Design Considerations for Integrating Brushless DC Motors with Li-ion Batteries in 3-Phase Motor Applications

Introduction

The market for battery powered motor driven products is growing rapidly with the introduction of brushless motors and Li-ion batteries used primarily to extend operating time. Examples of traditional markets that are upgrading to these new devices include battery powered tools (drills, chainsaws, leaf blowers, etc.), small electric vehicles (e-bikes, wheelchairs, etc.) and uninterruptable power supplies, to name a few. These new generation products also require updated MOSFET bridge drivers to take advantage of the features and to lessen the problems associated with the integration of brushless DC (BLDC) motors with Li-ion batteries.

Upgrading to Li-ion and Brushless DC Motors

The high energy density of Li-ion batteries is a significant advantage over other battery technologies such as Ni-Cd, Ni-MH or lead acid. Typically, Li-ion has two to three times the energy density of these other battery technologies. Higher energy density translates to smaller battery packs for lighter and more compact hand held tools. Additionally, greater operating times can be achieved without increasing the original battery pack size or weight for applications such as e-bikes or wheelchairs.
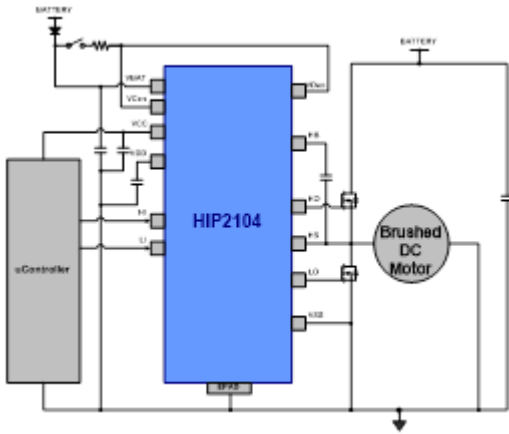
But the increased energy density of Li-ion is not without application problems. Li-ion batteries are not voltage sources as we typically think of batteries. The significant internal inductance of Li-ion batteries (100-500nH) leads to considerable ripple voltage that is the consequence of using PWM to drive the motor. The simple and obvious solution is to add sufficient capacitance across the MOSFET bridge, but enclosure limitations or costs can be prohibitive.

In addition to tight space, PCB outline constraints are a significant issue for many battery powered hand tools. In some of these applications, only minimal capacitance is applied across the bridge resulting in significance voltage ripple on the bridge. The battery valley ripple of a typical 18-20V Li-ion battery under heavy load with minimal bridge capacitance can be as low as 5V and the hilltop voltage can be as high as 36V. Another consideration is that during overload conditions such as a locked rotor, the battery voltage can droop to very low values. In these examples, it is desirable for the controller and not the driver to decide how to react to these severe operating conditions.
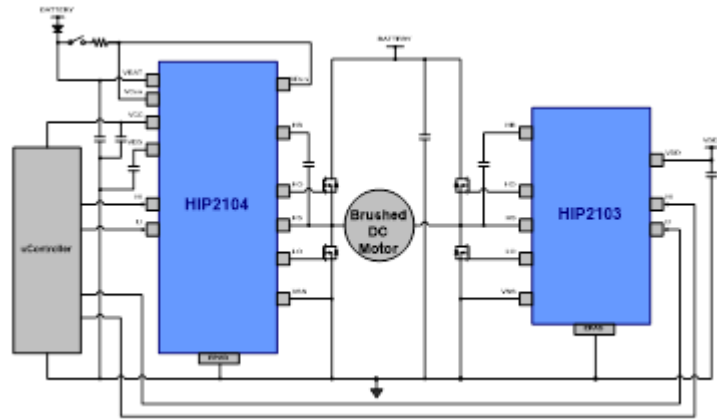
There are several motivations for using BLDC motors. The maximum RPM of a BLDC motor is limited primarily by the construction of the rotor, whereas the RPM of a brushed DC motor is limited primarily by the brushes themselves. In most applications, a transmission with gear reduction is used to reduce the RPM of the motor down to the desired RPM of the application. Consequently, because the BLDC motor can rotate many times faster than a brushed motor, a physically smaller BLDC motor size with a corresponding adjustment to the transmission gear ratio will produce the same RPM and applied torque to the output of the product. Another obvious advantage is the elimination of brushes that wear out and generate significant EMI. For increased operating time, a significant advantage of a BLDC motor is the increase of efficiency, typically 150% or better, over a similar brushed DC motor.

