a periodic signal with a certain peak value, repetition rate, and duty cycle. The power dissipation and temperature response in such a situation is shown schematically in **Figure 18**. Using the thermal resistance and impedance enables at least an approximate calculation of the most important characteristics of this behavior without performing dedicated simulations: The amplitude of the temperature oscillation ΔT is given by:

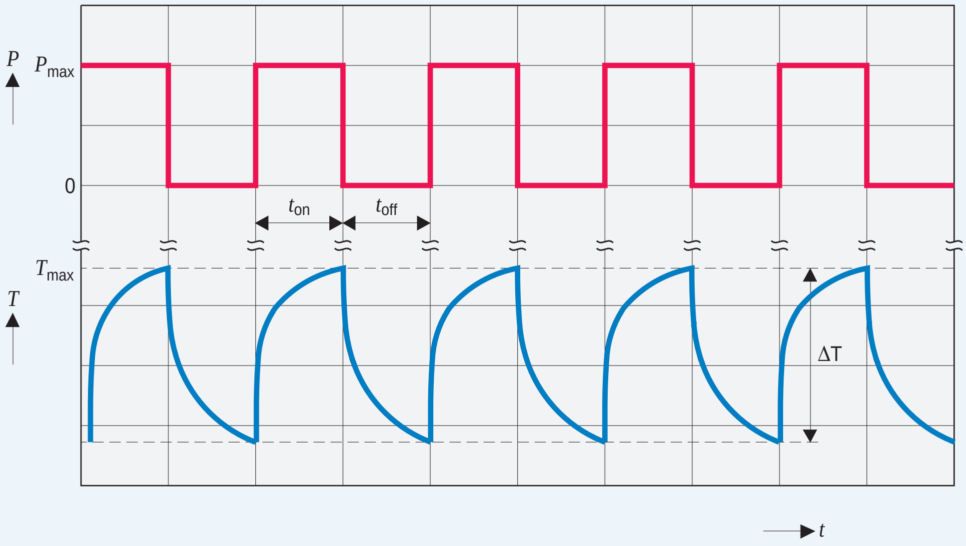
$$\Delta T = Z_{\mathrm{th}}(t_{\mathrm{on}})\, P_{\mathrm{max}}.$$

And the peak temperature T_{max} is given by

$$T_{\mathrm{max}} = T_{\mathrm{ambient}} + [\, Z_{\mathrm{th}}(t_{\mathrm{total}})\, DF + 1/2\, Z_{\mathrm{th}}(t_{\mathrm{on}})\,]\, P_{\mathrm{max}}$$

where $DF = t_{\mathrm{on}} / (t_{\mathrm{on}} + t_{\mathrm{off}})$ is the duty factor and t_{total} is the total time since the pulsed operation was started. For the example of the **BTS 7750 G** on the reference PCB with a repetition rate of $t_{\mathrm{on}} + t_{\mathrm{off}} = 1$ s and a duty factor of 50 % for a total time of 100 s at an ambient temperature of 8 5°C, the result is P_{max} = (150 °C - 85 °C) / (35 K/W x 0.5 + 0.5 x 10 K/W) = 2.9 W, which corresponds to a maximum pulse current of 3.2 A.

Figure 18
Power Dissipation and Chip Temperature for Pulsed Operation with 50 % Duty Factor

