International Rectifier

Integrated Power H-Bridge Controller For 80-Watt Automotive DC Motors

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as presented at PCIM Europe 02

Abstract:
A 6-amp monolithic H-bridge controller has been designed for automotive applications using a self-isolated vertical CMOS process. The controller integrates system-level interfacing circuitry and control strategy. In addition, it provides protection features including short circuit protection through over-temperature and over-current detection, as well as over-voltage protection from integrated active clamping circuitry. The H-bridge controller IC combined with few external components provides a cost-effective motor control circuit that fits within a 25 x 21 millimeter footprint.

The high side switches are integrated in the controller in a standard SO-20 package for low cost, ease of drive and protection. The low side switches are in two separate SO-8 packages developed specifically for use with the controller. The controller limits the in-rush current of a DC motor and hard start-up of the motor is avoided and replaced by a smooth and a low-stress speed ramp-up. The controller drives the motor in both directions and offers a braking mode without any external power management.

Automotive applications for the controller include any brush type dc motor, such as seat motors, and many other body electronics applications. The self-isolated process makes the IC very cost effective. In addition, the circuit provides a flexible architecture to cost-effectively address a wide variety of applications. This paper will describe the process, key elements of the circuit design and provide an application example for the motor controller.

INTRODUCTION

The IR3220 is a fully protected, Dual High Side Switch that features a complete H-Bridge control. With two additional Low Side MOSFETs, it limits the in-rush current of a DC motor, drives the motor in both directions and offers a braking mode without any external power management. Current protection (short-circuit) and Temperature shutdown (over-load) give the IR3220 the ability to meet most customers' mechatronics requirements.

The High Side (HS) switches provide the directional capability and the H-Bridge protection. The Low Side (LS) MOSFETs provide flexibility by offering the high frequency switching ability. Therefore, hard start-up of the motor is avoided and replaced by a smooth and low-stress speed ramp-up. Figure 1 shows the architecture for the dc motor control.

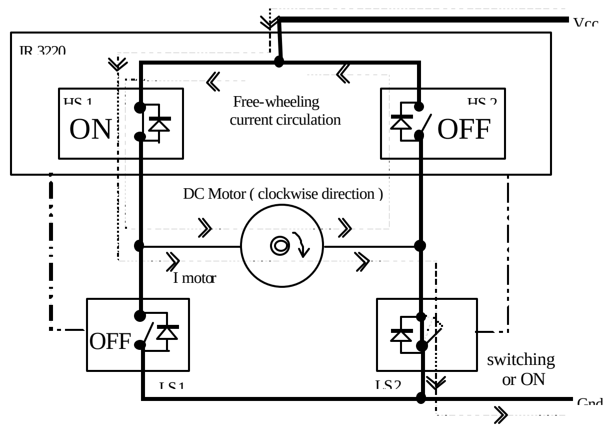


Figure 1 - Architecture of the IR3220 H-bridge motor control. The circuitry and high side drivers in the surface mount SO-20 require only two low side MOSFETs in SO-8 packages to provide forward, reverse and braking for a dc motor.

A summary of the features of this controller is:

- Over-temperature protection
- Over-current shutdown
- Status feedback
- ESD protection
- H-bridge control embedded (shoot-through protection, etc.)
- Internal switching oscillator (20 kHz)
- Inrush current limited by PWM soft-start sequence
- Braking / non-braking mode
- Sleep mode for direct battery connection

The IC Process
One of the key factors that make the controller extremely cost effective is the IC process used for this design. A self-isolated vertical process shown in Figure 2 provides the ability to combine power MOSFETs with breakdown capability up to 60V with P-MOS, N-MOS and a parasitic NPN transistor. The process is relatively simple with fewer masking steps than processes that integrate bipolar, CMOS and DMOS, but provides useful BiCMOS circuit elements for many power circuits.

