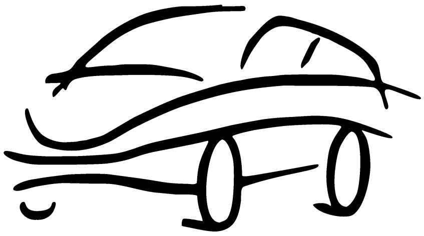
System Engineering Automotive Application Note



Throttle Control with Smart Power Bridges and Microcontrollers of the C500 and the C16x-families.

This application note shows different solutions for electronic throttle control with components of Infineon Technologies.

Authors: Andreas Pechlaner, Hermann Kern, AE SE
Co-Author: Frank Auer, PS PM2

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1. Introduction

In modern cars, electronic control units (ECU) become more and more important. Also classic mechanical systems like throttle valves will in the future be driven by electronic components. An electric motor on the throttle and an electromechanical gas pedal will replace the accelerator lever linkage. An ECU, for example the engine management, controls the new configuration. There are high requirements for the system, regarding the dynamic behavior of the throttle. The throttle position has to be controlled very precisely, and the movement of the mechanics must be very fast. Therefore relatively strong motors and corresponding gearboxes are necessary.
A further feature of such an ETC-system (Electronic-Throttle-Control) is the possibility of idle speed control with the throttle itself. The intake air bypass valve is no longer necessary. The construction of some throttle valves supports this operating mode. In the standard off-position, the throttle is not completely closed. There is a small air gap, fixed with two springs. Around this position, the throttle can be positioned in small angles to control the idle speed. In this case the throttle motor has to rotate in both directions. This operation mode is described in chapter 2.
One main advantage of this step in development is that the throttle is not only controlled by the driver's foot, but also by other systems. A traction control or a vehicle dynamic control, for example, can be realized with only one throttle. In the past, additional throttles were used in series with the main throttle.
For this kind of application Infineon Technologies has a broad range of products for DC-motors as well as for stepper motors. But in this Application Note the focus is directed mainly to the DC-motor drives. Different throttle concepts need different power devices:

- For a simple idle speed control, Infineon can supply you with a smart power bridge called TLE5205-2 or a logic variant of it, the TLE5206-2.
- Discrete solutions, e.g. for throttles which are driven only in one direction, can be realized with several standard power MOSFETs and diodes (see also table in chapter 2.1.).
- The TRILITHIC-Power Bridges like the BTS780GP, the BTS7710GP or the monolithic devices like TLE5209 G and the TLE6209 G are excellently suitable for driving throttle motors with high currents in both directions.
- The microcontrollers of the C500 (8-bit), C16x (16-bit) and TriCore (32-bit) families provide a powerful set of peripherals to control ETC applications.

2. Typical System Configuration

2.1. Driving DC-throttle-motors with additional air-bypass valve

The main characteristic of a throttle valve, which is used tandem with a bypass valve, is the neutral position. In the idle mode it is completely closed with a strong spring and the air-bypass valve controls the idle speed. This means that the motor has only to drive the throttle in one direction. Therefore the electronic driving unit needs a half-bridge or a single-switch together with a freewheeling diode. One standard PWM-

capable output pin of a microcontroller can be used for this task. Dead time generation is not required.
The rated position of the throttle is given by an ETC potentiometer. A potentiometer is coupled with the gas pedal mechanics and gives a linear voltage signal as input to the ECU.
To generate a feedback signal, which is important for the control circuit, two potentiometers are connected internally to the throttle valve. They supply the ECU with two independent analog signals, in order to give information about the actual position of the throttle. Normally one signal decreases while the other signal increases. Both signals are proportional to the revolution angle of the system. In principle only one of these two position signals is necessary for the control circuit. But to improve the system accuracy, the second signal is used as an additional control value (e.g. to compensate temperature effects). Block diagram 1 shows the principle setup of such a valve.

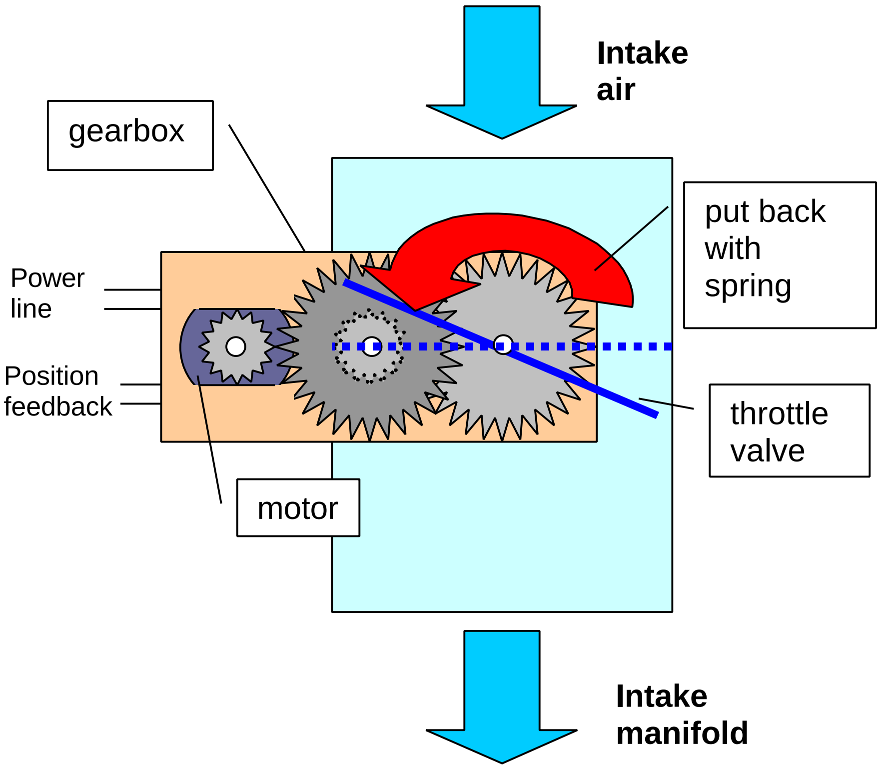


Figure 1: Principle construction of an electromechanical throttle

The complete control circuit for an electronic throttle control may look as shown in Figure 2.1. The throttle motor is supplied by 12V and pulsed with a lowside power switch. For the freewheeling phase a diode can be used. The lowside switch needs only one PWM-channel of the microcontroller. If a very low power dissipation is required, the diode can be replaced by a further power transistor (the same type as the lowside switch, in a half-bridge configuration). Figure 2.2 shows such a circuit. The highside switch is active while the motor inductance is in the freewheeling phase.

