Using FREDFETs in BLDC Motor Drivers to Overcome Thermal Challenges

A recent IHS report suggests that the global market for brushless DC (BLDC) motors in home appliances is set to rise from around 430 million units per year to 750 million units per year over the next five years. This enormous growth is due to the fact that BLDC motors are smaller and more efficient across a wider range of operating speeds than their more traditional AC induction counterparts – and there are other advantages too. Yet conventional means of driving BLDC motors may be compromising their effectiveness. New solutions are needed. **Cristian Ionescu-Catrina. Product Marketing Manager, Power Integrations, San Jose, California**

BLDC motors are being used in all sorts of household appliances – air conditioning, dish washers, washing machines, refrigerators, pumps, fans – to replace AC motors. The main reason for this is that BLDC motors more efficient than AC motors, particularly when not operating at maximum power and are more controllable. They also run quieter making them the ideal choice for appliances. Efficient operation across the load range is often necessary for products that must meet global energy efficiency regulations.

Software-controlled BLDC motors have the flexibility of programmability, variable speed and/or torque can be achieved with high levels of precision. Reliability is another important issue. BLDC motors do not require the provision of power for the rotor eliminating - brushes and slip rings - so reliability and lifetime is increased compared to brushed motors. Given the level of efficiency and controllability that can be brought to BLDC motor the most important considerations for the BLDC drive are the inverter and controller designs

Efficiency and thermals

Thermal challenges limit inverter performance. It's pretty obvious that increased device temperature decreases inverter life time, thereby adversely affecting reliability.

Increased temperatures will also make it harder to pass safety regulations, and may dictate the need for a heatsink and a cooling fan. This all adds to the BOM, size and cost, increases module size (negating another key advantage of BLDC motors) and will have a negative impact on reliability.

It is perhaps surprising how great an effect an apparently-small increase in inverter efficiency can have in reducing power losses – which translates into heat savings. For example, if you can increase the inverter efficiency by 1 % from 97 % to 98 %, given an inverter input power of 260 W the power losses will drop from 7.8 W to 5.2 W - a power saving of 2.6 W and a whopping 33 % less dissipated heat.

Power Integrations has very successfully delivered products into the appliance sector for many years. Devices such as the InnoSwitch™-EP and LinkSwitch™ families are highly-integrated, high-voltage ICs for off-line power conversion, and they are widely specified because of their high efficiency and ruggedness. So when Power Integrations decided to enter the brushless DC motor driver market already replete with excellent switching devices, the company realized that it needed to take a new approach, in order to deliver class-leading efficiency and performance.

The BridgeSwitch™ IC family of Integrated Half-Bridge (IHB) motor drivers delivers 98.5 % efficiency for designs from 30 W to 300 W – largely eliminating any

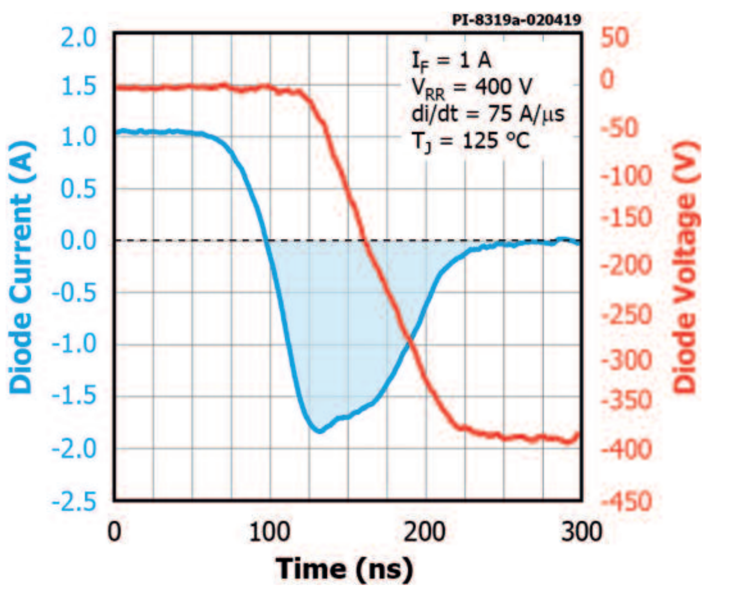


Figure 1: **Reverse-recovery charge, Q_{RR}, of the BridgeSwitch FREDFETs and Reverse Recovery Softness Factor (SSVR) in normal operation**