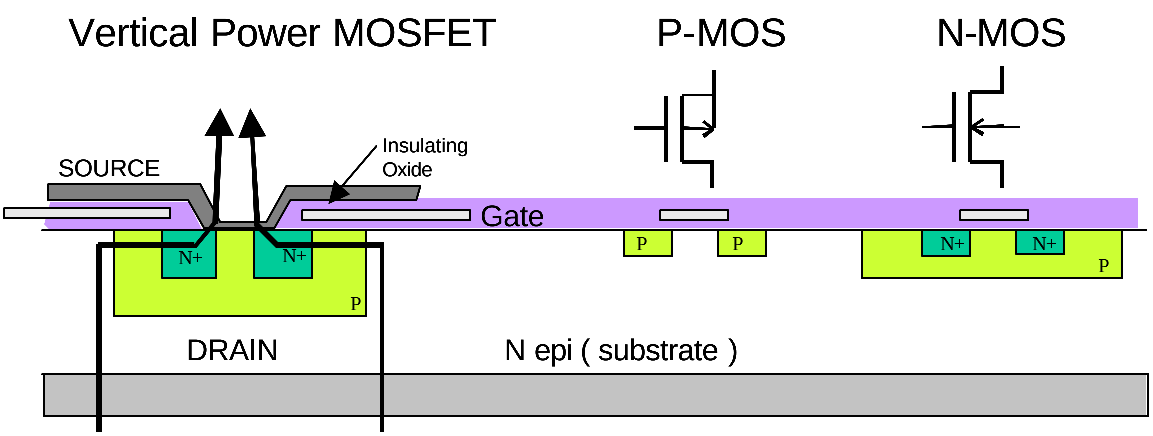


Figure 2 - The Self-Isolated Vertical (SIV) process allows BICMOS control & protection circuitry to be combined with vertical power MOSFETs with 40 to 60-V breakdown using a second-generation 2-µm monolithic process.

INTEGRATED ARCHITECTURE

The IR3220 architecture relies on three basic principles:

- Each leg of the H-Bridge is totally independent of the other. Each leg features separate Current Protection and its own Shoot-Through circuitry. No diagonal command among the four MOSFETs is allowed.

- The normal quiescent state of the two Low Side MOSFETs is ON. Since each leg is independent, it is the input signal [IN 1(2)] that drives the corresponding High Side FET. The Shoot-Through circuitry then generates the proper Low Side command in order to avoid any conflict.

- The Soft-Start circuitry limits in-rush current and provides a smooth and low-stress speed ramp up. It brings a PWM signal generated in the IC to both Low Side MOSFETs without having to take the H-bridge direction into consideration. Therefore, the PWM circuitry is almost independent and offers flexibility to extended operations (controlling the speed or the torque.)

Each of the above techniques has been chosen for either its inherent safety for the H-bridge topology or its ability to increase the independence of the IC functions. Implementing those principles allows a safe behavior of the topology without any H-Bridge logic circuitry. Nevertheless, some other IC functions are implemented: Under-Voltage Lock Out, Non-Braking Mode, Temperature Protection and the Diagnostic Feed-back. These functions are all contained under the title “IC Logic Control” in

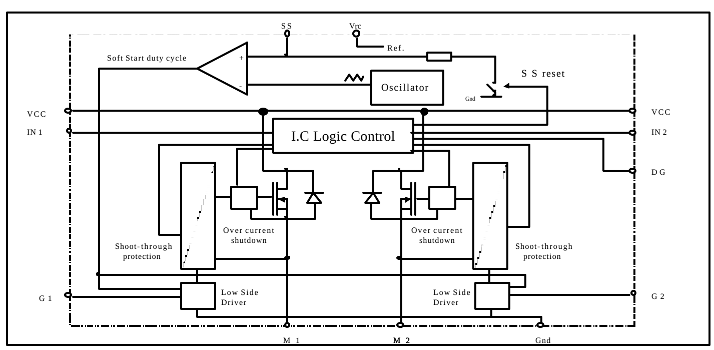


Figure 3 - Circuitry in the IR3220 that drives and protects the integrated high side switches and separate low side switches. The IR3220 contains 2 HS switches with Rdson = 12 mΩ (max) that can carry I_{DC} @ 85°C = 6A. The control circuitry can operate with V_{CC} op = 5.5 to 35 V and

provides I shutdown = 30 A and T shutdown = 165 °C.

