Smart Power and Power Discretes Hardware-software co-design for reliability improvement of BLDC power drivers for eMobility by key BCD Technologies running in Europe

Grzegorz Janczyk*, Tomasz Bieniek**

* Łukasiewicz Research Network - Institute of Microelectronics and Photonics
Integrated Circuits and Electronics Systems Design Research Group
Al. Lotników 32/46, 02-668 Warszawa, Poland
grzegorz.janczyk@imif.lukasiewicz.gov.pl, imif.lukasiewicz.gov.pl

** Łukasiewicz Research Network - Institute of Microelectronics and Photonics
Silicon Technology and Sensor Systems Research Group
Okulickiego 5E, 05-500 Piaseczno, Poland
tomasz.bieniek@imif.lukasiewicz.gov.pl, imif.lukasiewicz.gov.pl

ABSTRACT

Unprecedented diversity of microcontroller driven high-end electronic devices and applications stimulates the increase of customer expectations for product functionality flexibility and reliability. Advanced integration techniques and controlled product lifetime techniques applied by producers make products hard for service actions, whereas device disassembly before repair is very risky (if only available). Product replacement becomes the most common option instead of the repair for relatively cheap products or modules. Such a situation applies to small electric devices like vehicles, white goods (cookers, hovers, washing machines…) and many more tools and appliances/gadgets periodically appearing nowadays. All of them are exposed for exploitation overload and stress which should be kept under designers control in modules, devices and systems development stage. Following the fact that numerous above mentioned applications do not face voltages over 1kV, the set of Bipolar-CMOS-DMOS (abbr. BCD) technologies is a key branch of ICs development driven by the need to offer more and more complex integrate solutions incorporating diversified/mutual/redundant/complementary functions on the same chip and to guarantee high quality and reliability in all types of application environments. Hardware implementation scenarios available for fully integrated and for hybrid solutions are also discussed.

Keywords: Power electronics, BLDC Driver, BCD technology, brushless motor, UAV demo, R3-PowerUP, ECSEL, Łukasiewicz Research Network.

1. R&D TRANSFORMATION CONTEXT IN POLAND

Łukasiewicz Research Network – Institute of Microelectronics and Photonics (Łukasiewicz-IMiF) [5] is a member of the Łukasiewicz Research Network [6] which constitutes 26 research institutes spread across 12 cities in Poland, staff around 8,000 employees. The goal is to achieve the state of coordinated research and development activities between the member institutes of the network. Łukasiewicz-IMiF is a member of the Łukasiewicz Research Network since 1st of April 2019, that is, from the day the network was established. The Łukasiewicz-IMiF is the legal successor of the Łukasiewicz Research Network – Institute of Electron Technology (former Institute of Electron Technology, ITE) and Łukasiewicz Research Network – Institute of Electronic Materials Technology (former Institute of Electronic Materials Technology, ITME), both located in Warsaw. Łukasiewicz-IMiF is a major Polish R&D Centre in the field of semiconductor electronics and physics research with a focus on the development of innovative micro/nano-technologies and systems. The institute is managed by a director appointed by the president of the Łukasiewicz Research Network. The activities are coordinated by the Łukasiewicz Center and supervised by the Ministry of Science and Higher Education. The structure of revenues Łukasiewicz-IMiF is as follows: 35 % statutory funding, 28% domestic and international projects, 20%, services, 17% other. Łukasiewicz-IMiF has over 50 years of tradition and proven experience in the development, dissemination, and commercialization of innovative technologies and designs in a wide range of integrated circuits, detectors, sensors, and microsystems. The Łukasiewicz-IMiF consists of technology oriented research departments, research laboratories, and design groups, working in close internal, domestic and international cooperation. The creation of the Łukasiewicz Research Network is intended to achieve and profit "*economies of scale*" and enable the creation of comprehensive research services for entrepreneurs based on their shared potential. The Łukasiewicz Research Network will be an effective technological and intellectual background of public administration, but above all a real bridge between science and the economy.

2. R3-POWERUP PROJECT

STMicroelectronics – which is the R3-PowerUP project [1][2] coordinator and global leader in power technologies - develops the set of long-lasting BCD technologies combining strength of three different technologies available in a single chip instance: precise analog functions (Bipolar), digital design (CMOS – Complementary MOS) and high-voltage/power elements (DMOS – Double Diffused Metal Oxide Semiconductor).