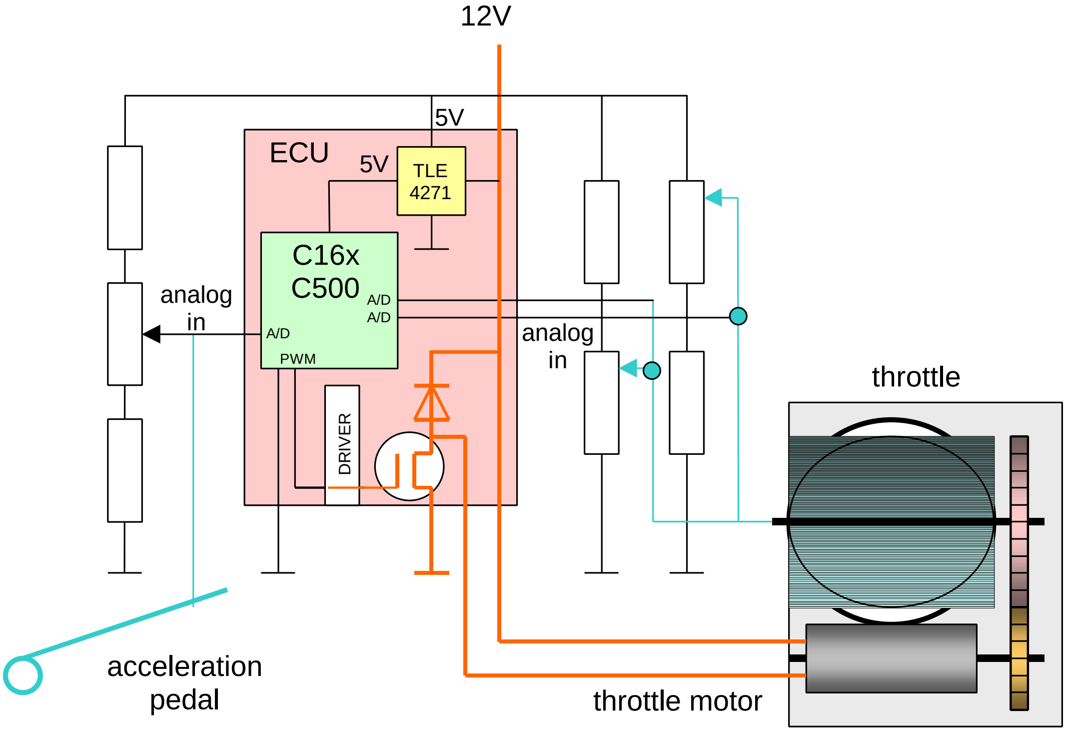


Figure 2.1.: system configuration with freewheeling diode

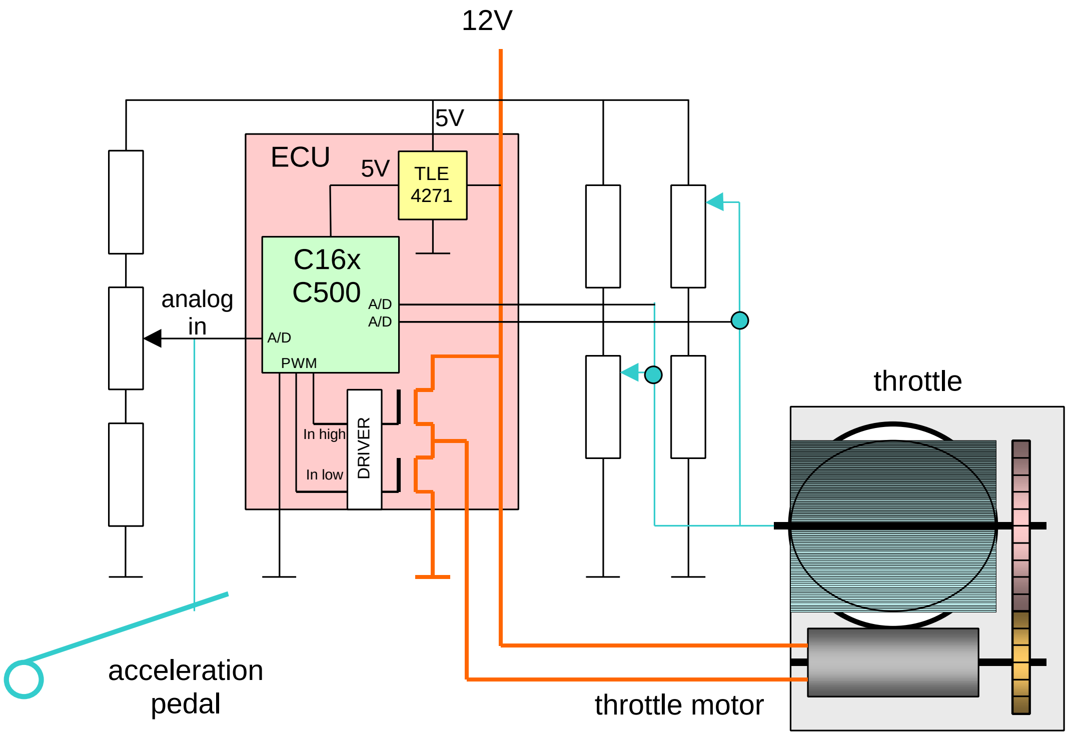


Figure 2.2.: system in half-bridge configuration

That way there is only a small voltage drop across the highside FET and the power dissipation decreases dramatically. In this case some more effort has to be done on the driving circuit. A special half-bridge driver and two PWM-channels of the microcontroller are necessary. Crossover currents in the half-bridge should not occur. Therefore a special dead time control of the two PWM signals, generated by the microcontrollers CCU, must be realized. Figure 3 shows this relationship.

