Bulb Driving Capability of HITFET+

About this document

Scope and purpose

One of the target applications of HITFET+ device family is bulb driving, particularly for interior lightning bulbs. This application note gives some inspirations to select appropriate low side switches (HITFET+) for bulb applications (LED's are not considered in this document, at all), based on technical approaches.

Intended audience

This application note is targeted for all design engineers who need low side switches for bulb applications.

Table of Contents

1 Abstract

Note: The following information is only given as a hint for the implementation of the device, and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.

This Application Note describes the background of the bulb switching capability of HITFET+ devices and shows the practical considerations. It analyzes the switching capability of HITFET+ devices. The aim is to give hints on how to determine the right device for a dedicated load setup.

2 Bulb Load Current Model

2.1 Introductions

One of the main applications of HITFET+ is to switch on bulbs. During the switching phase, the bulb exhibits an important transient current called the inrush current. This current appears for the HITFET+ to be similar to short circuit and it implies a risk that the device switches off by activating the over current protection mechanism. This means HITFET+ devices are limited in terms of bulb driving capability.

2.2 Mathematical Reminder

The inrush current of a bulb resembles the initial response of a RC network. **Figure 1** provides circuit and current timing characteristic of an RC circuit, assuming an ideal supply (VBAT) and a switch (SW).

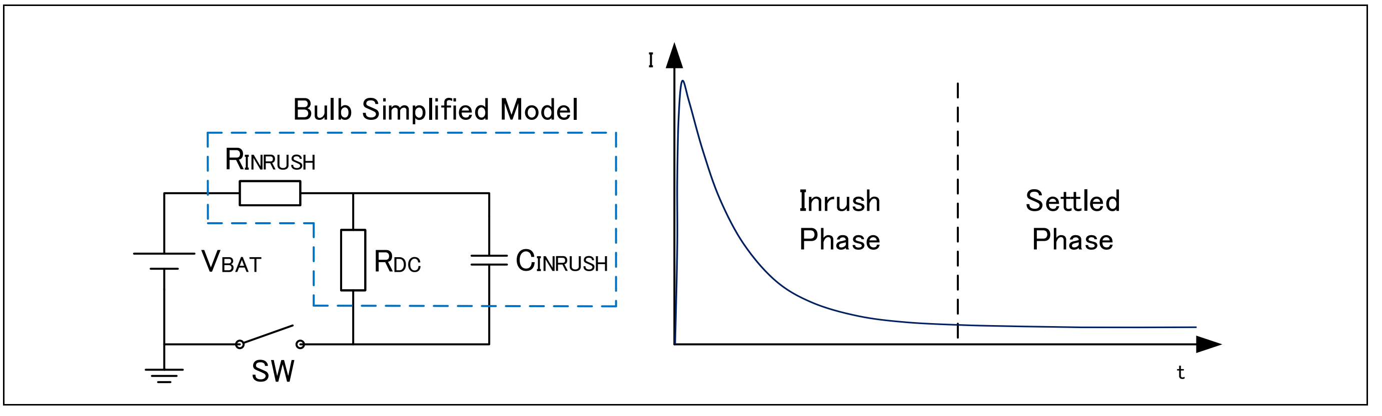

Figure 1 Equivalent simplified model of a bulb and simulated current profile

2.3 Application to Bulb Inrush

Figure 1 shows the typical inrush phenomenon. The set-up is ideal, meaning there's none or negligible parasitic impedance between the switch and GND, and almost no parasitic impedance between the bulb and the switch. The inrush current we see at the beginning of a switch ON event of a bulb is due to the fact that the filament is cold and the resistance is low, therefore consuming a lot of power. As the filament temperature raises its resistance increases until it reaches a temperature stable point.

The three physical values R_{INRUSH}, C_{INRUSH} and R_{DC} define the simplified model of a bulb. C_{INRUSH} represents the inrush current and the equivalent energy to be stored to reach thermal balance of the filament. R_{INRUSH} limits the current of the inrush. R_{DC} represents the current flowing during DC operation in the filament, when the filament temperature has stabilized. R_{INRUSH} and C_{INRUSH} represent the filament impedance at the inrush phase while R_{INRUSH} and R_{DC} equate to the resistance in the settled phase.

2.4 Inrush current

Before switching on, the bulb is cold. To produce light, it's necessary for the bulb filament to reach a very high temperature (above 1000℃). At switching on, a significantly higher current is flowing in the filament. This current is called inrush current. Depending on the OEM or tier1 manufacturer, a certain ratio is applied which relates the nominal current of the bulb to the inrush current. As a general specification, Infineon considers an inrush factor of 10.

3 HITFET+ Protection

IMPORTANT NOTE:

Protection mechanisms are integrated and are designed to prevent IC destruction under fault conditions. Fault conditions are defined as conditions outside normal operation of the device. Protection functions are not designed for continuous repetitive operation. Also, protection functions are not available during reverse/inverse current condition.

3.1 Introduction

The new HITFET+ family consists of 14 devices divided in two main categories: Standard devices (BTS***) and fully featured devices (BTF***). Both groups have a $R_{DS(ON)}$ ranging from 35mΩ to 125mΩ providing overcurrent, overtemperature and overvoltage protection. The standard devices have 3 functional pins (Drain, Source and Input) in a TO-252-3 DPAK package and an additional 4th pin (STATUS) in the smaller TDSO-8 package (see chapter 3.2.2). The fully featured devices include all the features and protection present in the standard devices but adding extra functionality such as a dedicated logic supply voltage, enable input, slew-rate control and a new smart over current protection ($I_{L(LIM)\_TRIGGER}$) consisting of two thresholds to ensure driving loads with high inrush current without compromising short circuit robustness over the life time of the device (see chapter 3.2.1)

The HITFET+ family includes also two dedicated devices in TO-252-5 DPAK: a 50mΩ BTF3050TE with $I_{L(LIM)\_TRIGGER}$ and slew-rate control concept and a 11mΩ BTS3011TE with $I_{L(LIM)\_TRIGGER}$ concept and fixed slew-rate.

In general, overcurrent and overtemperature protection should be considered for bulb applications during device selection phases, because overcurrent protection (current limitation) and/or overtemperature protection (thermal shutdown) might be observed, if a wrong device is selected.

Therefore, in this section, the overcurrent protection and overtemperature protection functions are introduced.

3.2 Overcurrent protection

3.2.1 Fully featured Devices

All BTF*** devices are called fully featured devices in HITFET+family. All BTF*** and BTS3011TE devices have smart overcurrent limitations providing protection against short circuit conditions and any other increased current conditions, while also allowing load inrush currents higher than the current limitation, $I_{L(LIM)}$, level. To achieve this, the device has a higher current trigger level $I_{L(LIM)\_TRIGGER}$ which triggers a lower current limitation level $I_{L(LIM)}$.

This enable the device to take currents higher than $I_{L(LIM)}$ (overload condition) provided the device is not heated up so much that the overtemperature protection (OT) is triggered. In case of a short circuit, $I_{L(LIM)\_TRIGGER}$ will be triggered, which will limit the current to $I_{L(LIM)}$.

Figure 2 depicts the functioning of the overcurrent protection for a short circuit behavior.

