

BLDC Motor Control in Automotive Environment

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Abstract

Automotive environments that approach the operational limits of semiconductor devices are a challenge for system designers. Under-the-hood applications require a wide supply voltage range and have high maximum junction temperatures. Designers must integrate increasing functionality within their electronic units, hence the ICs need to provide higher device integration levels. The environment is also subject to stronger EMC radiation levels. Actuators close to the turbocharger are typical examples for such high-temperature applications. These actuators serve to adjust the flaps of exhaust gas recirculation systems, the so-called waste gate. Further examples are coolant or oil pumps operating at 125°C and more.

Remove Belt-Driven Actuators

With limited engineering resources and more stringent CO₂ emission requirements, designers need to consider all the power appliances within a car. It is no longer sufficient to optimize just the engine. Continuously operating loads waste a lot of energy. Loads driven by the engine's belt are using power, even if not needed. It would be preferable to operate the water pump or the cooling fan, for example, according to

actual requirements. Driving uphill the fan and water pump must dissipate plenty of heat. When driving downhill the motor is running in fuel cut-off and minimal heat is generated. Unlike belt-driven devices, you can control electronic actuators according to real demand while considering all relevant parameters.

Unlike DC motors, BLDC (brushless DC) motors allow precise control over a wide dynamic range of revolution speed. BLDC motors help to efficiently and flexibly control loads according to the power actually needed. This is why electronically-commutated actuators should be your first choice for automotive applications such as power steering, HVAC (heating, ventilation and air conditioning) fans, power windows, and all kind of pumps.

Automotive Requirements

High Integration Level

A typical BLDC motor control application comprises various functions. There is the microcontroller (MCU), high-current external MOSFETs, a pre-driver to switch those external MOSFETs, the power supply plus a voltage regulator for the digital supply of the ECU (engine control unit), and a communication interface to the car (see figure 1).

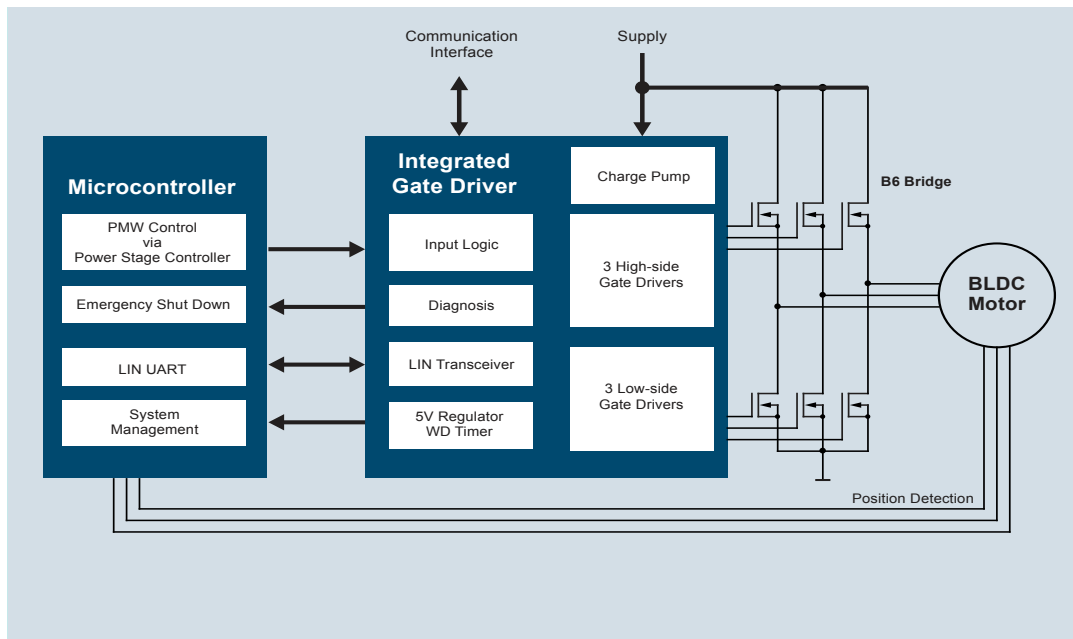


Figure 1. BLDC System Architecture

IC manufacturers integrate as many functions as possible to ease your design effort. A higher integration level also saves space. If the chip has an integrated LIN (local interconnect network) physical layer function, it does not need a discrete LIN transceiver. If you reduce the size of the electronic park brake control, you might have room to add ESP (Electronic Stability Control) functions on your ECU.

