International Rectifier

APPLICATION NOTE

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Using Trench Technology MOSFETs in Hot Swap Applications

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Description of Hot Swap Applications

Hot Swap circuits are used to allow for “Hot Plugging” of circuit boards into back planes. The applications that require such functionality are mission critical, such as servers and communications equipment that must operate continuously. These circuit boards are usually employed in a rack mount system which consists of an array of boards that cannot be powered down. Thus hot swapping allows for a bad board in the array to be replaced without powering down the entire system.

In essence the Hot Swap circuit, which is between the board input rail and the rest of the board’s circuitry, is an inrush current limiter that allows for charging of the bulk capacitance in a controlled manner. Also faults, such as over current and overvoltage are managed by Hot Swap circuits.

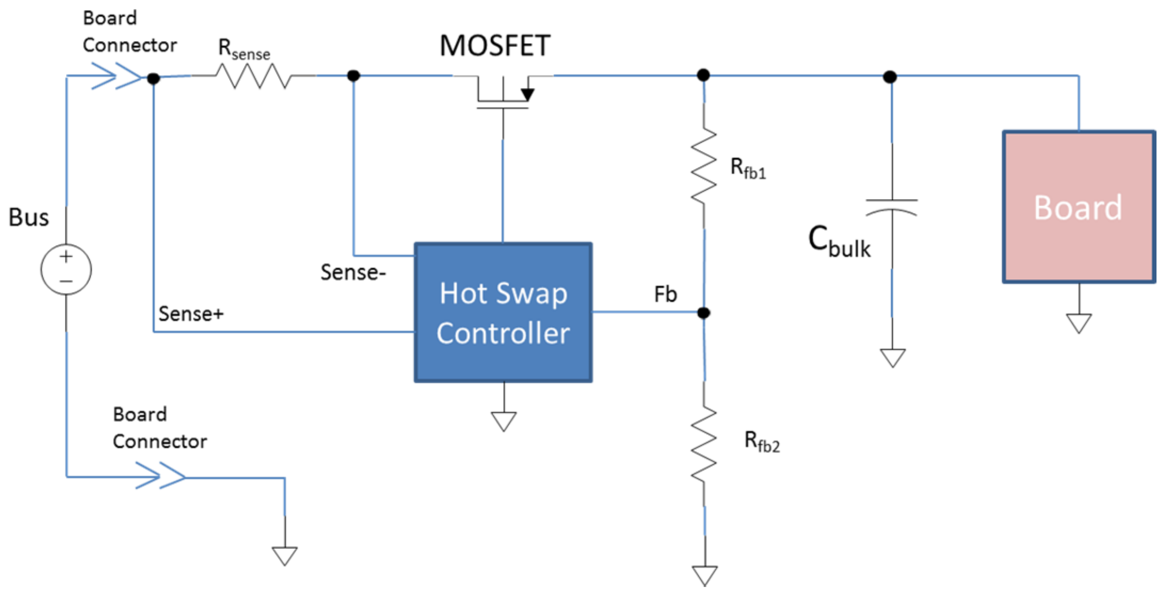

Figure 1 - Generic Hot Swap Circuit

Figure 1 depicts a generic Hot Swap implementation. When the board in connected to the bus C_{bulk} will charge with a large inrush current if the Hot Swap circuit is not present. With the Hot Swap circuit in place the inrush current is sensed via the voltage drop across R_{sense} (Sense+ - Sense-). This voltage is used to limit the current with an opamp feedback circuit with a fixed reference. The Fb pin is used to monitor the output voltage for under and over voltage conditions.

The challenge in designing this application is choosing the correct MOSFET. At issue is that while charging C_{bulk} the MOSFET will be in the linear region, thus risking an overheating failure due to fast joule heating. Criteria for choosing a MOSFET include:

- Steady State Current carrying capability (R_{dson})
- Max V_{gs}
    - For standard gate drive MOSFET (R_{dson} defined at V_{gs}=10V) V_{gsmax}=+/-20V
    - For logic level MOSFETs (R_{dson} defined at V_{gs}=4.5V) V_{gsmax}=+/-16V
    - For low voltage drive MOSFETs (R_{dson} defined at V_{gs}=2.5V) V_{gsmax}=+/-12V
- V_{dsmax} (Breakdown Voltage)
- The Hot Swap event must not violate the MOSFET’s SOA

The capability to handle the current charging is ***related*** to the MOSFET's SOA. This capability depends on the die size, package and SOA.

Planar vs Trench MOSFETs

Much has been written contrasting Planar and Trench MOSFET technology over the years. This application note will only discuss the differences in their respective SOA's as it relates to the Hot Swap application.

Planar MOSFETs have a SOA that are a family of parallel lines plotted on a log-log graph.

