How to cost-effectively transition to Brushless DC Motors for Your Applications

The Benefits of the Micronas HVC 4223F single-chip solution

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The various options of semiconductor integration are opening up an ever-growing array of applications for distributed intelligent small drive solutions based on synchronous motors. These include brushless DC motors (BLDC), permanent magnet synchronous motors (PMSM) and stepper motors. Because of their technical advantages and increased efficiency, these types of motors are replacing brush-type motors in many existing applications. Automobiles are a great example.

Typically automotive components must support low system cost, small, light and reliable, and show a high degree of efficiency. It is also important to reduce exhaust emissions and lower the fuel consumption. The need for drive concepts that work with a wide range of motors, and the extreme demands made on efficiency, system design and networking options have major impact upon the actuator electronics.

The BLDC motor market

There are plenty of BLDC manufacturers in the US. Most companies are still focused on motor technology like brush-type DC motors, stepper motors, etc. But many of them are establishing the BLDC motor as a basis for new product developments. Even though there are many BLDC motor manufacturers in place, especially for the tiny BLDC motors, there are not so many integrated control electronic solutions on the market. Companies capable to manufacture BLDC motors with integrated intelligent electronics inside, together with a low cost approach are still not easy to find.

The level of adoption of BLDC motor technology is increasing. Many automotive functions such as fuel or water pumps, HVAC (Heating Ventilation and Air Conditioning), curve light, head-lamp levelling, and many others, are converting from brush-type DC motor or stepper motor technology to BLDC motor technology. Yes, this is not a general proof that all brush DC or stepper motors will convert to BLDC motor technology. But the main argument that the electronic to control the motor is too expensive compared to the price of the motor itself is becoming less valid every day. Furthermore, the BLDC motor advantages can significantly enhance other system properties (refer to the Table 1). Hence it can be foreseen an evolution to intelligent motion control.

Table 1: Summary of brushless DC motor advantages

BLDC Motor Advantage	Description
Smaller motor geometry and lower weight	Powerful permanent magnets in the rotor and the missing brush mechanism enable BLDC motor to be smaller and lighter compared to both brush-type DC motors or induction AC motors.
Enhanced motor efficiency	No core losses in the rotor due to the usage of permanent magnets. The motor efficiency can be further enhanced with dedicated commutation algorithms.
Thermal performance	The motor windings as heat generating elements are outside of the motor (in-runner) allowing a better thermal coupling.
High motor speed range	BLDC motors have no brush system which limits the speed. They have been designed for speeds > 100,000 RPM (e.g. dental drill). Low speed control is easier with appropriate commutation algorithms.
Enhanced motor dynamic response time	The rotor inertia is lower compared to a brush-type DC motor carrying the copper windings in the rotor.
No motor maintenance and long lifetime	No replacement or inspection of the commutator system is needed.
Lower Radio Frequency Interference (RFI) for better EMC	Unlike brush-type DC motors there is no brush system inside BLDC motors causing RFI.
Commutation control	The commutation electronics can be used for various commutation schemes and can be tailored to the system/motor by software without cost adder. This allows also a good control of torque behavior (e.g. by adjusting the commutation angle).
"Intelligent motor" with self-diagnostic functions	The integrated electronics can provide programmable diagnostic functions, e.g. allowing identification of motor characteristics for automatic adjustment of system parameters.

Brushless DC motor advantage

BLDC motors have several advantages over competing motor technologies, summarized in Table 1.

Problems of the transition from brush-type DC motors towards BLDC motors?

When looking at motion control systems including brush-type DC motors (BDC), it is obvious, that control is less complex compared to a BLDC motor. In simple words: you have only to apply a voltage to the motor and it starts to move. Engineers with little experience in BLDC motor control system design often fear that they will have difficulty converting to BLDC motor technology, even though they know about the advantages. Complex electronics and the programming of such a system are thought to be a barrier. Also the higher system cost due to the electronic commutation is often considered as a showstopper.

