International Rectifier

# DESIGN TIP

DT 99-7

International Rectifier • 233 Kansas Street, El Segundo, CA 90245 USA

## Alleviating High Side Latch on Problem at Power Up

**By Toshio Takahashi and Hoa Huu Nguyen**

### *TOPICS COVERED*



## *I - INTRODUCTION*

In a typical IR2xxx high voltage IC application with bootstrap power supply, the bootstrap capacitors are charged before the system becomes operational. In the process of charging up the bootstrap capacitor prior to establishing the high side supply voltage, if the high side output inadvertently turns on and stays on, it may cause a shoot through and may damage the IGBT devices. Even though the data sheet does not specify this power up transient case, the startup behavior is crucial for motor drive applications.

In general, the high side outputs of most of our control IC products rely on the high side Under Voltage Lock out circuit (UVBS) during power up to stay low during the power up. Under a combination of certain overstress and startup conditions, however, the high side output can inadvertently turn on and such an operating condition must be avoided.

## *II - TYPICAL APPLICATION PROBLEM*

The high side output could latch on during a power up sequence in the system if a combination of the following conditions takes place:

1. No load condition (no motor lead connection to each VS nodes): The voltage at Vs node could be anywhere between the positive and the negative DC bus prior to charging the bootstrap capacitor.
2. High dVbs/dt: Fast charging of the bootstrap capacitor.
3. Vbs is biased at a negative voltage prior to power up.

An AC motor drive system which uses a high voltage IC with bootstrap power supply initially goes through a power up sequence in which the bootstrap capacitors are charged up. Figure 1 shows a typical power up sequence. The following description assumes the three conditions listed above:

> At start up, the units go through several stages before the drive is ready for normal operation. One of these stages involves charging up the bootstrap capacitor by turning on the low side IGBT devices. When the VS node is pulled down to the ground from high voltage floating node, the bootstrap capacitor charges through the bootstrap diode as shown in Figure 2. At this moment, if the conditions mentioned above are all met, the following events could occur:
>
> - Vbs is charged at a very fast rate when the low side outputs are turned on.
> - The whole high side circuit is biased to the negative DC bus at a very fast rate of dVs/dt due to high impedance floating condition (no motor connection).
> - If a negative voltage is applied to VBS, when the high side circuit is powered up, the output can be latched on due to unwanted current flow into all of the high side circuit through its internal ESD diode structure.
>
> (d) As a result, the high side output can be latched on while the associated low side output has already been turned on.

This is a mode of potential shoot through during a power up. The key to avoiding the shoot through is to properly initialize the high side circuit during a power up.

