International Rectifier

APPLICATION NOTE

Application Note AN- 1118

IR331x : Current Sensing High Side Switch – P3

By David Jacquinod

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Introduction

The new IR331x devices designed in P3 technology provide more accuracy of the current feefback.

The IR331X devices suit for any application where the load current sensing is required. IR331X is fully protected : programmable current shutdown, over temperature shutdown and reverse battery protection.

The current sensing features offer current readout accuracy, high frequency bandwidth, a versatile way to control the current shutdown and replaces the shunt resistor.

1. Inner Architecture

Reverse Battery Protection

The IR331X family features a reverse battery protection. In such condition, the current flows in the load and the body diode of the power MOSFET, so the power dissipation is much higher than in normal condition.

In a power MOSFET the current can flow in both direction from drain to source or from source to drain. The system switches on the MOSFET in order to reduce power dissipation.

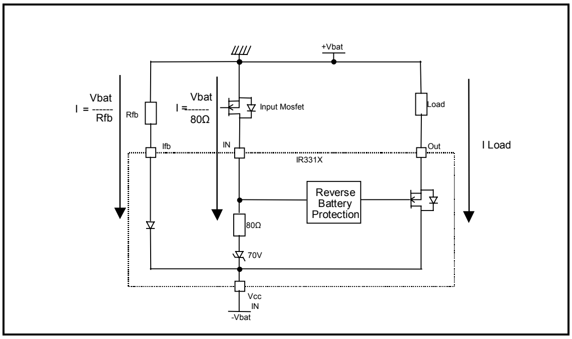


Figure 1 : Reverse battery connection

In reverse battery condition, the current flows through the body diode of the Input MOSFET, so Vin = Vbat – 0.6V. And the load current flows in the body diode of the power MOSFET, Vout = 0.6V

When Vin-Vout (= Vbat – 1.2V) i.e. Vgate-Vsource reaches the threshold (typ. 2V), the transistor turns on.

The IR331X reverse battery function works only if a discrete MOSFET is used to drive the input. If a bipolar transistor is used, a diode in parallel is required.

So the power dissipation is :

P dissipated = Pd (Power MOSFET) + Pd (R=80Ω)

= Rdson x $ILoad^2$ + $Vbat^2$ / 80Ω

When designing with reverse battery operation, the heat sink calculation must take in account the power dissipation in the 80Ω resistor i.e. $Vbat^2$ / 80Ω.

For example : IR3313

- Iload = 30A
- Tj=125°C
- Tamb=85°C
- Vbat = 14V
- Rdson typ.@125°C = 8.8m Ω

P dissipated = 8.8m Ω x 30^2 + 14^2 / 80 Ω = 10.4 W

Rth junction to amb = Tj – Tamb / P dissipated = 3.9 °C/W

WAIT Function

To provide a high level of protection, the IC features a WAIT function.

Without the WAIT function, a thermal runaway would occur:

When the IC reaches the over temperature shutdown threshold, the IC switches off. If the user restarts the IC immediately, the IC temperature goes beyond the temperature shutdown threshold because of the over temperature circuitry's delay (due to the turn on delay) . Permanently switching on a short circuit would end up in a destructive thermal run away.

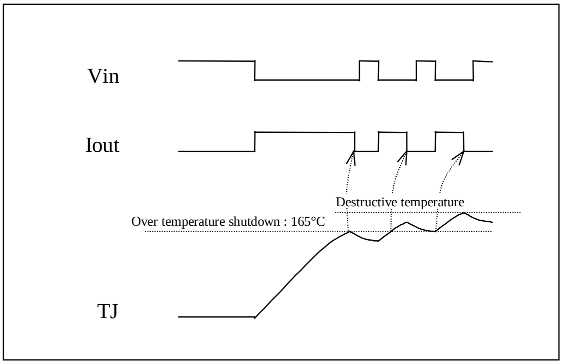


Figure 2 : Waveforms during temperature cycling

Thanks to the WAIT function, the IC turns on after a delay to insure that the IC is cooled enough. So the IC never reaches the destructive temperature. The WAIT delay starts when the system turns off the IR331X by releasing the input pin. The IR331X restarts only if input pin is kept high during a time which is longer than the T reset specified in the datasheet (see figure 7 in the datasheet).