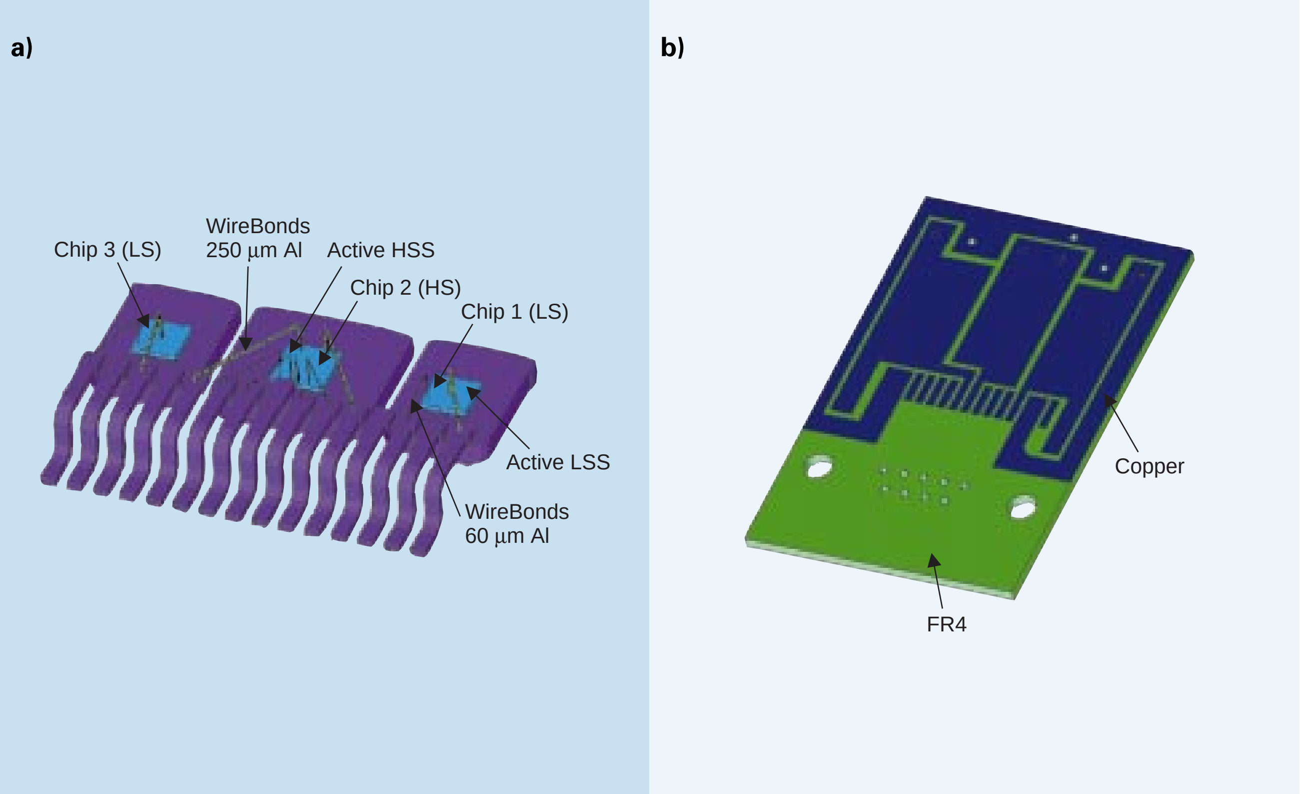


Simulation Results for P-TO263-15

The same simulations as just described were also performed for the **PowerPak**, **P-TO263-15**. This is the package of choice if large continuous currents must be handled. The package is offered for the products **BTS 7710 GP**, **BTS 7750 GP**, **BTS 7790 K**, and **BTS 780 GP**. In **Figure 19a**, the internal model set-up of the package is shown for the example of the **BTS 780 GP**, again without molding compound. **Figure 19b** shows the device on the reference PCB. For this case, a double-sided PCB was considered. It has cooling areas on both sides which are connected by a 1.1 mm x 1.1 mm pattern of thermal vias. The PCB layout is shown in detail in **Figure 20**. This layout allows the possibility of applying additional cooling on the bottom of the PCB. However, it must be recognized that the center heatslug is at supply voltage and the two other heatslugs are the low-side drains, that is, the outputs. Therefore, an additional metallic heatsink must be electrically insulated form the PCB cooling areas. This can be done by a polyimid-foil. This situation was also considered in the simulations, leading to the following three boundary conditions:

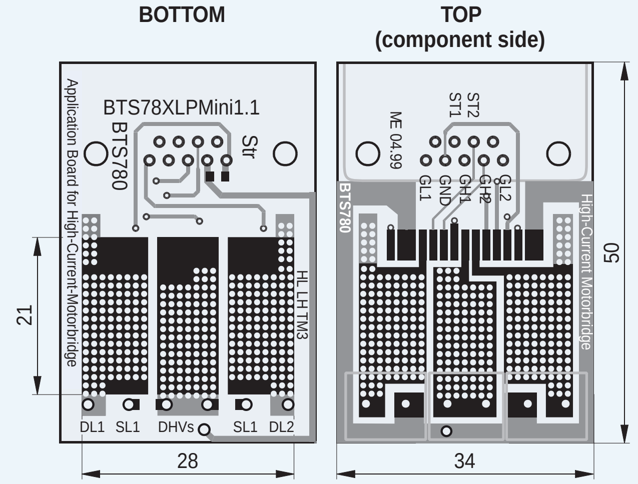
- The PCB surface, that is, the solder area of the pins, and the three heatslugs was kept at a constant temperature of 85 °C. This simulation gives the thermal resistance between junction and lead, $R_{\text{th,J-Lead}}$
- A 300 µm thick polyimid foil was put underneath the PCB and the temperature on the foil surface was kept at a constant temperature of 85 °C. This simulation gives the thermal resistance between junction and an external metallic heatsink that is mounted on the polyimid foil, $R_{\text{th,J-H}}$
- The PCB was kept in still air and the ambient temperature was kept at 85 °C. This simulation gives the thermal resistance between junction and ambient for the reference PCB, $R_{\text{th,J-Amb}}$

Figure 19
Set-up of the Finite-Element Model for Thermal Simulations (P-TO263-15)



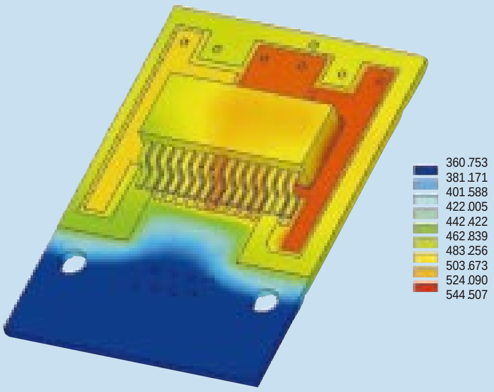
Once again, the steady-state results will be reviewed first. As an example, **Figure 21** shows the temperature distribution of the **BTS 780 GP** with a total power dissipation of 7 W. Again, the power is subdivided over the two active power stages according to their ON-state resistances. The result is $R_{\text{th,J-Amb}}$ = 23 K/W. At an ambient temperature of 85 °C, this corresponds to a maximum continuous current of 5 A. The results of the static simulations for the other boundary conditions and the other **PowerPak** products are given in **Table 2**.

Figure 20
Outline of the Reference-PCB for the P-TO283-15. The Cooling Areas are Trough-Connected with a 1.1 mm x 1.1 mm Pattern of Thermal Vias



Dimensions in mm

Figure 21
Steady-State Temperature Distribution for the BTS 780 GP at a Power-Dissipation of 7 W in Full-Bridge Operation



The advantages of the **PowerPak** over the **P-DSO-28** are obvious, the thermal resistance junction-lead is as low as 1 K/W for the **BTS 7710 GP**, **BTS 7750 GP** and **BTS 7790 K** and even as low as 0.3 K/W for the **BTS 780 GP**. The result on the reference-PCB shows that the **PowerPak** versions of the **BTS 7710**, **BTS 7750**, and **BTS 7790 K** offer a reduction in $R_{\text{th,J-Amb}}$ of 40 % compared to the **P-DSO-28** versions. Again, the maximum permissible output current can now be calculated for a given ambient temperature. The values for the **BTS 7710 GP** and **7750 GP** can be read from **Figure 16**; for the **BTS 780 G**, from **Figure 22**

As for the **P-DSO-28** package, transient simulations were also performed; the results are shown in **Figure 23**. In comparison to the **P-DSO-28** package, the time-constants are even larger, allowing for longer and larger current pulses. If the same considerations for pulsed operation as above for the **BTS 7750 G** are made for the **BTS 780 GP** (t_{on} = t_{off} = 500 ms, t_{total} = 100 s, T_{ambient} = 85 °C), the result is a maximum power dissipation of as much as 7.9 W which means a current of 8.5 A can be delivered during the pulses.

Determining $R_{\text{th,J-Amb}}$ for a Given Application

How well does theory stand up in practice? To find out, the simulation of the **BTS 7750 G** and **BTS 780 GP** on the reference-PCBs in still air were verified by measurements.

To determine $R_{\text{th,J-Amb}}$, the chip temperature was measured for various power dissipations. The chip temperature minus the ambient temperature divided by the dissipation gives the required thermal resistance.