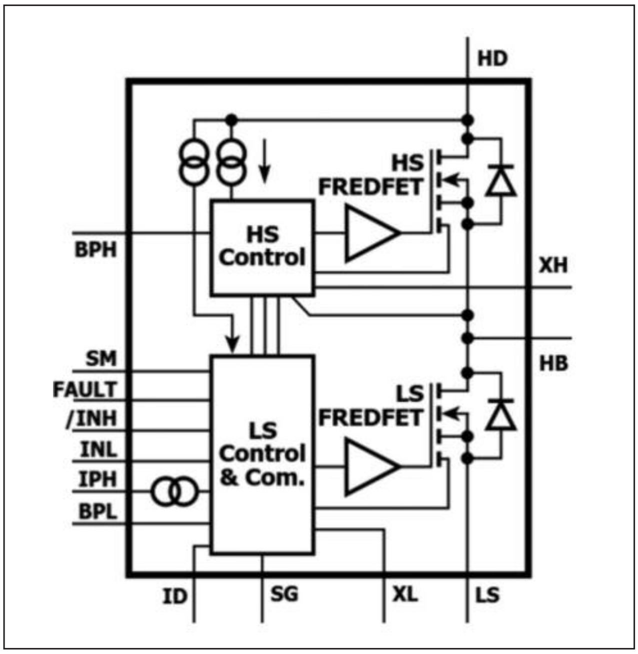


Figure 2: Block diagram showing the elements that are included within a BridgeSwitch IC

thermal challenge. It does this by integrating 600 V FREDFETs which incorporate fast but ultra-soft-recovery body diodes. A FREDFET is a fast-reverse (aka fast-recovery) epitaxial diode field-effect transistor. This specialised FET is designed to provide a very fast recovery (turn-off) of the body diode. Figure 1 shows the low reverse-recovery charge, Q_{RR}, of the BridgeSwitch FREDFETs in normal operation. The curve also shows the Reverse Recovery Softness Factor (SSVR) which is greater than one and indicates that the switch will have an excellent EMI characteristic.

Fast recovery body diode

The body-diode in a typical switching MOSFET is a parasitic device, derived from the structure of the switch. The diode so formed is not optimized for conduction and has poor performance. IGBT structures do not form an intrinsic body-diode. In order to overcome these issues, integrated switch solutions will often co-package anti-parallel diodes with the switching devices, which adds significant cost. Provided that these diodes exhibit a lower forward voltage drop than the intrinsic body-diode they will effectively shunt the body-diode (reducing its effect) and provide a more efficient demagnetization-current-path. As we will see later, the behaviour of the anti-parallel diode is important in determining switching efficiency and limiting EMI.

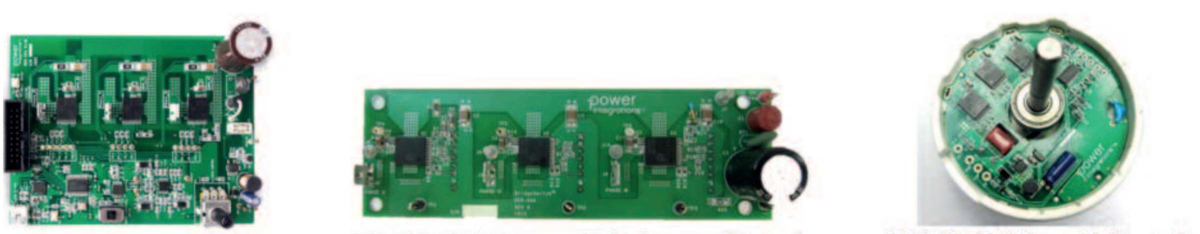
The negative slope of the current curve is dictated by circuit-inductance and is independent of the switching device. At the beginning of the reverse recovery period the diode voltage bias reverses. This causes carriers in the PN structure to also reverse direction. The carriers continue to carry charge (in the opposite direction) until they are swept-out of the P-N depletion zone giving rise to the reverse diode current.