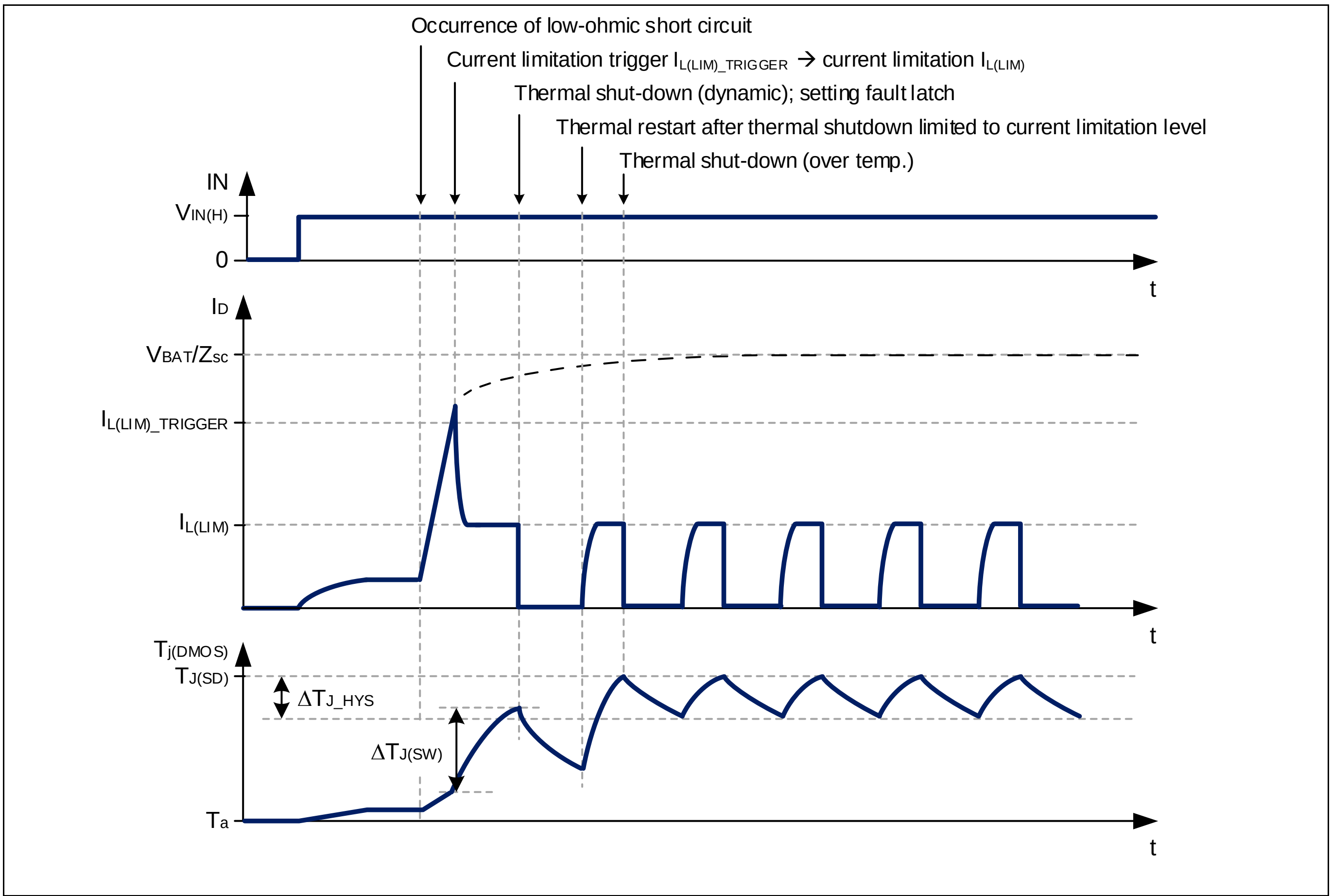

Figure 2 **Example of short circuit protection with thermal protection (fully featured devices)**

3.2.2 Standard Devices

All BTS*** devices except BTS3011TE are called standard devices in HITFET+family, and have traditional overcurrent limitations same as HITFET family (predecessors of HITFET+ family). If the load current reaches the limitation value of $I_{L(LIM)}$, the device limits the current and therefore will start heating up. When the thermal shutdown temperature is reached, the device turns off.

Figure 3 depicts the functioning of the overcurrent protection for a short circuit behavior.

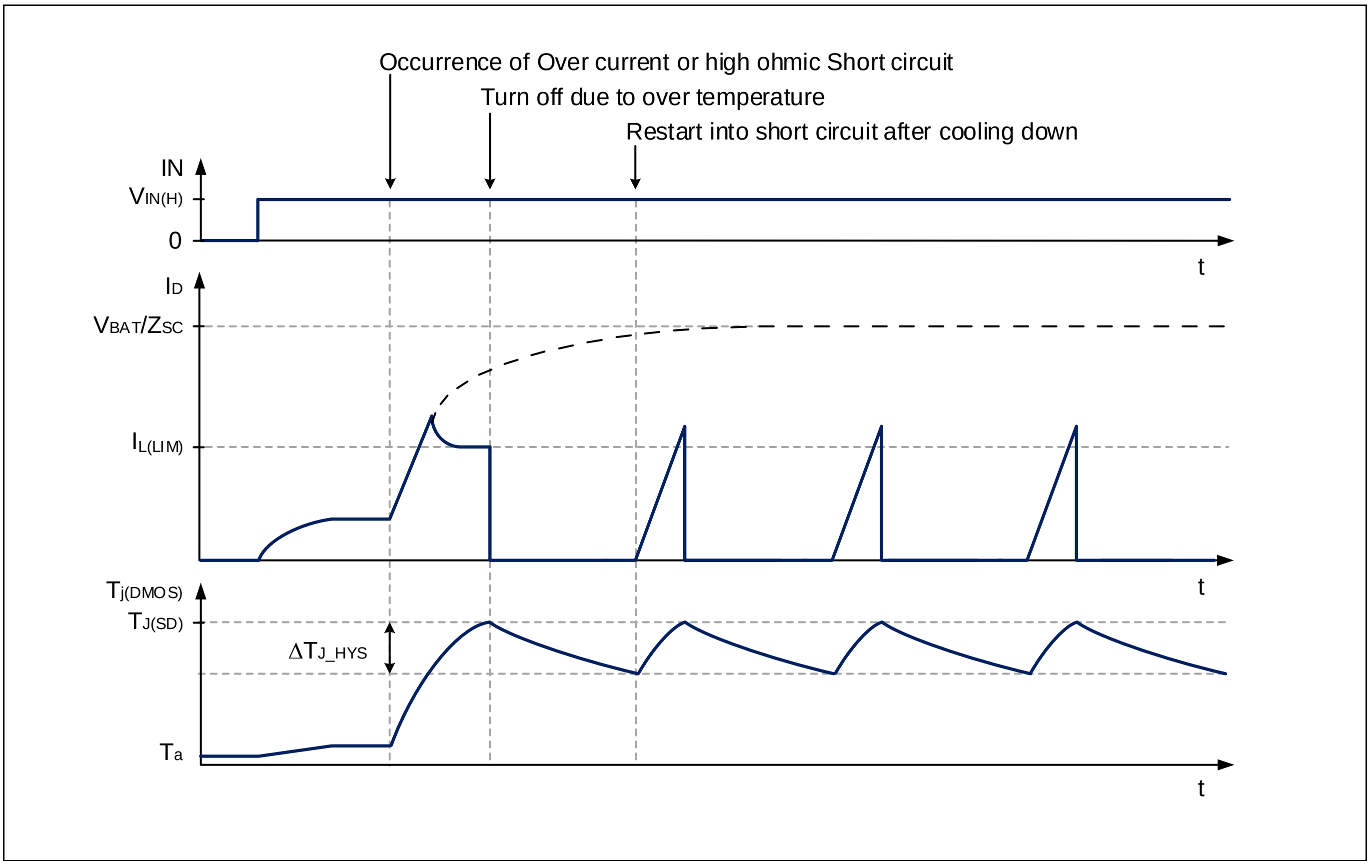

Figure 3 Example of short circuit protection with thermal protection (standard devices)