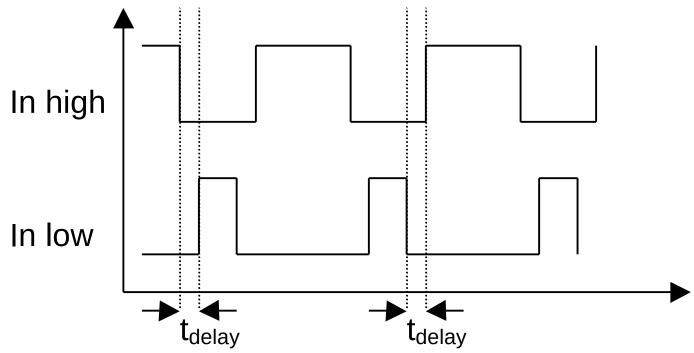


Figure 3: driving of a half-bridge with active freewheeling

To avoid a noisy operation of the throttle, it is recommended to use a driving frequency between 20kHz and 30kHz. The deflection of the throttle valve is adjusted by the duty cycle of the signal. To reach high dynamic behavior in combination with high positioning accuracy the PWM-signal needs the full range of 0-100% duty cycle and a high resolution of at least 7bits.
The potentiometers of the acceleration pedal and the throttle should be supplied with the stable 5V of a voltage regulator. That way the input and feedback signals will be very precise. For the evaluation of the analog signals, the A/D converter should have a resolution of 10bit at least.
Different throttles work with motor peak currents of 5A to 15A. The needed power switches and, if used, the freewheeling diode have to be calculated according to the maximum allowable power dissipation of the packages, the thermal resistance of the board and the maximum permitted power losses in the ECU.
Infineon Technologies supports you for such a calculation also with Simulation models for Spice and Saber (download from the Internet page: http://www.infineon.com/products/36/36.htm).

Load	Current	Rthja=30K/W	Rthja=10K/W
Throttle motor L=1.3mH f=20kHz, dc=96%, Tamb=85°C	I=6A I=10A I=12A	BUZ101S(L), SPD21N05L BUZ102S(L), BUZ111S(L)	BUZ104S(L), SPD13N05 BUZ101S(L), SPD21N05L BUZ103S(L), SPD28N05L
Bypass valve L=40mH F=100Hz Dc=50% Tamb=85°C	I=0.5A	BSP78, BSP320S,	BSP296, BSP295,...

Table 2.1.: Standard products for throttle control.

Table 2.1. contains some power-product proposals for this kind of throttle control based on those simulation models. The assumption for these results was a ambient temperature of 85°C. If higher ambient temperatures occur, the simulation has to be repeated with these new conditions. The simulation circuit for the throttle motor was similar to Figure 2.1. The bypass valve has two windings, one for turning clockwise and one for turning counterclockwise. So two of the recommended switches are necessary.

2.2. Driving DC-Throttles without additional air-bypass valve

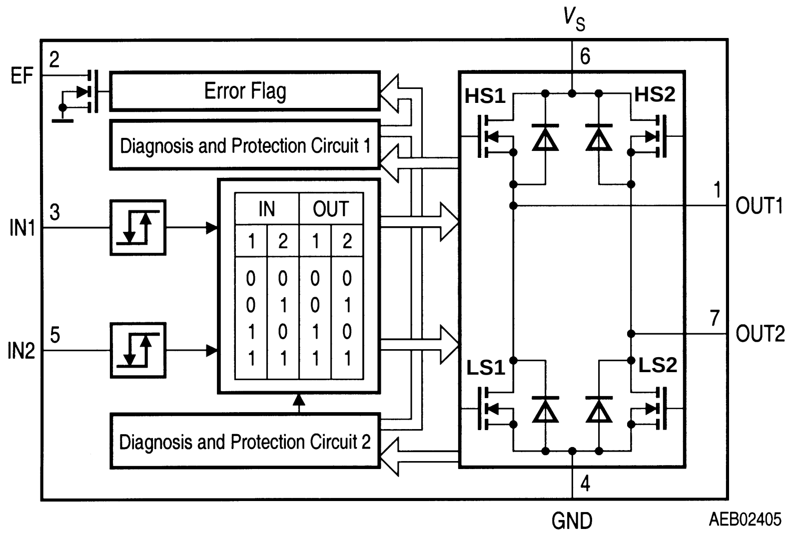
As described in the introduction, the throttle itself can also adjust the idle speed. Small air masses must be controlled precisely. Therefore it is necessary to drive the motor very exactly in both directions around the neutral position. This system requires power-stages in an H-bridge configuration to realize the bi-directional mode of the DC-motor. The capture compare unit of the microcontroller should support the functionality of full bridge driving (e.g. CAPCOM6 of C504, C164).

2.2.1. Control of the idle speed only

Some throttles adjust only the idle speed with a motor, but the acceleration and driving of the engine is still done by a mechanical coupling to the acceleration pedal. As already mentioned Infineon Technologies has two products in the portfolio which support full bridge driving combined with some additional functionality. The devices can be controlled by PWM up to 2kHz.

Type	Electrical parameters	Functionality	Protection features	Packages
TLE5205-2	>I_{cont}=5A >I_{peak}=6A >Vbb_{max}=40V >R_{DSon}=200mΩ >f_{max}=2kHz	>Turn clockwise >Turn counter clockwise >Brake with lowside switches on > Open load detection in OFF-state	>full short circuit protection >over-temperature protection >diagnosis with error flag >under-voltage lockout >CMOS/TTL input >No crossover current	>P-TO218-7-11 >P-DSO-20-10 >P-TO263-7-1 >PTO220-7-12
TLE5206-2	Same as TLE5205-2	Same as TLE5205-2, but brake H H instead of open Load detection	Same as TLE5205-2	Same as TLE5205-2