A watchdog timer is mandatory in automotive safety applications. For failsafe reasons, it needs to be on a different die than the MCU. Since the watchdog timer consists of digital logic and a counter, Atmel® integrated this function onto the MOSFET gate-driver chip to save cost and space.

Automotive Supply Voltage Range

A wide supply voltage range is a key criterion for applications within an automotive environment. Both high as well as low battery voltages are a challenge for the ECU. It needs to withstand a high operating voltage during operation conditions such as jump-starting and load dump.

Starting an engine with an external starter battery is called jump start. The worst-case jump start is off a 24V truck battery with 12 instead of 6 lead acid cells. This creates a maximum voltage requirement of 28V. Load dump occurs when a mechanic disconnects the battery while the engine

is still running. The inductance of the alternator windings creates high-energy pulses with voltage peaks up to 120V. This voltage is limited by a central load-dump protection unit. The protected load dump output voltage depends on the individual OEM requirements (typical example 36V).

Low operating voltages also challenge electric motor controller systems. The most critical low-voltage condition occurs during car start. Activating the ignition key or starting the engine after the start/stop function can drop the battery voltage as low as 4.5V. This is called crank pulse (figure 2). The ECU must function properly during this crank pulse. You can achieve this with electrolytic capacitors that you size according to the lowest voltage and longest time expected for the crank pulse.

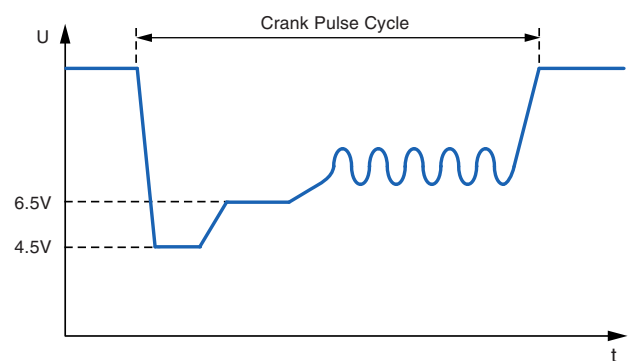


Figure 2. Typical Crank Pulse Waveform

External MOSFETs

There are both N-channel and P-channel high-current MOSFET switches. For the same die size, an N-channel MOSFET will have half the on-resistance ($R_{DS(on)}$) compared to a P-channel device. Since die size is the fundamental factor of the part's cost, N-channel MOSFETs are the preferred solution in most cases.

The control voltage that begins to turn on a MOSFET is called the gate threshold V_{Gth} . This voltage drops at high temperatures. In a hot engine compartment, logic-level MOSFETs may not switch off completely, whereas non-logic-level MOSFETs guarantee safe and proper switch-off.

Gate Drive

To turn on a high-side MOSFET, you need to raise the gate voltage above the supply voltage the MOSFET is switching (see figure 3).

Closing the high-side switch increases voltage on motor phase A to the level of the battery supply voltage V_{Supply} . This means the voltage on the source pin of the MOSFET is at V_{Supply} . The gate threshold voltage, V_{Gth} , is always relative to the FET source pin. Hence, the gate voltage V_{GSH} needs to reach a level of at least V_{Supply} plus V_{Gth} .