3.2.3 Current Limitation levels

HIFET+ devices limit the current during short circuit condition. **Table 1** shows current limitation levels for HITFET+ devices. If a HITFET+ device whose current limitation minimum level is less than the maximum inrush current is selected, the current limitation might be observed during the inrush current phase of the bulb. Therefore the maximum inrush current must be less than the current limit trigger, $I_{L(LIM)\_TRIGGER}$, or current limit, $I_{L(LIM)}$, minimum level.

Table 1 HITFET+ Current Limitation levels

Device Category	Part Number	Rds-on typ [mΩ]	Current Limitation trigger minimum level [A]	Current Limitation minimum level [A]
5pin	BTS3011TE	11	80	35
5pin fully featured	BTF3050TE	40	30	8
8pin fully featured	BTF3035EJ	28	41	14
	BTF3050EJ	40	29	10
	BTF3080EJ	64	18	7
	BTF3125EJ	100	12	5
8pin standard	BTS3035EJ	35	N.A.	20
	BTS3050EJ	45	N.A.	15
	BTS3080EJ	75	N.A.	10
	BTS3125EJ	110	N.A.	7
3pin standard	BTS3035TF	30	N.A.	20
	BTS3050TF	40	N.A.	15
	BTS3080TF	64	N.A.	10
	BTS3125TF	110	N.A.	7

☐ Infineon recommends that the inrush peak currents are less than the values mentioned above.

3.3 Overtemperature Protection

All HITFET+ devices are protected against over temperature due to overload and / or bad cooling conditions. To ensure this, a temperature sensor is located in the power MOSFET.

HITFET+ devices have thermal protection functions with automatic restart. After the device has switched off due to over temperature, the device will stay off until the junction temperature has dropped down below the thermal hysteresis.

4 Bulb Driving Capability with HITFET+

4.1 Introduction

In case of device selections for bulb applications, two of the important factors are the inrush peak current value and maximum junction temperature. Regarding the inrush peak current, theoretically it can be calculated by hand, when the specific conditions are given. On the other hand, regarding the junction temperature, it can't be calculated by hand, in general because it is calculated with the information of the Zthja, Rdson, the load current profile, and so on. Therefore to give some inspirations to select appropriate HITFET+ devices for bulb applications, thermal simulation results are introduced in this section.

NOTE: following information is given as a hint for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device. It must be verified by the recipient of this document in the real application.

4.2 Bulb Electrical Wattages

The bulb wattage is defined at a specific voltage with a percentage tolerance. **Table 2** shows the commonly used bulbs in terms of electrical wattage, tolerance (accuracy) and voltage. V_{REF} is the voltage specified by the bulb manufacturer.

Each bulb current depends on the supply voltage. And sometimes just one bulb is assigned to one low-side switch. Sometimes several bulbs are assigned to one low-side switch. In latter case, the total electrical wattage is, for example, 30W (e.g. 10W+10W+5W+5W), 40W (e.g. 4pcs of 10W) and so on.

Table 2 Bulb DC currents and inrush currents

Bulb [W]	Accuracy [%]	V_{REF} [V]	Maximum DC Current at 16V [A]	Maximum Inrush Current at 16V [A]
5	10	13.5	0.48	4.8
7	10	12.8	0.75	7.5
10	10	13.5	0.97	9.7
15	10	13.5	1.45	14.5
21	6	12	2.47	24.7

NOTE:
The formula for (Max DC Current at 16V [A]) is as follows.

$$Max\ DC\ Current\ at\ 16V\ [A] = \big(1 + (Accuracy\ [\%]) * (0.01)\big) * \frac{Bulb\ [W]}{VREF\ [V]} * \frac{16[V]}{VREF\ [V]}$$

4.3 Conditions

Table3 is the summary table on the thermal simulations used in this section.

Table 3 Thermal simulation conditions

Parameter	Condition A (Example)	Condition B (Conservative)	Condition C (Moderate)
Vbat	13.5V	16V	
Rds-on	Typ	max*1)	
Inrush factor	10		
Board	2s2p		
Wire Harness resistance	0 Ω		
Wire Harness Inductance	0uH		
Tj start	25℃	85℃	25℃
Bulb Wattage Tolerance	±0%	+10%*2)	±0%

*1) At each thermal simulation step, the maximum Rdson value is calculated based on the junction temperature.
*2) Consider accuracy of 10% for 5W, 7W, 10W and 15W bulbs.

4.4 Results

4.4.1 Example

Readers should be aware of a general load current model and thermal performance of HITFET+ device used in this document. Because lots of thermal simulation results are used for the figures in this section in the background. **Figure 4** depicts a load current model and the thermal simulation results (Rdson and junction temperature) as an example.

- Load current model:
  - The load current is maximum value at t=0ms, and the inrush factor is 10.
- Rdson:
  - It's not fixed value but changing, because it is calculated at each simulation step timing based on the junction temperature information.
- Junction temperature:
  - It's highest at the early timing of the inrush current phase (around 1ms after the switch-on timing) due to the inrush current. And then it's decreasing exponentially.

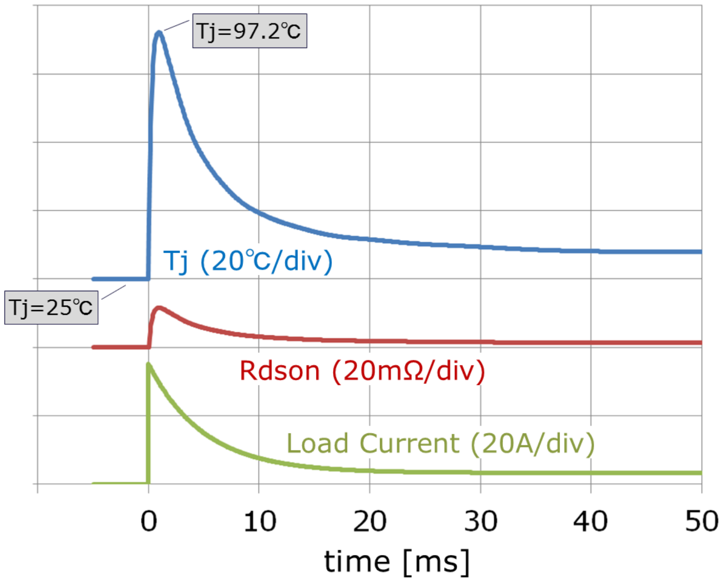

Figure 4 Thermal simulation results (BTF3035EJ, 40W) , condition A (Example) in the Table2

4.4.2 Inrush currents vs. Junction Temperatures

Figure 5 and **Figure 6** depict the effects of the inrush current peak values on the maximum junction temperatures in case of the condition B (Conservative) in **Table 3**, for both fully featured and standard devices.

