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APPLICATION NOTE

Application Note AN-1032

Fully Protected H-Bridge IR3220S Architecture and Typical Application

By Xavier de Frutos

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TOPICS COVERED

Inner Architecture
- *Shoot-through protection*
- *Soft-Start Sequence*
- *I.C Logic Control*

Typical Application
- *Layout & Thermal Considerations*
- *Selecting the Soft-Start RC network*

The IR 3220S is a fully protected Dual High Side Switch that features a whole H-Bridge control. With two additional Low Side MOSFETs, it limits the in-rush current of a DC motor, drives it in both directions and offers a braking mode without any external power management. Current protection (short-circuit) and Temperature shutdown(overload) give the IR 3220S the ability of meeting most of the Mechatronic's Customer Requirements.

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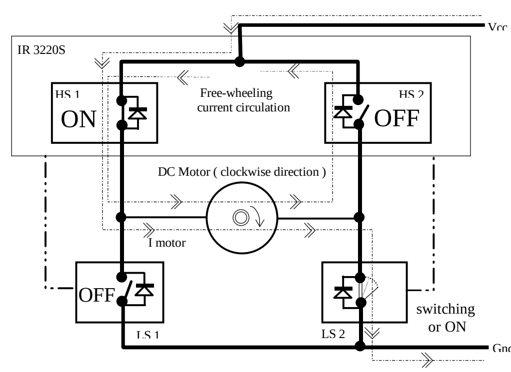


1. INNER ARCHITECTURE

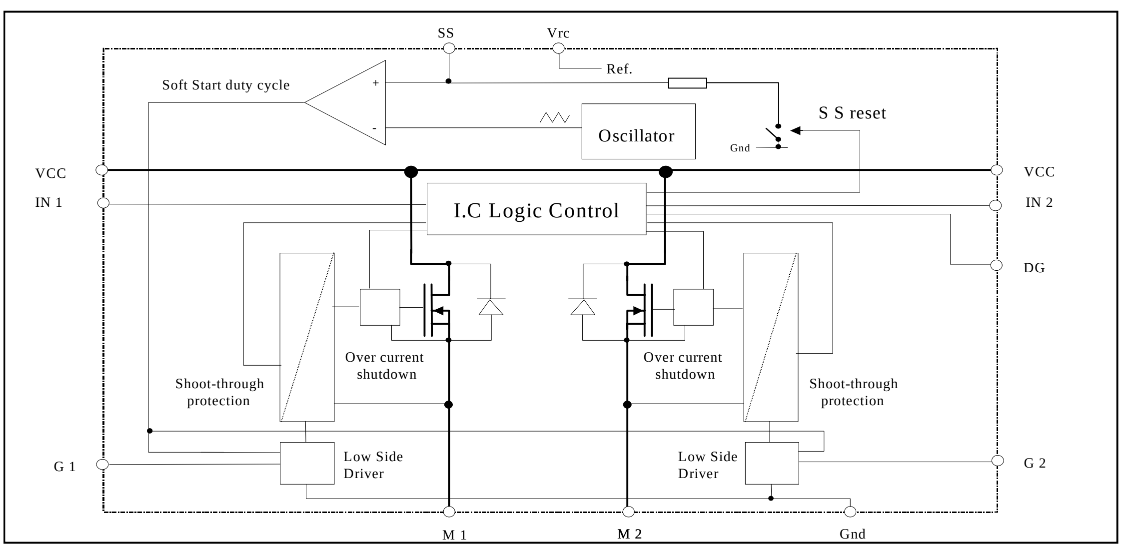
The IR3220S architecture relies on three basic principles:

- Each leg of the H-Bridge is totally independent of the other one. Each of them features its own Current Protection and also its own Shoot-Through circuitry. No diagonally command among the four MOSFETs is implemented.

- 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 brings a PWM signal to both Low Side MOSFETs without taking in consideration the H-bridge direction. Therefore, the PWM circuitry is almost independent and offers a great flexibility to extended operations (controlling the speed or the torque).