Table 2.2.1.: product overview for idle speed control



IN 1	IN 2	OUT 1	OUT 2
0	0	0	0
0	1	0	1
1	0	1	0
1	1	1	1

Figure 4.: Block diagram of TLE5206-2

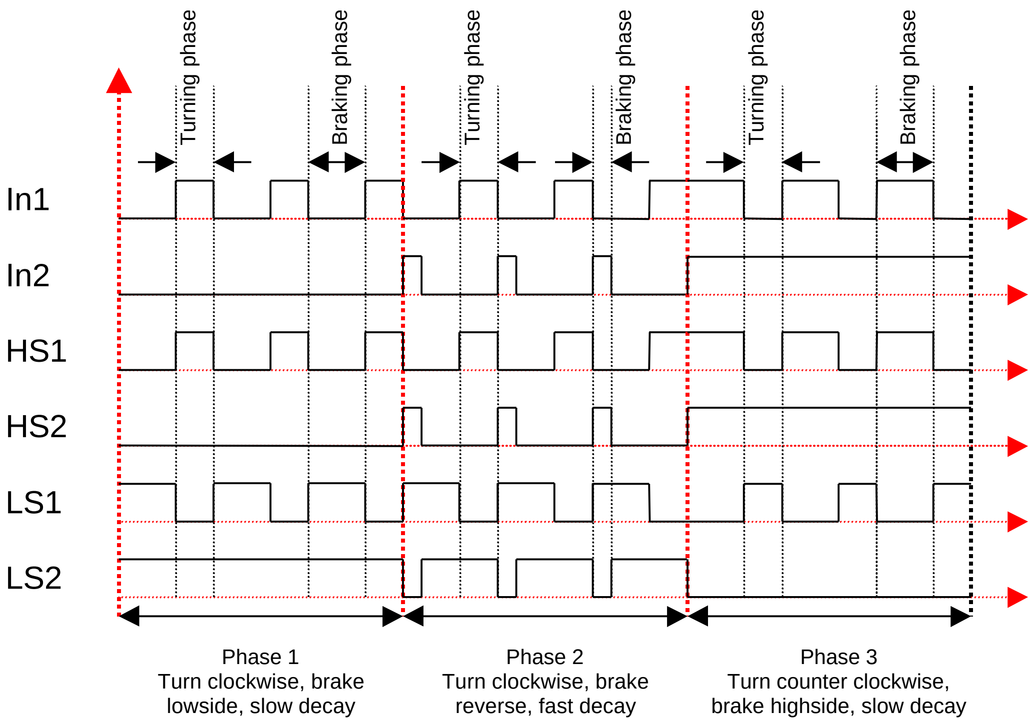


Figure 5.: Different solutions for driving the TLE5206-2

The functional modes (turn clockwise, turn counter clockwise and brake) are determined by the two input pins. Depending on the allowed power dissipation and the intended decay time the freewheeling can be done by switching over to the second path of the bridge, with the integrated diodes or with the brake-function, where both lowside switches are turned on. The TLE5206 additionally has the

possibility to alternatively switch on the two highside switches in the brake phase. An error flag monitors the state of the system. Any faults like short circuit to ground or Vbb, or open load can be detected. That way a safe operation is always guaranteed. Table 2.2.1 gives a short overview. Only two output pins (e.g. from a PWM-unit or software controlled) of the microcontroller allow very complex driving modes. A block diagram of the driver, shown in Figure 4, explains the effects of different possible input signals on the outputs.
In Figure 5 is an example of different input timings for a bi-directional driving of the throttle. In phase 1, the motor opens the throttle slowly, because the current is reduced with the duty cycle of the PWM on IN1. While IN1 is low, the two lowside switches are in on state and brake the motor. The freewheeling energy of the motor-inductance decays to ground and doesn’t disturb the supply-circuit. The second possibility to realize the freewheeling is shown in phase 2. The bridge is switched on for a short time in the opposite direction. That way the decay is very fast and the braking of the throttle is very strong. This action allows a precise positioning of the valve and decreases the power dissipation; but it causes negative peaks on the supply current. Phase 3 is the counter clockwise movement of the system. Exemplary, it shows a solution for a slow decay in the highside switches, which is possible only with the TLE5206-2.

2.2.2. Driving the full range of a throttle with standard H-bridges

If the complete deflection of the throttle is done with the motor, like in chapter 1 described, standard H-bridges like the BTS780GP or the BTS7710GP can be used. They are suitable for big throttles with high currents. These bridges consist of a two-channel smart power highside switch and two standard power-MOSFETs, which are protected by the highside switches against short of load and short circuit to ground. Figure 6 shows this construction. The power-MOSFETs can be pulsed with very high frequencies, up to 100kHz. But the highside switches can not be switched faster than 1kHz. Therefore they are not suitable to be switched on in the freewheeling phase of the motor (active freewheeling) at high frequencies. However, it is no problem to use the reverse diode of the highside switch as freewheeling diode. The special power package allows the bigger power losses caused by this kind of driving. An example for a driving circuit of a Trilithic-bridge is given in Figure 7. The highside switches can be controlled directly by the microcontroller pin. This is not true for the lowside switches. They have a gate capacity that has to be charged. In particular if they should be switched very fast, the required currents will be in the range of 200mA. A microcontroller output pin can’t supply such high currents by itself. Therefore a driver stage is necessary. This can be realized with discrete small signal transistors, or with special buffer ICs. Depending on the frequency you will need driving currents up to 500mA. The highside switches have an open-drain output for diagnosis feedback. With external pull up resistors, this signal is evaluated by the microcontroller. The resistor in the logic-GND path protects the device against over voltage peaks and reverse polarity. (A special Application-Note for reverse polarity of Smart-Power-Switches is available on the Internet: http://www.infineon.com/products/36/36.htm).

