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AN11156

Using Power MOSFET Z_{th} Curves

Rev. 1 — 28 September 2012 | Application note

Document information

Info	Content
Keywords	Power MOSFET, Z_{th} curves, Junction temperature, Single shot, Rectangular pulse, Composite waveform, Pulse burst, $Z_{th(j\text{-}mb)}$, Superimposition, Thermal impedance
Abstract	Most applications which include power semiconductors usually involve some form of pulse mode operation. This paper gives several worked examples showing how junction temperatures can be simply calculated using the device Z_{th} curves. Examples are given for a variety of waveforms.

Revision history

Rev	Date	Description
1.0	20120928	initial version

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1. Introduction

Most applications which include power semiconductors usually involve some form of pulse mode operation. This paper gives several worked examples showing how junction temperatures can be simply calculated using the device Z_{th} curves. Examples are given for a variety of waveforms:

- Single shot rectangular pulse
- Composite waveforms
- A pulse burst
- Non-rectangular pulses

Throughout this document we will use the SOT404 BUK961R6-40E device as an example.

2. Calculating junction temperatures

From the point of view of reliability it is most important to know what the peak junction temperature will be when the power waveform is applied. Peak junction temperature will usually occur at the end of an applied pulse and its calculation will involve transient thermal impedance. The temperature difference caused by the dissipated power is $\Delta T_{(j\text{-}mb)}$.

2.1 Single shot rectangular pulse

Referring to Figure 1 it can be see that for a single shot pulse, the time period between pulses is infinite, i.e. the duty cycle $\delta = 0$. In this example 1000 W is dissipated for a period of 20 μs. To calculate the peak junction temperature we use the following data:

$t = 20 \times 10^{-6}$ s

$P = 1000$ W

$\delta = 0$

$Z_{th(j\text{-}mb)} = 0.011$ K/W (value taken from the ‘single shot’ ($\delta = 0$) curve shown in Figure 2)

Therefore:

$$\Delta T_{(j-mb)} = P \times Z_{th(j-mb)} = 1000 \times 0.011 = 11°C$$

This result shows that the peak junction temperature will be 11°C above the initial mounting base temperature