A BLDC motor also has its own application problems; primarily the additional complexity of the drive electronics. In a unidirectional brushed motor drive application, only one MOSFET bridge circuit is necessary. In a bidirectional brushed motor drive, two bridge circuits are required. But a BLDC motor requires three bridge circuits even for unidirectional applications. This increased complexity requires physically smaller or
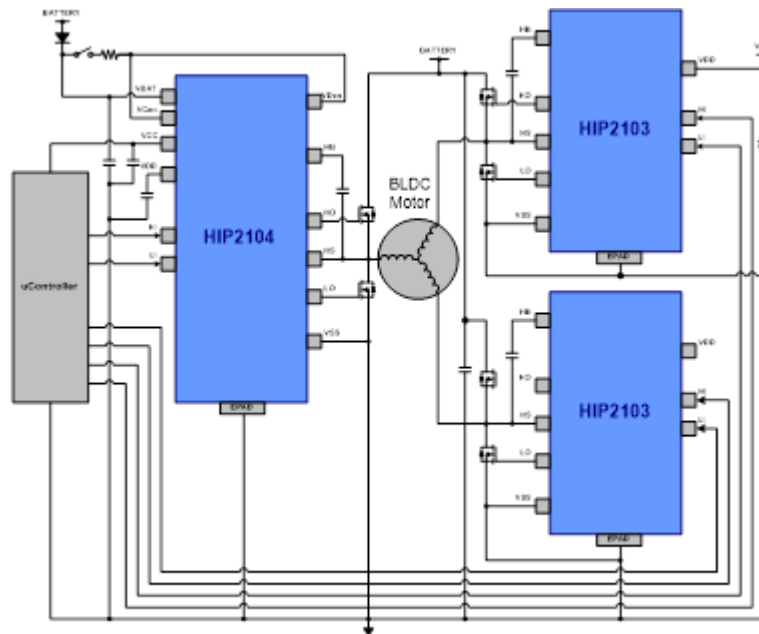
higher functioning integrated circuits to reduce component count, BOM cost and real estate, especially in space constrained applications.

Unidirectional Motor Drive

Bidirectional Motor Drive

3 Phase BLDC Motor Drive

Desirable Features for Bridge Drivers for Battery Powered Motors

1. Because many motor drive applications require relatively low bias currents for bridge drivers and similarly low bias currents for the controller (usually a DSP or microcontroller) it is desirable to integrate
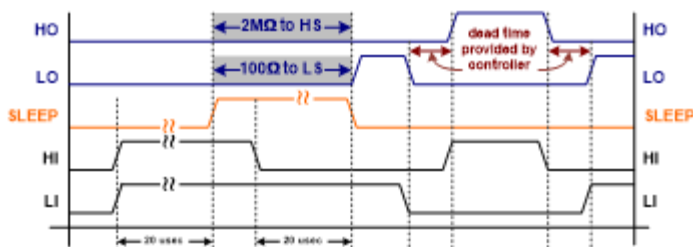
linear regulators (LDOs) with enable inputs into a bridge driver; 12VDD for the bridge drivers and 3.3VCC for the controllers.

2. Mechanical switch denouncing of the enable inputs for the LDOs are necessary to insure bounce free turn-on of the LDOs.

3. Ultra-low quiescent current to minimize battery drain is very desirable. Ideally, this would be achieved with a sleep mode that safely shuts down the driver when a bridge voltage is present but the application is not operating.

4. Uninterrupted bridge operation with battery voltage as low as 5V. This is accomplished with an under voltage lockout of ~4.2V. Traditional bridge drivers have a UVLO typically at 7.5V.

5. High immunity to negative transients on the phase node (HS) is necessary for robust operation. The trend in motor drives has been for higher levels of switching currents in the bridge FETs (> 200A). Along with the high switching currents and the constraints of non-optimal PCB outlines, minimizing negative transients on the HS pin that result from parasitic PCB inductance is a difficult PCB design issue.

6. The smallest possible packages to minimize board space are necessary in many applications. A small package also allows the driver to be located next to the driven FETs, alleviating some of the problems associated with less than optimum PCB layout.

7. The driver should be rated for bridge voltage up to 50V for reliable operation with battery voltages up to 36V.
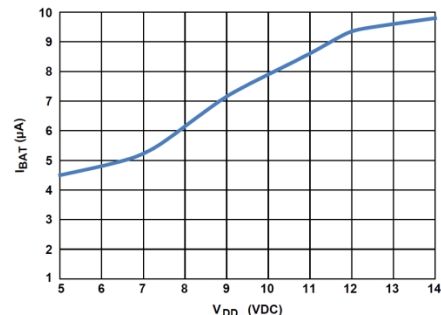
Half Bridge Driver Solutions for Motor Drive Applications

Intersil's HIP2103 and HIP2104 half bridge drivers provide all of the above features. The HIP2103 performs like a typical half bridge driver incorporating independent logic level inputs (LI and HI) for the high and low side bridge FETs. The phase node (HS) is rated for -10V to accommodate less than optimum PCB design. The maximum recommended operating bridge voltage is 50V to easily accommodate a 36V battery with transients above nominal. To allow the driver to function without interruption when low voltage valley transients are present, the under voltage lockout is ~4.2V.