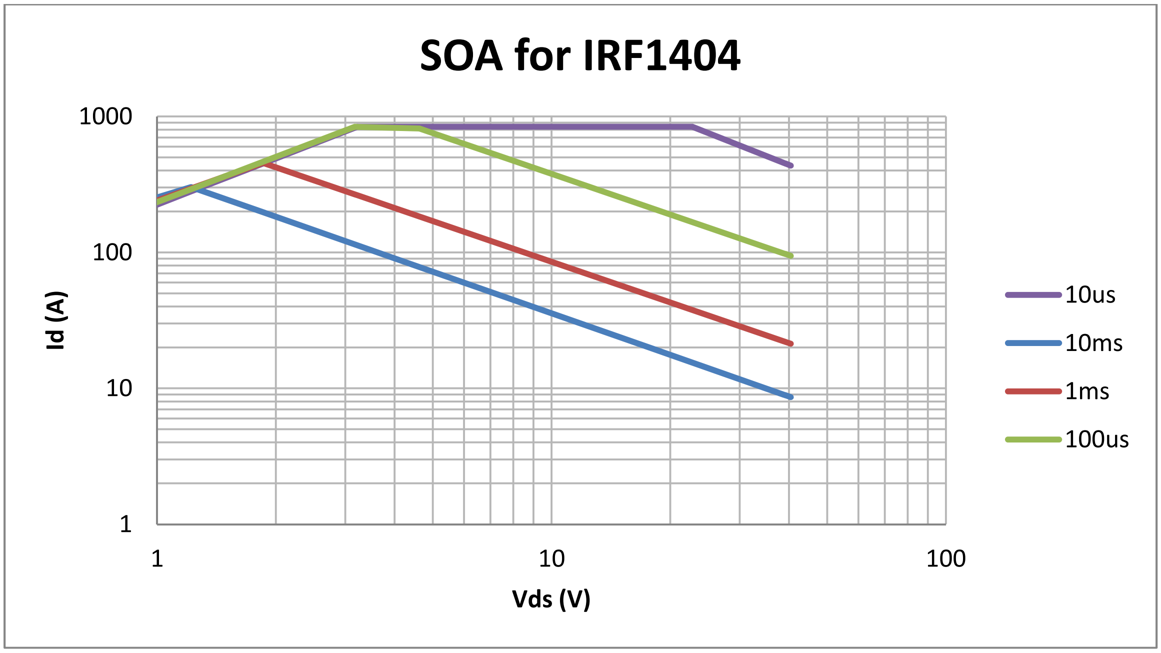

Figure 2 - SOA the IRF1404 (Planar MOSFET)

Figure 2 shows parallel SOA lines for Vds and Id for a given pulse width. Each line represents constant power as shown in Figure 3. The power is calculated as power=Id * Vds for each SOA line. This was taken with a start Tj=25C and a resulting Tj_{max}.