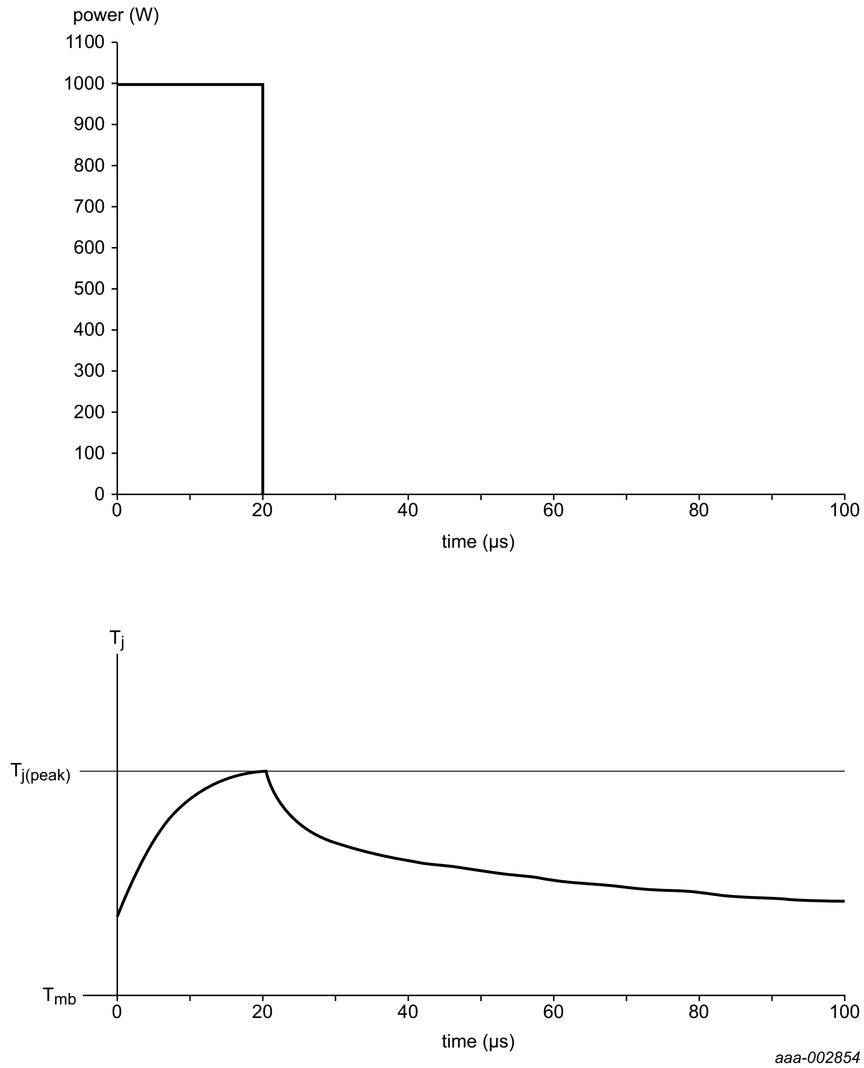
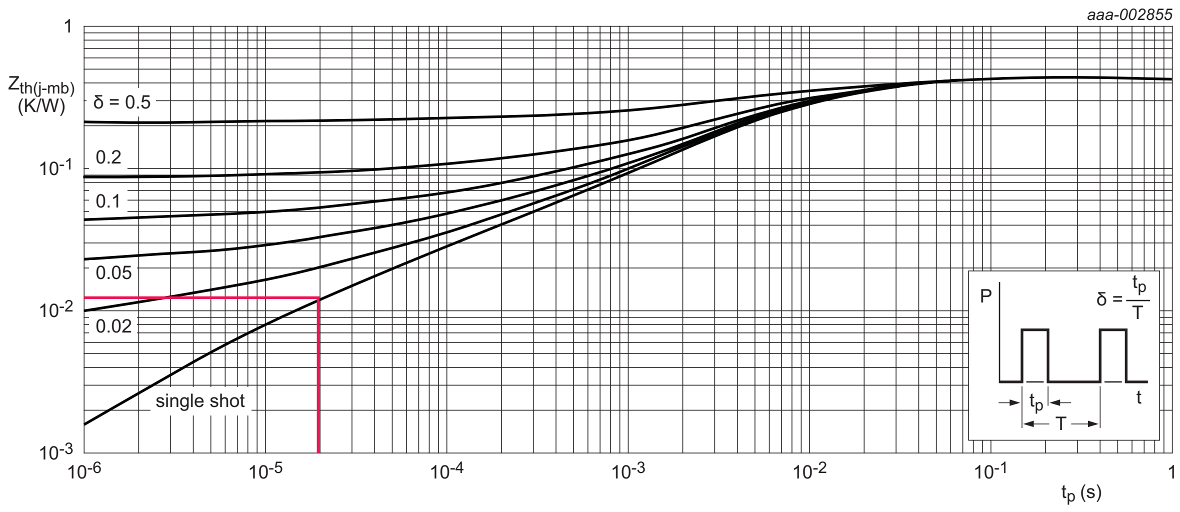


Fig 1. Single shot rectangular pulse



Transient thermal impedance from junction to mounting base as a function of pulse duration.

Fig 2. Transient thermal impedance curve for the BUK961R6-40E

2.2 Composite waveforms

In practice, a power MOSFET frequently has to handle composite waveforms, rather than the simple rectangular pulse shown so far. This type of signal can be simulated by superimposing several rectangular pulses which have both positive and negative amplitudes.

By way of an example, consider the composite waveform shown in Figure 3. The waveform consists of three rectangular pulses, P1 (400 W for 10 μs), P2 (200 W for 130 μs) and P3 (1000 W for 20 μs). The peak junction temperature may be calculated at any point in the cycle, although in this example we will consider only the temperature at endpoint time t(x). To be able to add the various effects of the pulses at this time, all the pulses, both positive and negative, must end at endpoint time t(x). Positive pulses increase the junction temperature, while negative pulses decrease it.