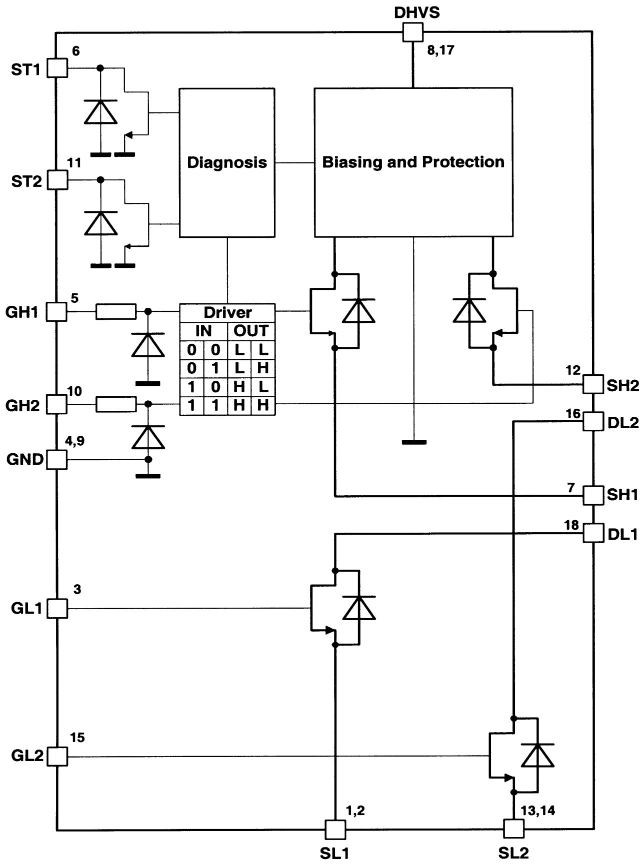


Figure 6.: Construction of a Trilithic bridge

Table 2.2.2 gives an overview of the TRILITH-bridges, which are recommended for throttle control systems with high currents.
If only low currents are required for a throttle control system, there are some more products available. The BTS7700 or the BTS7760, for instance, have the same functionality as the above-described devices, but with a P-DSO28 package. Therefore the occurring powerdissipation may not be too high. You can find more detailed information about these products in the datasheets.

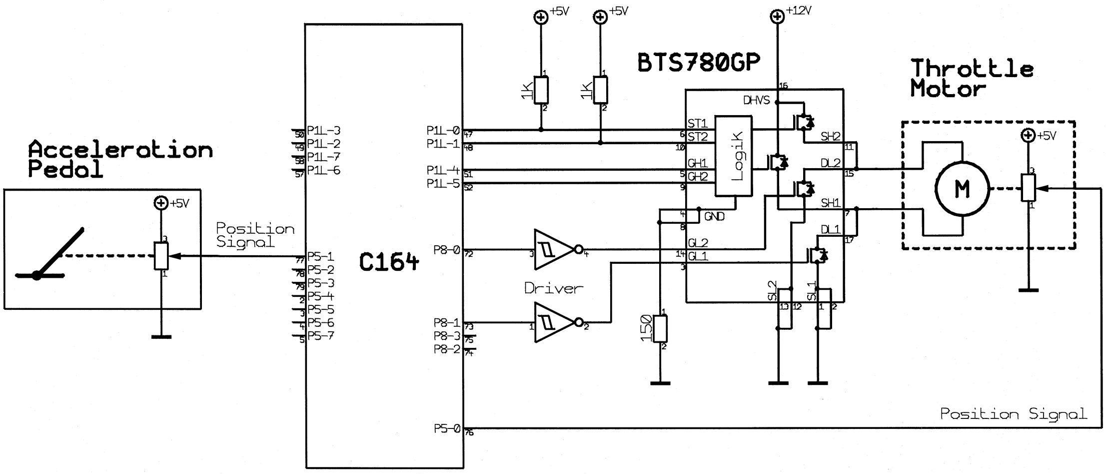


Figure 7.: Driving circuit of a BTS7xx for throttle control

Type	Electrical parameters	Functionality	Protection features	Packages
BTS780GP	>I_{cont}=15A >I_{peak}=30A >Vbb_{max}=40V >R_{DSon}=50mΩ >f_{max}=1kHz (HS)	>free configurable as H-bridge or 2 independent half bridges >fast PWM (up to 100kHz) with low-side switches >active freewheeling at frequencies <1kHz >advanced package for high power dissipation >very high peak current capability	>short circuit protection to ground >short of load protection >over-temperature protection >diagnosis with 2-bit error flag >over and under-voltage lockout >CMOS/TTL input >open load detection	>P-TO263-15-1

BTS7710GP	>I_{cont}=6A >I_{peak}=12A >Vbb_{max}=40V >R_{DSon}=120mΩ >f_{max}=1kHz (HS)	>free configurable as H-bridge or 2 independent half bridges >fast PWM (up to 100kHz) with low-side switches >active freewheeling at frequencies <1kHz >advanced package for high power dissipation >very high peak current capability	>short circuit protection to ground >short of load protection >over-temperature protection >diagnosis with 2-bit error flag >over and under-voltage lockout >CMOS/TTL input >open load detection	>P-TO263-15-1

Table 2.2.2.: Product overview

2.2.3. Driving with dedicated bridges for throttle control

Last but not least, Infineon Technologies has two new power-products on the roadmap, which are specially designed for ETC-Systems (TLE5209 and TLE6209). Similar to the TLE5205-2 family these devices consist of an H-bridge and are controlled by two input pins. However the new devices have a different input logic. One of the two pins is a direction control, and the other is an PWM-input. The first one, the direction pin, adjusts the different modes “forward” and “reverse”. The moving speed of the throttle control system is given by the duty-cycle of the PWM signal on the second input pin. That way only one fast PWM-channel of the microcontroller is required.
The TLE5209 is a low cost solution. It is designed for continuous currents up to 5A and peak currents of 7,5A at maximum which makes it suitable for small throttles or for throttle idle speed control. The maximum PWM-frequency is 1kHz. Internal monitoring functions protect the device against all possible faults. Two status pins allow an error diagnosis of the full-bridge. Figure 8 shows a block diagram of this device.
An example of how to drive the TLE5209 in different modes is given in Figure 9. If the direction pin is switched as in phase 2, even a fast decay is possible. If both inputs are on a high level, the bridge turns the current flow in the reverse direction. During this phase the motor is braked very strong. As a result, the decay time decreases compared to the normal braking phase, where only both highside switches are turned on.
In contrast to the TLE5209, the TLE6209 is a high-end product. More current, higher frequency, programmable operating modes and a serial interface are the main

characteristics of this Smart Power Bridge. Table 2.2.3. gives an overview of these two motor-bridges.