As shown in the **Figure 5** (fully featured devices with the condition B (Conservative)), when the inrush current peaks are getting higher, the junction temperatures are reached to 150℃ before the inrush peak currents reach to the current limitation trigger levels. Therefore, when conditions are conservative, the maximum junction temperature is the dominant factor to select an appropriate HITFET+ fully-featured device, in general. If the current limitation and/or thermal shutdown are observed with some conservative conditions, it is recommended to perform a feasibility study including measurements by the responsible of selecting the correct device.

Bulb Driving Capability with HITFET+

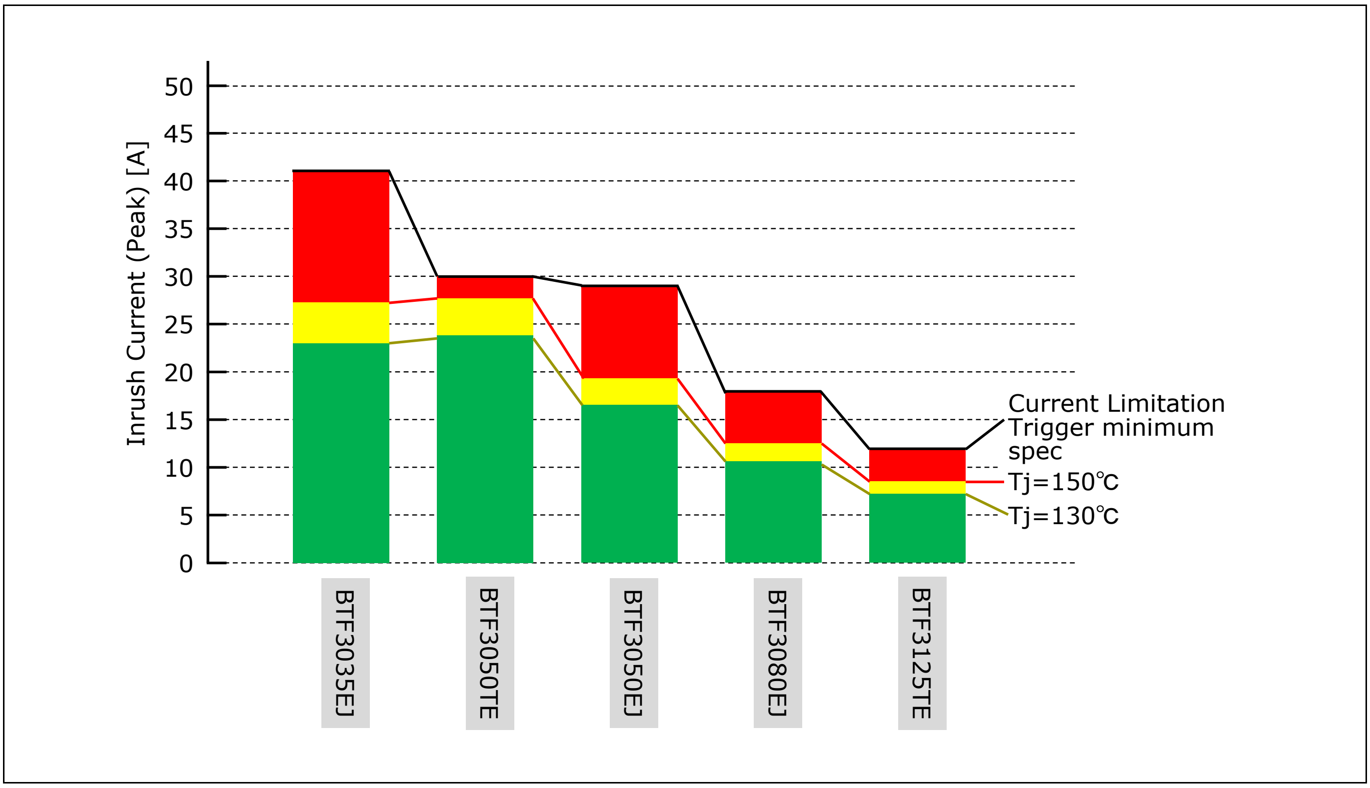

Figure 5 Bulb current capability; BTF* devices, Condition B (Conservative)**

On the other hand, as shown in **Figure 6** (standard devices with the condition B (Conservative)), in case of standard devices, when the inrush current peaks are reached to the current limitation levels, the junction temperatures are still less than 130℃ except BTS3125EJ. Therefore, even though the conditions are conservative, to select a standard device, the dominant factor is not maximum junction temperature but the worst case inrush current peak value.

Now, **Figure 7** and **Figure 8** depict the effects of the inrush current peak values on the maximum junction temperatures in case of the condition C (Moderate) in **Table 3**, for both fully featured and standard devices.

As shown in the **Figure 7** (fully featured devices with the condition C (Moderate)), when the inrush current peaks are getting higher, sometimes the junction temperatures are reached to 150℃ before the currents reach to the current limitation trigger levels, sometimes the junction temperatures are still less than 150℃.

Figure 8 (standard devices with the condition B (Moderate)) depicts the effects of the inrush current peaks on the junction temperatures. The results are almost same as **Figure 6**, as expected.