However, the transition from BDC to BLDC is not necessarily difficult. By using the Micronas HVC 4223F single-chip solution the electronic circuit can be quite simple.

In the example below, a solution is outlined that requires only 13 components, including the HVC 4223F itself. E.g. if the system includes already a PCB, the impact to the BOM is moderate. In many cases, a smaller motor can be utilized due to the better efficiency. The actuators can also be smaller further reducing material cost (motor, case, gear, etc.). Furthermore, the BLDC control system with the HVC 4223F can be programmed in a way that it behaves like a BDC motor from outside, comprising only a VBAT and ground supply as connections. Hence, existing motion control systems can be upgraded without changing the complete system design. And in the long term the system can be improved, e.g. with networking and/or diagnostic functions etc. Customers do not have to start from scratch with software development since the existing application notes and demo software can provide an adequate level of functionality.

A single-chip architecture for maximum system integration and flexible drive systems

The new Micronas High-Voltage Controllers (HVC) allow systems with highly integrated motor drive electronics to achieve the performance potential of modern permanently excited DC motors. The HVC 4223F is an integrated microcomputer system with all necessary peripheral modules for directly driving PMSM/BLDC motors and bipolar stepper motors. The programming capability of the peripheral modules and the user defined software allow the best possible adaptation to the properties and attributes of different drive systems.

The increasing integration density in drive solutions, made possible by the low power/weight ratio (W/kg) of the PMSM/BLDC motors, affects the power dissipation (power-/thermal management), the flexibility of driving circuit and the selected drive, and also the options for

Table 2: Overview of motor types and modes of operation with the new HVC

<table>
<tr><th>Motor type</th><th>Bridge configurations</th><th>Operating mode examples</th><th>Examples for applications</th></tr>
<tr><td>3-phase PMSM/BLDC motor</td><td>Bridge can be configured to match the motor phases.
Phase current: 0.6 A (effective)
Peak current 1 A</td><td>• Sensored and sensorless six-step commutation with PWM-modulation
• Space Vector Modulation with rotor position measurement, e.g. by Hall sensors via SPI interface.
• Current measurement possible in all operating modes via an external shunt resistor</td><td rowspan="3">• LED front light fan
• AGM
• HVAC
• Small / auxiliary pumps
• Optical distance measurement (LiDAR)
• Light adjustment
• Bending lights (AFS)
• Head-up display
• Mirror adjustment
• Navigation display adjustment
• Intelligent relays
• etc.</td></tr>
<tr><td>Bipolar stepper motor</td><td>Bridge can be configured to match the motor phases.
Phase current: 0.3 A (effective)
Peak current 0.5 A</td><td>• Full and semi-step operation
• Wave drive operation
• Commuted operation using the Back-EMF comparators. e.g. for accomplishing higher rotational speeds.
• Micro-step operation "Open Loop Voltage Controlled" or "Closed Loop Current Controlled" with programmable current thresholds via D/A converter ("Current-Shaping").
• The output stage includes circuits for the integrated current measurement for the programmable current thresh-olds. An external shunt is not required.</td></tr>
<tr><td>Brush-type DC motors</td><td>Depending on the configuration of the bridge, several DC motors can be activated up to a phase current of 0.6 A (effective)</td><td>• Self-commuting
• Measurement of motor current for control
• For positioning drives, read-in of encoder/sensor output</td></tr>
</table>

diagnosis. The high integration density of the electronics requires adapting the thermal operating conditions by means of a target-specified power management. The new HVC family provides many functions which precisely allow this adaptation.

Adjusted motor activation for different applications and operating modes

The use of different drive concepts in automotive actuators requires the easy adaptation of the motor power-bridge and how the bridge is activated. The HVC 4223F precisely addresses this issue with a configurable final output stage, fully integrated and programmable peripheral module, and a powerful ARM Cortex® -M3® Core. Six n/n half-bridges (incl. charging pumps) are integrated. These can be adapted to the type of motor by the appropriate wiring circuit of the output pin and by the configuration of the software.