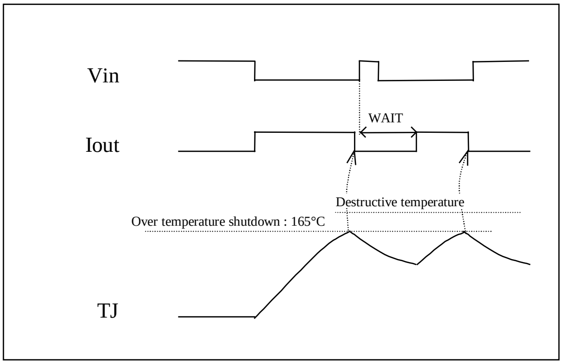


Figure 3 : Waveforms during temperature cycling with WAIT function

Min. Pulse function

When the system switches on IR331X for short times (<Min. Pulse), it doesn't have enough time to measure its temperature. If the system switches on IR331X for short times at high frequency, the temperature increases but the device has not enough time to detect an over-temperature.

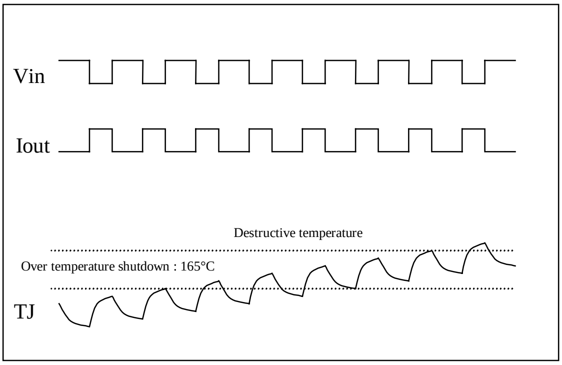


Figure 4 : Waveforms with short pulses

So if a short pulse on the input is detected, the device turns on only after the WAIT time.

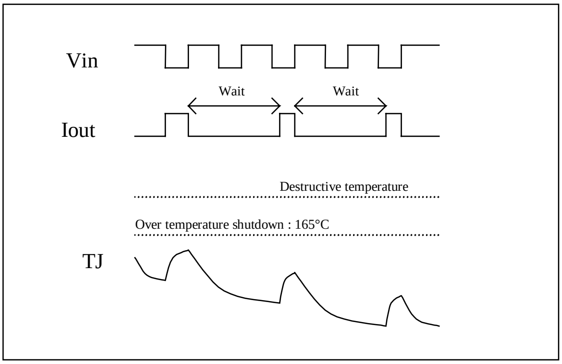


Figure 5 : Waveforms with Min. Pulse Function

Current sensing accuracy

The new IR331x family features a more accurate current feedback. The offset of the current sense amplifier has been divided by 10.

The IR331X family uses current sensing MOSFET to read the current in the load. A small MOSFET connected in parallel to the power MOSFET is flew by the load current divided by a ratio so far the same Vds voltage is applied to both MOSFET. An amplifier maintains the same voltage on the both MOSFET.

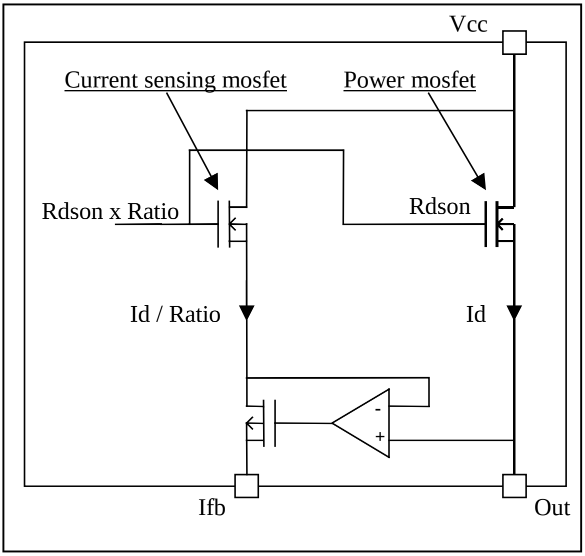


Figure 7 : Current sensing block diagram

I load = Ifb x Ratio + I offset

The accuracy of the current sensing depends on the ratio and the offset current. I offset is given by :

$$\text{Ioffset@25°C} = \frac{\text{Voffset@amplifier}}{\text{Rdson@25°C}}$$

The amplifier offset voltage drift is low over the temperature range. The I offset varies with Rdson when temperature changes :

$$\text{Ioffset@T°C} = \text{Ioffset@25°C} \times \frac{\text{Rdson@25°C}}{\text{Rdson@T°C}}$$

The worth case is at –40°C because :

$$\frac{\text{Rdson@25°C}}{\text{Rdson@-40°C}} = 1.25$$

Assuming a low offset voltage for the amplifier, the I offset is kept low : less than 0.4% of the full scale range over temperature (i.e. 0.25A/80A=0.31%) .