To create this gate drive voltage, chip designers use an integrated charge pump (figure 4). In addition, the charge pump helps to stabilize the drive of the external low-side MOSFETs. Non-logic-level MOSFETs require a gate voltage of 8V. If you derive the low-side gate drive directly from the battery you cannot maintain 8V during a crank pulse event. A 2-stage charge pump solves this issue. The charge pump output voltage is transferred by the VG regulator to the low-side gate circuitry (see figure 3).

Integrated Charge Pump vs. Bootstrap

The ATA6843/44 charge pump is similar to a Dickson charge pump with its 2-stage architecture (see figure 4). You can generate the output voltage of a 2-stage charge pump to a maximum value two times higher than the input supply voltage. The 2-stage configuration enables a reliable gate supply voltage range for the external MOSFETs. The MOSFET gates are protected from load dump and the gate drive voltage is maintained during a crank pulse event.

Competing products often use bootstrap gate drive techniques. Bootstrap circuits will double the power supply voltage. But bootstrapping will not maintain gate drive during a low-voltage crank pulse condition. Bootstrap circuits need an oscillating motor drive output to work. If the motor output is fully on or fully off the bootstrap circuit cannot keep its

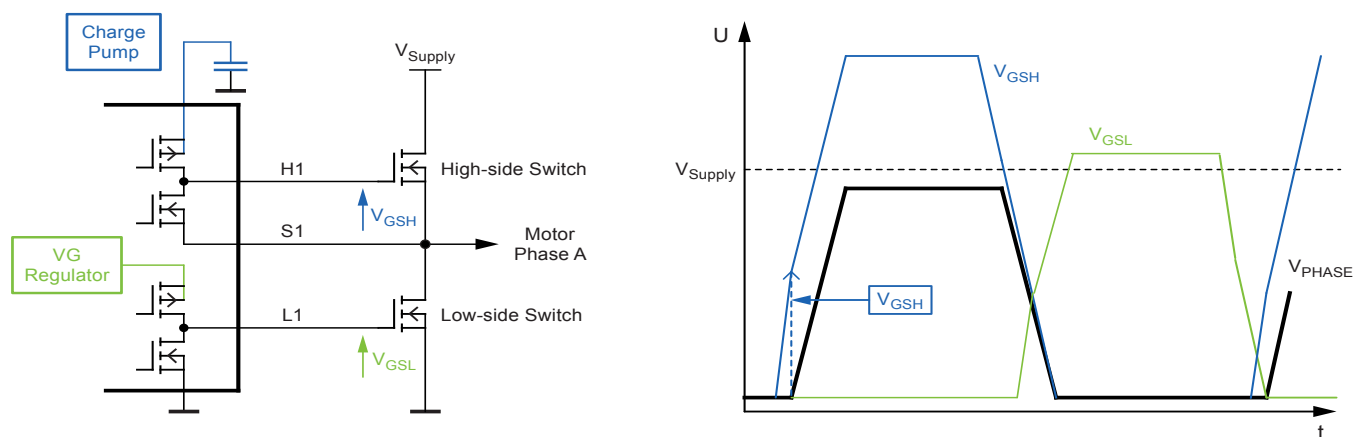


Figure 3. Gate Drive

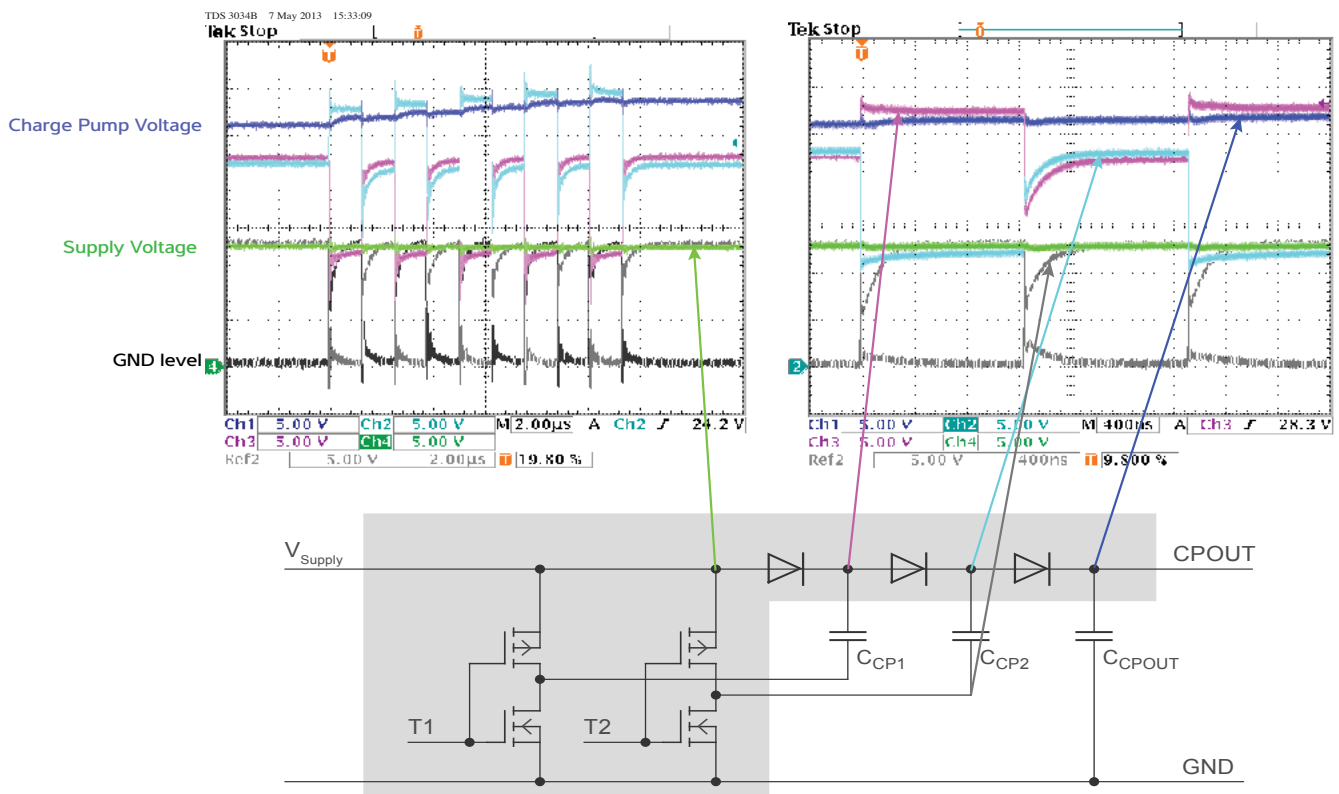


Figure 4. ATA6844 Charge Pump Waveforms