Figure 22
Maximum Permissible Continuous Current for the BTS 780 as a Function of Ambient Temperature and Junction-to-Ambient Thermal Resistance

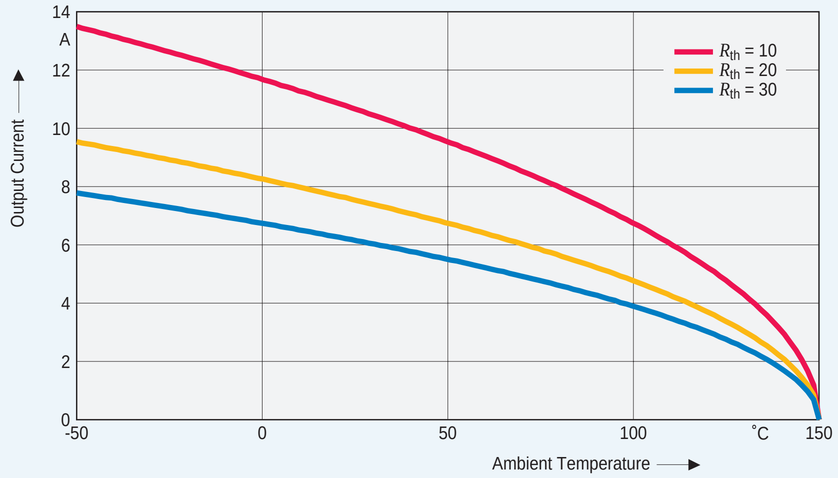
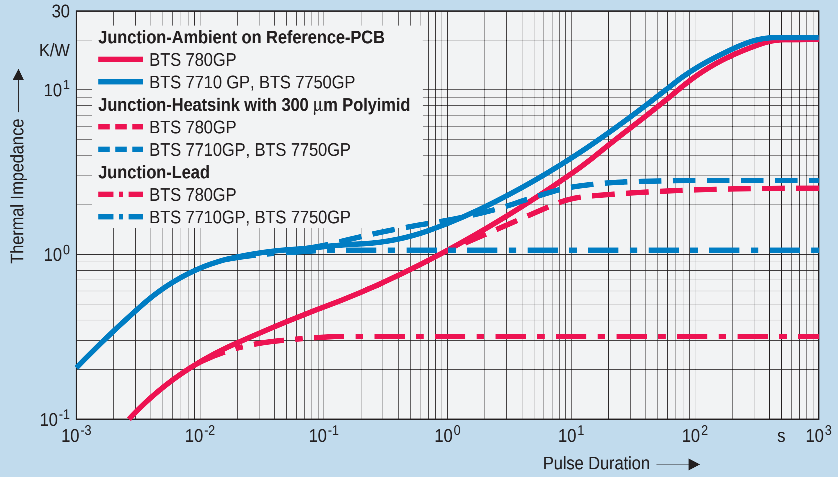


Figure 23
Thermal Impedances of the TrilithICs™ in the P-TO263-15 Package



Measurement of the chip temperature of the device uses the temperature dependence of an on-chip diode, most preferably the body-diode of the status output (diode to ground with cathode at status output). First, the forward voltage of the diode at low current (e.g. 1 mA) is measured as a function of the chip temperature. The measurement can easily be performed in a temperature chamber because the power dissipation during this calibration measurement can be ignored and thus the chip temperature can be considered to be equal to the ambient temperate. The resulting temperature calibration curve $V_{\mathrm{FST}} = f(T_{\mathrm{j}})$, is applicable to all **TRILITHIC™** types and is shown in **Figure 24**.

Power is now applied to a bridge circuit, and the forward voltage V_{FST} of the status output diode is measured at the same time. With the help of the calibration curve, this yields the function $T_{\mathrm{j}} = f(P_{\mathrm{tot}})$ and, after division by P_{v}, the thermal resistance $R_{\mathrm{th,J\text{-}Amb}}$ as shown in **Figure 25**. Note that the thermal resistance shows a slight decrease with increasing temperature, which is caused by nonlinear effects in convection and heat radiation.

For the **BTS 7750 G**, the result at a dissipation of 2 W is slightly less than 40 K/W which fits nicely to the simulation result of 41 K/W; the simulation was also performed at 2 W. The **BTS 780 GP** shows 23 K/W at a power of 5 W, again confirming the simulation which gave exactly the same value.

The method just described can be used to determine the thermal resistance for any given PCB layout and thermal environment. This gives the engineer the ability to determine the maximum deliverable current in an application. For a first evaluation, however, the data shown in **Figure 26** can be used to obtain approximate values for smaller cooling surfaces without dedicated measurements. Simulations were performed for a number of PCB-layouts with decreasing cooling surface areas. The figure shows the result, the thermal resistance as a function of the cooling surface area. 100% corresponds to the reference PCB as depicted in **Figure 12**. As this function is dependent on a large number of parameters, it is only strictly valid for the reference board.

Figure 24
Calibration Curve $V_{FST} = f(T_j)$ for Determining the Chip Temperature of the High-Side Chip

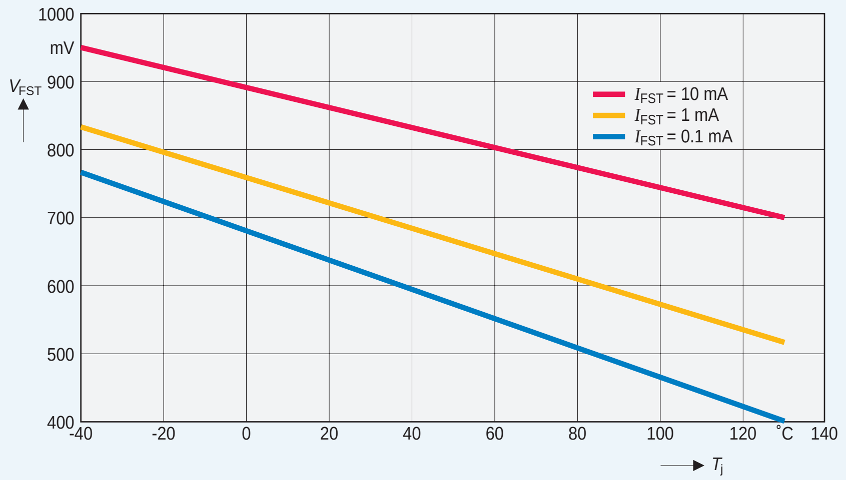


Figure 25
Measured Chip Temperature and Thermal Resistance of BTS 7750 G and BTS 780 GP on Reference PCBs as a Function of the Dissipated Power

