TA0331
Technical article

A single chip octal high-side driver for process control

Introduction

This paper presents a single chip octal high-side driver able to drive any type of load with one side connected to ground. The device is named VN808-E and has 8 low voltage MOSFET channels (45 V Breakdown voltage, 160 mW maximum $R_{DS(ON)}$ at 25 degrees Celsius) with protection and diagnostic functions integrated on a single chip. The device is housed in the Jedec standard PowerSO-36 package.

The VN808-E is developed in VIPower M0-3 technology. This is an STMicroelectronics' proprietary Smart Power technology that allows the integration in the same chip of both the control part and the power stage.

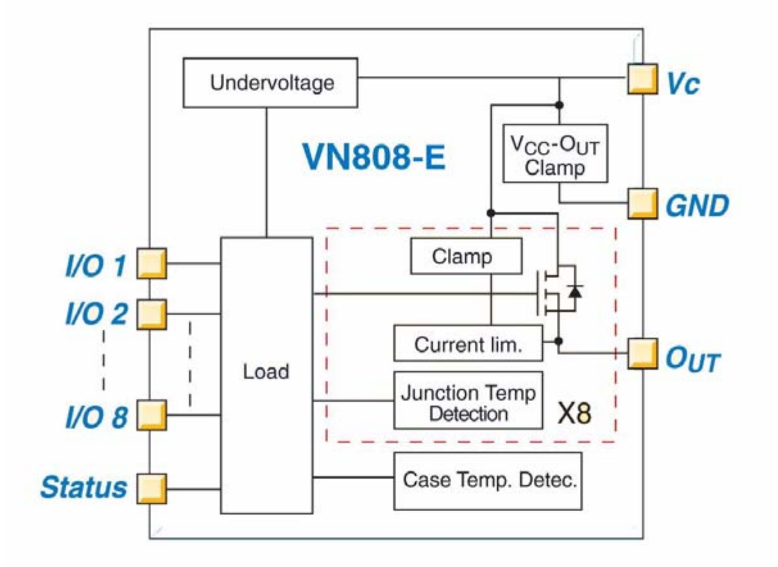
The VN808-E has been designed to be compliant with the IEC 1131 (Programmable Logic Controller International Standard), nevertheless it can also be used in any other similar application.

Contents

1 Technical description at block level

The block diagram of the device is shown in *Figure 1*.

Figure 1. VN808-E block diagram



Looking at the block diagram you can note that each channel is fully protected. Built-in on silicon we have: Junction over temperature protection which is thermally independent for each of the 8 channels, current limitation (typically 1.1 A), inductive clamp (typically – 52 V). Thanks to the built-in protection, each channel is self-protected against load short-circuiting and overloading, and it is able to manage inductive loads up to 2 H. Besides, the under-voltage protection and the loss of ground protection are added at chip level. The case over temperature protection realizes a double thermal protection integrated on chip.

The input pins blocks of the device are $V_{CC}/2$ compatible, they are designed to allow the direct connection of an optocoupler with a dark current (I input low minimum) of 80 µA and to minimize input switching times.

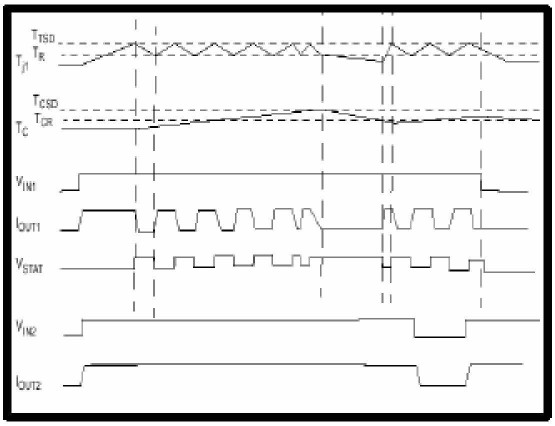
Figure 1 highlights the basic protection blocks of which each output channel of the VN808-E device is equipped. The current limitation at 1.1 A typical is a must for each HSD used in industrial automation, because it is required by the IEC 1131 (Programmable Controllers International Standard). The junction shut-down temperature for each channel has a maximum value of 200 °C; it protects the channel in case of a generic overload. The clamping chain at –52 V realizes the demagnetization of inductive loads.