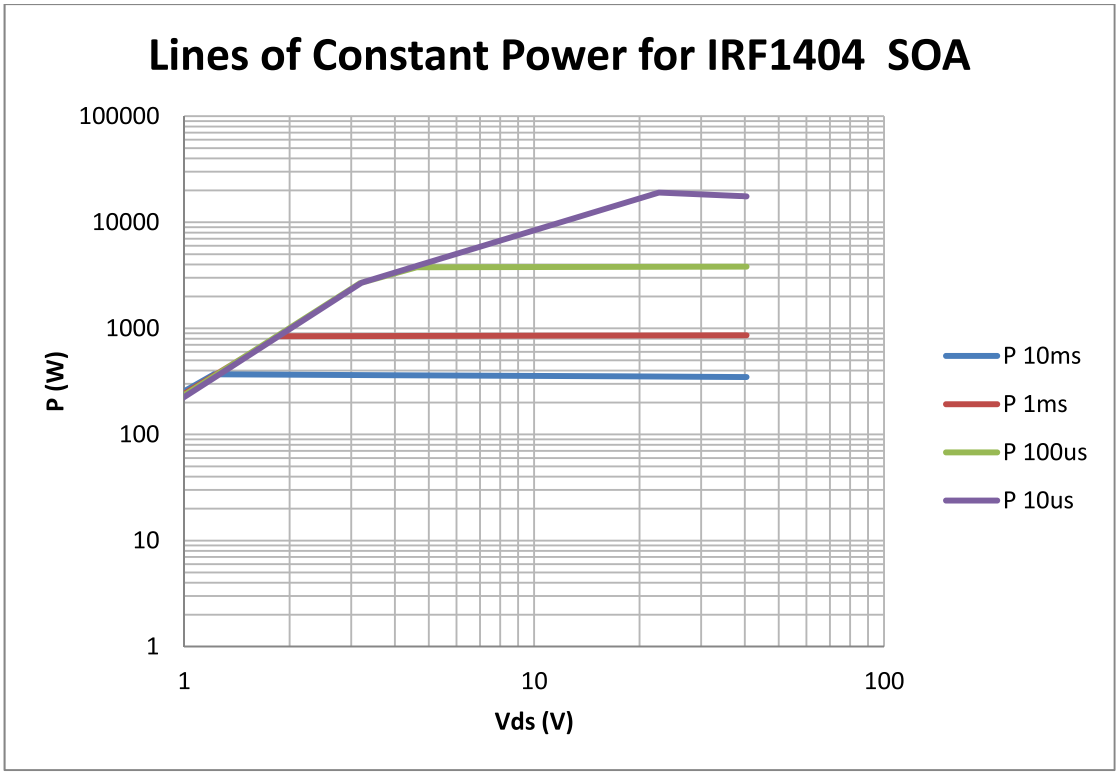

Figure 3 - Constant Power lines of the SOA for the IRF1404 (Planar MOSFET)

Figure 3 illustrates that for Planar MOSFETs their SOA is essentially a series of constant power lines over a range of Vds, thus allowing for a simple calculation of junction temperature rise for each pulse duration.

In general:

$$\Delta Tj = Z_{thjc} * P_{fet} \qquad \text{Eq. 1}$$

Where:
ΔT_j=MOSFET junction temperature
Z_{thjc}=Dynamic thermal impedance
P_{fet}=Power dissipation of the MOSFET

Figure 4 illustrates the Single Pulse Dynamic Thermal Impedance of the IRF1404.

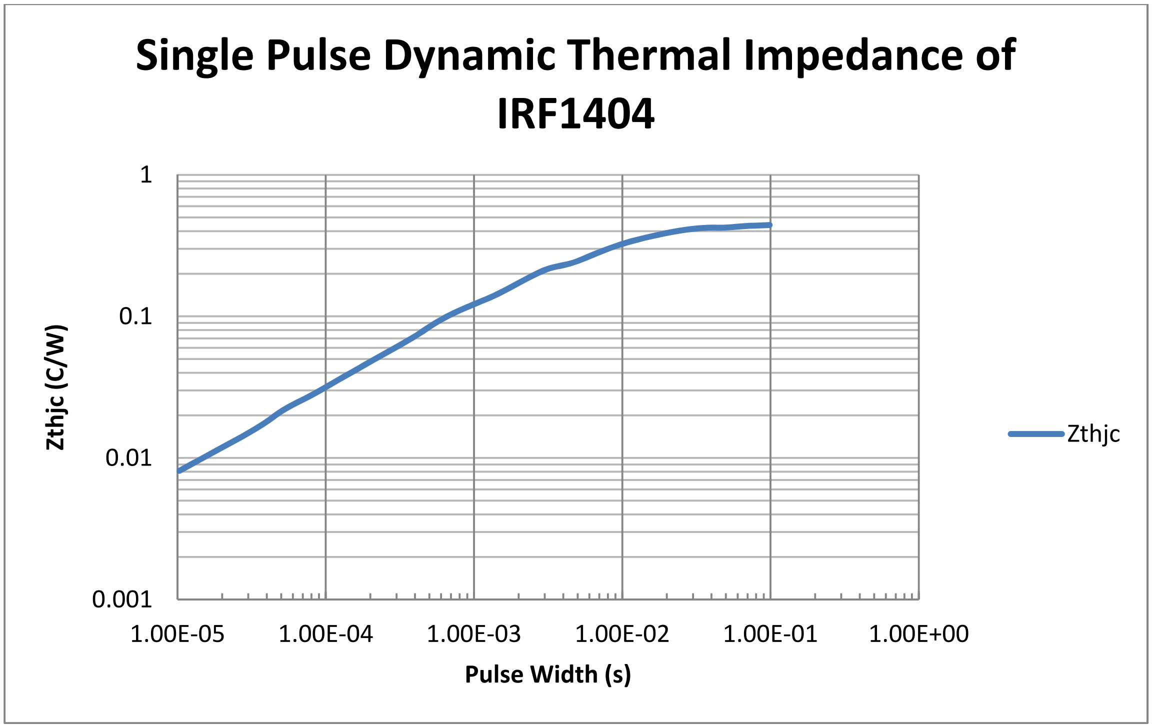

Figure 4 - Zthjc of the IRF1404 Planar MOSFET

If three of the constant power line values were used to calculate the ΔTj using Equation 1 it can be shown that ΔTj will be the same in all cases. From Figures 3 and 4

Table 1- Junction Temperature for Constant Power Pulses

Power (W)	Pulse Width	Zthjc(Pulse Width) (°C/W)	ΔTj (°C)
350	10ms	0.33	116
860	1ms	0.13	111
3800	100µs	0.03	114

Note: Z_{thjc} is chosen from Figure 4 using the Pulse Width from the SOA curves.