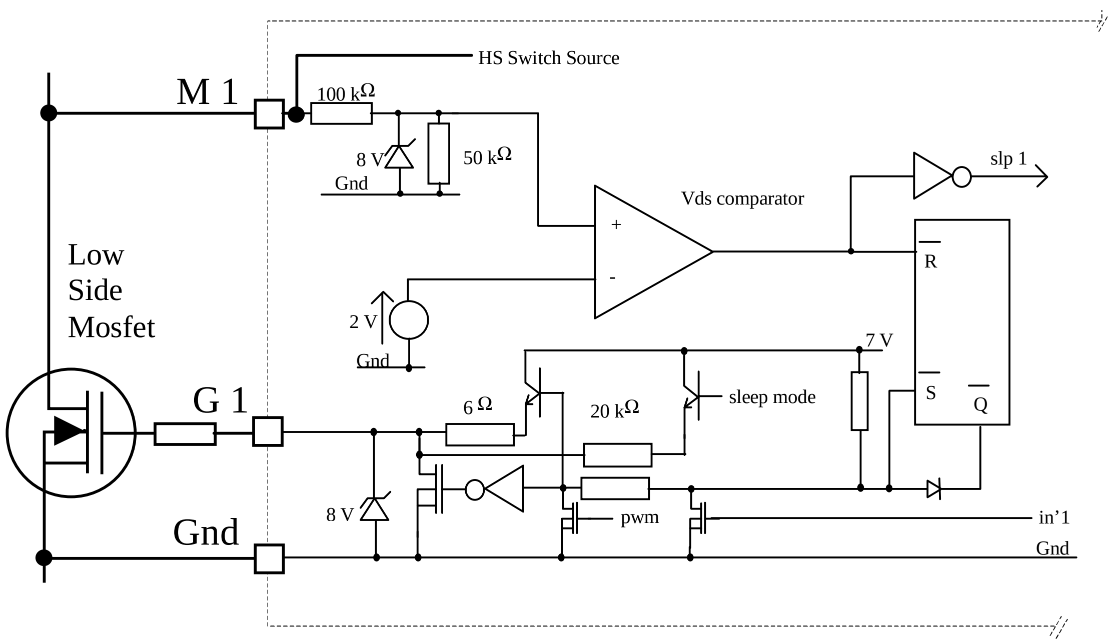
Each of the above has been chosen for either its natural safety with regard to the H-bridge topology or its ability to increase the independence among the I.C functions. Implementing those principles allows a safe behavior of the topology without any H-Bridge logic circuitry. Nevertheless, some other functions more related to the IC are still implemented: Under-Voltage Lock Out, None-Braking Mode, Temperature Protection and the Diagnostic Feed-back. They are all gathered under the title '' I.C Logic Control '' in the following Diagram.



The following block descriptions explain in detail how each function is achieved and also give an equivalent schematic of the I.C interface. Finally, the over-Current and Over-Temperature protections are also presented.

Shoot-Through Protection

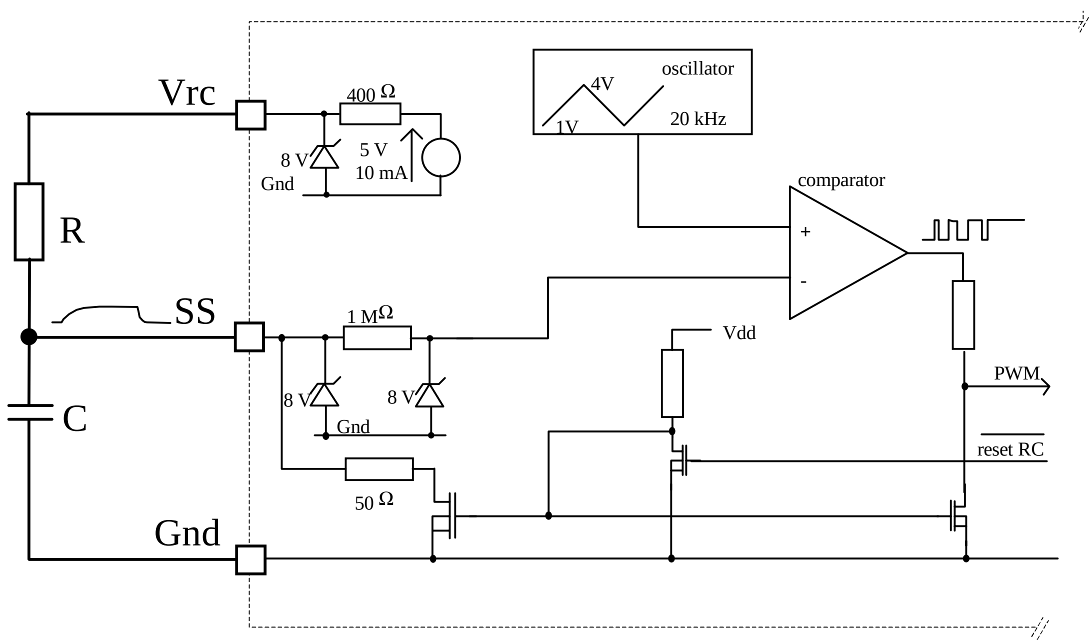
The Shoot-Through Protection of each leg takes advantage of the switching time difference between the Low Side MOSFET and the High Side Switch. Due to the charge pump circuitry, the HS switch has slow turn-on / turn-off times compared to the direct drive of the LS MOSFET.
Therefore, when IN 1 (2) is set high, the complemented signal immediately turns-off the LS MOSFET while the charge pump circuitry hasn't 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 isn't turned-on again until its Vds voltage has gone down to two volts (back to its quiescent ON state).
By this way, a self-adaptive deadtime circuitry is achieved without any temporization.