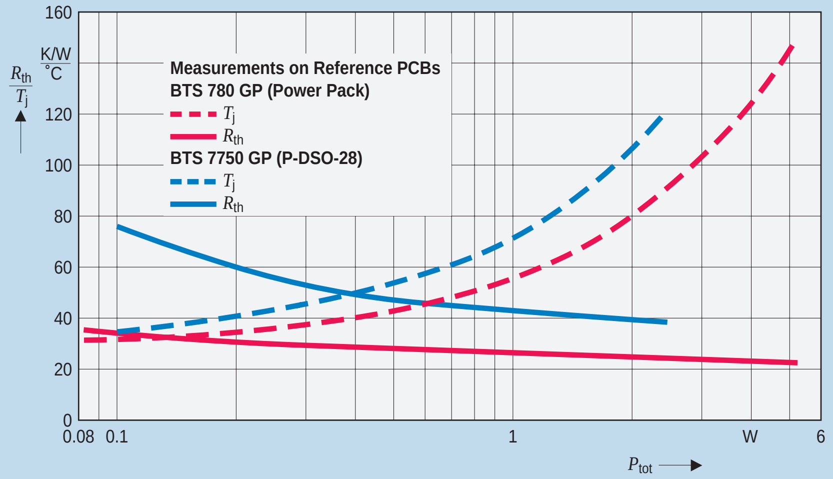
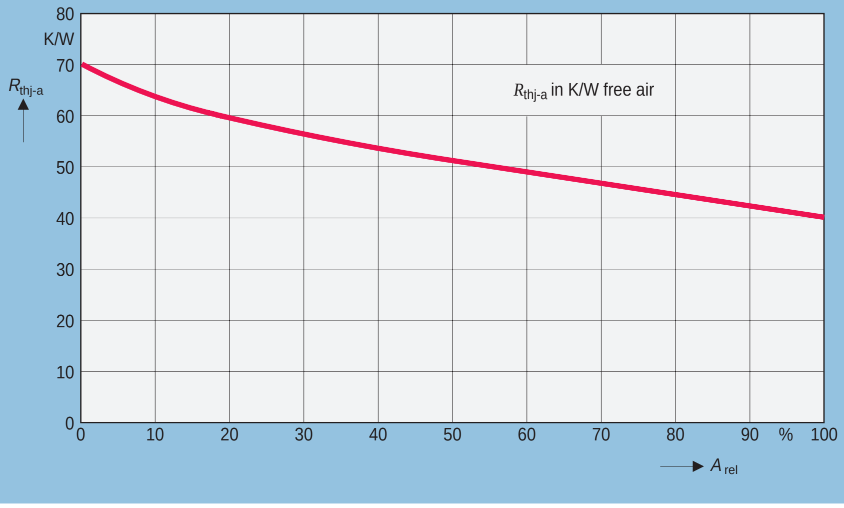


Figure 26
Thermal Resistance of the TrilithICs™ in the P-DSO-28 Package on the Reference PCB as a Function of the PCB Cooling Surface. 100 % Corresponds to the PCB as Depicted in Figure 12



Application Circuit

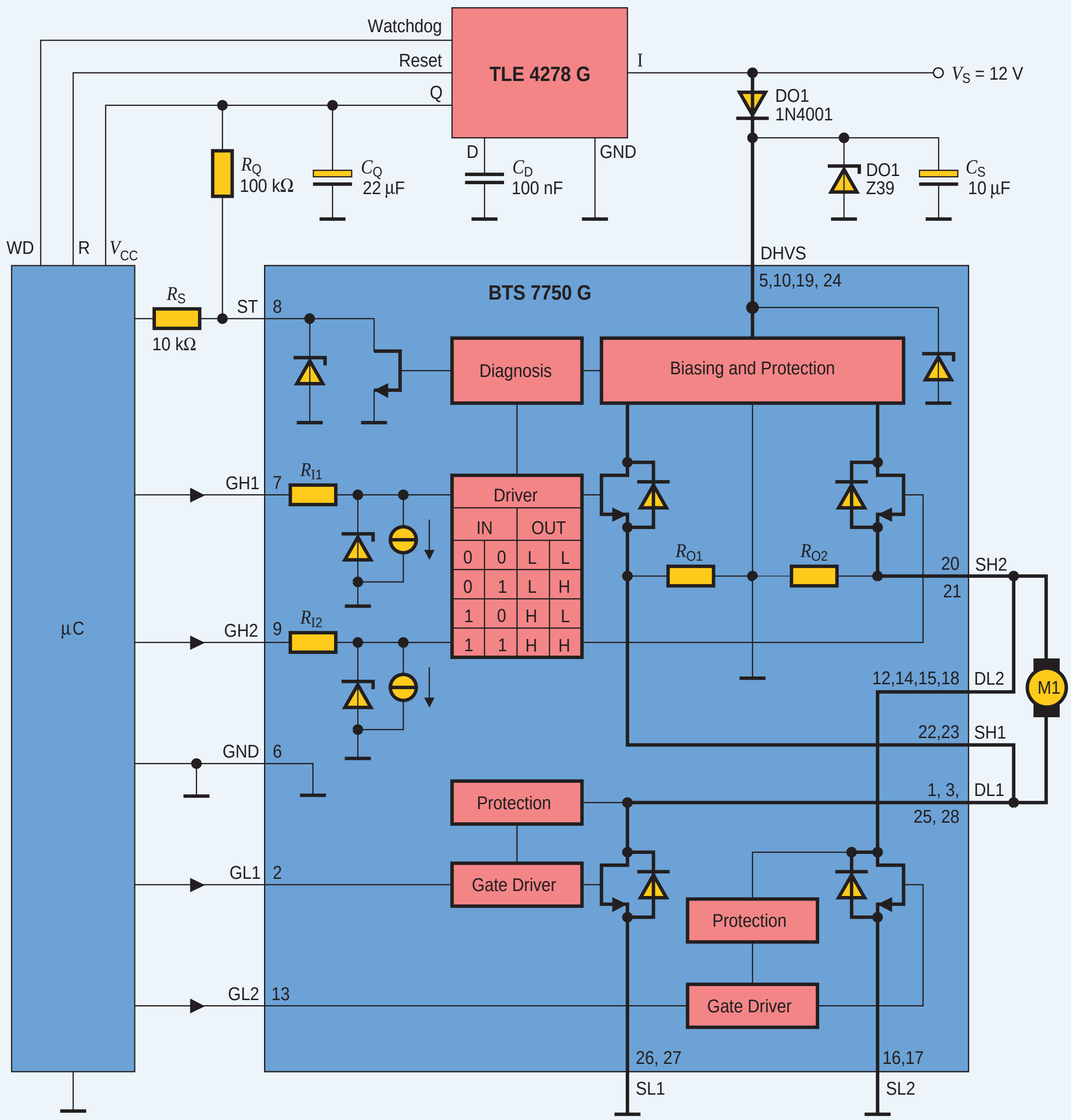
A typical application is illustrated in **Figure 27**. It shows the **BTS 7750 G** as driven by a microcontroller.