Calibration :

For application where the Ifb pin is connected to an analog input, a calibration can be performed in order to reach a good accuracy. By injecting 2 calibrated currents (Id1 and Id2) and by measuring Ifb1 and Ifb2, the system can calculate the Ratio and the offset by the following equations:

$$\text{Ratio} = \frac{\text{Id1} - \text{Id2}}{\text{Ifb1} - \text{Ifb2}}$$

$$\text{I offset} = \text{Id1} - \text{Ifb1} \times \text{Ratio}$$

If the calibration is made at 25°C, Id is calculated using Ratio@25°C and I offset@25°C measured during calibration:

$$\text{Id} = \text{Ifb} \times \text{Ratio@25°C} + \text{I offset@25°C}$$

The parameters Ratio and I offset vary over the temperature range :

I offset@-40°C = I offset@25°C / 0.8

I offset@150°C = I offset@25°C / 1.9

Ratio@-40°C = Ratio@25°C +/- 5%

Ratio@150°C = Ratio@25°C +/- 5%

So the total error at 150°C is :

$$\text{I error} = \frac{\text{Id} - \text{Id calculated}}{\text{Id}}$$

Where :

Id calculated= Ifb@150°C x Ratio@25°C + I offset@25°C

$$\text{Ifb@150°C} = \frac{\text{Id} - \text{I offset@150°C}}{\text{Ratio@150°C}}$$

Example : IR3313 new family

- Id = 80A
- I offset@25°C = +/- 0.2A
- I offset@-40°C = +/- 0.25A
- I offset@150°C = +/- 0.11A
- Ratio@25°C = 8800
- Rdson@25°C = 5.5mΩ

The worst case is at 150°C

with ratio@150°C = ratio@25°C – 5%

$$=> \ Ifb@150°C = \frac{80A - 0.11A}{8800 - 5\%} = 9.56mA$$

=> Id calculated=9.56mA x 8800 + 0.2A = 84.2A

=> Error = 5%

So the calibration insures that the total error in the temperature range is 5%.

2. Typical Applications

Programmable current shutdown

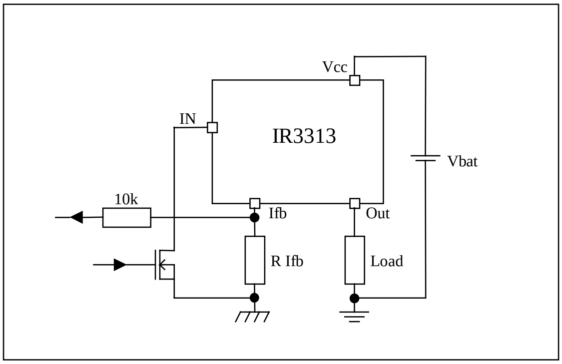


Figure 8 : Typical application

The following oscilloscope waveforms are an example with a pure inductive load.

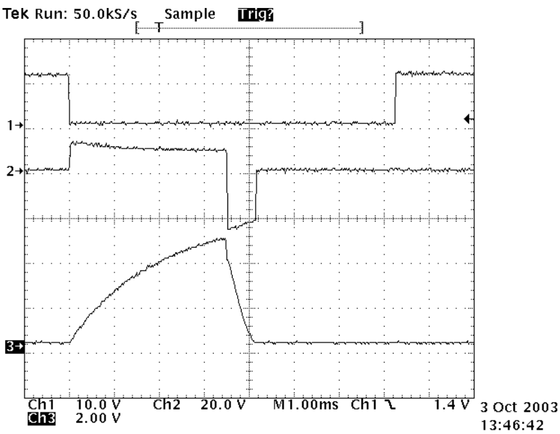


Figure 9 : Waveforms during current shutdown

Trace 1 : Input voltage

Trace 2 : Output voltage

Trace 3 : Ifb pin voltage

When the device turns on, the current increases in the load. The Ifb pin voltage increases until reaching the current shutdown threshold (typically 4.5V) and the device turns off. The voltage across the load is the active clamp voltage.