The core of this Shoot-Through circuitry is composed of a 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). One can notice that 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

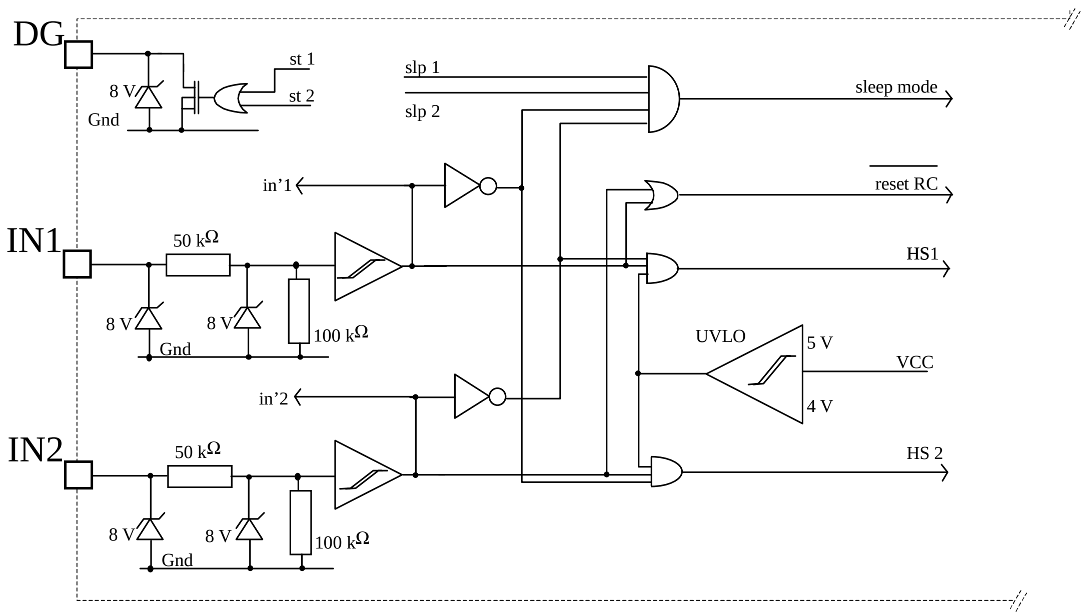
This block generates the PWM signal for the switching start-up. It is composed of a 20 kHz oscillator, a voltage comparator and a RC charge/discharge circuitry. A 3 V symmetrical saw-tooth is compared to the SS pin voltage and the PWM signal created is sent to the LS MOSFETs. The saw-tooth goes from 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.



When one of the IN 1(2) pin 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 stress-less 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 50Ω resistor when the H-Bridge stops. One has to wait the complete discharge of the capacitor before any new start-up. Furthermore, the complete stop of the mechanical load on the shaft must be achieved before requesting another Soft-Start Sequence. The optimized Soft-Start duration could not be easily determined since many parameters should be taken into account (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. However, a simple and general method is explained at the end of this Application Note.