The R3-PowerUP project is focused on BCD 90nm (BCD9) and 110nm (BCD10) feature size processes. According increasing market demand for cheap electronics and components BCD9 and BCD10 have been selected for migration from 200mm Si substrates (the technology now available and running) to 300mm diameter substrates in order to reduce final price of the single chip and to have it fabricated in the Europe in European Pilot Line Facility for Smart Power technology in Agrate (Italy). The migration to 300mm wafer size involves both power discrete and advanced smart power/logic/PCM (non-volatile memories).

Growing number of power electronic applications needs high volume FABs capable to produce relatively cheap power electronic components. One can identify power-electronics market demand in area of power management and power supply. White goods such as cookers, vacuum cleaners, washing machines also incorporate power electronic controllers and drivers. Computer peripherals (HDD, printers, fans, optic-readers), home and building automation for lighting, climate (HVAC), entertainment, security and appliances form another field of power electronics application.

It is the process necessary power semiconductor IC electronics to develop it and keep in Europe. This paper will focus on a single R3-PowerUp demonstrator development focused on power electronics hardware and software solutions. The above mentioned demonstrator embraces Brush-Less-Direct-Current (BLDC) motors driver development. Preliminary applications and electro-mechanical parameters will be discussed and presented along with analog power modules and digital controlled modules development constrains, reliability issues and software "fuses" to assure the driver security and reliability features. The control unit – based on the polish SME microcontroller IP module – application intentionally localized for in BCD9 technology (available for prototyping at STMicroelectronics) will be discussed in parallel with hardware and software security extensions.

The set of 90nm and 110nm BCD technologies by STMicroelectronics, the clue of the R3-PowerUP project, have been selected for migration from 200mm to 300mm substrates expected to be run on the European pilot line facility for Smart Power technology in Agrate (Italy). High volume scaled up technology is expected to lower chip fabrication costs.

The R3-PowerUP project joins 35 partners from 14 countries. There are two partners from Poland: Łukasiewicz Research Network - Institute of Microelectronics and Photonics (as research institute) and Tritem (former Automatix) (as SME). The overarching goal of the project is to enable the largest European industrial base to keep the leadership on Smart Power technology and the related product platforms. It positions itself mainly towards the higher technology readiness levels mainly TRL5 – TRL8. Efficient design and optimization of Intelligent Power Modules (IPM) for various application fields are addressed by 10 test-vehicle designs (technology demonstrators) to be pre-validated at 200mm substrates and selectively adopted for qualification on the 300mm wafers in the European FAB line. The migration to 300mm wafer size shall involve both: power discrete and advanced smart power, logic and PCM (non-volatile memories). It is highly innovative feature for power semiconductor IC electronics.

Power electronics hardware and software solutions development of a driver (the controller with electronic commutator) for brushless direct current (BLDC) motors are pursued by the authors' team and R3-PowerUP project partners. Various BLDC control modes are available for implementation to achieve operation in controlled power or torque modes assuring precise rotation speed control. Available BLDC driving modes have been presented in details along with hardware implementation scenarios available for integrated and for hybrid solutions. Preliminary applications and electro-mechanical parameters are discussed.

3. BCD DEMONSTRATOR

The BCD technology demonstrator lead by Łukasiewicz-IMiF is the BCD technology based, BLDC driver for synchronous DC motors commutated electronically. There is permanent, rotor-attached magnet in BLDC whereas BLDC coils are located outside the rotor. Therefore there is no need to implement electro-mechanical interface to supply BLDC rotor it with current. It is a pure brushless structure.

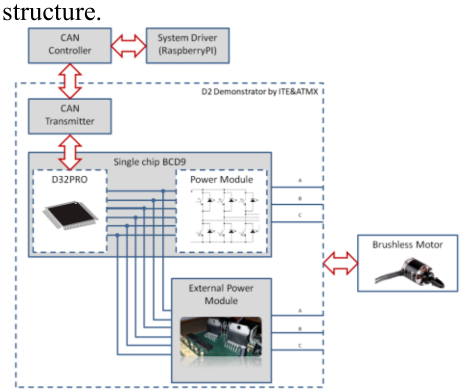

Figure 1: BLDC driver with dual interface for 3-phase BLDC test setup.