storage capacitor charged. Only a free-running charge pump is able to provide a stable output voltage above battery supply no matter what the motor duty cycle is.

Engineers often believe that a charge pump is a complicated device and difficult to design into their application. Atmel developed the ATA6843/44's integrated charge pump to drive six N-channel MOSFETs. The chip only requires three external ceramic capacitors. The on-chip charge pump guarantees to easily create a reliable BLDC gate drive system. There is no additional effort for comparators, chopping, or switching. You don't have to agonize over complex design issues. The Atmel engineers considered EMC (electromagnetic compatibility) radiation when they developed the ATA6843/44's internal push/pull stages. They included sufficient cross-conduction times to keep emissions low so you can meet strict automotive regulations.

Reverse-Voltage Protection

The integrated charge pump allows you to implement a reverse-voltage protection circuit (figure 5). This requires a single external N-channel MOSFET wired in the reverse direction. At power-on the N-channel MOSFET conducts via its intrinsic body diode. This starts the integrated charge pump. Since the motor is not operating, the supply current is low. The intrinsic body diode can power the chip without overheating. As soon as the charge pump voltage exceeds the protection MOSFETs' gate threshold, the MOSFET is driven into active mode and conducts through its low on resistance. The charge pump can now also provide the gate drive voltage to the motor MOSFETs.