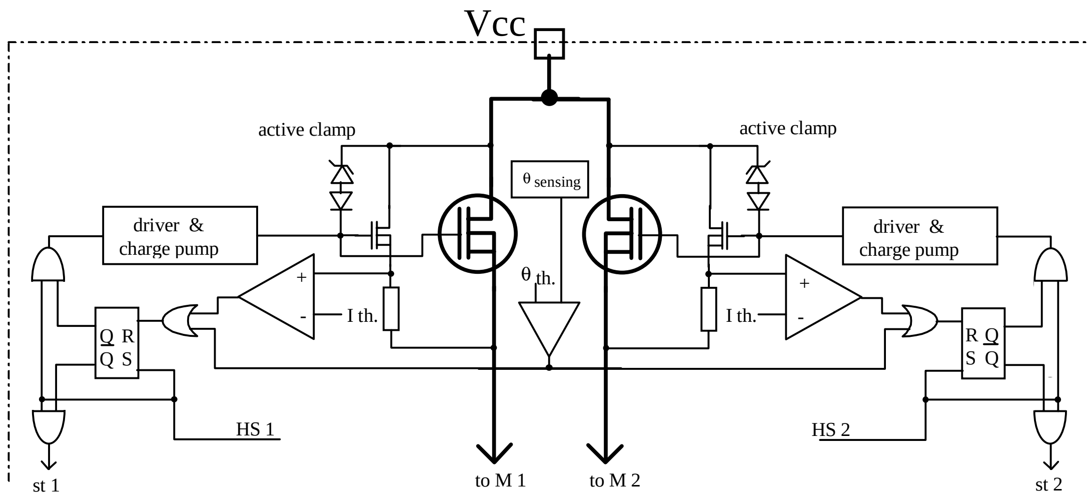
I.C Logic Control

This block gathers some functions that really simplify the use of the IR 3220S. One of them is the Under Voltage Lock Out that inhibits the I.C when the Vcc voltage goes down to 4V. Restart by cycling IN 1 (2) is allowed as soon as Vcc exceeds 5V. The Sleep Mode circuitry switches the whole I.C in the low current consumption mode (10 uA typ.) when IN 1 = IN 2 = 0. One has to 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 thanks to the inner HS switch status.



Protected High Side Switches

The high side switches of the IR3220S are derived from the I.P.S Family. They feature charge- pump, over-current protection (shutdown type), Status Feedback and Active Clamp capability. Regarding the latter, one may argue that there is no need for an Active Clamp in an H-Bridge topology. With regard to the load, this is true but the Active Clamp can help in some abnormal conditions (for example during ' 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. Fault condition of each HS switch is sent to the IC Logic Control and then forwarded to the DG pin . Protections are reset when the condition IN1 = IN2 = 0 is valid for a minimum of 50 uS. Current and Thermal Shutdowns only act on the HS switches so that the LS MOSFET remains ON until the '' reset condition " is applied.



2. TYPICAL APPLICATION

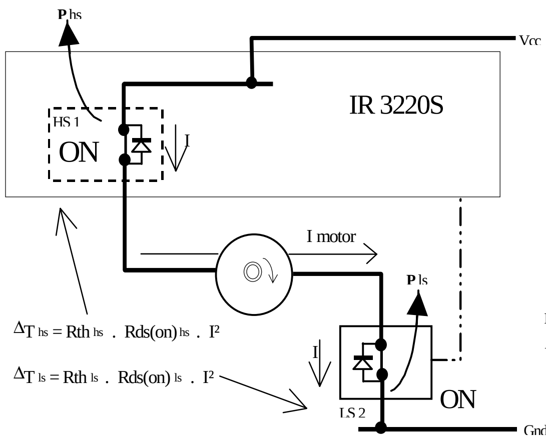
All the above functions make the IR3220S particularly suitable for DC Actuator applications. It offers Sleep Mode that shorts the DC Motor (braking Mode - IN1 = IN2 = 0) and a soft switching ramp-up for both directions without any additional circuitry. Since the IR3220S features the 20kHz switching capability, reservoir and HF 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(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 them to the Ground. Assuming a sufficient cooling capability of the LS MOSFETs, the whole H-Bridge is also protected against over-temperature. A particular care in designing the layout and/or selecting the LS MOSFETs will help to keep this '' sufficient cooling condition '' valid.