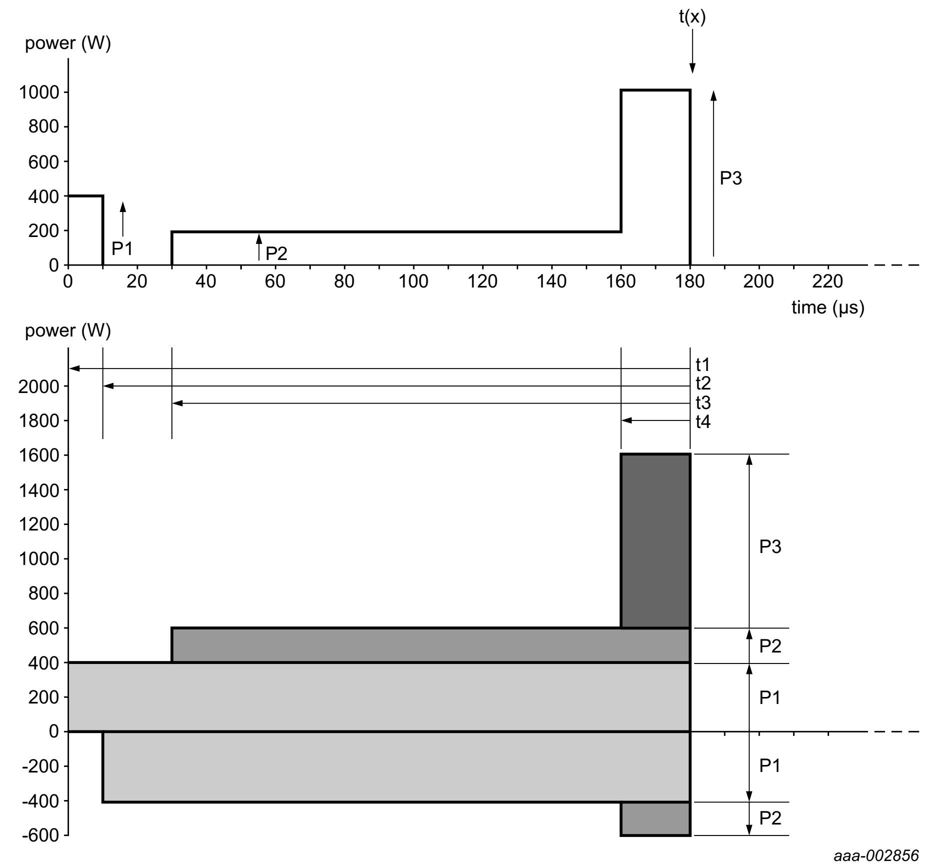


Fig 3. Composite waveform

2.2.1 Calculation of T_j at time endpoint time t(x)

To calculate the junction temperature at endpoint time t(x) we use the following equation:

$$\Delta T_{j-mb} = (P1 \times Z_{th(j-mb)t1}) + (P2 \times Z_{th(j-mb)t3}) + (P3 \times Z_{t(h(j-mb)t4)}) \\ -(P1 \times Z_{th(j-mb)t2}) - (P2 \times Z_{th(j-mb)t4}) \quad (1)$$

The values for P1, P2 and P3 are known:

P1 = 400 W

P2 = 200 W

P3 = 1000 W

The thermal impedance values are taken from Figure 2. Table 1 summarizes the $Z_{th(j-mb)}$ for this example.

Table 1. Z_{th} values summarized

t(x)	time (µs)	Z_{th} (K/W)
t1	180	0.040
t2	170	0.038
t3	150	0.034
t4	20	0.011

Substituting these values into Equation 1 for $T_{(j\text{-}mb)}$ gives:

$$\Delta T_{(j-mb)} = (400 \times 0.04) + (200 \times 0.038) + (1000 \times 0.011) - (400 \times 0.038) - (200 \times 0.011) = 17.2°C$$

Assuming T_{mb} = 75 °C:

$$T_j = T_{mb} + \Delta T_{(j-mb)} = 75 + 17.2 = 92.2°C$$

Hence, the peak value of T_j is 92.2 °C at t(x).

This technique could be extended to any waveform capable of being broken up into constituent rectangular parts.

2.3 Burst pulses

Power devices are frequently subjected to a burst of pulses. This type of signal can be treated as a composite waveform and as in the previous example simulated by superimposing several rectangular pulses which have a common period, but both positive and negative amplitudes.