An NPN transistor plus a diode in series protects against fast negative voltages. When the battery input goes negative relative to chassis common, it turns on the NPN transistor. The transistor then clamps the MOSFET gate and source together.

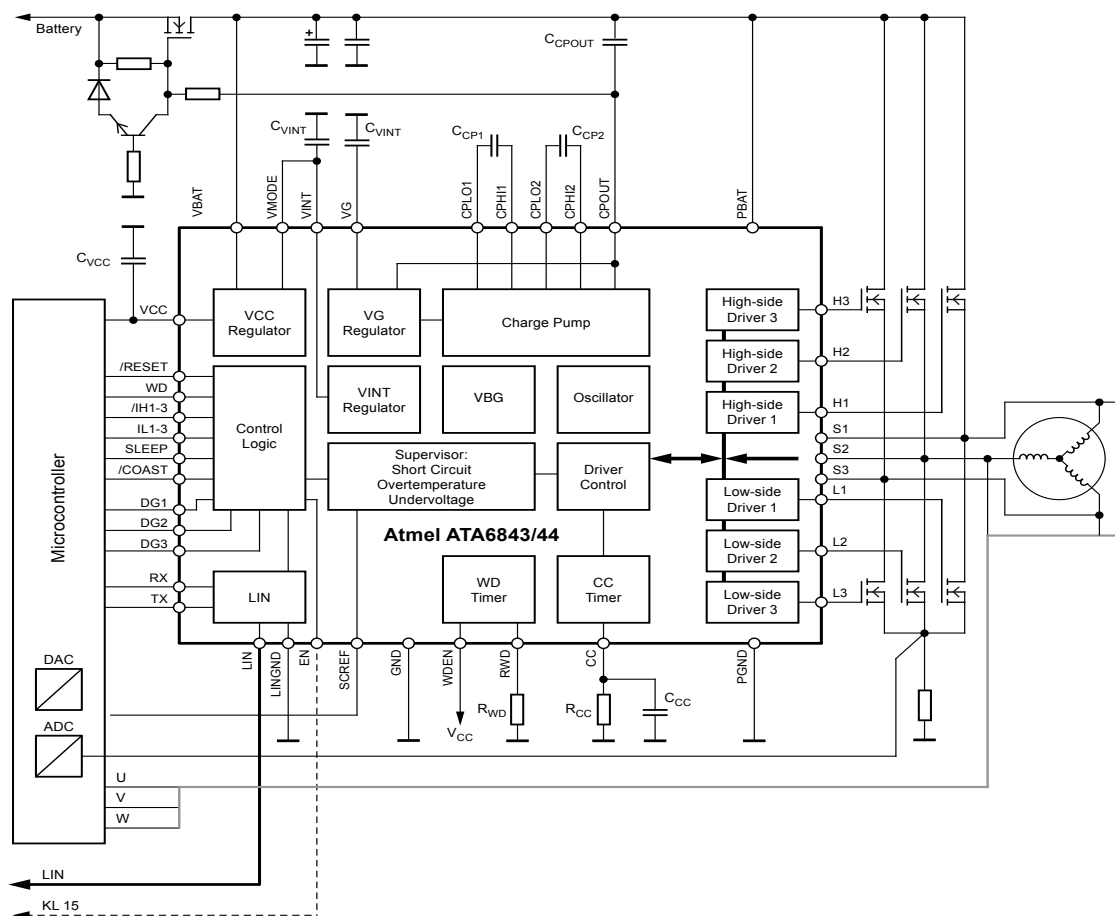


Figure 5. ATA6843/44 Application Schematic

High-Temperature Operation

The AEC-Q100 standard defines ambient temperature ranges for automotive applications. Grade 1 covers ambient temperatures of -40°C to 125°C, grade 0 is suitable for under-the-hood applications up to 150°C ambient temperature.