Due to the extended drive control [3] dependent on set of application and exploitation real-time parameters like rotation speed, allowed power, dynamic load, requested torque etc. the device structure it is complex but more flexible and effective in comparison with brushed drives to drive the BLDC. Therefore BLDC drives controlled by the BLDC driver (Fig. 1) embedded application present significant advantages over classical DC drives. Several important advantages over the brushed drives ones make BLDC more and more popular. Main advantages over brushed solutions are low price, high efficiency, high speed, high power and high torque, low dimensions, accurate and quick regulation of rotor speed/torque, good power to weight ratio and high mechanical reliability.

DC inverter-based power solutions are applicable and available for BLDC controllers. A dedicated closed-loop controller with back electromotive force (BEMF) feedback produces the phased AC current signal. In the case considered in this paper there are three phased PWM driving signals formed by an electronic commutator system (Fig. 2) implemented by the authors team from Łukasiewicz-IMiF project research partner of the R3-PowerUP project consortium using BCD9 technology operated by STMicroelectronics – the project leader.

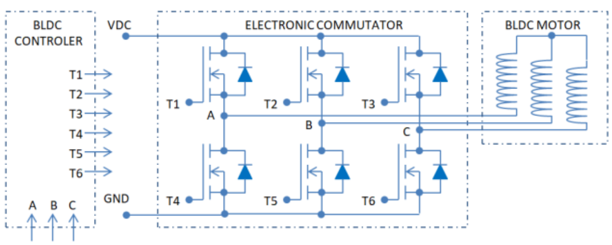

Figure 2: The BLDC driver general diagram.

Stator currents amplitude, phase and frequency control (Fig. 3) are indirectly driven by the rotor flux. The motor rotation speed and direction are controlled by sending a sequence of AC signals generated by the ESC's circuitry. The rotor positioning system is necessary to correct real-time rotation phase shifts that cannot let the drive to loose of rotation synchronism leading the drive to stop definitely. Varying mechanical load (typical for BLDC applications) results in an extended, real-time PWM regulation driven by BEMF reverse signals from driver. PWM controls rotation speed and drive torque. Therefore, the rotor positioning system necessary to adapt real-time rotation phase shifts is supported by BEMF signal processing.

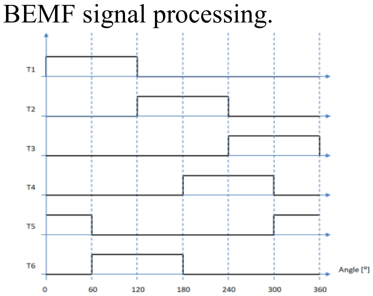

Figure 3: 3-phase BLDC control module driving phases/signals.

Dedicated current monitoring and angular velocity deviation and rotor position phase BMF sensing have been successfully implemented in both: hardware and software system layers. The most significant BLDC advantages over brushed drives are reduced dimensions for comparable mechanical performance, reduced price, improved power efficiency, electrical performance, lower acoustic noise and higher durability, electronically controlled rotation speed, power, torque, good power to weight ratio and high mechanical reliability. Real time adaptive control algorithm, BLDC state feedback to the controller and operation mode switching are a bit challenging.

3.1 Digital part

The PWM phase regulation leads the digital microcontroller controller (Fig. 4) to regulate BLDC torque and power. Pure electric methods like electromotive force detection (back-EMF) are the most reliable but due to fundamental physics applicable over some threshold rotation speed. The algorithm BLDC Motor Controller is implemented as mixed-signal System-On-Chip, including microcontroller-based digital part and analog part with 3 Half-bridge DMOS output drivers. Each phase module is formed by a pair of drivers (high-low). The power controls current through single coil of the BLDC. Driver block controls gates of output MOS transistors basing on the control signals from the controller and on the output current value.

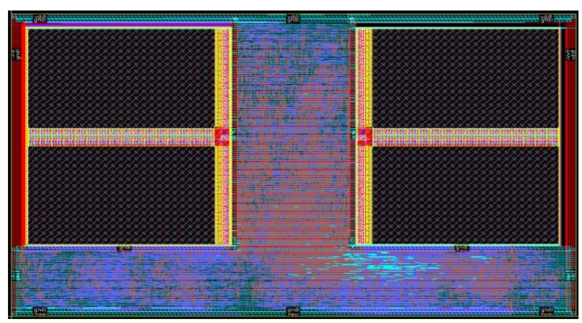

Figure 4: Digital control module layout of the D32PRO microcontroller.