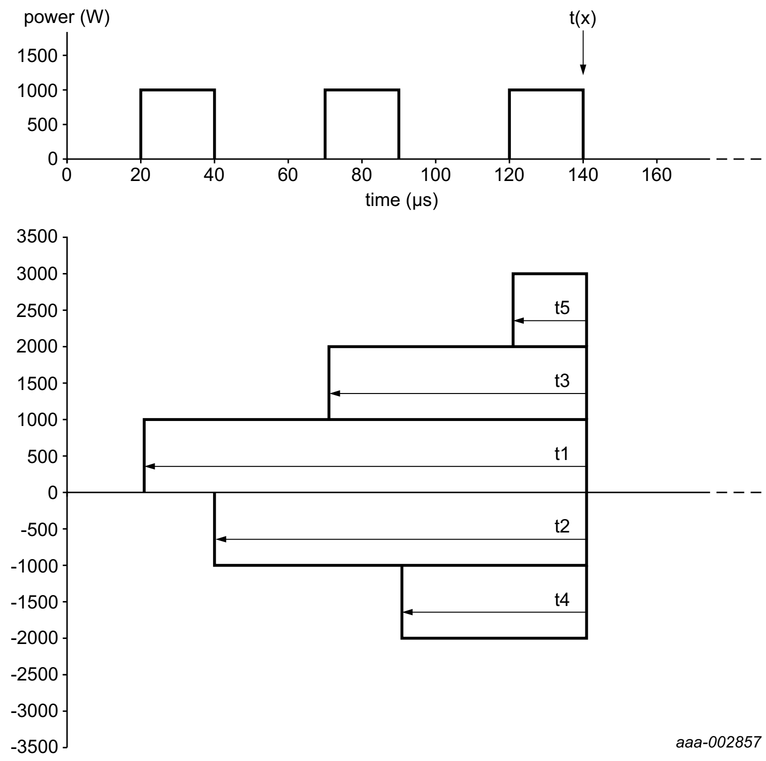


Fig 4. Burst mode waveform

Consider the waveform shown in Figure 4. The burst consists of three rectangular pulses of 1000 W power and 20 µs duration, separated by 30 µs. The peak junction temperature will occur at time t = t(x) = 140 µs. To be able to add the various effects of the pulses at this time, all the pulses, both positive and negative, must end at time t(x). Positive pulses increase the junction temperature, while negative pulses decrease it.

$$\Delta T_{t-mb} = (P \times Z_{th(j-mb)t1}) + (P \times Z_{th(j-mb)t3}) + (P \times Z_{th(j-mb)t5}) - (P \times Z_{th(j-mb)t2}) - (P \times Z_{th(j-mb)t4}) \quad (2)$$

Where $Z_{th(j\text{-}mb)}(t)$ is the transient thermal impedance for pulse time t

The Z_{th} values are taken from Figure 2. Table 2 summarizes the $Z_{th(j\text{-}mb)}$ for this example.

Table 2. Z_{th} values summarized

t(x)	time (μs)	Z_{th} (K/W)
t1	120	0.032
t2	100	0.028
t3	70	0.022
t4	50	0.020
t5	20	0.011

Substituting these values into Equation 2 for $T_{th(j\text{-}mb)}$ gives:

$$\Delta T_{(j-mb)} = (1000 \times 0.032) + (1000 \times 0.022) + (1000 \times 0.011) - (1000 \times 0.028) - (1000 \times 0.02) = 17°C$$

$$T_{j(peak)} = 75 + 17 = 92°C$$

Hence, the peak value of T_j is 92 °C at t(x).

2.4 Non-rectangular pulses

So far, the worked examples have only covered rectangular waveforms, or waveforms which could easily be broken down into rectangles. However, triangular, trapezoidal and sinusoidal waveforms are also common. In order to make thermal calculations for non-rectangular waveforms, the waveform is approximated by a series of rectangles. Each rectangle represents part of the waveform. The equivalent rectangle must be equal in area to the section of the waveform it represents (i.e. the same energy) and also be of the same peak power. With reference to Figure 5, a triangular waveform has been approximated to one rectangle in the first example, and two rectangles in the second. Obviously, increasing the number of sections the waveform is split into will improve the accuracy of the thermal calculations.