Rifb is calculated using the following equation :

$$RIfb = \frac{4.5V * Ratio}{Isd}$$

Important notice : Rifb should not be lower than the min. recommended in the datasheet.

Filament lamp and DC motor application

Both in filament lamp and DC motor application, the main concern is the inrush current. When the filament is cold, its resistance is very low. The inrush current can reach 7 times the nominal current. For DC motor operation, the inrush current is due to the direct start sequence.

The current shutdown strategy must be adapted for such loads, a high current shutdown during start up and a low current shutdown for nominal current.

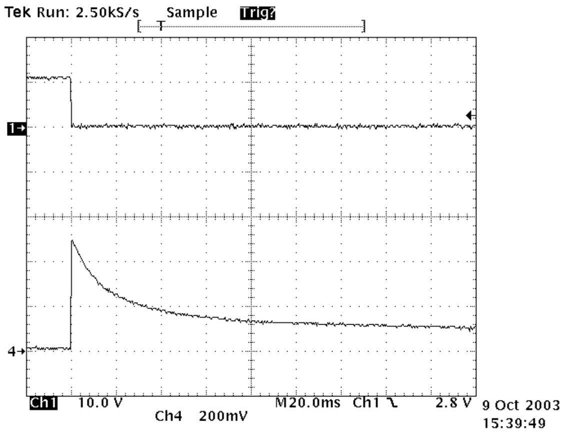


Figure 10 : Typical Inrush current for 2x45W filament lamp.

Trace 1 : input. Trace 2 : load current 20A/div.

I Peak = 50A

I Nom = 7.5A

2 steps current shutdown

The easiest way to implement two programmable current shutdown is to change the resistor Ifb value, one for the inrush current and one for the nominal current. A resistor ifb calculated for the inrush current is connected in parallel by a MOSFET :

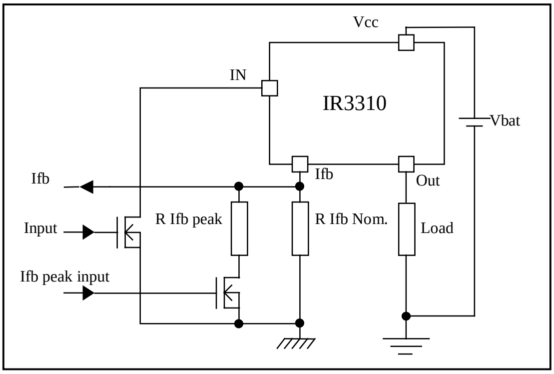


Figure 11 : 2 Steps current shutdown schematic

During inrush current, the system connects the R Ifb peak resistor to increase the current shutdown. When the load reaches the nominal current the system disconnects R Ifb peak to provide a good over current protection.

R Ifb is calculated with :

I shutdown = VIfb-Vin@Isd min x Ratio min/ Rfb

=> R Ifb = VIfb-Vin@Isd min x Ratio min / I shutdown

Example : 2x45W filament lamp and IR3310

I Nom=7.5A => I shutdown nom = 10A

I shutdown peak = 10 x I nom = 75A

=> R Ifb Nom = 4V x 7500 / 10A = 3 kΩ

=> R Ifb peak = 4V x 7500 / 75A = 400 Ω

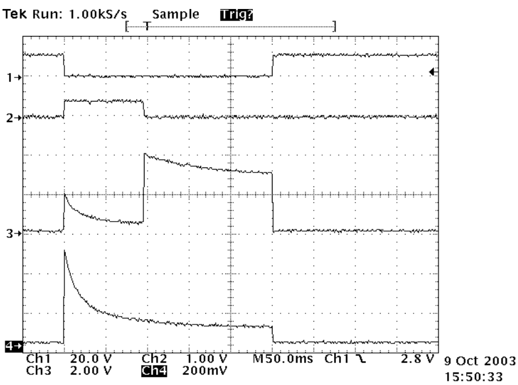


Figure 12 : Waveforms with 2x45W filament lamp.