Atmel manufactures motor driver ICs on its own BCD-on-SOI (bipolar/CMOS/DMOS on silicon-on-insulator) technology. This enables the IC to operate at junction temperatures up to 200°C and ambient temperatures up to 150°C. SOI technology offers specific design advantages. There is significant cross-talk reduction between power and digital circuits on the same die, as well as easy integration of high-quality power devices, and immunity to radiation. Compared to devices manufactured with existing bulk technology, devices manufactured with SOI wafers achieve a higher level of integration and processing speed at reduced power consumption. The isolation of devices through an oxide layer

eliminates problems of parasitic capacitance and latch up, thus minimizing internal coupling. This helps to simplify the design and reduce risks.

Switching the MOSFETs

MOS gate threshold voltages typically decrease at higher junction temperatures. This disturbs the IC-internal timing and may prevent the MOS switches from turning off. Atmel adjusts the gate threshold voltage of the high-temperature BCD-on-SOI process to meet these high-temperature gate threshold requirements.

Likewise, the decreasing gate threshold voltage affects the external MOSFETs. The higher the temperature the lower the MOSFET gate threshold voltage. One solution is to apply non-logic level MOSFETs with higher gate threshold voltages instead of P-channel MOSFETs. At the same die size, N-channel MOSFETs have only half the R_{DSon} resistance. The reduction of thermal dissipation is an important benefit, in particular for applications in hot environments.

Diagnostics and Monitoring

In automotive applications monitoring and diagnostic functions are mandatory. Voltage failures, thermal overload, or overcurrent are events that require immediate action, for example, instant stop or motor driver unlock, independent of any microcontroller operation. In addition, ECUs must provide feedback on malfunctions to the host controller, and record them in central failure protocols to enable appropriate countermeasures.

One emergency shut-down function is the coast feature. The ATA6844's COAST pin enables the motor to rotate in coasting mode by activating a single input pin. In case of emergency, all six output gate drivers immediately switch to off mode, the external MOSFETs are deactivated, and the motor will coast to a stop.

Support Tools: The Development Kit

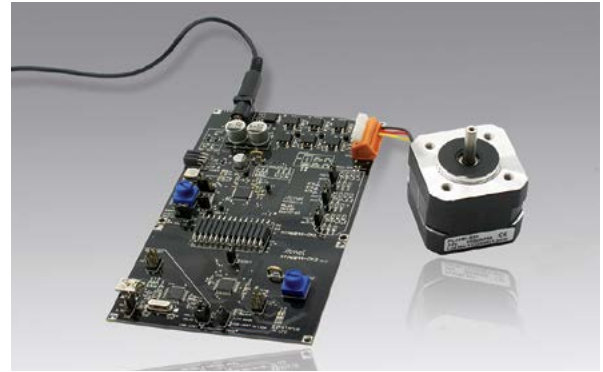


Figure 6. Development Kit ATA6844-DK

The ATA6844-DK development kit enables designers to take first steps in high-temperature BLDC motor control. It consists of two connected boards plus a standard BLDC motor. The