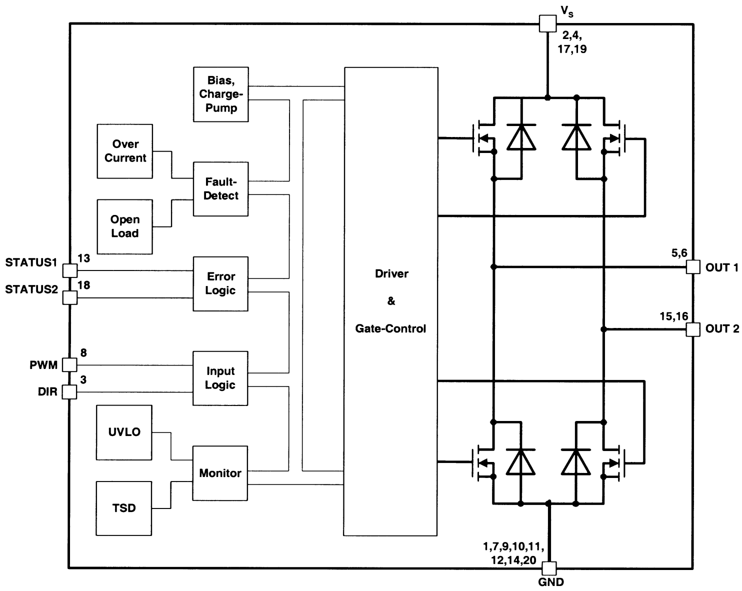


Figure 8.: Block diagram of TLE5209

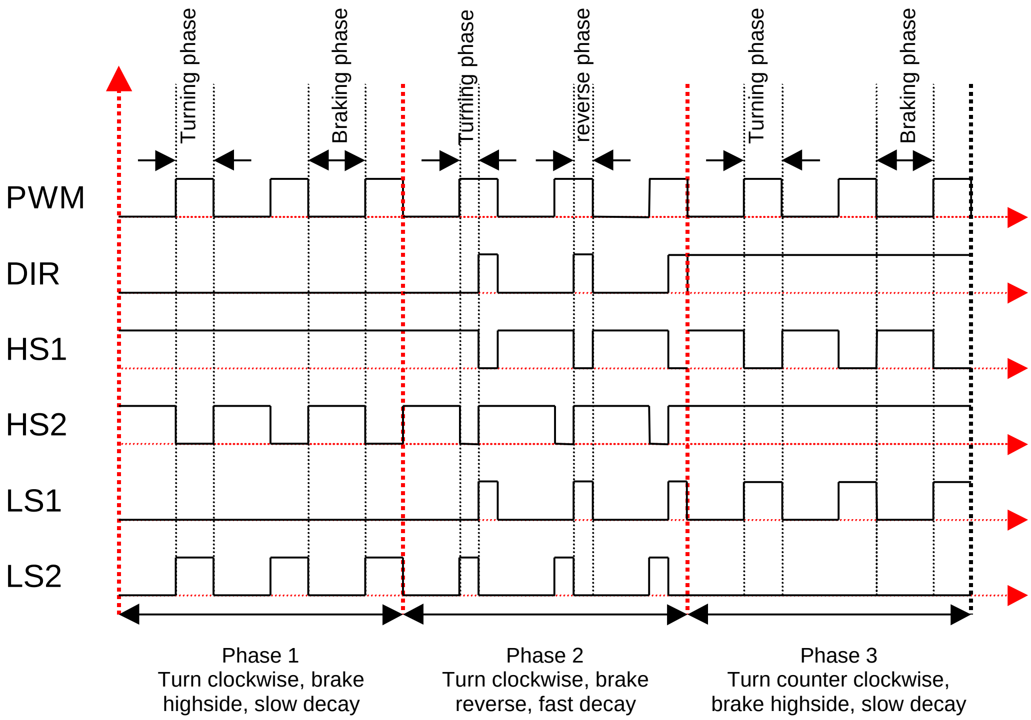


Figure 9.: Different input combinations for TLE5209

Type	Electrical parameters	Functionality	Protection features	Packages
TLE5209	>I_{cont}=5A >I_{peak}=7.5A >Vbb_{max}=40V >R_{DSon}=280mΩ >f_{max}=1kHz	>Turn clockwise >Turn counter clockwise >Brake with highside switches on >Brake with reverse operation (active freewheeling by input signal)	>full short circuit protection >over-temperature protection >diagnosis with 2 error flags >under-voltage lockout >CMOS/TTL input >No crossover current	>P-DSO-20-10
TLE6209 R	>I_{cont}=6A >I_{peak}=7A >Vbb_{max}=40V >R_{DSon}=150mΩ >f_{max}=25kHz >adjustable current regulation >very low standby current (20µA)	>Turn clockwise >Turn counter clockwise >Brake with highside switches on >Brake with reverse operation >active free-wheeling programmable >adjustable current limitation	>full short circuit protection >over-temperature protection >over-voltage protection >SPI interface for diagnosis- and control-functions >over and under-voltage lockout >CMOS/TTL input >No crossover current >over-temperature pre-warning and warning	>P-DSO-20-10

Table 2.2.3.: Product overview

As mentioned in the table, the TLE6209 is suitable for PWM applications up to 25kHz. This is requested more and more by many car manufacturers. Therefore this product is also optimized regarding EMI-behavior. A voltage slope regulation minimizes the electro-magnetic-imission. How the TLE6209 can be used in an application is shown afterwards in the block diagram.
A full duplex 8 bit SPI-Interface is used to control the power device. Different operating modes are set by sending a command on the SPI. The current limitation can be adjusted with the bits 0 and 1. The current range is in 1A steps between 4A and 7A. Bit 2 defines the operation modes “fast decay” or “slow decay”. The current in the current limitation mode is internally controlled by PWM. The off time of the PWM signal, which is responsible for the flyback pulses on the output, can be chosen between 20µs and 80µs by the bits 3 and 4. Bit 5 is not used, bit 6 activates or deactivates the over-voltage-lock-out, and bit 7 resets the status register.