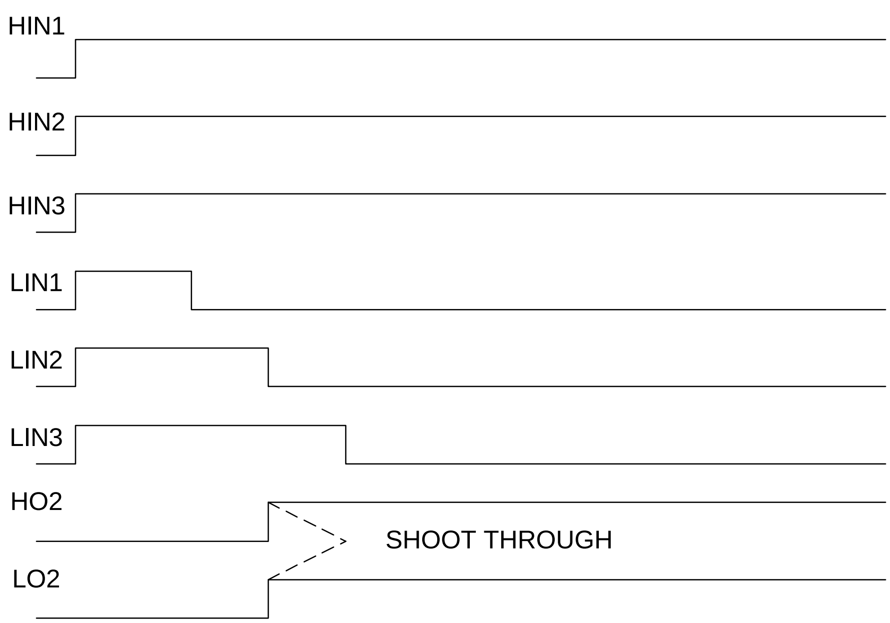


**Figure 1: Power up sequence of Bootstrap Capacitor Charging**

## *III - RECOMMENDED SOLUTION*

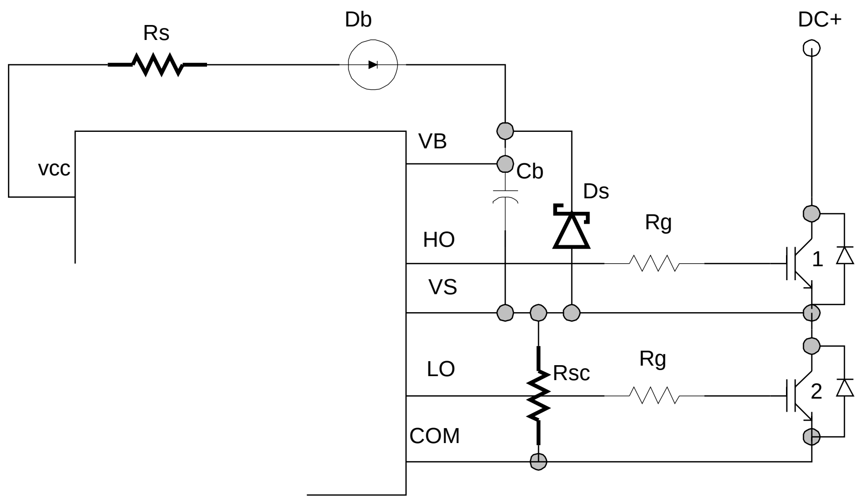


**Figure 2: Typical bootstrap scheme with preventative elements**

The most effective way of eliminating a potential shoot through is to eliminate the overstress condition of a negative voltage on VBS. Prior to a power up, if Vbs is biased to negative voltage which exceeds more than -0.3V as specified in the Absolute Maximum Rating specification - i.e. the condition #3 mentioned above -, then a forward diode current would flow through the ESD diode for the internal circuit in the high side as well as all P/N junctions in the high side well. One of the cause for such an overstress condition could be that, under a no load condition – i.e. condition #1 mentioned above -, the VS node is floating and the VS voltage could be high anywhere between DC+ and COM prior to charging up the bootstrap capacitor. To avoid both negative bias on VBS and a high dv/dt on the Vs node when the low side turns on, one can connect a bleeding resistor (Rsc) between VS and COM (Figure 2) so that the high side voltage can stay roughly at the negative DC bus potential prior to normal operation mode. Note that the Rsc value should both satisfy normal operation condition and minimize the power dissipation across Rsc – e.g when M1 switches on, the Rsc should be able to dissipate Pd = DC+ x DC+ / Rsc.

If a Schottky diode (Ds) must be connected between VB and VS – see Figure 4 – to avoid a negative bias on VBS, the Schottky diode should have the following specification:

- low forward voltage drop, e.g. Vf =0.2V
- minimum 35V reverse breakdown voltage
- low reverse leakage current
- fast reverse recovery time

One effective method of slowing down the dVbs/dt is to add a resistor in series with the bootstrap diode (figure 2). The value of series resistor relative to the bootstrap capacitor value should be chosen such that the RC time constant is equal or greater than 10usec. Note that if the rising dVbs/dt is slowed down too much, it could result in a few missing pulses temporarily during the start-up phase due to insufficient VBS voltage. This possibility is more likely in a higher frequency application, and detailed guidelines are given in the Appendix. For bootstrap capacitor selection, refer to the design tip DT 98-2.