Bulb Driving Capability with HITFET+

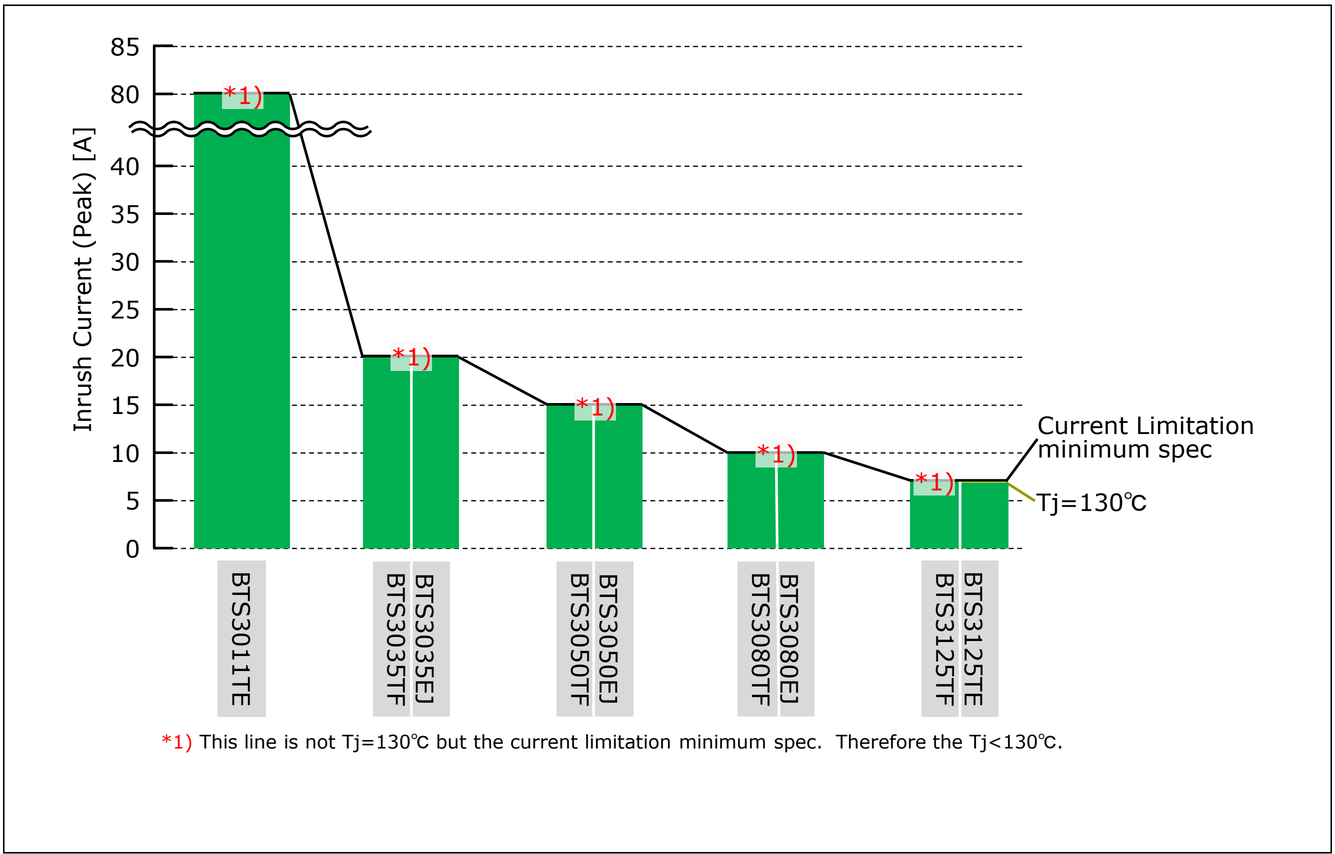

Figure 6 **Bulb current capability; BTS*** devices, Condition B (Conservative)**

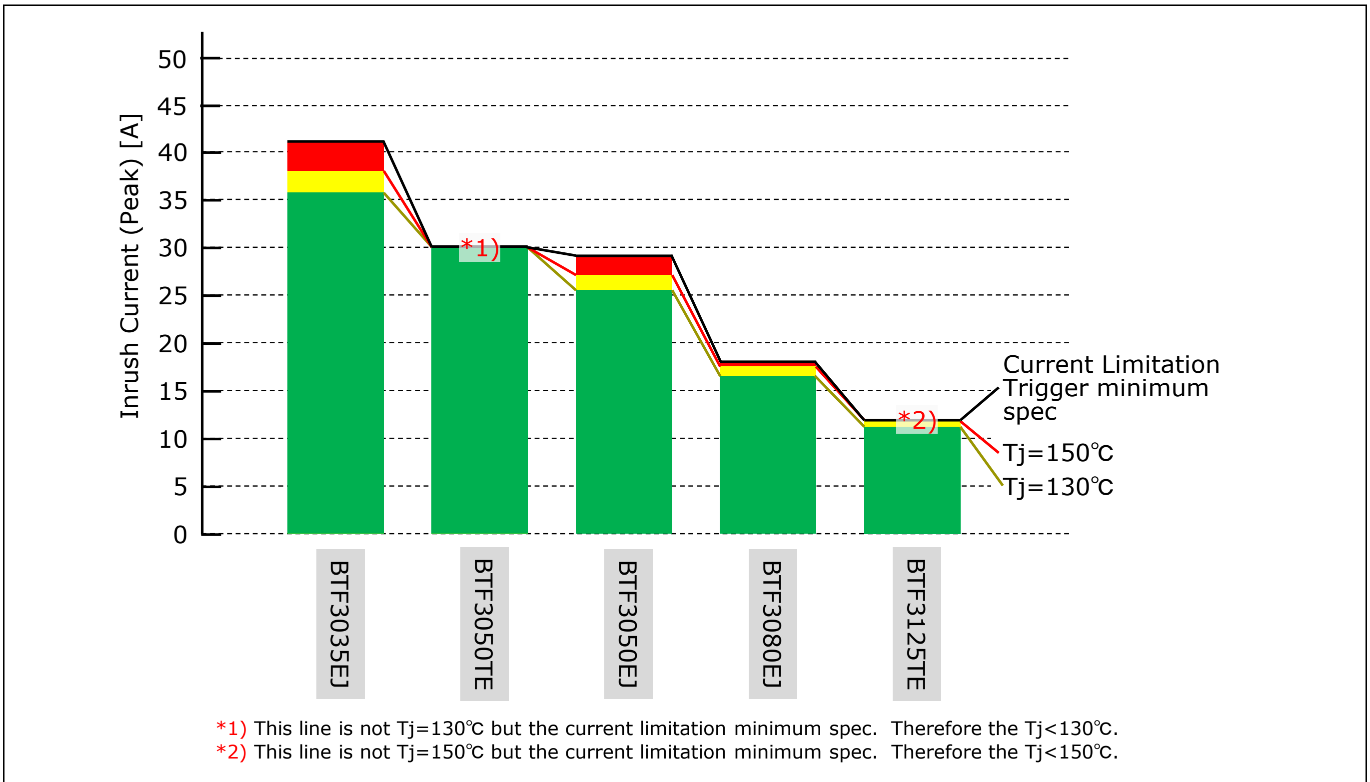

Figure 7 **Bulb current capability; BTF*** devices, Condition C (Moderate)**

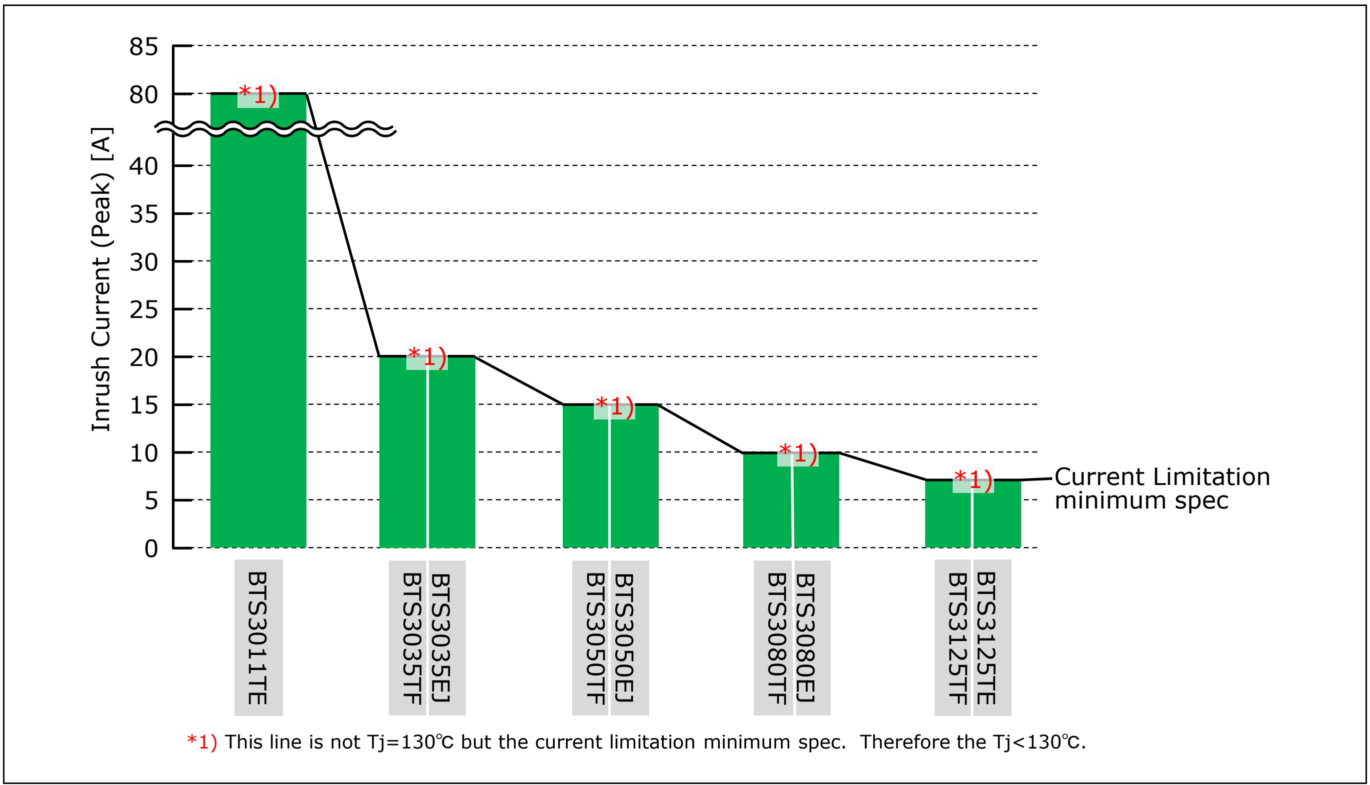

Figure 8 Bulb current capability; BTS* devices, Condition C (Moderate)**

4.4.3 Bulb Wattages vs. Junction Temperatures

In case of **Figure 5**, **Figure 6**, **Figure 7** and **Figuire 8**, each vertical axis is the inrush current peak value. These figures provide fundamental links on the inrush