R Ifb nom=3.3kΩ, R ifb peak=390Ω

Trace 1 : Input

Trace 2 : Ifb peak input

Trace 3 : Ifb pin voltage

Trace 4 : Current load

2 steps current shutdown controlled by RC

If an logical output is not available to drive 2 scales current shutdown, a simple circuit can increase the current shutdown.

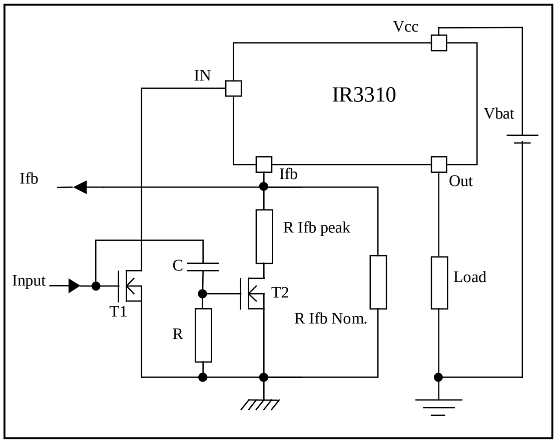


Figure 13 : 2 steps current shutdown schematic

R Ifb Nom. and R Ifb peak is calculated as above. RC networks provides the time during R Ifb peak is connected to Ifb pin.

$$RC = \frac{t\,peak\,step}{\ln\frac{Vin}{Vgsth}}$$

t peak step : time during R Ifb peak is connected

Vin : input voltage

Vgsth : threshold of T2

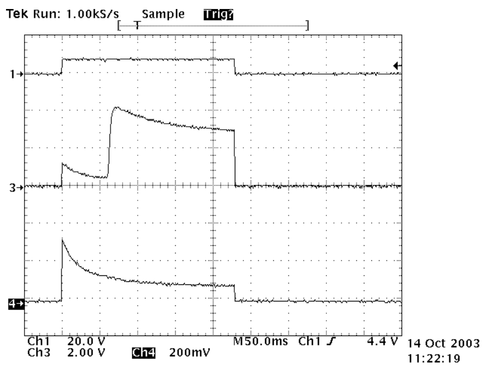


Figure 14 : Waveforms with 2 x 45W filament lamp

R Ifb nom=3.3kΩ, R ifb peak=390Ω, R=470k, C=100nF

Trace 1 : Input

Trace 3 : Ifb pin voltage

Trace 4 : Current load

Current shutdown programmed by analog voltage

A versatile solution is to connect a controlled current source to Ifb pin in order to control dynamically the current shutdown threshold.

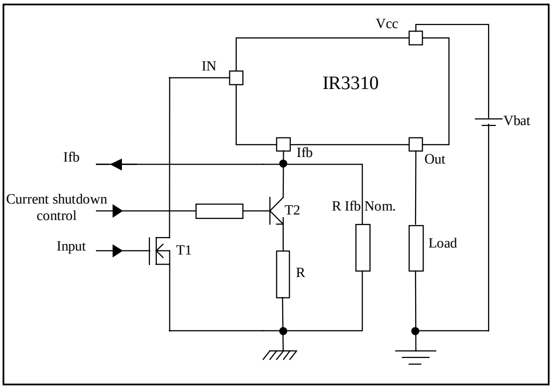


Figure 15 : Dynamically current shutdown threshold

For a filament lamp application the best profile for current shutdown threshold is the current profile plus a little margin :

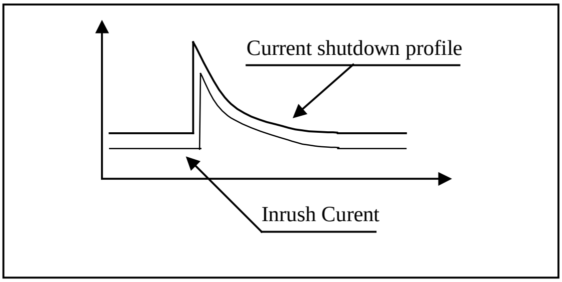


Figure 16 : Current shutdown profile

The current shutdown control voltage waveform applied to T2 is calculate with :