From Table 1 the ΔTj's are within measurement error.

A Trench MOSFET has a similar SOA with one major difference. There are breaks in the constant power portions of the curves at higher voltages. These breaks indicate that the SOA curves do not represent lines of constant power. Trench MOSFETs can experience a thermal run away condition if the power pulse (Vds, Id) for a given T_{pulse} is above the corresponding SOA curve. There are a number of papers that describe the mechanics of this phenomenon. Figure 6 shows a SOA curve for a modern Trench MOSFET.

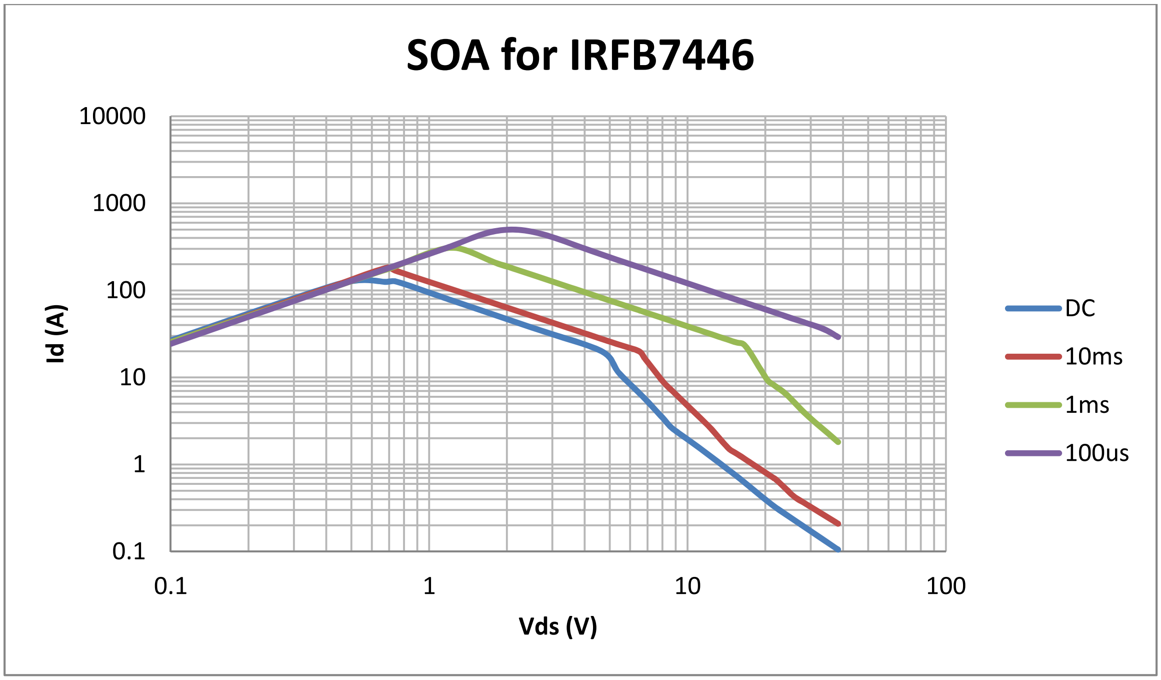

Figure 5 - SOA for the IRFB7446 Trench MOSFET

Analysis of a HOT Swap MOSFET Application

It has been written that Trench MOSFETs are not recommended for linear applications because of the thermal instability that is illustrated by the break in the SOA curves. Therefore relating the SOA to the Hot Swap application of a MOSFET appears to be difficult. However there is a procedure that provides a conservative evaluation of its fit for use. All that is needed to perform the analysis is the load capacitance being charged, the bus voltage, the constant charging current and the SOA curves. The procedure is as follows:

1) Determine the time it takes to charge the load capacitance to half the bus voltage
2) Choose a curve for a time greater than the 50% charge time.
3) If the bus voltage and constant current point plotted on the SOA curve is below the chosen curve then the MOSFET is fit for the application.

Example Analysis

If a Hot Swap circuit is set for a 10A limit, the Bus voltage is 12V and the load capacitance is 100uf then:

$T = 0.5 \cdot C \cdot \frac{dv}{i}$ Eq. 2

Where:
T = The time it takes the load capacitance to charge to 50% of the bus voltage
dv = The bus voltage
i = Hot Swap charging current

C = Load capacitance

In this case the IRFB7446 will be considered.

$$T = 0.5 \cdot 100uf \cdot \frac{12V}{10A} = 60us$$

With T=60us, V=12V and I=7A can be plotted on the SOA and compared to the 100us SOA for the IRFB7446.