Shoot-Through Protection

The Shoot-Through Protection of each leg takes advantage of the switching time difference between the Low Side MOSFET and the High Side Switch. Due to the charge pump circuitry, the HS switch has slow turn-on / turn-off times compared to the direct drive of the LS MOSFET. Therefore, when IN 1 (2) is set high, the complemented signal immediately turns-off the LS MOSFET while the charge pump circuitry has not switched ON the HS part yet. On the other hand, when IN 1 (2) is set low, the HS switch turns-off slowly and the LS MOSFET is not turned-on again until its Vds voltage has decreased to two volts (back to its quiescent ON state). With this technique, a self-adaptive dead time circuitry is achieved without any time-dependent elements.

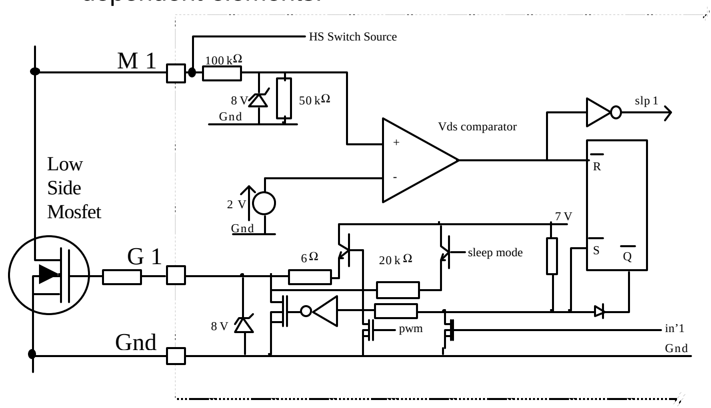


Figure 4 - Shoot-through circuitry.

As shown in Figure 4, the core of this Shoot-Through circuitry consists of an RS Flip-Flop and a voltage comparator. This configuration memorizes the request of the HS turn-on and the latter resets the memory when it is fully OFF ([M1 – Gnd] < 2 V). The low side driver features a low consumption "Sleep Mode Pull-up" for the quiescent ON state. Although the PWM signal is sent to both LS MOSFETs at the same time, the leg with the IN input at 0V is the only one that cycles its LS MOSFET.

Soft-Start Sequence

This block (shown in Figure 5) generates the PWM signal for the switching start-up. It is composed of a 20 kHz oscillator, a voltage comparator and a RC charge/discharge circuitry. A 3 V symmetrical saw-tooth is compared to the soft start (SS) pin voltage and the PWM signal created is sent to the LS MOSFETs. The saw-tooth goes from 1 V to 4 V so that the SS pin drives a duty cycle from 0% (SS < 1 V) up to 100% (SS > 4 V). The SS pin is normally the central point of a RC network powered by the Vrc pin. Finally, a discharge circuitry is implemented in order to reset and hold the SS pin at low level while the H-Bridge is Off.

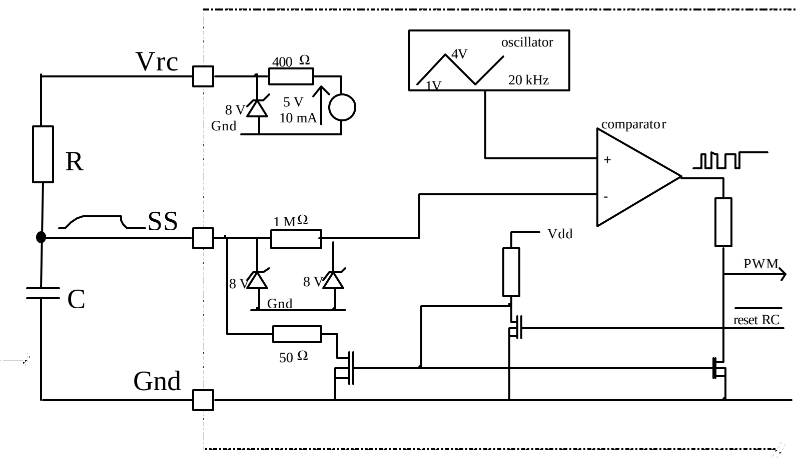


Figure 5 - Circuitry for Soft-Start Sequence.