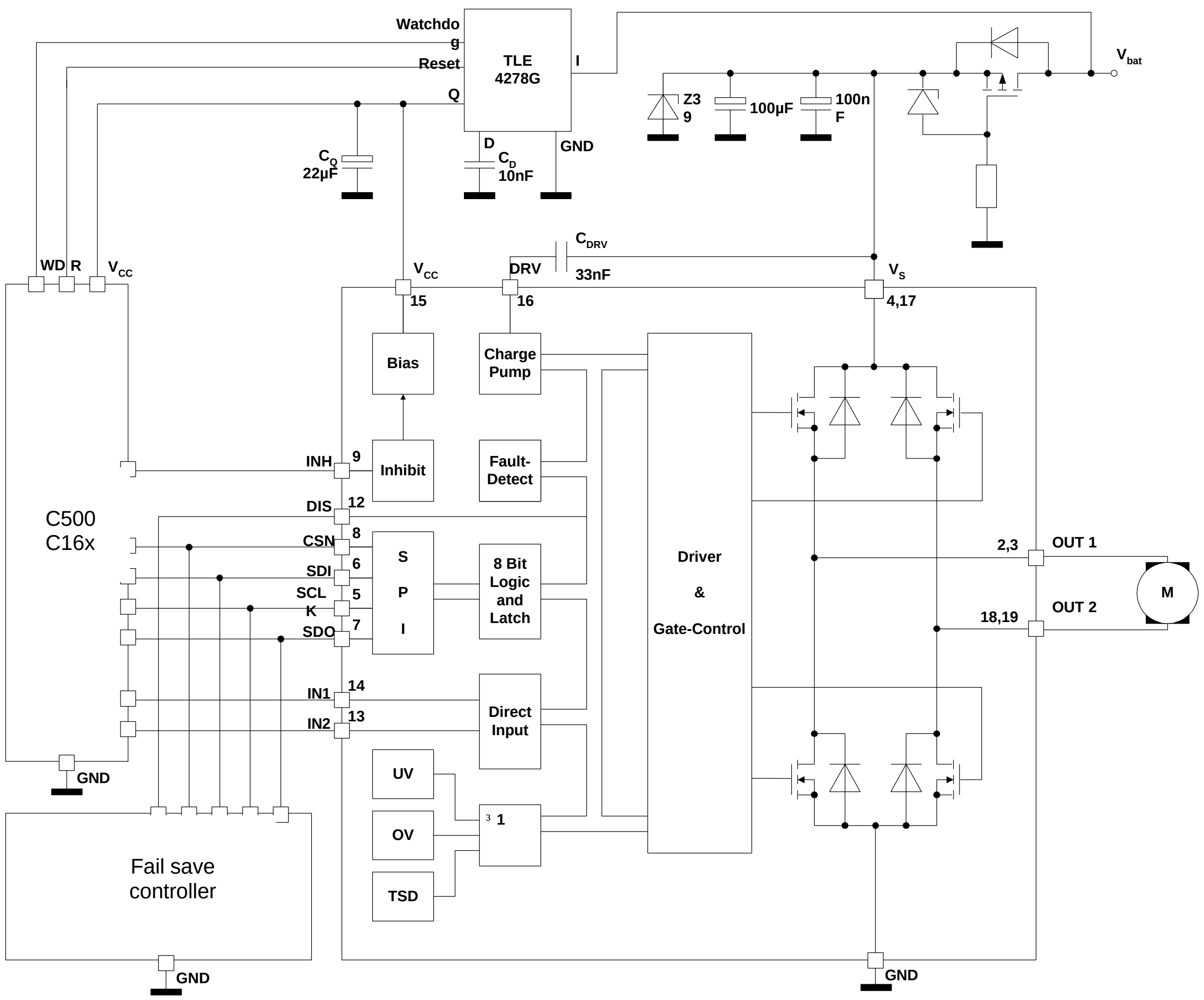


Figure 10.: Application circuit of TLE6209

The simultaneously received bits display the status of the TLE6209. Bit 0 is an error flag, which is set if any fault occurs. If it is a low signal, the rest of the byte can be ignored. But if this first bit has a high level, the following 7 bits have to be checked. Bit 1 gives a temperature prewarning, if the junction temperature is between 140°C and 160°C. A temperature warning is given on bit 3, if the junction is between 160°C and 180°C. If both bits (1 and 2) are high, an internal over-temperature shutdown has occured. The faults “open load”, overcurrent in the high-side switch (=short circuit to GND) and overcurrent in the low-side switch (= short circuit to Vs) are represented by the bits 3, 4 and 5. Bit 6 is unused and bit 7 displays a fail of the supply voltage. The following table summarizes this SPI-data-protocol again:

BIT	INPUT PROTOCOL
7	Status Register Reset
6	OVLO on/off
5	Not used, static high
4	MSB of PWM-Off-time
3	LSB of PWM-Off-time
2	Slow/fast decay
1	MSB of current limit
0	LSB of current limit

BIT	OUTPUT PROTOCOL
7	Power supply fail
6	Not used
5	Overcurrent LS / short to Vs
4	Overcurrent HS / short to GND
3	Open load
2	Temperature warning
1	Temperature prewarning
0	Error flag

2.3. Microcontroller for ETC Systems

Infineon Technologies provides a variety of excellent microcontroller architectures which contain with a rich set of powerful peripherals dedicated for automotive applications: the 8 bit C500 Family, the 16 bit C16x family which has become a standard for automotive real time applications and last but not least the 32-bit TriCore architecture.

As discussed in the previous chapters there are several approaches for building up an electronic throttle control system. The overall system functionality and performance depends on the partitioning of power devices and microcontrollers. Each driver for the DC motor has different demands on the types of control signals provided by the microcontroller. This chapter of the application note introduces several PWM-Units and Serial Peripheral Interfaces (SPI) implemented on Infineon Technologies 8 and 16 bit microcontrollers. Moreover, different ways of controlling the drivers will be discussed.

2.3.1. Basic Requirements on Microcontrollers

From the microcontrollers point of view an electronic throttle control system consists of a DC motor whose position has to be placed very precisely. The driving of a DC motor requires dedicated power devices. General purpose I/O pins, PWM signals, or the SPI (Serial Peripheral Interface) are used for controlling the motor driver.

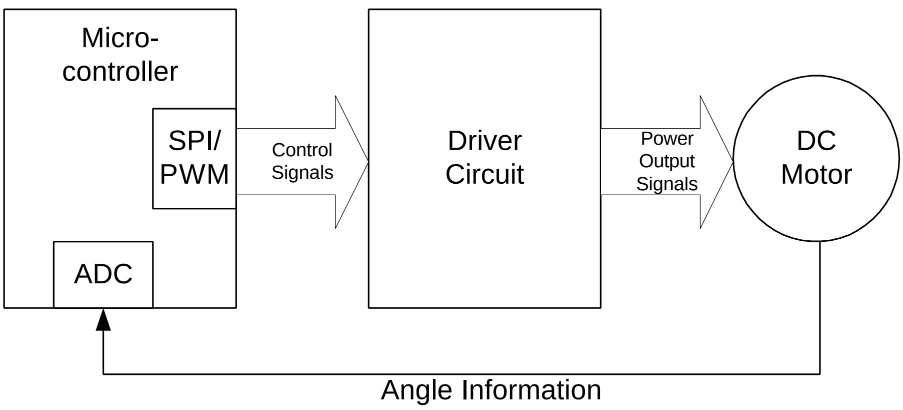


Figure 11.: Block Diagram of an ETC system

The position feedback is given by a potentiometer which corresponds to the throttle angle. This analog signal is converted to an digital Information by an ADC (Analog to Digital Converter).