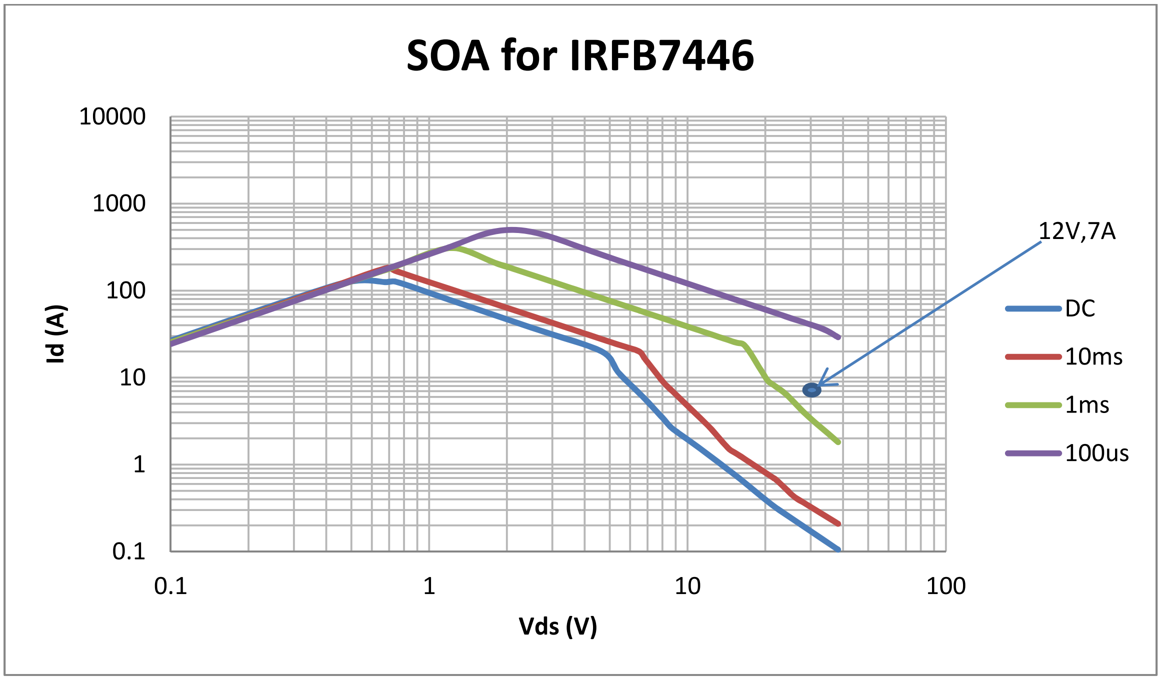

Figure 6 - Plotted Operating Point of IRFB7440 SOA

The plotted operating point is below the 100us curve thus the IRFB7440 is suitable for this application.

Simulation of a Hot Swap Application

Before a thermal simulation should be performed, a SOA analysis should be done to determine if the MOSFET is suitable for use in this application.

For this application:

Considering IRFHM4234
I=5A
dv=12V
C=250uf

Giving:

$$T = 0.5 * 250uf * \frac{12V}{5A} = 300us$$

Comparing the operating point (12V,5A) to the 1ms SOA shows that the IRFHM4234 is suitable for this application as shown in Figure 7.