The developed solution profits from NMOS transistors applied for both High and Low side of power stage of the drivers. Digital part is implemented as 32-bit microcontroller with embedded application software. The BLDC ASIC design is based on D32PRO 32-bit MCU soft IP. The microcontroller configuration embraces 32-bit RISC CPU, hardware program bootloader, 16kB program RAM, 16kB data RAM, SPI interface, CAN 2.0 interface, programmable timers, programmable PWM modules, a set of dedicated internal and external interrupts, single 8-bit I/O port. Hard IP RAM cells are licensed from STMicroelectronics for BCD9 process. The D32PRO 32-bit MCU soft IP licensed from DCD (Digital Core Design) the polish SME [4] has been synthesized for BCD9 and FPGA implementation. BLDC's are electronically commutated, synchronous DC motors.

3.2 Analog part

The analog part operates under 24V power supply voltage and consists of Six digital driving signals from microcontroller and two signals controlling maximum output current value. Three output signals drive three coils of a BLDC motor. If the current value is too high, it is limited by a next analog circuit module - the limiter. Half-bridge configuration module implements three low-side and three high-side drivers. Each of them consists of a driver block supplying driving signals to gates of output transistors and output power stage. The voltage regulator module generates 5V and 1.8V supply signals. The task of the analog part of the driver (TopLevel) is to deliver supply current to coils of a three phase BLDC motor. Driving signals (follow Fig. 3) are generated by the microcontroller It is necessary to shift and amplify driving signals levels' to drive the motor. It is served by the analog front end. The final layout of the driver incorporating digital (microcontroller, memories), and analogue (power stage, shifters, filters, half-bridges and feedback) modules is presented on Fig. 5.

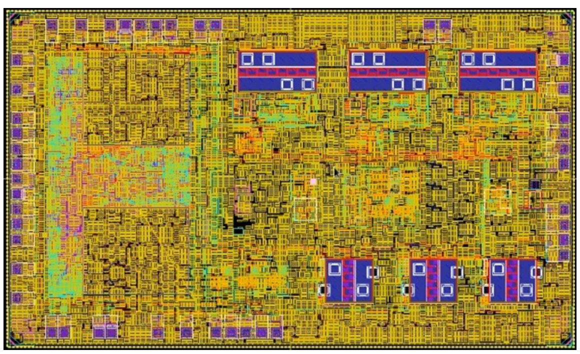

Figure 5: The final driver layout

The driver is designed in half-bridge configuration so it includes three low-side and three high-side drivers - each power output is formed by one pair of them. Each of them consists of a driver block (DriverLow or DriverHigh), supplying driving signals for gates of the output transistors of the power stage (EndLow or EndHigh).

High and low power stages have similar structure, but as high output transistors are p-channel, they have to be larger than n-channel low output transistors, as they have much worse parameters. Application of two types of transistors results in higher area of the output stages bur also in much simpler structure of the analog block.

Supply voltage of the chip is to be 24V. As inside of the chip also 1.8V (for digital part) and 5V supply signals are required, they are generated by the voltage regulator block. Supply currents for the analog part are generated in the bias block. As the input signals from the microcontroller are 1.8V signals, there are also level shifter circuits modifying them to 5V and 24V signals.

4. THE CURRENT STATUS & NEXT STEPS

In frame of the R3-PowerUP project Łukasiewicz-IMiF steps through the design, verification and testing of the BLDC driver in the BCD9 technology by STMicroelectronics. Current design activities have been concluded by the BCD IC tapeout served by STMicroelectronics yet in 2021. Reprogrammable solution with flexibile algorithm & software development and testing are ongoing in cooperation with Tritem.

5. CONCLUSIONS

The interest in drives with brushless DC motors is constantly growing. In the case of engines equipped with position sensors, the engine control system is simple, reliable and cheap. Sensorless drives in comparison with drives equipped with sensors advantage is higher reliability. The relative disadvantage of such solutions is higher complexity of the control system and obligatory start-up procedure – not important in case of fully integrated driver solution with BCD technology operated by STMicroelectronics. The BLDC driver development aim is mainly to participation in broad BCD9 technology validation after up-scaling to 300mm substrate wafers.

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