2.3.2. Overview on Infineon Technologies Microcontrollers

The following table summarizes the features of several derivatives of the Infineon Technologies 8 and 16 bit microcontroller family. The scope is on PWM capability, SPI and ADC functionality.

C500 8 bit Microcontroller Family

C504		
PWM	ADC	SPI
CAPCOM unit 3 channel, 16 bit capture/compare unit 1 channel, 10 bit compare unit Automatic dead time generation Min. resolution 50ns (fosc/2) @40MHz 20kHz with 10 bit accuracy @40MHz	10 bit ADC with 8 channels	no

C505CA		
PWM	ADC	SPI
CAPCOM unit 4 channel, 16 bit capture/compare unit Min. resolution 300ns (fosc/6) @20MHz 20 kHz with 7 bit accuracy @20MHz	10 bit ADC with 8 channels	no

C515C		
PWM	ADC	SPI
CAPCOM unit 4 channel, 16 bit capture/compare unit Min. resolution 600ns (fosc/6) @10MHz 20kHz with 6 bit accuracy @10MHz	10 bit ADC with 8 channels	8 bit data width

C16x 16 bit Microcontroller Family

C161Cx		
PWM	ADC	SPI
CAPCOM unit 32 channel, 16 bit capture/compare unit, 16 I/O Min. resolution 400ns (fosc/8) @20MHz 20kHz with 6 bit accuracy @20MHz	10 bit ADC with 12 channels	2-16 bit data width

C164CI		
PWM	ADC	SPI
CAPCOM6 3 channel, 16 bit capture/compare unit 1 channel, 10 bit compare unit Automatic dead time generation. Min. resolution 50ns (fosc) @20MHz 20kHz with 10 bit accuracy @20MHz CAPCOM unit 16 channel Min. resolution 400ns (fosc/8) @20MHz 20kHz with 6 bit accuracy @20MHz	10 bit ADC with 8 channels	2-16 bit data width

C167CR		
PWM	ADC	SPI
CAPCOM unit 32 channel, 16 bit capture/compare unit, 32I/O Min. resolution 400ns (fosc/8) @20MHz 20kHz with 6 bit accuracy @20MHz PWM unit 4 channel 16 bit compare unit Min. resolution 50ns (fosc) @ 20MHz 20kHz with 10 bit accuracy @20MHz	10 bit ADC with 16 channels	2-16 bit data width

Table 2.3.2.: PWM, ADC and Communication functionality of Infineon µCs

2.3.3. Controlling different types of power devices

2.3.3.1. Controlling single switches and half-bridges

Single switches and half-brides in configurations as discussed in the previous chapter require one or two PWM capable output pins, respectively. In case of a single low side switch a standard PWM channel is used. 20 kHz is a typical setting for the PWM frequency. Depending on the architecture used, 8 or 16 bit, and the peripheral used different resolutions can be achieved. Please refer to table x above.
In general these discrete semicondutors cannot be driven directly by a microcontroller pin. For example, the output stages of the C16x family have the following characteristics:

Output high voltage:	$V_{OH} = 0.9\ V_{DD}$ $V_{OH} = 2.4V$	@ $I_{OH} = -250µA$ @ $I_{OH} = -1.6mA$
Output low voltage:	$V_{OL} = 0.45V$	@ $I_{OL} = 1.6mA$

Dedicated pins on the C164CI are capable to sink or source more current. These pins are assigned to the CAPCOM6 unit.

Output high voltage:	V_{OH} = 0.9 V_{DD} V_{OH} = 2.4V	@ I_{OH} = -500µA @ I_{OH} = -2.4mA
Output low voltage:	V_{OL} = 0.45V	@ I_{OL} = 2.4mA

The CAPCOM6 unit is a very powerfull peripheral for PWM generation. It allows automatic deadtime generation, which is essential for controlling half bridge arrangement to avoid cross currents. Another highlight of this peripheral is the high PWM resolution of 50ns @ fcpu = 20MHz. This allows generation of 20kHz PWM frequencies with an accuracy of 10bit.

2.3.3.2. Controlling Thrilitic power-bridges

The BTS780 GP and BTS7710 GP allow the driving of a DC motor in both directions. Line drivers are required for controlling the low side switches. In contrast to that the high side switches can be directly connected to a general purpose output. The low side switches can be controlled either by one of the CAPCOM units or by the PWM Unit of Infineon microcontroller. Please refer to table 2.3.2. above.

2.3.3.3. Controlling specialized bridges

The TLE5205, TLE6205 and TLE5209 can be directly controlled by a microcontroller. These devices are controlled by more or less complex pulse trains. This can be done by using PWM or CAPCOM units. As the switching frequency of the control signal is in a range of just a few kHz (see details in the data sheets) it can really make sense to generate these pulse patterns by setting and clearing output pins. This can be done with a reference to an internal timer source.

2.3.3.4. Controlling bridges with SPI

The TLE6209 provides a SPI compatible Interface for data exchange with a microcontroller. Complex control and diagnosis information can be transmitted via a three wire serial interface. The 8 and the 16 bit microcontroller families support the SPI standard. They differ in data width and in the maximum achievable baudrate. The eight bit data format of the TLE6209 can be handled by the C515C 8 bit microcontroller and by all derivatives of the C161, C164 and C167 with the on-chip SSC (Synchronous Serial Channel).

3. Conclusion

Infineon Technology is the right partner for automotive electronics. Innovative products and a lot of experience in the field of semiconductor components Not only power transistors and microcontrollers, but also voltage regulators, diodes and sensors are in the product portfolio.
If you need more information about the described products, just have a look into the internet homepage of Infineon (www.infineon.com) . There you can find any datasheet, application notes, simulation models, product short descriptions and contact addresses. In our system engineering department (AE SE) you will get also help for design in and engineering questions.