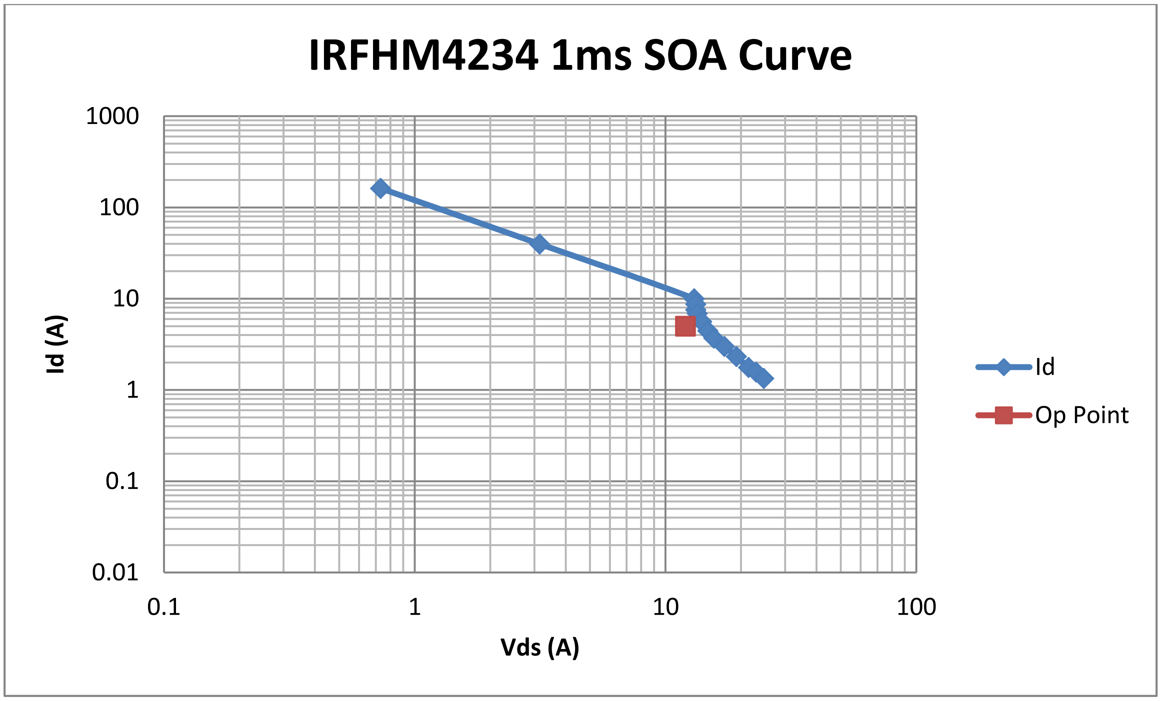

Figure 7 - IRFHM4234 1ms SOA compared to operating point

From a thermal transient stand point, the duration of the Hot Swap event is less than the time it takes for the Z_{thjc} curve to plateau to the R_{thjc} value. In Figure 8 this is about 50ms. In other words the heat is spreading in the package and not into the board. If the duration were longer than the time it took to plateau then the MOSFETs' mounting has to be taken into consideration. Since the Hot Swap event is usually less than the plateau time then the thermal RC thermal network provided in the Spice model can be used to determine the junction temperature rise in the MOSFET for the Hot Swap event.