The status pin is able to drive directly a light emitting diode (LED), and it is ESD protected according to the human body model up to 4 kV.

- Case temperature detection and protection

As before mentioned the VN808-E device has a double thermal protection integrated.

Figure 2. Waveforms in short circuit



Together with the junction temperature detection (TTSD) and protection, included on each channel, the device has also integrated the case temperature detection (TCSD) and protection, related to the whole device dissipation. This further protection avoids the PCB degradation in case of large number of channels in overload conditions, due to the quick increase of case temperature.

In overload condition, in fact, channel turns off and back on automatically so maintaining the channel junction temperature between TTSD and TR (junction reset temperature). This overload condition makes the case temperature increases. When the case temperature reaches TCSD the overload channel is turned off and it will restart again only when the case temperature has decreased down to TCR (case reset temperature). What is important to highlight is that the TCSD acts only on the overload channel; non overloaded channels continue to operate normally. In *Figure 2* and *Figure 3* over temperature waveforms during short circuit and overload are shown.

Figure 3. Waveforms in overload

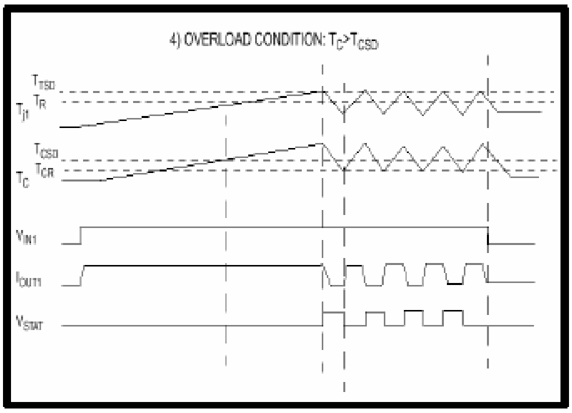
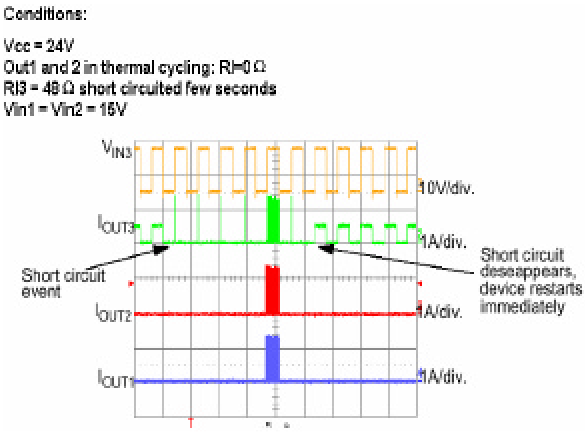


Figure 4 shows waveforms of three different output channels when a short circuit condition occurs in the channel number 3.

Figure 4. Waveforms in short circuit



As can be noted the other two channels are in permanent short circuit. It is evident that as soon as the short circuit condition disappears on channel 3, this one restarts immediately.

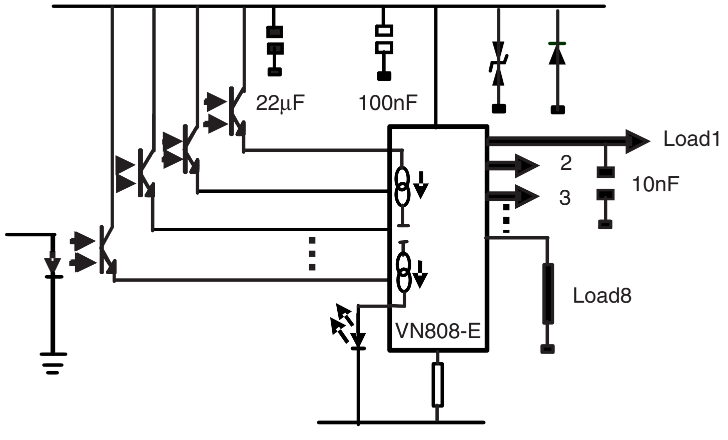
2 Application description

In *Figure 5* a typical VN808-E application circuit is shown. The drawing also shows the external components required to be compliant with:

1. IEC 801-5 (surge test): a back to back zener structure has been added (like 1.5KE39xx) to the 24 V bus;
2. IEC 801-6 (current injection test): a 10 nF capacitor is added to the output pins;

Concerning IEC 801-2 (ESD test) and IEC 801-4 (burst test) the relevant protections are included on chip.