The control interface consists of four input and one output lines; one for each switch and one for the status signal, thereby providing maximum flexibility. It should be noted that the charge pumps of the High-Side Switches require a relatively long time (approximately 400 µs) for turning on/off the MOS-FET power stages. This is very slow compared to the extremely fast unprotected Low-Side Switches that are used in the products **BTS 7700 G**, **BTS 7710 G** and **GP**, **BTS 7760 G**, **BTS 7770 G**, and **BTS 780 GP**. When the bridge reverses direction with simultaneous control signals, High- and Low-Side Switches would briefly become conducting, producing a transverse current through the Half-bridge arm. Although this cannot damage the device, as it is controlled by the High-Side Switch, it may cause an unwanted power dissipation pulse. The current pulse also produces electromagnetic emissions. The simple solution to this problem is to provide suitable timing for the drive system; for example, by inserting a dead time of approximately 1 ms between High-Side Switch OFF and Low-Side Switch ON.

The microcontroller is fed by the **Infineon TLE 4278 G** low-drop voltage regulator designed for standalone systems. The microcontroller is initialized using the watchdog and reset functions of this highly EMI-resistant product.

The **TRILITHIC™** motor bridges require no external circuitry apart from the polarity reversal protection diode and a relatively small storage capacitor C_S.

Figure 27
Standard Application Circuit for the TRILITHIC™



Short-Circuit Behavior

First, consider the short-circuit behavior. If the **TrilithIC™** is switched on into a short circuit, the current rises steeply through the power transistors (retarded only by the parasitic inductance) - see **Figure 28**.

The High-Side Switch limits the current to a value depending on the relevant chip temperature (instant 1).

*Note: The peak power in the **P-DSO-28** package during this instant is approximately 12 V x 7 A = 84 W for the **BTS 7700 G** and as much as approximately 12 V x 13 A = 156 W for the **BTS 7710 G**.*

Controlled by the heat dissipation, the current value falls until the temperature protection threshold is reached (instant 2). The bridge is then clocked at a duty ratio controlled by the chip temperature. Observation of the drop voltages (voltage difference between the output and the supply voltage for the high-side switch and between the output and ground for the low-side switch) indicates that the low-side switch produces little dissipation during this time (peak values of only about 0.4 V x 7 A = 2.8 W for the **BTS 7700 G** and about 0.7 V x 13 A = 9.1 W for the **BTS 7710 G**).

To maintain the high-quality standards of Infineon Technologies, all **TrilithICs™** are subjected to this mode of operation for 2000 hours in the product qualification life test.

Pulse-Width Modulation (PWM)

The fast Low-Side Switches allow control of the motor current by pulse-width modulation without any additional components. Low-frequency current control at approximately 1 kHz is illustrated in **Figure 29**.

The commutation voltage and current peaks are clearly visible. The motor current response for a locked motor is shown as well. While the **BTS 7700 G** is shown to be capable of switching currents of 5.5 A, the **BTS 7710 G** is capable of correspondingly more.

The “sign-magnitude” control principle is illustrated in **Figure 30**. Here, the motor inductance is used to determine the current by higher-frequency switching of the relevant Low-Side Switch, such as in switched-mode power supplies. A chopping frequency of 100 kHz was selected for this example.

If the motor current is to be monitored, sense resistors can be inserted in the source lines of the Low-Side Switches. For the **BTS 7780 G**, **BTS 7790 G** and **K**, **BTS 7980 K**, and **BTS 7990 K** devices, no external sense resistor or OP-amp is necessary, because the integrated current sense gives the required information via the combined current-sense/status pin.

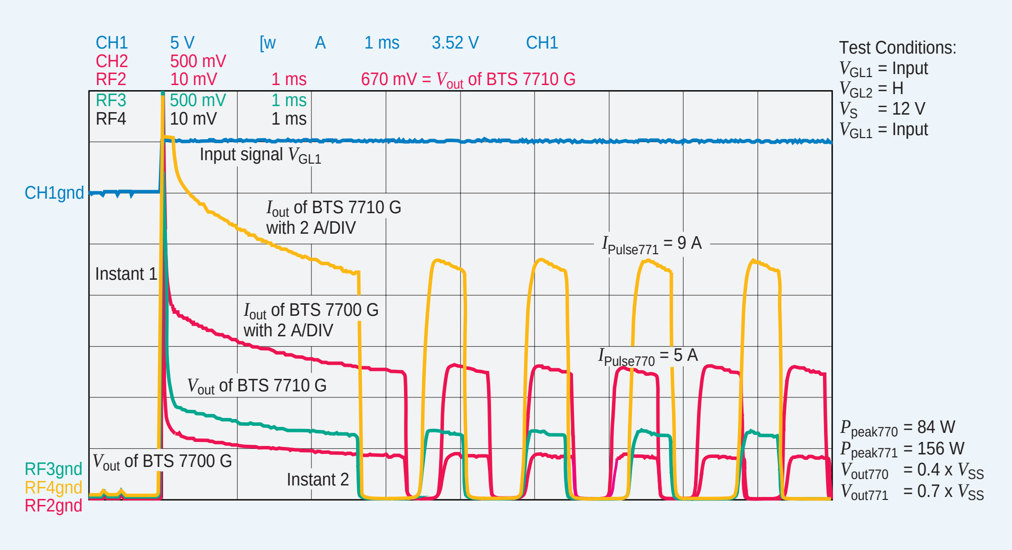


Figure 28
Response of the TRILITHIC™ when Switched on in Response to a Short-Circuited Motor

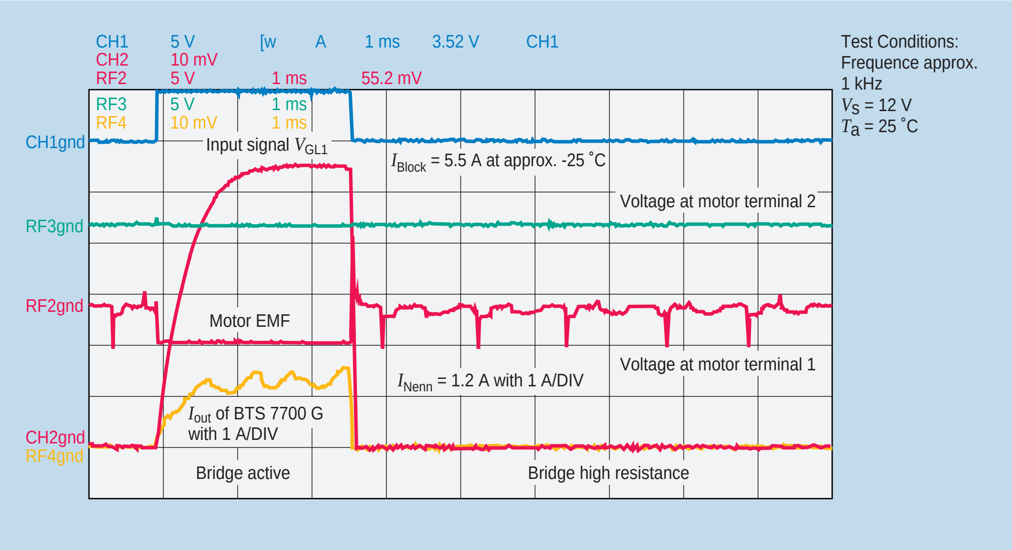


Figure 29
Low-Frequency Motor Current Control with a TRILITHIC™ Using the Low-Side Switch in Switched-Mode