currents (peak), the device current limitation (or current limitation trigger) minimum specs and the junction temperatures. But they don't give the direct information to select how much wattage bulbs could be selected. Therefore, regarding **Figure 9, Figure 10**, **Figure 11** and **Figure 12**, the Y-axis of each figure is converted from the inrush current (peak) to the bulb wattage.

Bulb Driving Capability with HITFET+

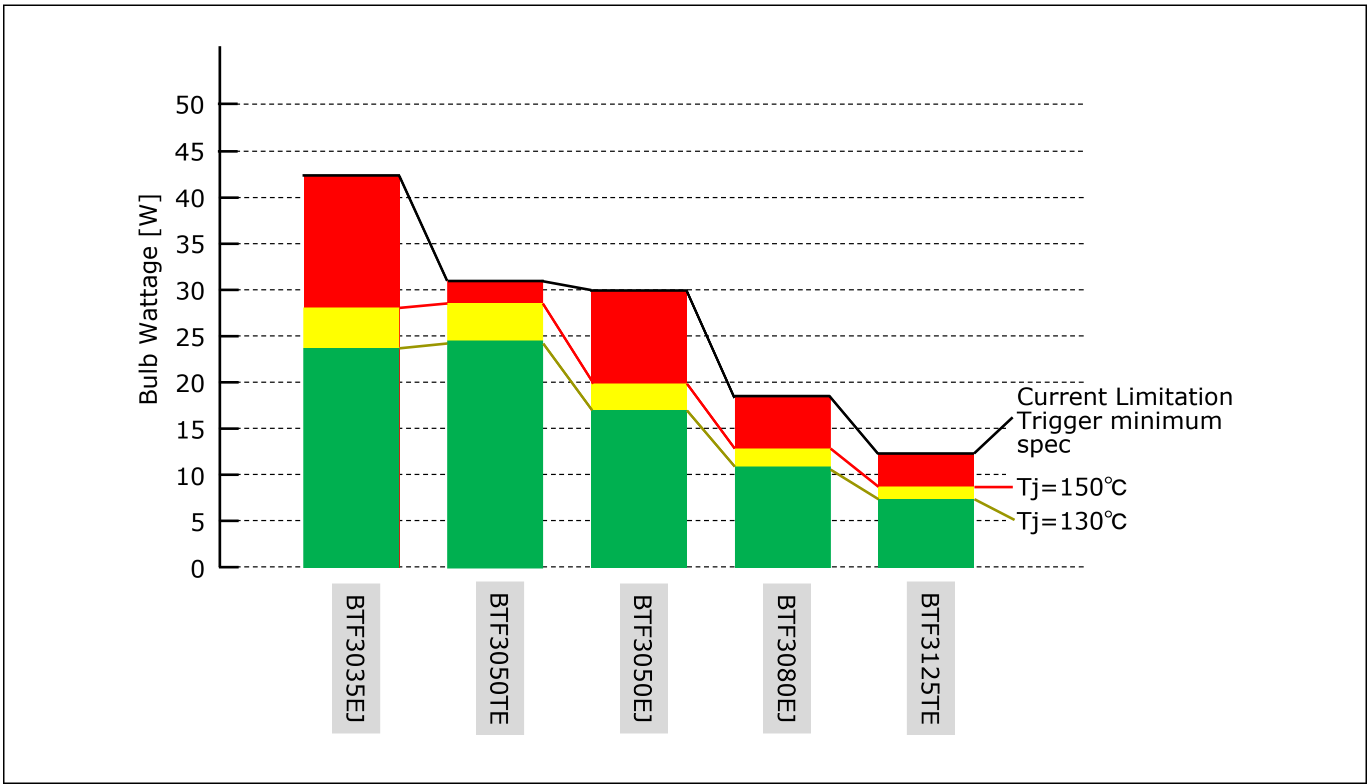

Figure 9 Bulb load power capability; BTF* devices, Condition B (Conservative)**

Figure 10 NOTE: The Y-axis represent bulb wattage [W], not inrush current [A].