When one of the IN 1(2) pins is set high, the corresponding leg of the H-Bridge is activated (the HS switch is turned-on / the LS MOSFET is turned-off) and the discharge circuitry is released. The SS voltage increases slowly resulting in a smooth duty cycle variation (PWM signal) at the gate of the LS MOSFET. Therefore, the switching waveform seen by the DC Motor goes from 0% to 100% duty cycle offering a low-stress ramp-up to the load on the shaft. The total switching duration of the Soft-Start Sequence is about 1.4 times the RC constant. The capacitor is discharged through a 50-ohm resistor when the H-Bridge stops. The complete discharge of the capacitor must occur before any new start-up. Furthermore, the mechanical load on the shaft must be in the stop position before requesting another Soft-Start Sequence.

The optimized Soft-Start duration could not be easily determined since many parameters must be taken into account (including the DC motor performances, mechanical characteristic of the load, friction, etc.). Successive start-up tests may help to evaluate the best trade-off between the limited inrush current and the response time to the final speed. An example of soft-start sequence waveforms is shown in Figure 6.

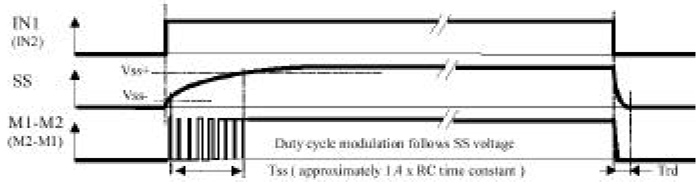


Figure 6 - Soft-start sequence waveforms.

IC Logic Control
This block, shown in Figure 7, contains functions that simplify the use of the IR3220. One of them is the Under Voltage Lock Out that inhibits the IC when the Vcc voltage goes down to 4V. Cycling IN 1(2) allows restart as soon as Vcc exceeds 5 V. The Sleep Mode circuitry switches the entire IC into the low-current consumption mode (10 µA typ.) when IN 1 = IN 2 = 0. Notice that both LS MOSFETs remain ON during the Sleep Mode. A Non-Braking Mode is added when IN 1 = IN 2 = 1. Finally, the charge/discharge-reset signal is generated when the H-Bridge is Off (braking or not) and the open collector output of the DG pin is activated due to the inner HS switch status.

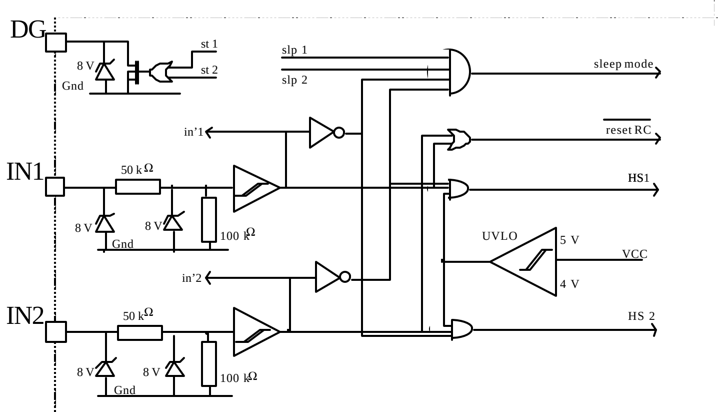


Figure 7 – IC Logic circuitry for under-voltage lockout, sleep mode, non-braking mode and charge/discharge reset signal.

Protected High Side Switches
The high side switches of the IR3220 are derived from an existing family of Intelligent Power Switches. They feature charge-pump, over-current protection (shutdown type), Status Feedback and Active Clamp capability. Normally, there is no need for an Active Clamp in an H-Bridge topology. However, the Active Clamp can help in some abnormal conditions (for example during an automotive load dump condition.) Since the two HS switches may have to dissipate energy at the same time (one ON and the other free-wheeling), the thermal protection latches off as soon as one of the junction temperatures exceeds 165 °C. The fault condition of each HS switch is sent to the IC Logic Control and then forwarded to the DG pin. Protection circuitry is reset when the condition IN1 = IN2 = 0 is valid for a minimum of 50 µS. Current and Thermal Shutdowns only act on the HS switches so that the LS MOSFET remains ON until the "reset condition" is applied. Figure 8 shows the high switches and the circuitry.