I T2 = (Current shutdown control voltage – 0.6V) / R

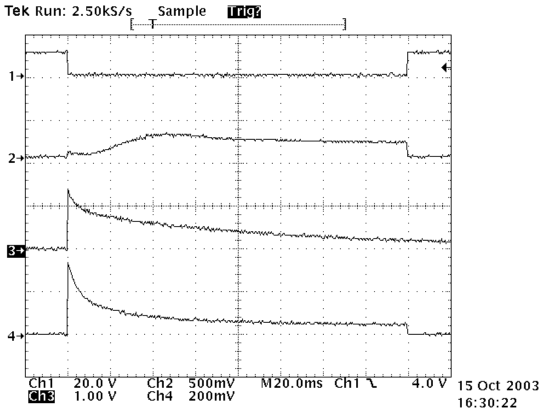


Figure 17 : Waveforms with 2 x 45W filament lamp

R Ifb nom=3.3kΩ, R =120Ω

Trace 1 : Input

Trace 2 : Ifb pin voltage

Trace 3 : Current shutdown control voltage

Trace 4 : Current load

20kHz current sense H bridge motor drive

With two IR331Xs and two MOSFETs, a fully protected H bridge can be designed. The IR331Xs feature the current sensing and the protections. The low side MOSFETs provide the 20kHz switching capability. In order to protect the low sides with the IR331X over temperature shutdown, the power dissipation must be lower in the low side. The designer may choose a Rdson half lower for the low sides.

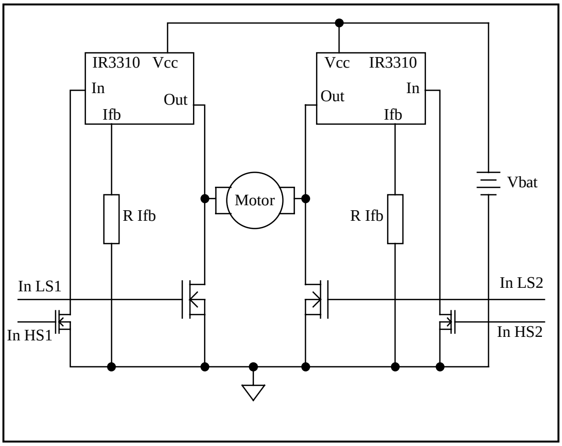


Figure 18 : H_Bridge schematic

Layout consideration

The designer must pay attention to the layout. If logic ground is connected to power ground, the load current can return into the logic ground. This current introduces an error voltage between Ifb and IN pin which can shutdown the device. Moreover the current sensing reading is disturbed.

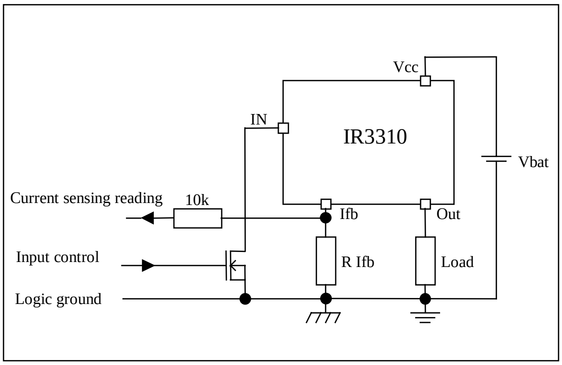
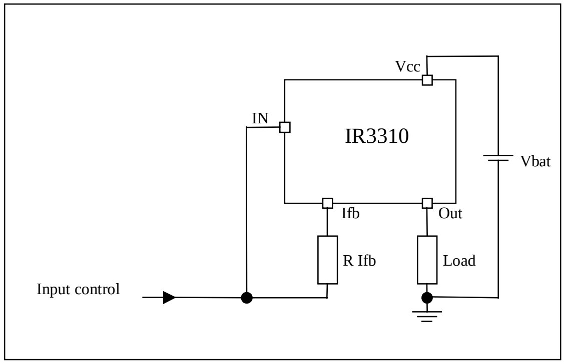


Figure 19 : Logic ground connected to power ground

To insure the integrity of current sensing reading and the current shutdown, the logic ground must be connected to body of the car near to the controller.

Controlling IR331X by one wire

If the system requires only the programmable current shutdown and not the current readout, the IR331X can be controlled by only one wire.



As the input threshold is referenced to Vcc, the device switches on when Vcc-Vin reaches VIH. The current shutdown is defined by the difference voltage between Vifb and Vin, so the input system does not need a ground reference.