The EPWM-Module (Enhanced Pulse-Width Modulation) supports passive and active free-wheeling current patterns ("Asynchronous/Synchronous Rectification") for different operating modes and types of motor (see Table 2). The integrated current measurement and the D/A converters allow the programming of nominal current values (e.g. for current-controlled micro-stepping). In the PMSM/BLDC motor, without using sensors, the feedback signal of the rotor position can be sent via comparators and integrated star-point references, or alternatively by means of Hall-effect sensors/encoders. Also, the commuted mode of operation for stepper motors can be selected, e.g. for accomplishing higher rotational speeds. Adapting stepper motors to different modes of operation (full / semi-step, wave drive, micro-step, commuted operations) is also possible or programmable.

Algorithms for speed and current control can be quickly executed with the ARM Cortex-M3 CPU – supported by the high-speed A/D converter and adjustable signal paths for voltage and current measurements. The output stage includes overload protection (overvoltage / excess current) and diagnosis functions. The integrated peripheral modules for the motor activation (EPWM, comparators, star point reference, D/A converter, diagnosis and overvoltage / excess current protection, temperature monitoring) can be programmed for the operating modes listed in the table.

Efficient system with ARM Cortex-M3 CPU

CPU and flash memory allow extremely high system flexibility by means of software, e.g. for real-time requirements for rotational speed and current control, communication in distributed actuator systems (e.g. in LIN clusters) and diagnosis functions. The main oscillator is already integrated. The CPU cycle can be stepped down to reduce power consumption or power dissipation without affecting peripheral functions. To reduce electromagnetic emission, an EMI reduction module (ERM) is included. All peripheral modules can be programmed via the AHB/APB bus system and are so adapted to the system requirements. The integrated NVRAM allows the storage of diagnostic and application data.

For power, the HVC family is supplied directly via the 12-volt on-board electrical system and complies with the ISO 7337 test pulses. Start-stop systems are supported by a special "retention mode". Compared with conventional linear regulators, the integrated switching regulator (buck converter) minimizes power losses. Energy-saving modes provide low power consumption, e.g. for Kl.30 applications. External loads (e.g. Hall sensors) can be supplied via a programmable high-side switch.

For communication in distributed small drive systems (e.g. HVAC systems), a LIN-UART and the LIN Physical Layer are integrated in the HVC. Also, a second LIN pin is available for use in LIN clusters with auto-addressing as, for example, in HVAC valve applications. The described system integration and network capability is an important step on the way to further miniaturization and integration in small and micro-motors.

The reliability of a drive system is crucially influenced by the drive electronics used. The architecture of the new HVC includes extensive diagnosis and protective functions with an SPFM greater than 60% ("ASIL ready"). This is important for the decomposition in accordance with ISO 26262 at system level, i.e., also for the assignment of the safety and security requirements to individual and independent system elements, and can be carried out at system, hardware, and software level.

The high system integration has a positive effect on the required system FIT (FIT = Failure in Time) rates since the number of components is reduced.

A good example for the flexible diagnosis is the implementation of a „thermal managements" in the software.