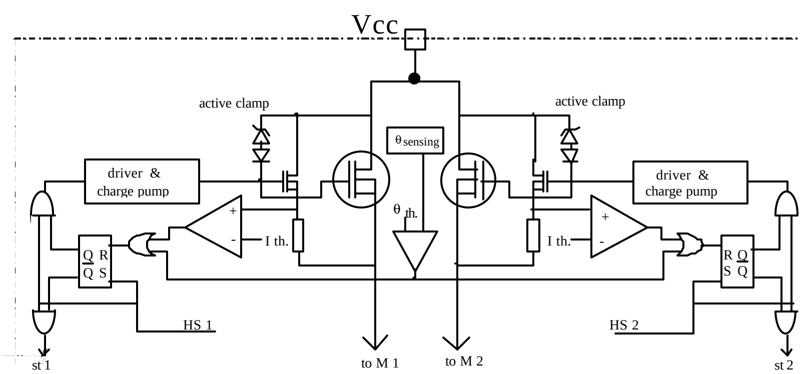
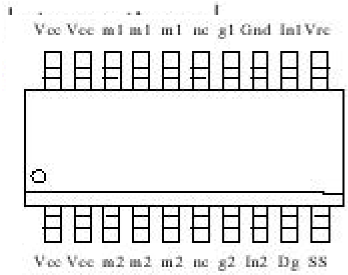


Figure 8 – High side switches and associated drive and protection circuitry.

PACKAGING

The low, 12-milliohm on-resistance of the high side switches allows the motor controller to be housed in a standard SO-20 IC package. The leadframe design accommodates both the high side switches and the control IC. Gold wires common to IC assembly are use to connect the bond pads to the leadframe. The connections and their definitions are shown in Figure 9.

In addition to a small footprint, the SO-20 package is only 2.5 mm thick (nominally) – over 40% thinner than a TO-220 that is 4.4 mm thick. This allows a thin motor control assembly that may enable packaging in very tight locations including inside the motor housing itself.



Vcc	Positive power supply	IN1	Logic input 1 (Leg 1 Cdt. / mode)
M1	Motor 1 output (high side source - leg 1)	IN2	Logic input 2 (Leg 2 Cdt. / mode)
M2	Motor 2 output (high side source - leg 2)	Dg	Diagnostic output (open drain)
G1	Gate 1 drive output (low side gate - leg 1)	Vrc	Voltage ref. output (soft-start RC)
G2	Gate 2 drive output (low side gate - leg 2)	SS	RC soft-start input (the voltage on this input drives the switching duty cycle)
Gnd	Power supply return		

Figure 9 - SO-20 package pinout and definitions.

TYPICAL AUTOMOTIVE APPLICATION

All of the previously described functions make the IR3220 particularly well suited for DC Actuator applications where small space and minimal heatsinking are required. Figure 10 shows the IR3220 in a complete motor design.

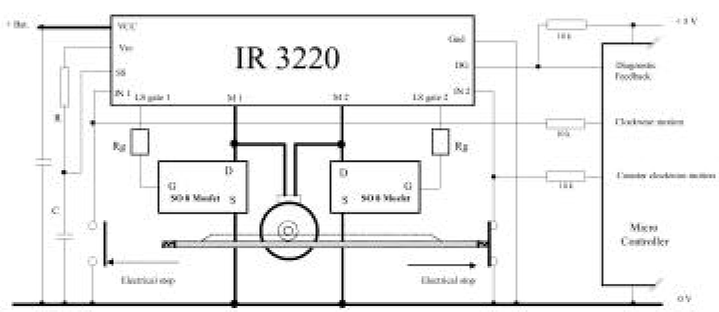


Figure 10 - IR3220. The IR3220 directly interfaces to a microcontroller and controls DC motors up to 80W in forward, reverse and breaking mode.

It offers Sleep Mode that shorts the DC Motor (braking Mode - IN1 = IN2 = 0) and a soft switching ramp-up for both directions without any additional circuitry and to remove conditions that create the highest heat dissipation. Since the IR3220 features a 20kHz switching capability, reservoir and high frequency decoupling capacitors have to be connected between the VCC pin and the power ground. When interfacing end switches, RC time constants may be needed on the IN 1 and IN 2 pins in order to mask mechanical bouncing issues.

The current shutdown will protect the application in case of either a short between the motor wires or a short of one of the switches to the Ground.