## *IV - CONCLUSION*

To eliminate the possibility of a latch-on at power up under a no load condition, the IC must be operated as follows:

- dVbs/dt higher than 10usec.
- Do not allow the VS node to float prior to normal operation mode.
- Do not allow VB to go below VS by more than one diode forward voltage drop prior to the power up of the high side circuit.

## *APPENDIX*

In order to choose the optimum value for Rs, the following two conditions must be satisfied:

1. Rs X Cb time constant (figure 4) must be greater than 10usec.
2. The bootstrap capacitor (Cb) would charge through not only the bootstrap diode (Db) but also through the series resistor (Rs) from the Vcc supply. Thus, the minimum charge which the bootstrap capacitor needs to supply would be:

$$Cb \times (Vcc - Vrs - Vf - VBSmin) > 2Qg + (Iqbs/fc) \quad (1)$$

Where:

Vrs: Voltage drop across series resistor.
Vf: Forward voltage drop across the bootstrap diode.
VBSmin: Minimum voltage across the bootstrap capacitor required for full enhancement.
Qg: Gate charge of high side IGBT.
Iqbs: high side channel quiescent current.
fc: switching frequency.

**Examples:**
The following two examples demonstrate the cycle-by-cycle fluctuation in the bootstrap voltage during the start-up phase over one PWM fundamental frequency.

Condition:
For both Case 1 and Case 2
Vcc= 15v, Vf= 1.5v, VBSmin= 12.5v, Qg= 200nC, Iqbs= 200uA, fc= 2kHz, Cb = 2uF
For Case 1, Rs = 9Ω and for Case 2, Rs = 10Ω

Each parameters in the table are derived by the following equations.

Tc= 1 / fc
m = (Sin2pft + 1) / 2 where f= 60Hz (fundamental frequency)
$\Delta$Vdis= (2Qg + (Iqbs x Ton)) / Cb
Vbsdis= Vbscharg(prev) - $\Delta$Vdis
$\Delta$Vch= (Vcc - Vf - Vbsdis) x (1 - exp(-t/RC)) Assume Vf is constant over charging current

Vbscharg= Vbsdis + $\Delta$Vch

Irs= (Cb x $\Delta$Vch) / Toff
Vrs= Irs x Rs

Where:

Tc: carrier period
m: modulation index [0 - 1 ]
ΔVdis: voltage difference for discharging period of Cb
Vbsdis: voltage across Cb after discharge
ΔVch: voltage difference for charging period of Cb

Vbscharg: voltage across Cb after charge
Vbscharg(prev): voltage across Cb after charge of previous state