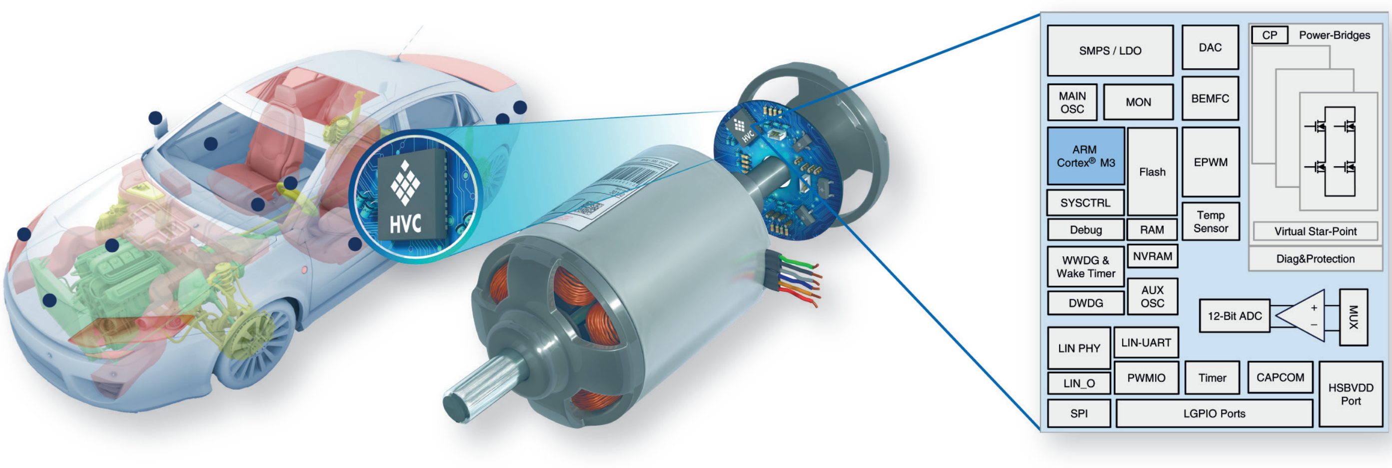

Fig. 1: Electronics integration in the BLDC motor

By evaluating current and temperature, measures can be taken to adapt to the operating profile, e.g. reducing the CPU cycle, restricting the motor current, adapting the free-wheeling current pattern in the motor bridge, etc.

The small 40-pin QFN 6x6 mm package of the new HVC 4223F is well suited for the miniaturization and the integration of the electronics into the motor or into the actuator. Also, the "exposed pad" (ePAD) guarantees a good thermal connection. A junction temperature range of –40 °C to +150 °C and the integrated overtemperature monitoring allow the use in temperature-critical applications.

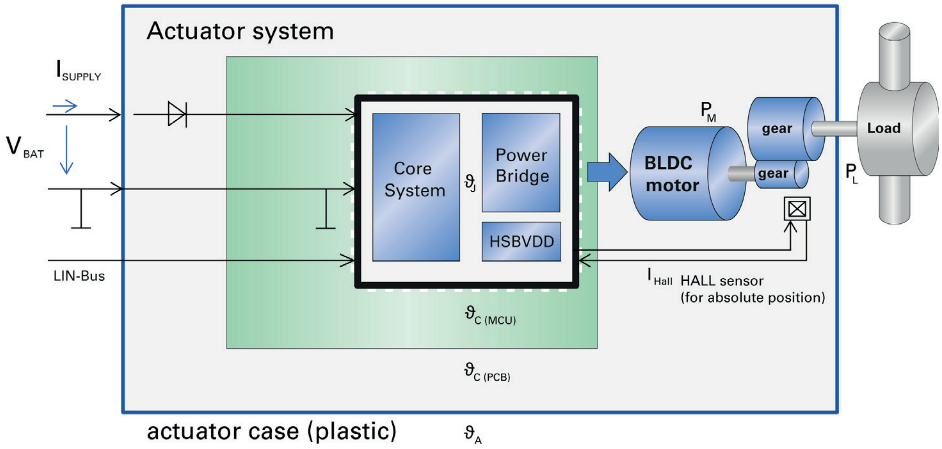

Fig 2: Example system with BLDC-motor

Application example for positioning actuator with BLDC motor

Mechanical actuators for positioning applications usually have to provide a high torque (e.g. in valves, flaps, etc.). Typically a gear is used to obtain low rpm at the load, introducing considerable losses due to friction. In many cases the actuator must apply a stable holding torque and the actuator shall not lose its last position to avoid calibration runs. Due to weight reduction and space constraints the motor and electronic geometry plays an important role. The example describes a solution for a single-chip motor actuator with the HVC 4223F driving a BLDC motor in sensor-less six-step commutation with a LIN communication interface. Figure 2 shows the principle system for a valve actuator integrating the complete electronic by the HVC 4223F single-chip solution.