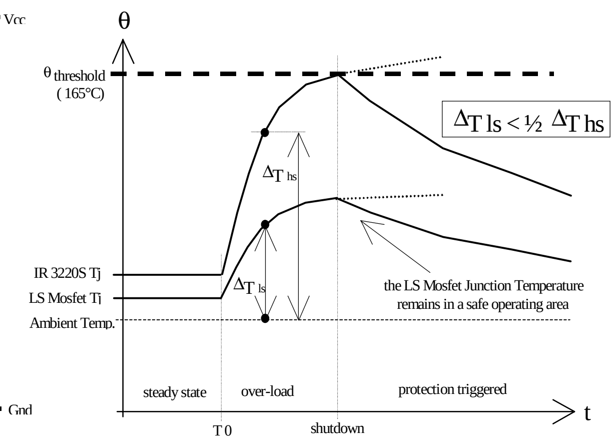
Layout & Thermal Considerations

In case of over-load, the IR 3220S inner temperature sensor latches off the proper HS switch when its Junction Temperature exceeds 165 °C. The protection assumes that the LS MOSFET junction doesn't reach such a high temperature so that the IC shutdown always acts first. A design rule offering enough margin is to consider that the low side ΔT has to be half the one of the HS switch. The following diagram shows the junction temperature profiles during over-load conditions. The LS MOSFET temperature remains in a safe area so that the design rule can be summarized in a very simple formula:

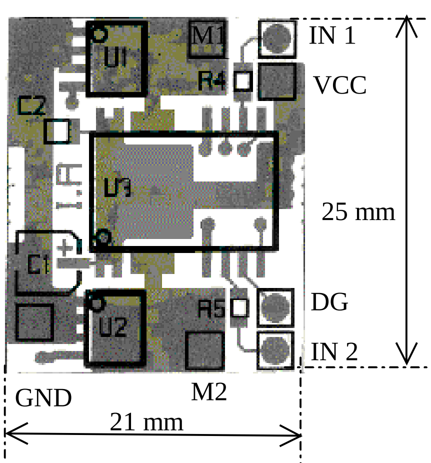
$$RDS(on)_{ls} \cdot Rthja_{ls} < 1/2\,[\,RDS(on)_{hs} \cdot Rthja_{hs}\,]$$

The LS MOSFET has to be cooler than the IR 3220S HS switch at all times. If the IC is continuously switching or used with special cooling conditions, a detailed analysis of the junction temperature profiles is recommended.

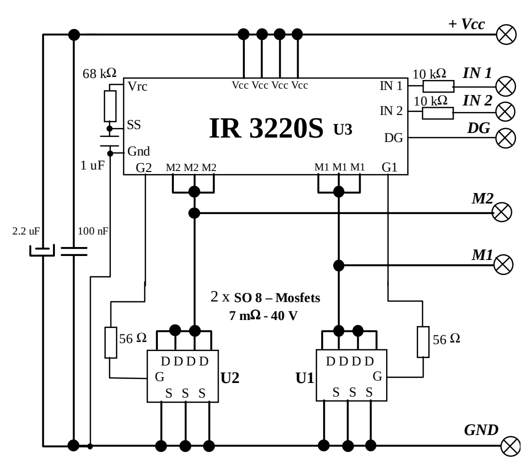




The Rds(on) (mΩ) is a characteristic of the MOSFET die itself while the Rthja (junction to ambient thermal resistance - °k/W) depends on the package and upon the heat-sink. A copper plate on the PCB constitutes one possibility the designer may use to improve the Rthja. This is particularly true for Surface Mount Packages like the SO 20 WB of the IR 3220S or the SO 8 Power MOSFETs. These packages usually spread out the heat thanks to the leadframe connected pins (Vcc for the IR 3220S or the Drain for Power MOSFETs). By adding a significant copper surface to the SO8 footprint, the Rthja is slightly increased and help to comply the ‘’sufficient cooling condition‘’. An example of such a layout is shown hereafter. It corresponds to a 6 A DC Motor Actuator with a PCB size down to 1 Inch ².