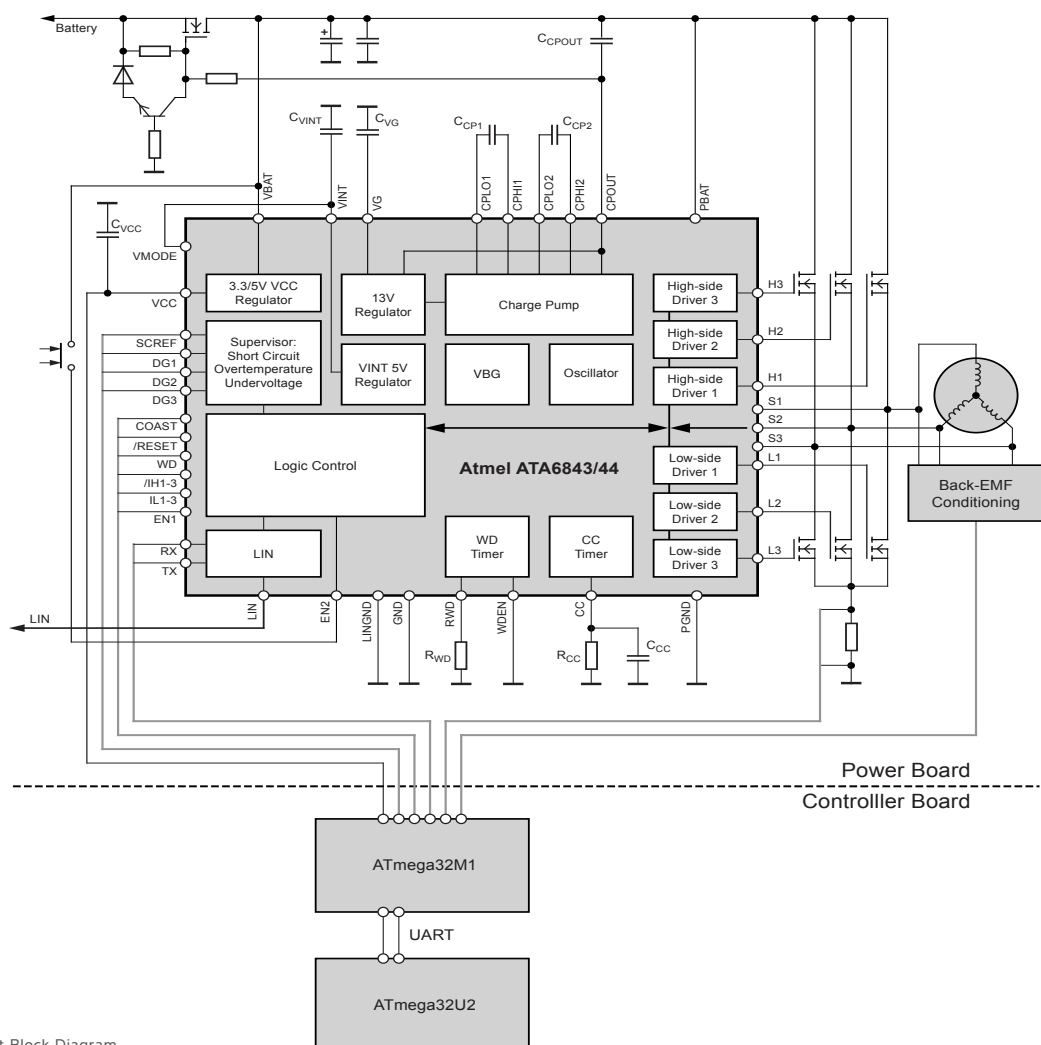


Figure 7. Evaluation Kit Block Diagram

power board handles all BLDC functions except the MCU microcontroller unit. Six discrete N-channel FETs are arranged in a B6 bridge architecture. An Atmel SBC ATA6844 handles the basic electronic control unit functions, a low-dropout regulator, LIN transceiver, and window watchdog. The controller board features the Atmel ATmega32M1 8-bit AVR® MCU dedicated to BLDC motor control. An ATmega32U2 microcontroller is on the board for debugging.

Power Board

The power board comprises all the BLDC motor control functions:

- Six N-channel MOSFETs arranged as a B6 bridge supply the motor current. The output terminals U, V, and W attach to the motor connector to operate the included BLDC motor.
- For emergency purposes, you can adjust the short-circuit shutdown current with potentiometer SCREF.
- For EMC purposes, you can modify the serial resistors to achieve gate voltage shaping to adjust the slew rates of the discrete MOSFETs.
- 82mOhm shunt for motor current measurement can be adjusted for various motor current loads
- Charge pump for external gate voltage supply
 - 3 capacitors for complete charge pump function
 - Test pin CPOUT allows access to the charge pump output voltage
- The charge pump output voltage is also used to implement reverse battery protection. Typical supply voltage is 12V. A seventh MOSFET the same size of the B6 bridge MOSFETs is controlled by the charge pump output. The reverse voltage protection control circuit ensures fast switch off during any negative supply voltage spikes.