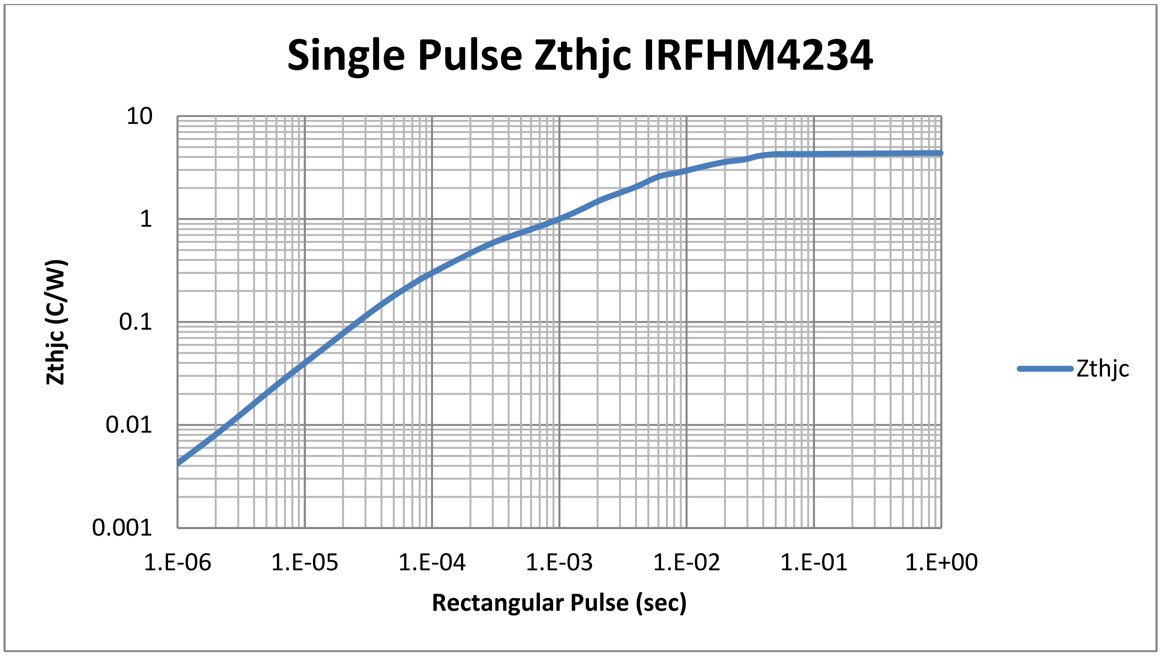

Figure 8 - IRFHM4234 Single Pulse Thermal Impedance Curve

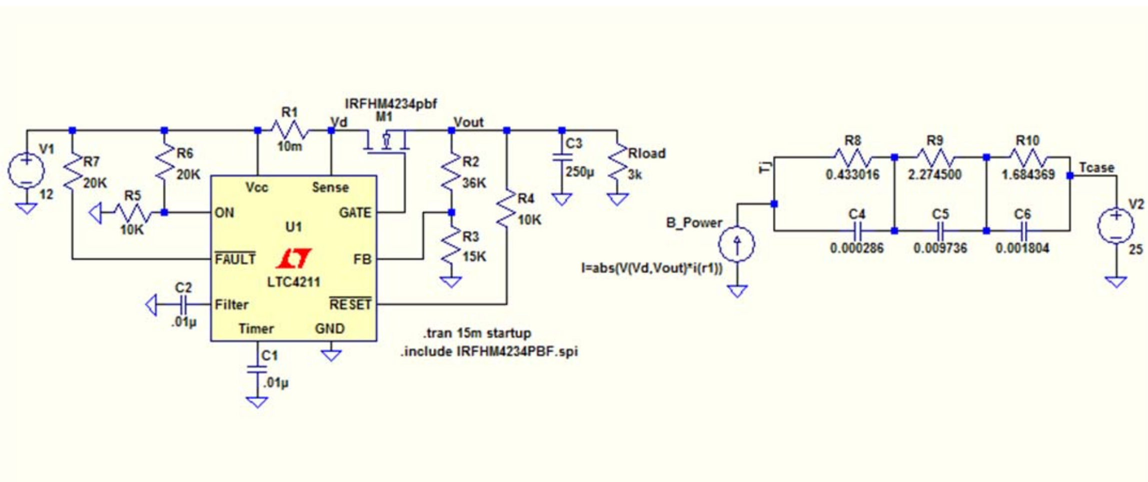

Figure 9 - Hot Swap Simulation Schematic

Figure 9 shows a schematic of a Hot Swap controller, an IRFHM4234 3x3mm PQFN Trench MOSFET and a Foster thermal network which was included in the online spice model file. In this schematic B_Power is a controlled current source that represents the power dissipation in the MOSFET. This controlled source drives the RC network which yields the junction temperature given a fixed case temperature. In this case the case temperature is assumed to be 25C. Temperature is represented as voltage in the simulation.