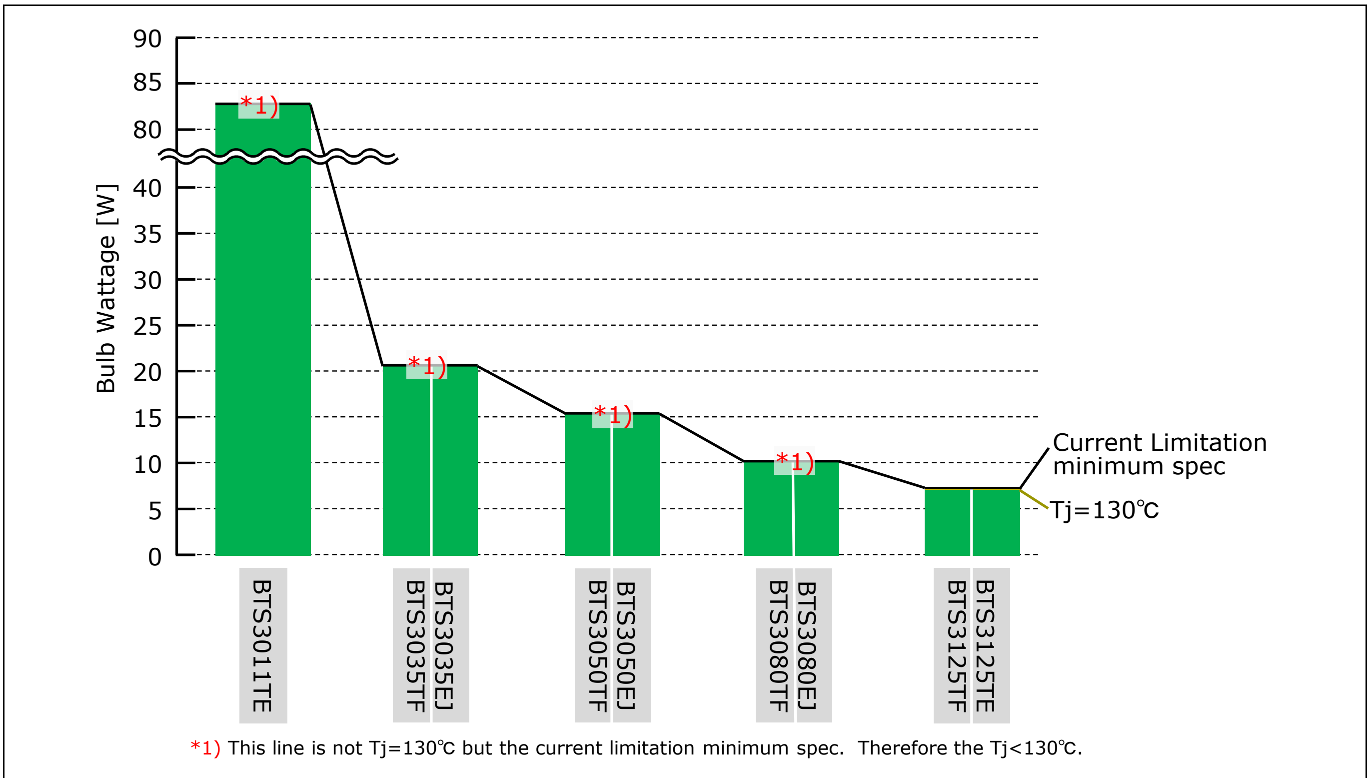

Figure 11 Bulb load power capability; BTS* devices, Condition B (Conservative)**

Figure 12 NOTE: The Y-axis represent bulb wattage [W], not inrush current [A].

Bulb Driving Capability with HITFET+

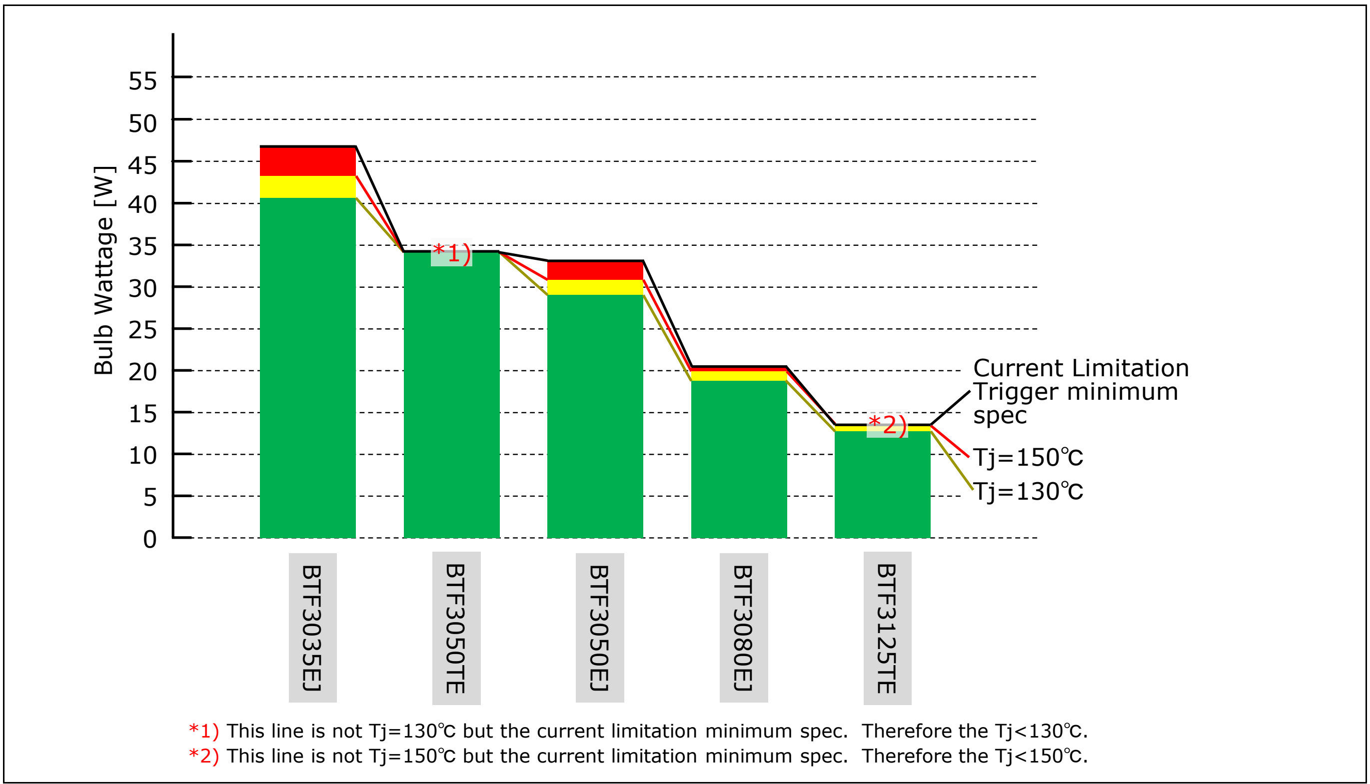

Figure 13 Bulb load power capability; BTF* devices, Condition C (Moderate)**

Figure 14 NOTE: The Y-axis represent bulb wattage [W], not inrush current [A].