Figure 5. VN808-E draft schematic of typical application circuit (Vcc= 24 V - 28,2 V)



To make the supply voltage stable, and in order to avoid under-voltage shut-down, to filter any bus inductive effect, it is advisable to put a 22 µF capacitor between the 24 V bus and ground. One 100 nF capacitor is instead sufficient, between the 24 V bus and ground, to filter any electro-magnetic conducted interference. An optional protection for V_{cc} disconnection can be realized putting a diode between the V_{cc} bus and the ground, while that one 10 Ω resistor between the ground pin of the device and the ground of the application must be surely add to realize an effective protection against V_{cc} disconnection when inductive loads are driven.

The status pin of the device is normally connected to a LED to signalize any over temperature protection intervention, the status output current range is 2 mA - 4 mA.

The input pins are normally electrically isolated by the Bus ASIC through opto-electronics devices, and are $V_{cc}/2$ compatible.

3 Driving an inductive load

The toughest loads can be driven in the process control application as the inductive ones; it is a common case to drive 1- 2 H inductive loads in this application field. The associated energy to manage such inductive loads is very appreciable, carrying out sensible power dissipation and a very high junction temperature.

Let us simulate theoretically one practical example to better understand the behavior of the VN808-E in such a tough environment.

We consider one device VN808-E working with 8 channels operative (ON state) and 4 channels turning off an inductive load at the same time (see *Figure 6*). Based on the theory we can calculate both the Energy per channel and the total Power managed by the device in the done hypothesis. In *Figure 6* are also shown typical waveforms of the main electrical parameters involved: V_{in}, V_{cc}, V_{clamp}, t_{off} and I_{out}.

Looking at figure 6 and based on the theory, we can hence write the following formulas:

Equation 1

$$t_{off} = \frac{L}{R_{load}} \bullet \ln\left(\frac{1 + V_{cc}}{V_{clamp} - V_{cc}}\right)$$

Equation 2

$$E_{off} = \frac{V_{clamp}}{R_{load}} \bullet \left(\frac{L - V_{cc}}{R_{load}} - (V_{clamp} - V_{cc}) \bullet t_{off}\right)$$

Equation 3

$$P_{off} = \frac{E_{off}}{t_{off}}$$

In the hypothesis that:

$$I_{out} = 0.5A \quad L = 1H \quad f = 0.5Hz \quad V_{cc} = 24V \quad R_{load} = 47\Omega \quad V_{clamp} - V_{cc} = 28V$$

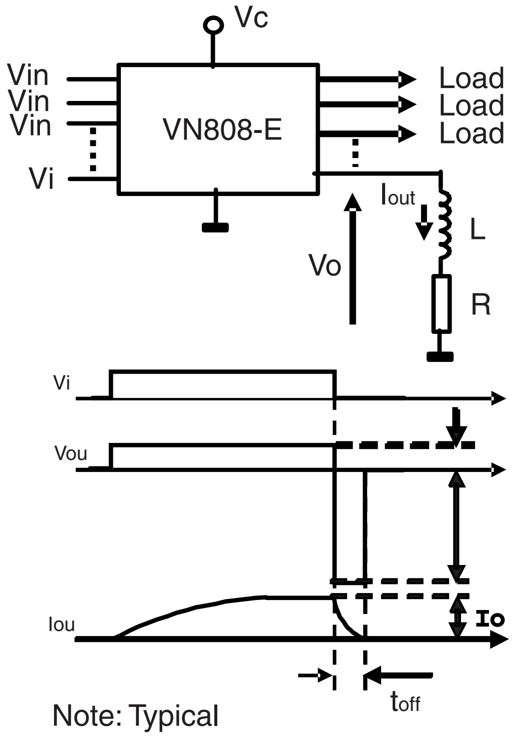
Applying the formulas above mentioned to the given hypothesis, we will get the following results:

$$t_{off} = 13 msec \qquad E_{off} = \frac{155 mJoule}{channel} \qquad P_{off} = 4 \bullet \frac{155 mJ}{13 msec} = 48W$$

- Power dissipation and junction temperature

It is now interesting to calculate both total power dissipation and maximum junction temperature during t_{off}. We perform the calculation in the same hypothesis underlined in the paragraph “Driving an inductive load” and considering an ambient temperature of 60 °C and 50% duty cycle.