The HIP2103 also incorporates a sleep mode feature when the motor drive is not active to minimize battery discharge. To keep the HIP2103 in the smallest 8-pin package, the sleep mode is invoked by setting both the LI and HI input high simultaneously for more than 20µs. To cancel the sleep mode, the LI input is set high while the HI input is low for more than 20µs. This is a normal startup sequence to insure that the boot capacitor is charged prior to setting the HI input for normal operation. Internal logic prevents both the high side and low side bridge FETs from being turned on simultaneously when enabling the sleep mode. However, dead time still must be provided by the controller to prevent shoot-through when one bridge FET is turned off and the other is turned on.
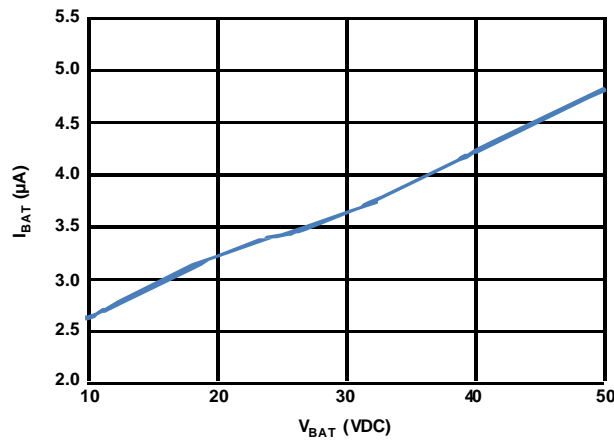

Sleep Mode and Normal Switching

Sleep Mode Current

The sleep mode is also activated by the under voltage lockout. After the UVLO is released, when VDD is > 5V, the sleep mode remains active until the startup sequence in invoked. When the driver is in sleep mode, both the LO and HO gate drive outputs are in a high impedance state with a 2Mohm resistor between the HO and HS pins and with a 100ohm resistor between LO and VSS. This ensures that the bridge FETs remain off while sleep mode is active. When sleep mode is canceled, the 100ohm resistor is disconnected.
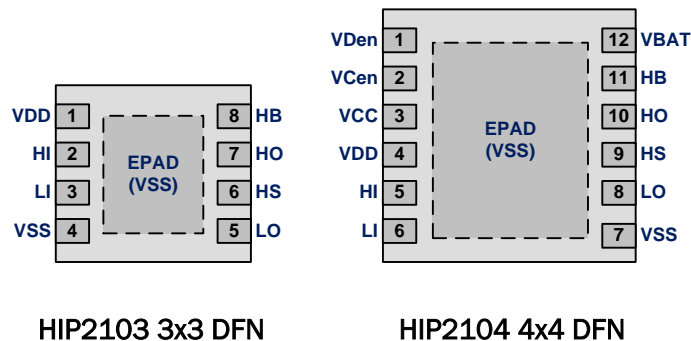
The HIP2104 bridge driver is identical to the HIP2103, but also includes two integrated linear regulators. One LD0 provides 12VDD up to 75mA for the gate voltage bias for the driver portion of the HIP2104. This same VDD can also be used to bias additional HIP2103 drivers. The 3.3VCC LDO is intended to bias a microcontroller or a DSP. Both LDOs have separate enable inputs that are battery voltage tolerant allowing a mechanical switch to be used to enable the LDOs using the battery voltage. Because these enable inputs have conventional logic thresholds, the LDOs can alternatively be controlled with external logic if desired.

Although the HIP2104 also has the same sleep mode feature of the HIP2103, ultra-low quiescent current can be achieved by turning off the LDOs of the HIP2104, thus removing bias voltage from all of the drivers connected to the VDD output of the HIP2104 and also removing the VCC bias from the controller. The quiescent current in this state only has battery voltage connected to the HIP2104, resulting in less than 5µA of current.

HIP2104 Shut Down Current

The HIP2103 is in an 8-pin 3x3 DFN package. The HIP2104 is in a 12-pin 4x4 DFN package and has a very low θ_{JC} of 7°C/W so that the PCB can act as a heat sink to keep the junction temperature to less than the internal 150°C thermal shut down.

HIP2103 3x3 DFN   HIP2104 4x4 DFN

Conclusion

Intersil's HIP2103 and HIP2104 half bridge drivers are well suited for new generation BLDC motor drives. Although the emphasis of this paper is the application of these drivers for 3-phase motors, they are also appropriate for conventional brushed DC motors or any other switch mode power application. Complete application information and parameters can be found in the HIP2103/4 datasheet. A motor drive demonstration board with Application Note AN1899 is also available for basic motor operation.

Next Steps

- Find out more about the HIP2103/4 MOSFET drivers

- Get the HIP2103/4 datasheet and app notes

- Order free samples

- Check out the HIP2103_4MBEVAL1Z eval board

- Search for power management parts using our parametric search

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