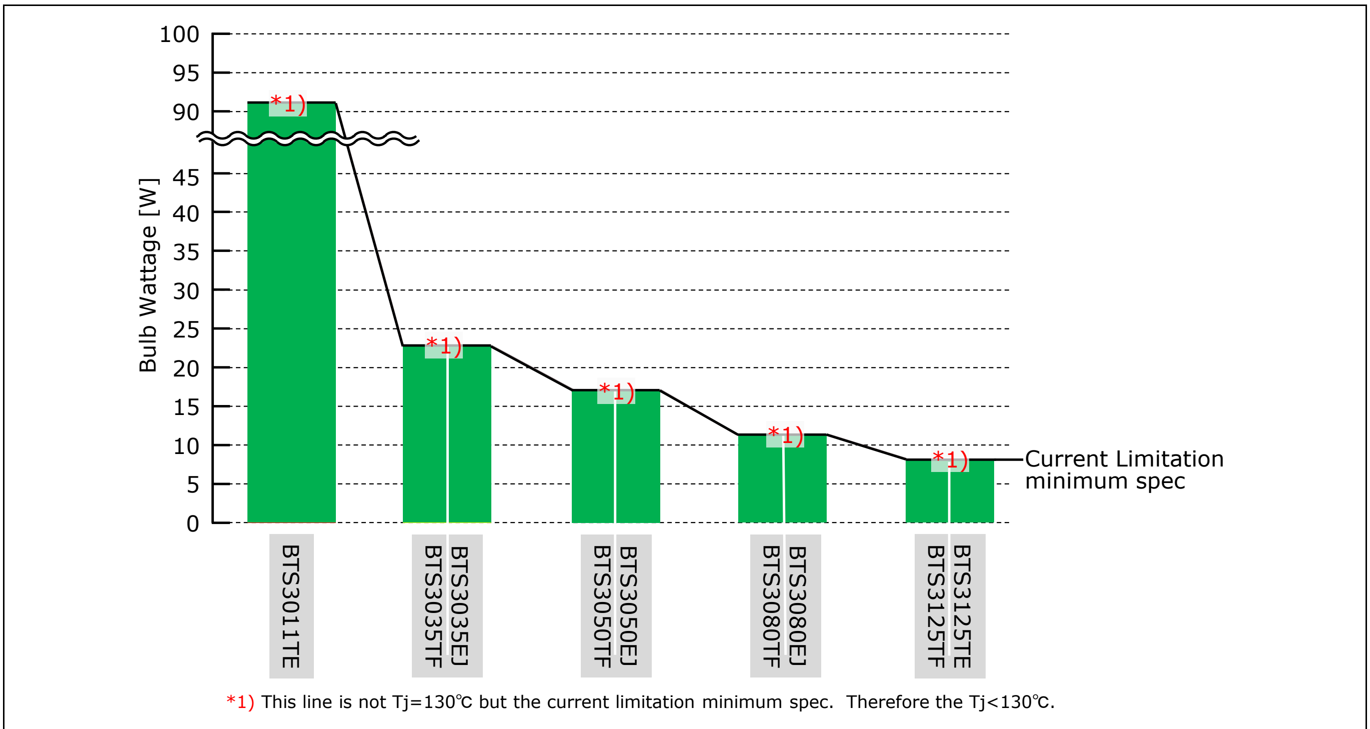

Figure 15 Bulb load power capability; BTS* devices, Condition C (Moderate)**

Figure 16 NOTE: The Y-axis represent bulb wattage [W], not inrush current [A].

5 Comparisons of HITFET and HITFET+

Regarding the themal performances for bulb applications, in some cases, HITFET+ family is more sensitive than HITFET family (the predecessor of HITFET+ family). This difference is mainly due to smaller packages and smaller die area considering same $R_{DS(ON)}$. Therefore the objective of this section is to provide some perceptions on the themal performances by using BTS142D (HITFET) and BTF3050TE (HITFET+), as an example.

Table 4 shows basic features of BTS142D and BTF3050TE. Both device packages are DPAK. And the minimum value of the current limitation for BTS142D is 30A. The minimum value of the current limitation trigger for BTF3050TE is 30A. Therefore, both devices have the potential to handle up to 30A in the inrush currents.

Table 4 Basic Features of BTS142D and BTF3050TE

Parameter	BTS142D	BTF3050TE
Device family	HITFET	HITEFT+
Package	DPAK 3pin	DPAK 5pin
Rdson (Tj=25℃, Typ)	27mΩ	40mΩ
Current limitation trigger	N.A.	30A min (-40℃≦Tj≦150℃)
Current limitation	30A min (Tj=25℃)	8A min (-40℃≦Tj≦150℃)

□ Infineon recommends that the inrush peak currents are less than these values.

Table 5 Thermal simulation conditions

Parameter	Condition
Bulb wattage	30W (V_{REF}:13.5V)
Vbat	16V
Rds-on	Max
Inrush factor	10
Board	2s2p
Wire harness resistance	0Ω
Wore harness inductance	0uH
Ta=Tj start	85℃
Bulb wattage tolerance	±0%

Table 5 shows the thermal simulation conditions for both devices (BS142D and BTF3050TE). And **Figure 13** depicts the thermal simulation results. The key message of Figure13 is as follows.

- The thermal impedance of BTF3050TE is bigger than that of BTS142D for bulb applications. This tendency is same as **Figure 4**.

Not only new users of Infineon low-side switches users but also tradicitonal users of HITFET should be aware of this thermal impedance difference on HITFET+ devices, especially in case of fully-featured HITFET+ devices.

Otherwise HITFET+ junction temperatures might touch the thermal shut-down threshold, which is not allowed to do it during the normal operation of the device (refer to **Section 3**).

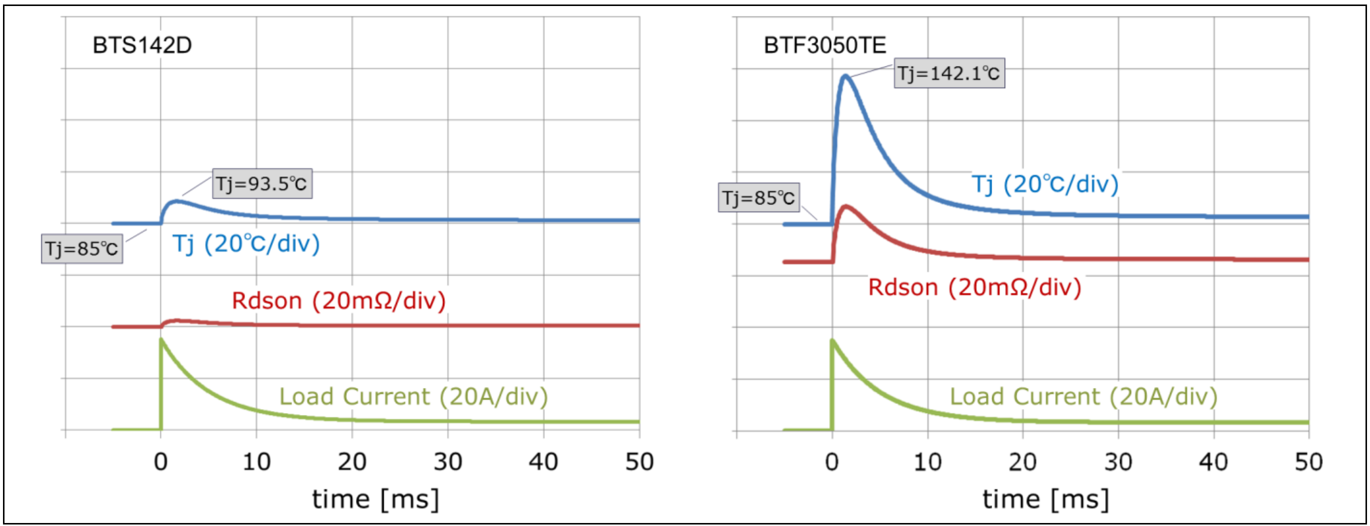

Figure 17 Thermal simulation results of BTS142D and B TF3050TE (30W bulb)

6 Summary

The HITFET+ device users should be awere of the items listed below.

- As noted at the beginning of this document, one of the target applications for HITFET+ device family is bulbs. In case of bulb applications, the HITFET+ junction temperature is highest at the early timing of the inrush current phase (around 1ms after the switch-on timing) due to the inrush current.
- This device family has fully featured and standard device groups. The two device groups are very different in balancing the current limitation (or current limitation trigger) specifications and thermal performances.
- Comparing to HITFET devices (predecessor of HITFET+ devices), HITFET+ devices have higher thermal impedance, which needs to be accounted during the bulb inrush phase, as introduced in the **Section 5**.
- Compared to the BTS*** HITFET+ family, the BTF*** HITFET+ family is more suitable to drive high inrush current's applications such as bulb driving due to the over current concept implemented $I_{L(LIM)\_TRIGGER}$.

Revision History

Major changes since the last revision

Revision	Date	Description of change
1.0	2017-07-12	Application Note released

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