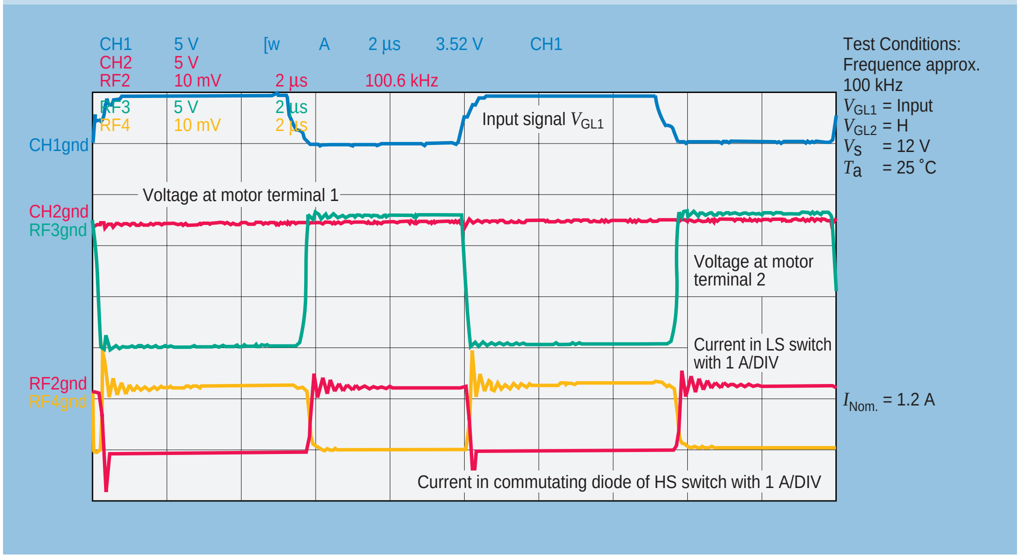


Figure 30
High-Frequency Motor Current Control (sign magnitude) with a TRILITHIC™ Using the Low-Side Switch in Switched-Mode

High-Current Automotive Applications

The TRILITHIC™ concept, implemented in a **P-DSO-28** package for the products **BTS 77x0 G** opened up new applications in the automotive area, such as doorlock, mirror-flap, etc. However, as illustrated in **Figure 31**, the automobile offers a host of applications for motor drivers if the output current of the TRILITHIC™ can be increased to approximately 20 to 30 A peak current. The most important applications are the power window drive (max. 30 A), the sun roof drive (max. 20 A), the power seat drive (max. 30 A) and the windscreen wiper drive (max. 20 A with two-motor drive).

As explained earlier, the **PowerPak P-TO263-15** was developed, starting with the **TO220** package with its massive cooling tab, which permits heat to be dissipated vertically from the chip to a heatsink. This package, equipped with the lowest ON-resistance chips, opens up these high current applications for semiconductor H-bridges.

Advantages over the Relay

The main competitor in this area is still the relay. But car manufacturers are increasingly forcing suppliers to replace electromechanical components by solid-state solutions. And the TRILITHIC™ H-bridges indeed have a number of advantages compared to the relay:

- No external freewheeling diodes are needed
- No mechanical fastening and additional socket
- Assembly-cost reduction due to SMD technology
- Small footprint and building height, less weight
- Higher reliability (mechanical shock, particles)
- No EME- and lifetime problems due to contact firing
- Protection of device and application against short circuit
- Protection of fusing and wire harness by current limitation
- Error-Flag diagnosis
- PWM is possible without additional fast switches
- TTL/CMOS compatible inputs, no pre-driver necessary.

As an example, the upper part of **Figure 32** shows the start-up behavior of a commercially available power window motor, driven by the **BTS 780 GP**. The yellow curve indicates the current pattern in the motor. The start-up operation, which has a peak current of more than 30 A, is completed after approximately 150 ms, where the motor current has dropped below 10 A.

Finally, the lower part of the same figure shows how the PWM capability of the **BTS 780 GP** can be used to improve system performance. Again, the startup phase of a power-window motor is shown. But, in contrast to the hard turn-on, a soft-start is performed here. The active Low-side Switch is chopped and the duty-factor is increased from 0 to 100 % within 300 ms. In this manner, the high peak current present at hard turn-on is avoided, reducing the peak power loss from more than 50 W down to only 4 W, thereby reducing the peak-current requirements for the entire system and increasing the lifetime of the motor.

Outlook - BTS 79x0 K

Finally, there are **Infineon's** leading-edge products: the **BTS 7980 K** and **BTS 7990 K**. For these products, the latest silicon technologies were used in combination with **Infineon's** Chip-on-Chip technology. This means that the devices consists of a sandwich of a low $R_{DS,ON}$ base-chip onto which a top-chip is mounted and connected with chip-to-chip bond wires. All the control, protection, and diagnosis functions are implemented on the top chip which is manufactured in **SPT**-technology. The base-chips are the power stages and are manufactured in **S-FET** technology.

This unique combination leads to an ON-state path-resistance of only 20 mΩ for the **BTS 7980 K** and even 13 mΩ for the **BTS 7990 K**. This ultra-low $R_{DS,ON}$ allows driving of even higher currents and enables applications such as high-end power windows, electric park brake, wiper and the like.

In addition to this, these products have integrated drivers for the Low-Side Switches, allowing powerless control by a mircrocontroller without any additional push-pull stages. The charge necessary to turn on the MOS-FET power stages is delivered by the device itself.

In high-current applications, such as operation of power window, it is often necessary to measure the load current, e.g. to detect a motor-block. This is mostly done by a large metal shunt-resistor and an OP-amp. With the **BTS 7980 K** and **BTS 7990 K**, these components become obsolete, because the products have an integrated current sense. Sense-cells are integrated on the base-chip of the high-side switches and are read out by the top-chip. All in all, the system performance is increased at reduced costs.