Table 3: Overview of the used peripheral function with the HVC 4223F

Function	Sub-function	Peripheral	Interrupts	Remark
Generic system and background tasks	Periodic call of software-tasks	CPU/Software, Timer/ ARM SYSTICK	TIMER or ARM SYSTICK timer	For execution of periodical tasks
Motor control	Motor driving / motor state-machine	MOUTx EPWM BEMFC CAPCOM	EPWM BEMFC CAPCOM	Commutation, PWM modulation, active/passive free-wheeling, Back EMF voltage evaluation („0"-Crossing), 30°-commutation information (CAPCOM Timer, coupled to BEMFC).
	RPM and current control	Timer or EPWM	Timer or EPWM	Periodic task within motor state-machine
	Motor current measurement	ADC	EPWM ADC	IRQ triggered by EPWM according to current sampling time
	Constant current for holding torque generation	8-Bit DAC EPWM	-/-	Allows the usage on non self-locking gears with better efficiency. The HVCF 4223F comprises a "Current-Limiting" function for this purpose.
Diagnosis and monitoring	Stall detection	ADC	ADC	Periodic task via ADC measurement
	Under- and over-voltage	MON / BVDD comparators	OV/UV interrupt	Periodic task to monitor the supply voltage
	Periodic ϑ measurement for thermal management	ADC	Timer	Monitoring of ϑ_J and ϑ_A (e.g. by external NTC). Internal temperature sensor can be read by ADC. The external NTC via an LGPIO-port by the ADC.
	Monitoring of program flow	Digital watchdog and window-watchdog	-/-	Monitoring of program flow. Window-Watchdog time-base with independent integrated auxiliary oscillator.
	Preservation of diagnostic data	NVRAM	-/-	E.g. for saving periodically changing mission data such as counters or data changing only once like SW version numbers etc.
Communication	LIN-bus software stack	LIN-UART and LIN-Port	LIN-UART	According to the LIN2.x specification.

ADC = Analog-to-Digital Converter, BEMFC = Back Electromotive Force Comparator, CAPCOM = Capture Compare Timer, EPWM = Enhanced Pulse-Width Modulator, LIN = Local Interconnect Network, MON = Supply Monitoring Pin, MOUTx = pins of integrated motor-bridge

Hardware – Software interaction and circuit solution

The efficient interaction of HW and SW inside a motion control system depends on the distribution of the particular functions of the available chip peripherals. Table 3 summarizes a possible approach for the system in Figure 2 with sensorless six-step commutation including rpm and current control, functions for diagnosis and communication stack. The software architecture can be e.g. a simple round-robin with interrupts.

A basic circuit solution for the system is outlined in Figure 3. The number of external components for the motor can be reduced to a minimum of 12 components (refer to the table in Fig. 3). In case of special system ESD and/or EMC requirements, some additional components like ferrite beads etc. might be required, e.g. in the DC supply link or LIN signal path.

Conclusion

The number of small motor driving solutions using BLDC motor technology will grow because of the declining cost of electronics. The highly integrated single-chip HVC 4223F solution from Micronas is an enabler for this development.

The diversity and functionality of motors will increase, including networking between intelligent drives. Furthermore, the requirements for lower weight, smaller size, higher power density, and lower cost must be met. The used motors need to be small, light and are used in distributed LIN bus networks.

The design-in time can be reduced because complete platforms of tiny motors can be developed using a single-chip solution. Tailoring to different motor types and properties can be achieved by means of adapting the software. Today's brush-type DC motor solutions can be replaced 1:1 by a BLDC motor system, that on the outside, look like a conventional motor but inside provide all advantages needed to realize intelligent motion control.

Self-diagnosis and functional safety increasingly play an important role. Drives with "integrated intelligence" by means of electronics can provide this diagnostic feature. E.g. the properties of a motor might change over life-time. These effects can be tracked and stored by the electronics and adjusted to a certain extent.