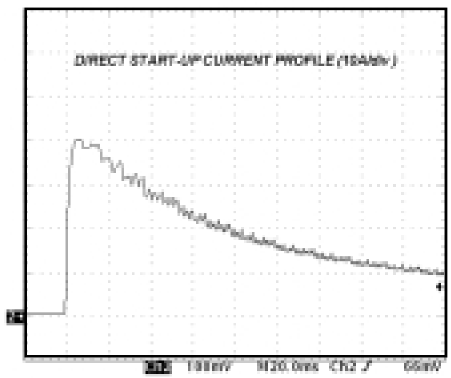


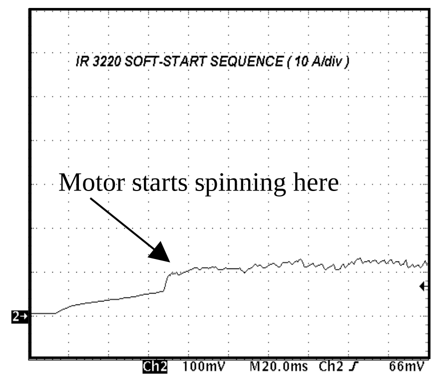
FR 4 – copper 70 um



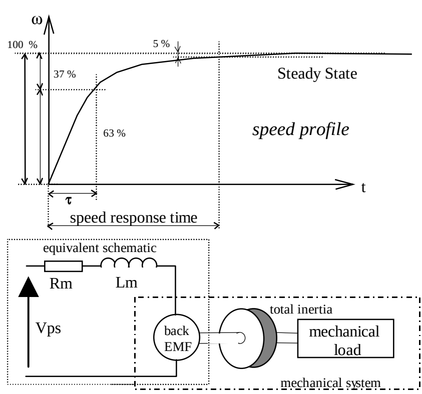
Selecting the Soft-Start RC network

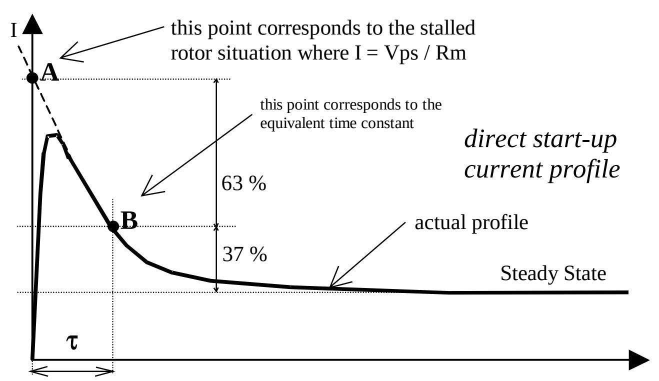
Direct start-up of a DC Motor assumes that both the electrical path and the power supply are able to sustain the inrush peak current. Life of the mechanical load is affected by such hard start-ups. The IR 3220S provides a Soft-Start Sequence to the motor, thanks to its switching mode. Therefore, the application has a better level of protection since the current threshold (Ish) is set in order to protect the PCB (it no longer has to be as high as the inrush current of the motor).





The RC network drives the Soft-Start duty cycle and the whole sequence duration equals 1.4 times the RC value. So, the question is what duration the application needs to ramp up properly? It depends on many electrical and mechanical factors but once the total equivalent time constant (τ) is identified, choosing the proper RC is easy. From the direct start-up characteristic, a simple geometric construction helps to evaluate this time constant. A heavy power supply or a battery may be needed to measure this current profile during the direct start-up. This profile has to be with the complete mechanical load in its actual situation (e.g. an oil pump has to be connected to





its jack).
The method consists in approximating the speed profile to a first order response. Therefore, the time constant (τ) is measured when the speed equals 63 % of the final steady state value. A similar profile is also found on the '' Direct Start-up Characteristic '' but reversed and with its origin on point ''A". This point corresponds to the maximum current that the motor can sink (Vps / Rm). Rotor resistances are usually given by Motor Suppliers (if not, it can be measured manually or approximated on the direct start-up current profile as it is shown on the example). Therefore, τ is measured on the time axis when the current profile is 37 % higher than the final value (point '' B '' on the direct start-up characteristic).

A Soft-Start Sequence is considered very smooth when its duration equals 10 times the constant measured (τ). Since the switching duration equals 1.4 x RC, the correct RC time constant is equivalent to 7 x τ. Depending on the nature of the load (e.g. a fan can speed up faster than a compressor), this factor can be reduced down to 5 or less. For the first tests, the RC value should preferably verify

$$\mathbf{5} \times \tau\ (s) \quad < \quad \mathbf{R} \times \mathbf{C}\ (s) \quad < \quad \mathbf{7} \times \tau\ (s)$$

A detailed analysis of the application (nature of the mechanical load, DC motor performances,start-up requirements at low temperature …etc) may lead to a different trade-off between the limited inrush current and the Soft-Start duration. For such applications, the RC value can go down to 2 x τ (low inertia, low torque) or up to 10 x τ (full torque start-up).

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