**Case 1**: Cb = 2uF, Rs = 9 Ohms

| seq # | Tc (ms) | m | T(on) (us) | T(off) (us) | ΔVdis (v) | Vbsdis (v) | ΔVch (v) | Vbscharg (v) | Irs (mA) | Vrs (v) | Vbsdis > Vbsmin ? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | .5 | 250 | 250 | 0.225 | 13.275 | 0.225 | 13.5 | 1.8 | 0.016 | Yes |
| 2 | 0.5 | 0.593 | 297 | 203 | 0.23 | 13.27 | 0.214 | 13.484 | 2.1 | 0.019 | Yes |
| 3 | 1 | 0.684 | 342 | 158 | 0.235 | 13.249 | 0.232 | 13.481 | 2.9 | 0.026 | Yes |
| 4 | 1.5 | 0.768 | 384 | 116 | 0.239 | 13.242 | 0.232 | 13.474 | 4 | 0.036 | Yes |
| 5 | 2 | 0.842 | 421 | 79 | 0.242 | 13.232 | 0.23 | 13.462 | 5.8 | 0.052 | Yes |
| 6 | 2.5 | 0.904 | 452 | 48 | 0.245 | 13.217 | 0.215 | 13.432 | 8.9 | 0.08 | Yes |
| 7 | 3 | 0.952 | 476 | 24 | 0.248 | 13.184 | 0.175 | 13.359 | 14.5 | 0.131 | Yes |
| 8 | 3.5 | 0.984 | 492 | 8 | 0.249 | 13.11 | 0.093 | 13.203 | 23.3 | 0.21 | Yes |
| 9 | 4 | 0.999 | 499.5 | 0.5 | 0.25 | 12.953 | 0.009 | 12.962 | 36.4 | 0.328 | Yes |
| 10 | 4.5 | 0.991 | 498 | 2 | 0.25 | 12.712 | 0.051 | 12.763 | 50.6 | 0.455 | Yes |
| 11 | 5 | 0.975 | 488 | 12 | 0.249 | 12.514 | 0.26 | 12.774 | 43.3 | 0.39 | Yes |
| 12 | 5.5 | 0.938 | 469 | 31 | 0.247 | 12.527 | 0.478 | 13.005 | 30.8 | 0.278 | Yes |
| 13 | 6 | 0.885 | 443 | 57 | 0.244 | 12.761 | 0.443 | 13.204 | 15.5 | 0.14 | Yes |
| 14 | 6.5 | 0.819 | 410 | 90 | 0.241 | 12.963 | 0.397 | 13.36 | 8.8 | 0.079 | Yes |
| 15 | 7 | 0.741 | 370 | 130 | 0.237 | 13.123 | 0.298 | 13.421 | 4.6 | 0.041 | Yes |
| 16 | 7.5 | 0.654 | 327 | 173 | 0.233 | 13.188 | 0.271 | 13.459 | 3.1 | 0.028 | Yes |
| 17 | 8 | 0.563 | 282 | 218 | 0.228 | 13.231 | 0.241 | 13.472 | 2.2 | 0.02 | Yes |
| 18 | 8.5 | 0.469 | 235 | 265 | 0.224 | 13.248 | 0.232 | 13.48 | 1.75 | 0.016 | Yes |
| 19 | 9 | 0.376 | 188 | 312 | 0.219 | 13.261 | 0.223 | 13.484 | 1.4 | 0.013 | Yes |
| 20 | 9.5 | 0.287 | 144 | 356 | 0.214 | 13.27 | 0.217 | 13.487 | 1.2 | 0.011 | Yes |
| 21 | 10 | 0.206 | 103 | 397 | 0.21 | 13.28 | 0.212 | 13.492 | 1.1 | 0.01 | Yes |
| 22 | 10.5 | 0.136 | 68 | 432 | 0.207 | 13.285 | 0.205 | 13.49 | 0.95 | 0.009 | Yes |
| 23 | 11 | 0.078 | 39 | 461 | 0.204 | 13.286 | 0.205 | 13.491 | 0.9 | 0.008 | Yes |
| 24 | 11.5 | 0.035 | 18 | 482 | 0.202 | 13.289 | 0.203 | 13.492 | 0.84 | 0.0076 | Yes |
| 25 | 12 | 0.009 | 5 | 495 | 0.201 | 13.291 | 0.201 | 13.492 | 0.81 | 0.0073 | Yes |
| 26 | 12.5 | 0 | 0.1 | 499.9 | 0.2 | 13.292 | 0.2 | 13.492 | 0.8 | 0.0072 | Yes |
| 27 | 13 | 0.009 | 5 | 495 | 0.201 | 13.291 | 0.202 | 13.493 | 0.81 | 0.0073 | Yes |
| 28 | 13.5 | 0.035 | 18 | 482 | 0.202 | 13.291 | 0.202 | 13.493 | 0.84 | 0.0075 | Yes |
| 29 | 14 | 0.077 | 39 | 461 | 0.204 | 13.289 | 0.204 | 13.492 | 0.9 | 0.0079 | Yes |

**Case 1**: Cb = 2uF, Rs = 9 Ohms

| seq # | Tc (ms) | m | T(on) (us) | T(off) (us) | ΔVdis (v) | Vbsdis (v) | ΔVch (v) | Vbscharg (v) | Irs (mA) | Vrs (v) | Vbsdis > Vbsmin ? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 14.5 | 0.135 | 68 | 432 | 0.207 | 13.286 | 0.206 | 13.493 | 0.95 | 0.0086 | Yes |
| 31 | 15 | 0.205 | 103 | 397 | 0.21 | 13.282 | 0.209 | 13.491 | 1 | 0.009 | Yes |
| 32 | 15.5 | 0.286 | 144 | 356 | 0.214 | 13.277 | 0.214 | 13.491 | 1.2 | 0.011 | Yes |
| 33 | 16 | 0.375 | 188 | 312 | 0.219 | 13.272 | 0.217 | 13.489 | 1.4 | 0.013 | Yes |
| 34 | 16.5 | 0.468 | 235 | 265 | 0.224 | 13.265 | 0.222 | 13.487 | 1.7 | 0.015 | Yes |