The diode structure in Power Integrations' FREDFET quickly causes elimination of these charge carriers which limits the amount of reverse charge that is transported during the recovery period. This results in a reduced reverse recovery current amplitude and duration (reduced-area-under-the-curve = total charge).

The rate of elimination of the charge carriers (slope of the recovery characteristic) must also be controlled to reduce EMI and defines the softness of the diode. Softness (SSVR) is now typically described using the steepest part of the recovery curve, and referenced to the negative current slope seen at the beginning of the reverse recovery event.

As can be seen, the reduction in switching losses is significant. In addition, the soft recovery characteristic, with well controlled current transition rates reduces system EMI.

Figure 2 is a block diagram which shows the elements that are included within a BridgeSwitch IC – two drivers, controller, level shifter and two FREDFETs. BridgeSwitch offers uniquely offers self-powered operation - there is no need for a low voltage secondary power supply, resulting in a smaller and simpler auxiliary power stage; for example this would enable the use of a single-output buck converter such as Power Integrations' LinkSwitch-TN2 rather than the



DER-653: 300 W FOC | DER-654: 300 W Supports Multiple types of Control | DER-749: 40 W Sinusoidal Control

DER	Part #	I_{DC} (A)	Power (W)	Control	Full Load Efficiency	Sensor	Microcontroller
DER-653	BRD1265C	5.5	300	FOC	98%	Sensorless	Toshiba MCU TMP375FSDMG
DER-654	BRD1265C	5.5	300	Any	98.3%	Hall Sensor input	Any Microcontroller
DER-749	BRD1260C	1	40	Sinusoidal	94%	Hall Sensor	Princeton PT2505

Figure 3: BridgeSwitch architecture flexibility. - the same layout can be used as a building block for either single or multi-phase BLDC motor

conventional multi-output flyback design for the motor drive stage. Overall, the level of integration has a significant impact on BOM size, PCB space and reliability.

One very significant benefit of this architecture is that not only does it not produce as much heat (in the form of wasted power) as traditional designs in the first place, but also that it eliminates hot spots by distributing the heat that is produced. A traditional IPM (Integrated Power Module) design showing a hot spot at 118°C; the IHB BridgeSwitch design which shows a maximum 'spot' temperature of 92.3°C (minimum in this example is 87.2°C). This means that the PCB alone can be used to dissipate the heat, eliminating heatsinks – a further BOM, weight, space and cost saving. Comparing the BridgeSwitch thermal performance against an IGBT or other FET-based solutions shows similar benefits.

A further advantage of the BridgeSwitch architecture is its flexibility. The same layout – shown in Figure 3 - can be used as a building block for either single or multi-phase BLDC motor. Reference designs are available that support the wide variety of control algorithms that exist in the BLDC motor market.

Compliance with international safety regulations

Achieving compliance with international safety regulations can be challenging. To gain IEC 60335-1 and IEC 60730-1 approval, traditional BLDC motor solutions require Class B software protection, which is not only expensive and time-consuming to obtain, but will also require re-certification for any software changes, and aadditional software integrity checks for OTA (Over-the-Air) updates. The IHB system architecture reduces these costs and saves time because BridgeSwitch has unique hard-wired cycle-by-cycle low-side (LS) and high-side (HS) over-current protection BridgeSwitch monitors line voltage, providing both OV and UV protection and also measures switch and winding/PCB temperature to provide additional system alerts and hard-wired end-stop safety. This simplifies the software requirement from Class B to Class A, simplifying and shortening the qualification process. Plus there is no need for any re-certification when system software changes occur. As well as hard-wired protection BridgeSwitch devices transmit fault information to the system microcontroller via a unique single wire bi-directional communication interface.

A higher level of protection is achieved by this method as the hardware implementation in BridgeSwitch safety features reacts very quickly (~150 ns). Each BridgeSwitch device in the circuit monitors switch current, adding redundancy for each winding phase. Lastly, precise control of switch slew rates (<3 V/ns turn-off and <2.5 V/ns turn-on) from the integrated HS/LS/driver combination means that EMI is significantly reduced when compared to conventional designs.

Aside from its various technical, regulatory and commercial benefits, the higher overall efficiency saves energy, enabling a superior market positioning ('Green' energy-efficiency branding) as well as permitting the designer to add extra system features (e.g. displays, connectivity) within the same system power budget.