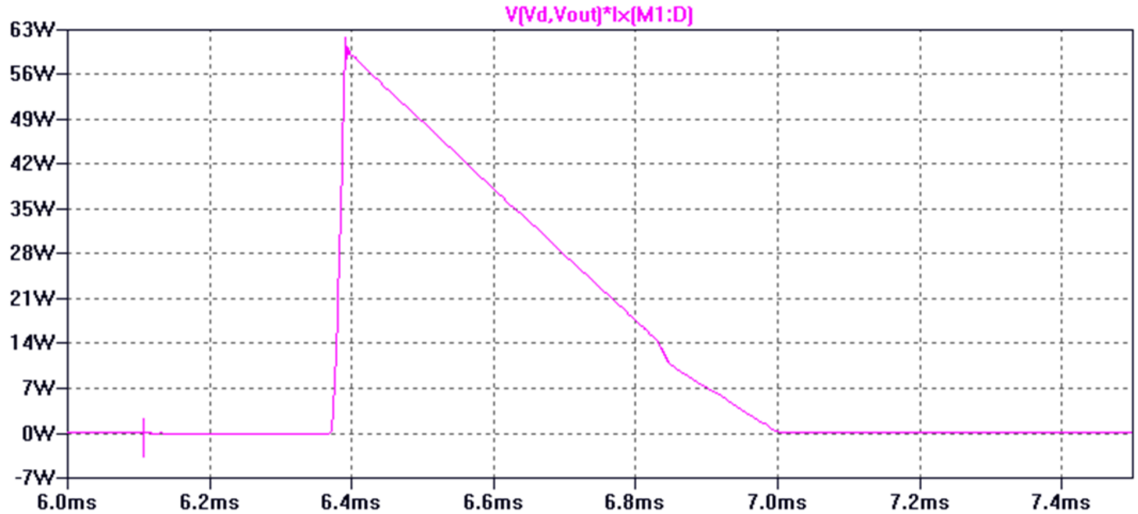

Figure 10 – MOSFET Power Pulse for the Hot Swap Event

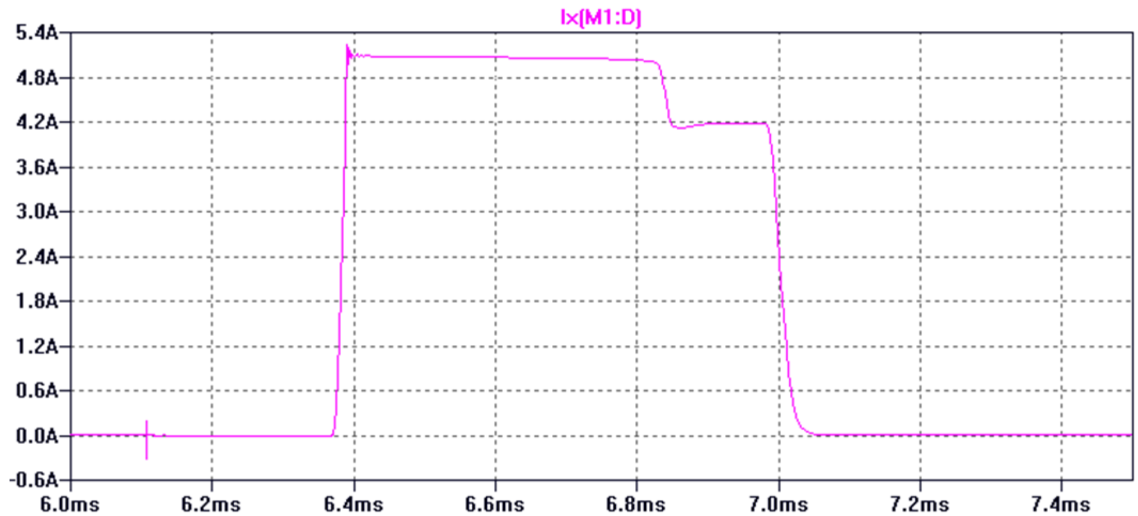

Figure 11 - MOSFET Current

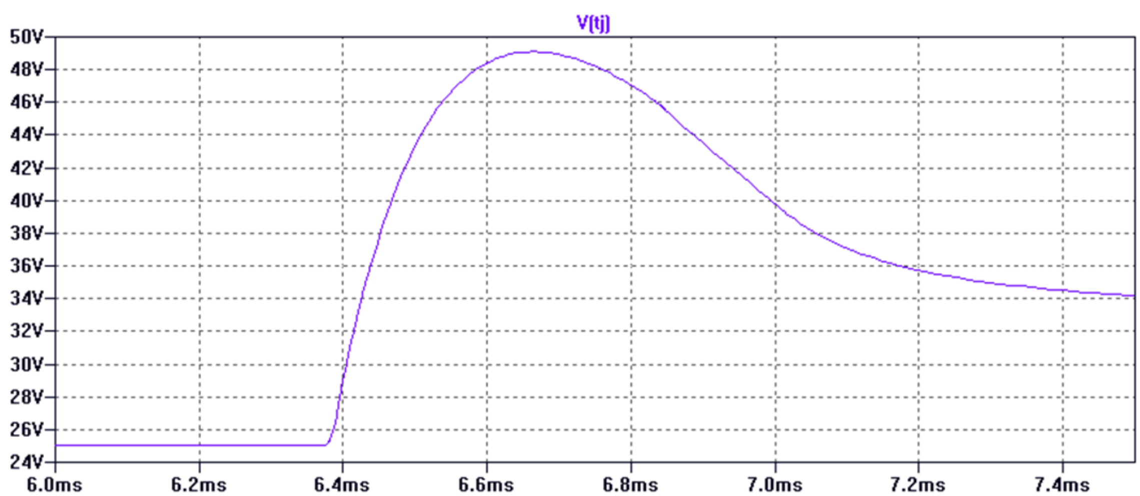

Figure 12 - MOSFET Junction Temperature (Volts=^{o}C)

Figure 10 is the instantaneous power in the MOSFET, Figure 11 is the system current during the Hot Swap event and Figure 12 is the junction temperature. In this case the IRFHM4234's max junction temperature is 49.1C which is well below its Tj_{max} of 150C.

Summary

Hot Swap applications are used in mission critical systems where taking an entire system down to replace a board is not feasible. When replacing a board in a system, the capacitance on the board would induce a large inrush current if it weren't for Hot Swap circuitry. A critical component in the circuitry is the power MOSFET. There are two basic types of MOSFETs on the market. (Planar and Trench) Since the Hot Swap function operates the MOSFET in the linear region for a short period there is concern that Trench MOSFETs are not suited for this application. As it turns out, since the Hot Swap circuit only operates the MOSFET in the linear region for a short period of time and the current is controlled it is only a matter comparing the operating condition of the MOSFET in the Hot Swap application to the SOA using a straight forward method. Thus Trench MOSFETs can be used in the Hot Swap applications. Spice can be used to determine the maximum junction temperature during a Hot Swap event.