Figure 6. Driving an inductive load



We can divide total power losses in: conduction losses, and switching losses.

1. Conduction losses

During the conduction phase, losses are due to the supply current (I_S) and to the Power channels. Concerning I_S looking at the VN808-E datasheet we note that this parameter (in ON state) has a maximum guaranteed value of 12 mA. Hence supply current losses are:

Equation 4

$$PI_s = V_{cc} \bullet Is = 24V \bullet 12mA = 288mw$$

Losses in the PowerMOS are calculated considering the worst case of $R_{DS(on)}$ at 125°C junction temperature and for 8 channels. Data-sheet value of $R_{DS(on)}$ at 100°C is 280 mΩ:

Equation 5

$$P_{MOS} = R_{DS(ON)} \bullet (I_{out})^2 \bullet 0.5 \bullet 8 = 280m\Omega \bullet 0.5^2 A \bullet 0.5 \bullet 8 = 280mW$$

2. Switching losses

During the switching phase losses (the 4 channels turning OFF the inductive loads at the same time) are due to the inductance discharge:

Equation 6

$$P_{off} = E_{off} \bullet f \bullet 4 = 155mJ \bullet 0.5 \bullet 4 = 310mW$$

So that total losses are:

Equation 7

$$P_{tot} = P_{is} + P_{MOS} + P_{off} = 0.878W$$

The thermal resistance junction to case of the PSO-36 leads package in the standard FR4 is:

Equation 8

$$R_{thj-a} = 50^{\circ}C$$

when a case temperature increases, with respect to the environment, of:

Equation 9

$$\Delta T = P_{tot} \bullet R_{thj-a} = 0.878W \bullet 50^{\circ}C/W \sim 44 \times C$$

the final case temperature in the given hypothesis will be:

Equation 10

$$T_{case} = T_{amb} + \Delta T = 60^{\circ}C + 44^{\circ}C = 104^{\circ}C$$

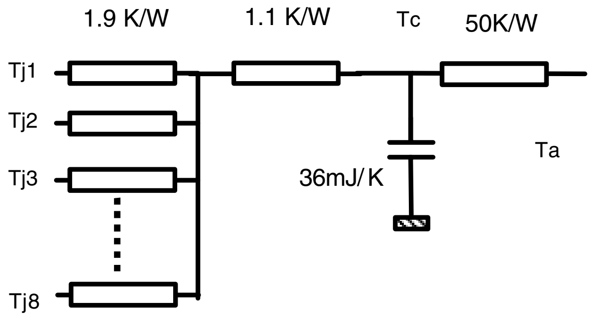
Hence, we are well inside the minimum case shut-down temperature guaranteed at datasheet, that is 125°C. Based on the thermal model of the VN808-E device (see *Figure 7*), the maximum junction peak temperature instead will be:

Equation 11

$$T_{jmax} = T_{case} + \left(1.1 + \frac{1.9}{4}\right) \bullet 48W = 180^{\circ}C$$

This means that for the analyzed case the device reach, on each of the 4 channels, the typical junction shut-down temperature reported at datasheet.

Figure 7. VN808-E thermal model



4 Conclusions

A smart monolithic octal high-side driver specifically developed for industrial applications has been presented. The internal structure of the device has been shown in detail, underlining the features and protection of the device. The typical application circuit has been analyzed, suggesting the external components to add to be compliant with the fundamental IEC rules. The device has been theoretically analyzed simulating the driving of big inductive loads, thus demonstrating its excellent behavior.

5 References

1. VN808-E datasheet
2. Technical presentation
3. VN808-E article on “Express” internal bulletin

6 Revision history

Table 1. Revision history

Date	Revision	Changes
09-Feb-2007	1	First issue

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