Adapting the software allows a large number of functions and applications to be addressed. The customer can efficiently equip a complete platform of actuators with just one type of controller. The small number of discrete components and the high integration provide a high degree of miniaturization and allow economic solutions with the advantages and benefits of modern types of motors. The high level of reusability of hardware and software permits quick responses to changes in customer requirements.

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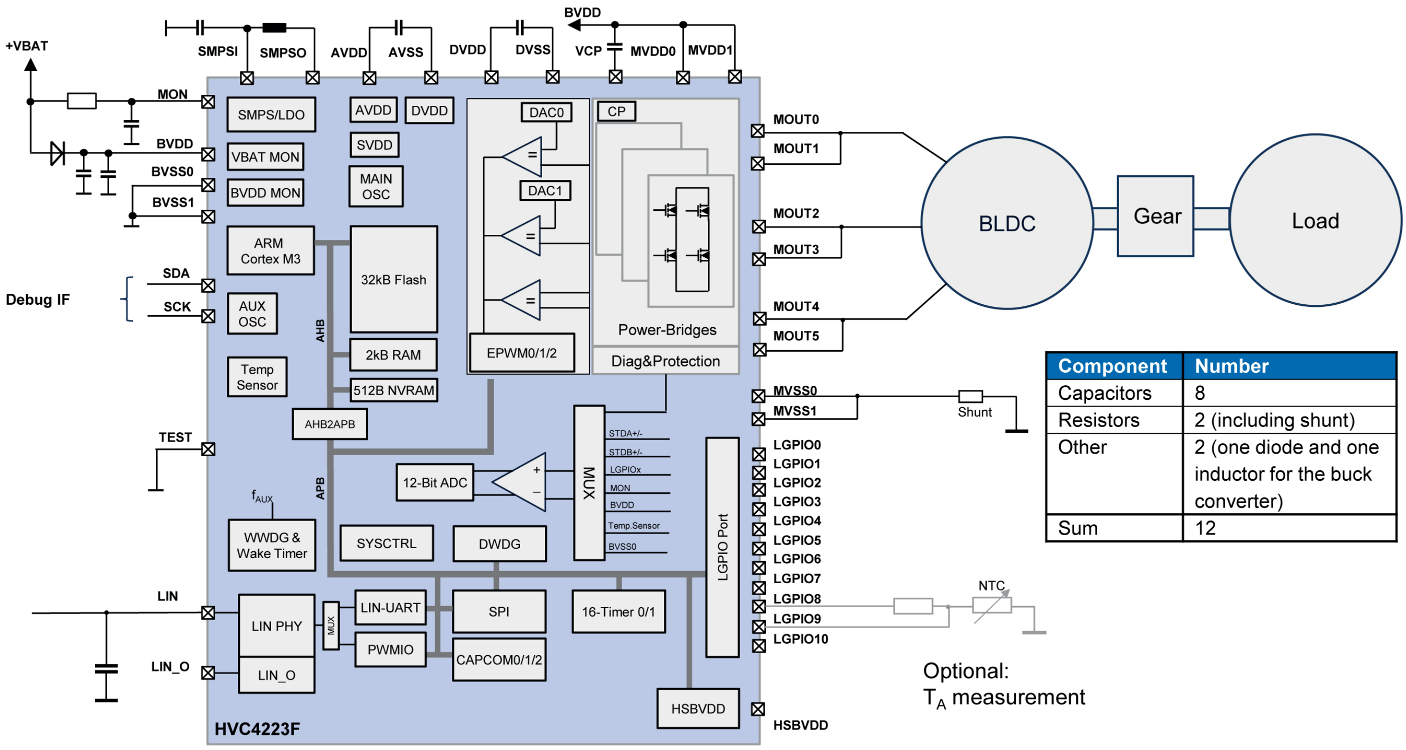

Component	Number
Capacitors	8
Resistors	2 (including shunt)
Other	2 (one diode and one inductor for the buck converter)
Sum	12

Fig 3: Principle circuit solution