Figure 31
Automotive Applications for High-Current Motor Bridges

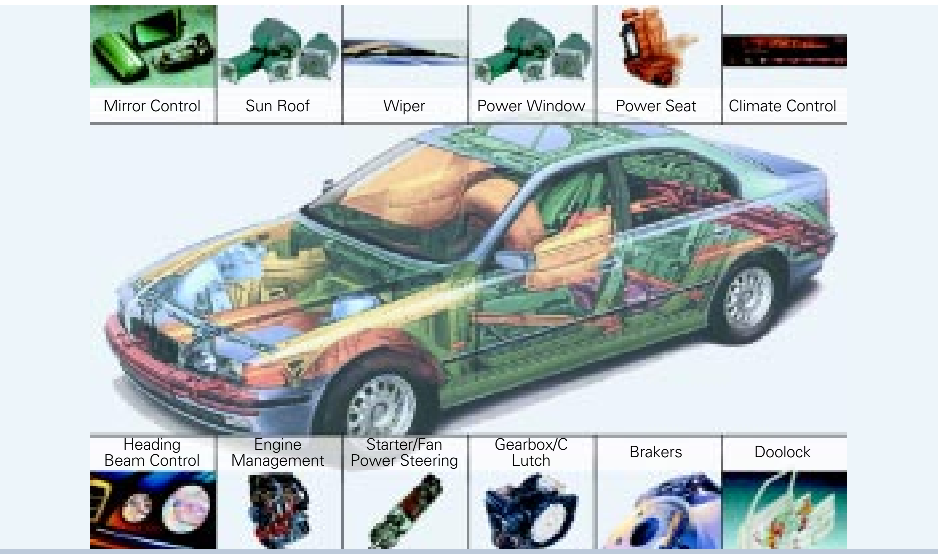


Figure 32
Start of a Power-Window Motor, V_s = 13 V.
Upper: Hard Turn-on,
Lower: Soft-Start

Summary

This special subject book introduces the second generation of Infineon's **TrilithIC™** product family. Technical background on the general idea is given, and the enhancements made since the release of the first **TrilithIC™** generation are described.

It is shown how the products work in practice, putting special attention on the thermal characteristics. The reader is supplied with the data, formulas, and measurement methods necessary to determine the maximum output currents in his application.

The typical application circuit is discussed, and some points to keep in mind when designing in a **TrilithIC™** are stressed. As the main competitor of the **TrilithIC™** is the relay, the advantages of a semiconductor solution like reliability, SMD-technology, small size, and features like TTL/CMOS compatible inputs, integrated freewheeling diodes, PWM capability, and the embedded protection and diagnosis functions are discussed from a system point-of-view.

As a result, the **TrilithICs™** in the **P-DSO-28** package, **BTS 77x0 G**, come up to be the components of choice for automotive applications with load currents of 3 - 5 A and peak current of 8 - 12 A. Examples are central doorlock, mirror-flap, and the like.

For even higher currents, the **PowerPak P-TO263-15** is offered. As an example for automotive high current applications, the power window has been looked at. It has been shown that the **BTS 780 GP** is capable of delivering the necessary peak- and load currents. It is also demonstrated how the PWM capability of the **TrilithIC™** can be used for a soft-start of the motor, which strongly reduces the system requirements.

As a preview, the latest products in development, the **BTS 7990 K** and **BTS 7980 K**, with an even lower ON-state resistance, full protection, PWM capability, and an integrated current sense is presented.

The full range of **TrilithIC™** products now covers virtually all applications in the automotive area which can be addressed by a single-package solution.

Further Information

This special subject book, data sheets of the **TrilithIC™** products, and additional application and device information are available via the Internet under:

www.infineon.com/products/power

or via our local sales representatives.

Infineon Technologies AG’s sales offices worldwide – partly represented by Siemens AG

A

Siemens AG Österreich
Erdberger Lände 26
A-1031 Wien
☎ (+43) 1-17 07-3 56 11
Fax (+43) 1-17 07-5 59 73

AUS

Siemens Ltd.
885 Mountain Highway
Bayswater, Victoria 3153
☎ (+61) 3-97 21 21 11
Fax (+61) 3-97 21 72 75

B

Siemens Electronic Components
Benelux
Charleroisesteenweg 116/
Chaussée de Charleroi 116
B-1060 Brussel/Bruxelles
☎ (+32) 2-5 36 69 05
Fax (+32) 2-5 36 28 57
Email: components@siemens.nl

BR

Siemens Ltda.
Semiconductores
Avenida Mutinga, 3800-Pirituba
05110-901 São Paulo-SP
☎ (+55) 11-39 08 25 64
Fax (+55) 11-39 08 27 28

CDN

Infineon Technologies Corporation
320 March Road, Suite 604
Canada, Ontario K2K 2E2
☎ (+1) 6 13-5 91 63 86
Fax (+1) 6 13-5 91 63 89

CH

Siemens Schweiz AG
Bauelemente
Freilagerstrasse 40
CH-8047 Zürich
☎ (+41) 1-4 95 30 65
Fax (+41) 1-4 95 50 50

D

Infineon Technologies AG
Völklinger Str. 2
D-40219 Düsseldorf
☎ (+49) 2 11-3 99 29 30
Fax (+49) 2 11-3 99 14 81

Infineon Technologies AG
Werner-von-Siemens-Platz 1
D-30880 Laatzen (Hannover)
☎ (+49) 5 11-8 77 22 22
Fax (+49) 5 11-8 77 15 20

Infineon Technologies AG
Von-der-Tann-Straße 30
D-90439 Nürnberg
☎ (+49) 9 11-6 54 76 99
Fax (+49) 9 11-6 54 76 24

Infineon Technologies AG
Weissacher Straße 11
D-70499 Stuttgart
☎ (+49) 7 11-137 33 14
Fax (+49) 7 11-137 24 48

D

Infineon Technologies AG
Halbleiter Distribution
Richard-Strauss-Straße 76
D-81679 München
☎ (+49) 89-92 21 40 86
Fax (+49) 89-92 21 20 71

DK

Siemens A/S
Borupvang 3
DK-2750 Ballerup
☎ (+45) 44 77-44 77
Fax (+45) 44 77-40 17

E

Siemens S.A.
Dpto. Componentes
Ronda de Europa, 5
E-28760 Tres Cantos-Madrid
☎ (+34) 91-5 14 71 51
Fax (+34) 91-5 14 70 13

F

Infineon Technologies France,
39/47, Bd. Ornano
F-93527 Saint-Denis CEDEX 2
☎ (+33) 1-49 22 31 00
Fax (+33) 1-49 22 28 01

FIN

Siemens Components
Scandinavia
P.O.Box 60
FIN-02601 Espoo (Helsinki)
☎ (+3 58) 10-5 11 51 51
Fax (+3 58) 10-5 11 24 95
Email:
scs@components.siemens.se

GB

Infineon Technologies
Siemens House
Oldbury
GB-Bracknell, Berkshire
RG 12 8FZ
☎ (+44) 13 44-39 66 18
Fax (+44) 13 44-39 66 32