**Table 1**

**Case 2**: Cb = 2uF, Rs = 10 Ohms

| seq # | Tc (ms) | m | T(on) (us) | T(off) (us) | ΔVdis (v) | Vbsdis (v) | ΔVch (v) | Vbscharg (v) | Irs (mA) | Vrs (v) | Vbsdis > Vbsmin ? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | .5 | 250 | 250 | 0.225 | 13.275 | 0.225 | 13.5 | 1.8 | 0.018 | Yes |
| 2 | 0.5 | 0.593 | 297 | 203 | 0.23 | 13.27 | 0.212 | 13.482 | 2 | 0.02 | Yes |
| 3 | 1 | 0.684 | 342 | 158 | 0.235 | 13.247 | 0.233 | 13.48 | 2.9 | 0.029 | Yes |
| 4 | 1.5 | 0.768 | 384 | 116 | 0.239 | 13.241 | 0.23 | 13.471 | 3.9 | 0.039 | Yes |
| 5 | 2 | 0.842 | 421 | 79 | 0.242 | 13.229 | 0.227 | 13.456 | 5.8 | 0.058 | Yes |
| 6 | 2.5 | 0.904 | 452 | 48 | 0.245 | 13.211 | 0.21 | 13.421 | 8.8 | 0.088 | Yes |
| 7 | 3 | 0.952 | 476 | 24 | 0.248 | 13.173 | 0.167 | 13.34 | 13.9 | 0.139 | Yes |
| 8 | 3.5 | 0.984 | 492 | 8 | 0.249 | 13.091 | 0.089 | 13.18 | 22.3 | 0.223 | Yes |
| 9 | 4 | 0.999 | 499.5 | 0.5 | 0.25 | 12.93 | 0.009 | 12.939 | 34.7 | 0.347 | Yes |
| 10 | 4.5 | 0.991 | 498 | 2 | 0.25 | 12.689 | 0.044 | 12.733 | 44.1 | 0.441 | Yes |
| 11 | 5 | 0.975 | 488 | 12 | 0.249 | **12.484** | 0.259 | 12.743 | 43.1 | 0.431 | **No** |
| 12 | 5.5 | 0.938 | 469 | 31 | 0.247 | **12.496** | 0.453 | 12.949 | 29.2 | 0.292 | **No** |
| 13 | 6 | 0.885 | 443 | 57 | 0.244 | 12.705 | 0.472 | 13.177 | 16.6 | 0.166 | Yes |
| 14 | 6.5 | 0.819 | 410 | 90 | 0.241 | 12.936 | 0.394 | 13.33 | 8.8 | 0.088 | Yes |
| 15 | 7 | 0.741 | 370 | 130 | 0.237 | 13.093 | 0.319 | 13.412 | 4.9 | 0.049 | Yes |
| 16 | 7.5 | 0.654 | 327 | 173 | 0.233 | 13.179 | 0.272 | 13.451 | 3.2 | 0.032 | Yes |
| 17 | 8 | 0.563 | 282 | 218 | 0.228 | 13.223 | 0.245 | 13.468 | 2.2 | 0.022 | Yes |
| 18 | 8.5 | 0.469 | 235 | 265 | 0.224 | 13.244 | 0.234 | 13.478 | 1.8 | 0.018 | Yes |
| 19 | 9 | 0.376 | 188 | 312 | 0.219 | 13.259 | 0.223 | 13.482 | 1.4 | 0.014 | Yes |
| 20 | 9.5 | 0.287 | 144 | 356 | 0.214 | 13.268 | 0.218 | 13.486 | 1.2 | 0.012 | Yes |
| 21 | 10 | 0.206 | 103 | 397 | 0.21 | 13.276 | 0.212 | 13.488 | 1.06 | 0.0106 | Yes |
| 22 | 10.5 | 0.136 | 68 | 432 | 0.207 | 13.281 | 0.208 | 13.489 | 0.96 | 0.0096 | Yes |
| 23 | 11 | 0.078 | 39 | 461 | 0.204 | 13.285 | 0.205 | 13.49 | 0.89 | 0.0089 | Yes |
| 24 | 11.5 | 0.035 | 18 | 482 | 0.202 | 13.288 | 0.203 | 13.491 | 0.84 | 0.0084 | Yes |
| 25 | 12 | 0.009 | 5 | 495 | 0.201 | 13.29 | 0.202 | 13.492 | 0.81 | 0.0081 | Yes |
| 26 | 12.5 | 0 | 0.1 | 499.9 | 0.2 | 13.292 | 0.2 | 13.492 | 0.80 | 0.008 | Yes |
| 27 | 13 | 0.009 | 5 | 495 | 0.201 | 13.291 | 0.202 | 13.493 | 0.81 | 0.0081 | Yes |