Assuming a sufficient cooling capability of the LS MOSFETs, the whole H-Bridge is also protected against over-temperature. Particular care in designing the layout and/or selecting the LS MOSFETs will help to keep this "sufficient cooling condition" valid. To further simplify design, a Low Side, 40V, N-Channel IRF7484 MOSFET has been designed to provide the best protection when using IR3220.

Layout & Thermal Considerations

In case of over-load, the IR3220 internal temperature sensor latches off the proper HS switch when its Junction Temperature exceeds 165°C. The protection scheme requires that the LS MOSFET junction does not reach a higher temperature than the integrated HSD switch so that the IC shutdown always acts first.

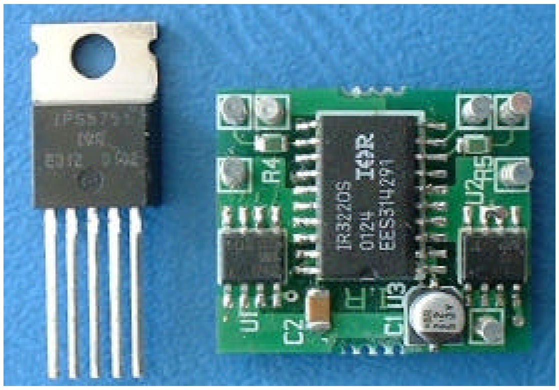
A design rule offering enough margin is that the low side ΔT has to be half that of one of the HS switches. The design rule can be summarized in a very simple formula:

$$R_{DS(on)}\ LS \bullet R\theta ja\ LS < 1/2\ [R_{DS(on)}\ HS \bullet R\theta ja\ HS]$$

Equation 1

The IRF7484 has been designed to provide a low $R_{DS(on)}$ of 10mΩ in an SO-8 package. The $R_{DS(on)}$ (mΩ) is a characteristic of the MOSFET die itself while the Rθja (junction to ambient thermal resistance - °k/W) depends on the package and upon the heatsink. A copper plate on the PCB constitutes one possibility the designer may use to improve the Rθja. This is particularly true for Surface Mount Packages such as the SO-20 WB of the IR3220 or the SO-8 Power MOSFETs. These packages usually spread out the heat due to the leadframe connected pins (Vcc for the IR3220 or the Drain for Power MOSFETs). By adding a significant copper surface to the SO-8 footprint, the Rθja is slightly increased and helps to satisfy the "sufficient cooling condition" without the need of a heatsink.

An example of a layout (reference design) is shown in Photo 1. It corresponds to a 6-A DC Motor Actuator with a PCB size less than 1 Inch ² (25 x 21 millimeter footprint).



(a) (b)

Photo 1 - The IR3220 reference kit (b) compared to a TO-220/5-pin Intelligent Power Switch (IPS) package (a).

With as few as 6 resistors and 2 capacitors, the IR3220 combined with 2 LS MOSFETs provides a cost-effective, complete, fully operational and fully protected H-Bridge control circuit up to 6A (80W). This compares to more than 100 components in a discrete circuit with the same functionality and protection. Development time is shortened from months to weeks by cutting design iterations and validation steps.

With 12 milliohms on-resistance (maximum) for the high side switch, the IR3220 reference design has 4 Power MOSFETs with less than 22 milliohms on-resistance (maximum per leg) in a H-bridge topology with protection, soft-start sequence, PWM oscillator and several additional system-level features.

FUTURE POSSIBILITIES

An H-bridge controller that integrates system-level interfacing circuitry and control strategy has been described. It provides protection features including short circuit protection through over-temperature and over-current detection, as well as over-voltage protection provided by an integrated active clamping circuitry. The H-bridge controller IC combined with a few external components provides an 80W motor control circuit that fits within a 25 x 21 millimeter footprint. The separate control IC and low side MOSFETs provide a flexible architecture for the system designer and have very high level of efficiency (low on-resistance) minimizing the heatsinking requirements.

The separate IC and high side switches combined by package level integration provide a flexible architecture for the IC designer. This architecture allows higher and lower current designs as well as different voltage levels to be easily implemented by merely choosing the appropriate discrete MOSFETs and packaging. A higher current package has already been defined using a 15-pin power SIP that will extend the current range to 20 amps without having to redesign the controller IC.

[1] IR3220 Application Note.