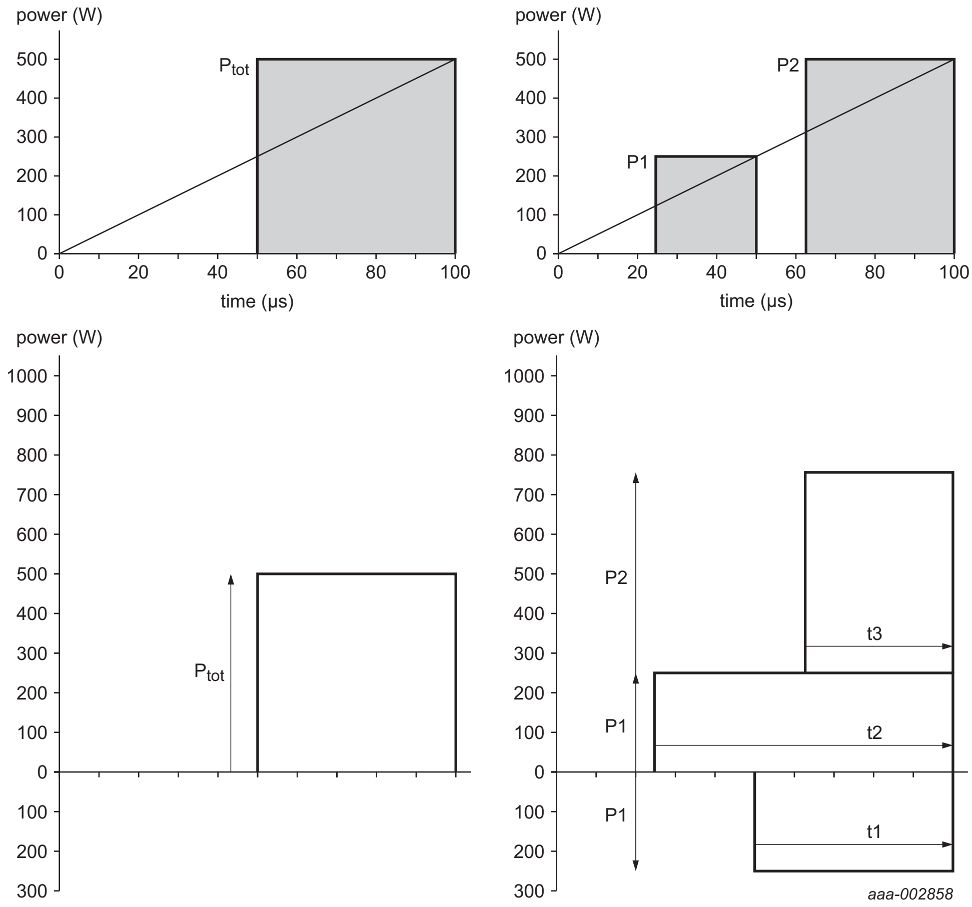


Fig 5. Non-rectangular waveform

In the first example, there is only one rectangular pulse of duration 50 µs, dissipating P_{tot} = 500 W. Therefore:

$$\Delta T_{(j-mb)} = P_{tot} \times Z_{th(j-mb)} = 500 \times 0.02 = 10°C$$

$$T_{j(peak)} = 75 + 10 = 85°C$$

When the waveform is split into two rectangular pulses:

$$\Delta T_{(j-mb)} = (P2 \times Z_{th(j-mb)t3}) + (P1 \times Z_{th(j-mb)t2}) - (P1 \times Z_{th(j-mb)t1}) \quad (3)$$

In Equation 3, the values for P1 and P2 are known:

P1 = 250 W

P2 = 500 W

The Z_{th} values are taken from Figure 2. Table 3 summarizes the $Z_{th(j-mb)}$ for this example.

Table 3. Z_{th} values summarized

t(x)	time (μs)	Z_{th} (K/W)
t1	75	0.023
t2	50	0.020
t3	37.5	0.018

Substituting these values into Equation 3 for $T_{(j\text{-}mb)}$ gives:

$$\Delta T_{(j-mb)} = (500 \times 0.018) + (250 \times 0.020) - (250 \times 0.023) = 8.3°C$$

$T_{j(peak)}$ = 75 + 8.3 = 83.3 °C

Note the difference in calculated peak temperature when the two different methods of approximation are used.

3. Conclusion

A method has been presented to allow the calculation of peak junction temperatures for a variety of pulse types. Several worked examples have shown calculations for various common waveforms. The method for non-rectangular pulses can be applied to any wave shape, allowing temperature calculations for waveforms such as exponential and sinusoidal power pulses. For pulses such as these, care must be taken to ensure that the calculation gives the peak junction temperature, as it may not occur at the end of the pulse. In this instance several calculations must be performed with different endpoints to find the maximum junction temperature.

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