**Case 2**: Cb = 2uF, Rs = 10 Ohms

| seq # | Tc (ms) | m | T(on) (us) | T(off) (us) | ΔVdis (v) | Vbsdis (v) | ΔVch (v) | Vbscharg (v) | Irs (mA) | Vrs (v) | Vbsdis > Vbsmin ? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 13.5 | 0.035 | 18 | 482 | 0.202 | 13.291 | 0.201 | 13.492 | 0.83 | 0.0083 | Yes |
| 29 | 14 | 0.077 | 39 | 461 | 0.204 | 13.288 | 0.204 | 13.492 | 0.88 | 0.0088 | Yes |
| 30 | 14.5 | 0.135 | 68 | 432 | 0.207 | 13.285 | 0.206 | 13.491 | 0.95 | 0.0095 | Yes |
| 31 | 15 | 0.205 | 103 | 397 | 0.21 | 13.281 | 0.21 | 13.491 | 1.1 | 0.011 | Yes |
| 32 | 15.5 | 0.286 | 144 | 356 | 0.214 | 13.277 | 0.212 | 13.489 | 1.2 | 0.012 | Yes |
| 33 | 16 | 0.375 | 188 | 312 | 0.219 | 13.27 | 0.218 | 13.488 | 1.4 | 0.014 | Yes |
| 34 | 16.5 | 0.468 | 235 | 265 | 0.224 | 13.264 | 0.222 | 13.486 | 1.7 | 0.017 | Yes |

**Table 2**

In case #1 with Rs= 9 Ohms, the high side supply voltage at the end of Ton (Vbsdis) is greater than the required minimum voltage (Vbsmin= 12.5v) at all times, while in case #2 with Rs= 10 Ohms, Vbsdis is smaller than Vbsmin in two of the sequences 11 & 12. Therefore, to satisfy the two conditions mentioned the optimum value of the Rs would be:

$$5\ \Omega < R_s < 10\ \Omega$$

International IOR Rectifier

**IR WORLD HEADQUARTERS:** 233 Kansas St., El Segundo, California 90245 Tel: (310) 252-7105
**IR EUROPEAN REGIONAL CENTRE:** 439/445 Godstone Rd, Whyteleafe, Surrey CR3 0BL, United Kingdom Tel: ++44 (0) 20 8645 8000
**IR JAPAN:** K&H Bldg., 2F, 30-4 Nishi-Ikebukuro 3-Chome, Toshima-Ku, Tokyo, Japan 171-0021 Tel: 81 (0) 33 983 0086
**IR HONG KONG:** Unit 308, #F, New East Ocean Centre, No. 9 Science Museum Road, Tsimshatsui East, Kowloon, Hong Kong Tel: (852) 2803-7380
*Data and specifications subject to change without notice. 3/15/2000*