H

Simacomp Kft.
Lajos u. 103
H-1036 Budapest
☎ (+36) 1-4 57 16 90
Fax (+36) 1-4 57 16 92

HK

Infineon Technologies
Hong Kong Ltd.
Suite 302, Level 3,
Festival Walk,
80 Tat Chee Avenue,
Yam Yat Tsuen,
Kowloon Tong
Hong Kong
☎ (+8 52) 28 32 05 00
Fax (+8 52) 28 27 97 62

I

Siemens S.p.A.
Semiconductor Sales
Via Piero e Alberto Pirelli, 10
I-20126 Milano
☎ (+39) 02-66 76-1
Fax (+39) 02-66 76 43 95

IND

Siemens Ltd.
Components Division
No. 84 Keonics Electronic City
Hosur Road
Bangalore 561 229
☎ (+91) 80-8 52 11 22
Fax (+91) 80-8 52 11 80

Siemens Ltd.
CMP Div, 5th Floor
4A Ring Road, IP Estate
New Delhi 110 002
☎ (+91) 11-3 31 99 12
Fax (+91) 11-3 31 96 04

Siemens Ltd.
CMP Div, 4th Floor
130, Pandurang Budhkar Marg,
Worli
Mumbai 400 018
☎ (+91) 22-4 96 21 99
Fax (+91) 22-4 96 22 01

IRL

Siemens Ltd.
Electronic Components Division
8, Raglan Road
IRL-Dublin 4
☎ (+3 53) 1-2 16 23 42
Fax (+3 53) 1-2 16 23 49

IL

Nisko Ltd.
2A,Habarzel St.
P.O. Box 58151
61580 Tel Aviv – Isreal
☎ (+9 72) 3-7 65 73 00
Fax (+9 72) 3-7 65 73 33

J

Siemens Components K.K.
Talanawa Park Tower 12F & 17F
3-20-14, Higashi-Gotanda,
Shinagawa-ku
Tokyo
☎ (+81) 3-54 49 64 11
Fax (+81) 3-54 49 64 01

MAL

Infineon Technologies AG
Sdn Bhd
Bayan Lepas Free Industrial Zone 1
11900 Penang
☎ (+60) 4-6 44 99 75
Fax (+60) 4-6 41 48 72

N

Siemens Components
Scandinavia
Østre Aker vei 24
Postboks 10, Veitvet
N-0518 Oslo
☎ (+47) 22-63 30 00
Fax (+47) 22-68 49 13
Email:
scs@components.siemens.se

NL

Siemens Electronic Components
Benelux
Postbus 16068
NL-2500 BB Den Haag
☎ (+31) 70-3 33 20 65
Fax (+31) 70-3 33 28 15
Email: components@siemens.nl

NZ

Siemens Auckland
300 Great South Road
Greenland
Auckland
☎ (+64) 9-5 20 30 33
Fax (+64) 9-5 20 15 56

P

Siemens S.A.
an Componentes Electronicos
R. Irmaos Siemens, 1
Alfragide
P-2720-093 Amadora
☎ (+351) 1-4 17 85 90
Fax (+351) 1-4 17 80 83

PK

Siemens Pakistan Engineering
Co.Ltd.
PO Box 1129, Islamabad 44000
23 West Jinnah Ave
Islamabad
☎ (+92) 51-21 22 00
Fax (+92) 51-21 16 10

PL

Siemens SP. z.o.o.
ul. Zupnicza 11
PL-03-821 Warszawa
☎ (+48) 22-8 70 91 50
Fax (+48) 22-8 70 91 59

ROK

Siemens Ltd.
Asia Tower, 10th Floor
726 Yeoksam-dong, Kang-nam Ku
CPO Box 3001
Seoul 135-080
☎ (+82) 2-5 27 77 00
Fax (+82) 2-5 27 77 79

RUS

INTECH electronics
ul. Smolnaya, 24/1203
RUS-125 445 Moskva
☎ (+7) 0 95-4 51 97 37
Fax (+7) 0 95-4 51 86 08

S

Siemens Components Scandinavia
Österögatan 1, Box 46
S-16493 Kista
☎ (+46) 8-7 03 35 00
Fax (+46) 8-7 03 35 01
Email:
scs@components.siemens.se

RC

Infineon Technologies
Asia Pacific Pte. Ltd.
Taiwan Branch
10F, No. 136 Nan King East Road
Section 23, Taipei
☎ (+8 86) 2-27 73 66 06
Fax (+8 86) 2-27 71 20 76

SGP

Infineon Technologies Asia
Pacific, Pte. Ltd.
168 Kallang Way
Singapore 349 253
☎ (+65) 8 40 06 10
Fax (+65) 7 42 62 39

USA

Infineon Technologies Corporation
1730 North First Street
San Jose, CA 95112
☎ (+1) 4 08-5 01 60 00
Fax (+1) 4 08-5 01 24 24

Siemens Components, Inc.
Optoelectronics Division
19000 Homestead Road
Cupertino, CA 95014
☎ (+1) 4 08-2 57 79 10
Fax (+1) 4 08-7 25 34 39

Siemens Components, Inc.
Special Products Division
186 Wood Avenue South
Iselin, NJ 08830-2770
☎ (+1) 7 32-9 06 43 00
Fax (+1) 7 32-6 32 28 30

VRC

Infineon Technologies
Hong Kong Ltd.
Beijing Office
Room 2106, Building A
Vantone New World Plaza
No. 2 Fu Cheng Men Wai Da Jie
100037 Beijing
☎ (+86) 10-68 57 90-06, -07
Fax (+86) 10-68 57 90 08

Infineon Technologies
Hong Kong Ltd.
Chengdu Office
Room 14J1, Jinyang Mansion
58 Tidu Street
Chengdu,
Sichuan Province 610 016
☎ (+86) 28-6 61 54 46 / 79 51
Fax (+86) 28-6 61 01 59

Infineon Technologies
Hong Kong Ltd.
Shanghai Office
Room 1101, Lucky Target Square
No. 500 Chengdu Road North
Shanghai 200003
☎ (+86) 21-63 61 26 18 / 19
Fax (+86) 21-63 61 11 67

Infineon Technologies
Hong Kong Ltd.
Shenzhen Office
Room 1502, Block A
Tian An International Building
Renim South Road
Shenzhen 518 005
☎ (+86) 7 55-2 28 91 04
Fax (+86) 7 55-2 28 02 17

ZA

Siemens Ltd.
Components Division
P.O.B. 3438
Halfway House 1685
☎ (+27) 11-6 52 -27 02
Fax (+27) 11-6 52 20 42

Internet-address: http://www.infineon.com

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