Motor position feedback is a key feature of BLDC applications. The ATA6844-DK offers both Hall sensor feedback and B-EMF (back-electromotive force) feedback. The option can be set via jumpers.

For Hall sensor feedback the jumpers directly connect the motor Hall sensor output signals to the microcontroller. The microcontroller uses these digital Hall signal outputs for commutation. A resistor and capacitor network provide for B-EMF feedback position detection. For this mode the jumpers connect 3 motor control signals and their dedicated neutral point signals to the microcontroller interface.

Controller Board

While an actual automotive application will have the BLDC microcontroller placed close to the gate driver chip, this kit has the MCU on a separate board to increase flexibility. All MCU signals required to drive the power board are available on the interface connector. This approach enables the customer to use any motor control MCU by simply connecting the relevant control signals to the interface connector. All Atmel MCU evaluation boards, e.g. STK®600, can be used.

The controller board provides three debugging methods. The standard debug interface is a UART interface. The Tx and Rx connections are accessible via jumper connectors. Since the ATA6844 has a LIN transceiver, diagnostics can also be done via the LIN interface. Thirdly, the on-board ATmega32U2 enables RS232 interfacing. The MCU's output USB interface can be directly connected to a PC and controlled by a hyper terminal application.

For further information please refer to the ATA6844-DK application note at <http://www.atmel.com/tools/ATA6844-DK.aspx>.

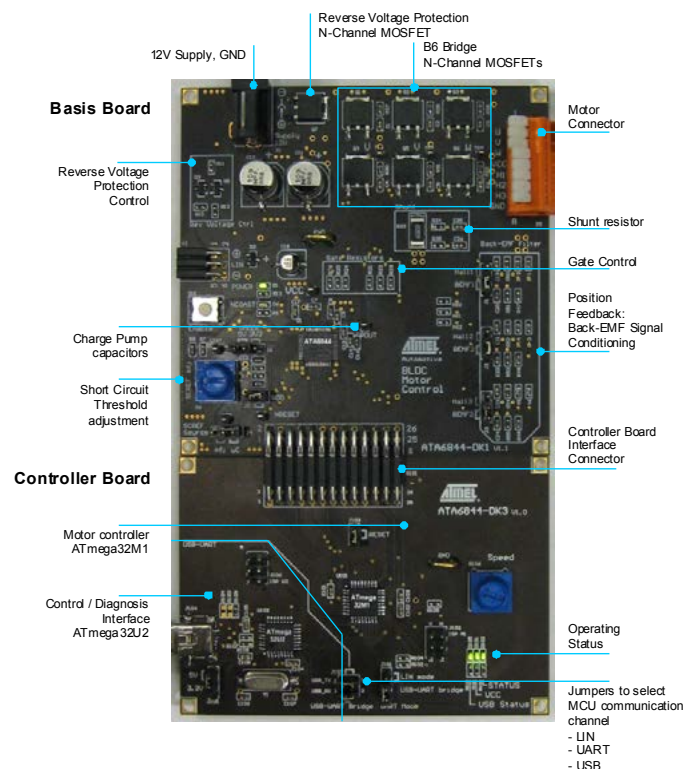


Figure 8. Application Board Top View, Functional Blocks

Summary

The Atmel ATA6843/44 integrated gate driver enables to overcome the challenges of present day automotive BLDC designs. It lets you design such applications utilizing fewer external components. These motor driver devices feature a high maximum junction temperature to meet the strict automotive grade 0 requirements for under-the-hood-applications. The IC has an integrated 2-stage charge pump ensuring that designers can easily create a reliable BLDC gate drive system without any additional design effort. The development kit allows engineers to quickly get familiar with high-temperature BLDC motor control.

For further information on AVR motor control designs, see http://www.atmel.com/products/AVR/mc/?family_id=607.