Avalanche Energy (E_{AS}) caluculation of Power MOSFET

Outline

When a voltage exceeds breakdown voltage of a MOSFET, breakdown phenomena occurs and current flows. It's called "Avalanche break down", the current flowing at that time is called avalanche current, and the energy applied to the MOSFET is called avalanche energy.

This column is showing how to calculate Avalanche energy related on avalanche current by using datasheet value or graphs. The energy stored in circuit inductance is transformed to rise device temperature under break down condition. Single pulse avalanche current "I_{AS}" is the peak current allowed during avalanche breakdown. Single pulse avalanche energy "E_{AS}" is the maximum energy permissible at single pulse "I_{AS}". So avalanche energy is calculated value related on avalanche current.

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1. What about guaranteed value on datasheet ?

Figure 1.1 shows the example of maximum ratings related avalanche phenomena on a datasheet. It's defined maximum ratings of channel temperature, avalanche energy and avalanche current in single-pulse avalanche mode that important parameter to think avalanche mode.

Characteristics		Symbol	Rating	Unit
Single-pulse avalanche energy	(Note 4)	E_{AS}	14	mJ
Single-pulse avalanche current	(Note 4)	I_{AS}	92	A
Channel temperature		T_{ch}	175	°C

Note 4: V_{DD} = 32 V, T_{ch} = 25 °C (initial), L = 1.3 μH, I_{AS} = 92 A

Figure 1.1 Maximum rating / avalanche measurement condition of TPH3R704PL

1.1. Single pulse avalanche current I_{AS}

Single pulse avalanche current "I_{AS}" means the maximum current capacity under break down condition. If avalanche current exceeds it, the device can be broken regardless of channel temperature or energy.

1.2. Single pulse avalanche energy E_{AS}

The avalanche energy "E_{AS}" that shown on datasheet is the maximum guaranteed value calculated from the defined "I_{AS}" and channel temperature. Therefore, the avalanche energy also changes according to the avalanche current.

Avalanche energy is calculated as following:

$$E_{AS} = \frac{1}{2} \cdot L \cdot I_{AS}^2 \cdot \frac{BV_{DSS}}{BV_{DSS} - V_{DD}} \quad \text{-- Formula 1-1}$$

BV_{DSS} : Break down voltage

I_{AS} : Single pulse avalanche current

It's one of avalanche energy defined in datasheet condition, different from actual usage condition. In this formula, BV_{DSS} can be measured with scope or estimated from V_{DSS}, however, the inductance "L" of the circuit (although the datasheet example (Figure 1.1) shows 1.3μH) is not easy to measure. The unknown parameter from the formula should be removed to understand the relation between I_{AS} and E_{AS} easily.

2. How to calculate avalanche energy related on current ?

The channel temperature is calculated as following:

$$T_{ch(Avalanche)} = 0.473 \cdot BV_{DSS} \cdot I_{AS} \cdot r_{th(ch-a)\_tw} + T_a \quad \text{-- Formula 2-1}$$

0.473 : Effective factor of wattage

$T_{ch(Avalanche)}$: Peak channel temperature between avalanche mode period

$r_{th(ch-a)\_tw}$: Transients thermal resistance of Avalanche period

t_w : Avalanche period

T_a : Ambient temperature (Initial temperature)

During avalanche period, channel temperature should be kept lower than maximum rating. Therefore, the relationship between the maximum channel temperature and the avalanche current should be shown at first. Assuming $T_{ch(Avalanche)} = T_{ch(Max)}$ then formula 2-1 is revised as following:

$$T_{ch(Max)} = 0.473 \cdot BV_{DSS} \cdot I_{AS} \cdot r_{th(ch-a)\_tw} + T_a \quad \text{-- Formula 2-2}$$

Thermal resistance of Avalanche period "$r_{th(ch-a)\_tw}$" can be shown as formula 2-3 revised from formula 2-2.

$$r_{th(ch-a)\_tw} = \frac{T_{ch(Max)} - T_a}{0.473 \cdot BV_{DSS} \cdot I_{AS}} \quad \text{-- Formula 2-3}$$

Next step is to think avalanche period length "t_w". In normal case, the avalanche period length "t_w" is calculated from formula like as V=L dI/dt_w using parameter "L". This parameter is unknown, so to erase "L", using another parameter thermal resistance that related on time.

Thermal resistance of avalanche period "$r_{th(ch-a)\_tw}$" is one of parameters that related period length. The avalanche period t_w is shorter than 1ms in most cases. In such cases, the heat generation is converged inside MOSFET die and the thermal resistance can be approximated as following:

$$r_{th(ch-a)\_tw} \approx r_{th(ch-a)\_1ms} \sqrt{\frac{t_w}{t_{1ms}(=0.001s)}}$$

$$t_w = 0.001 \cdot \left(\frac{r_{th(ch-a)\_tw}}{r_{th(ch-a)\_1ms}}\right)^2 \quad \text{-- Formula 2-4}$$

Substituting formula 2-3 in formula 2-4 as following:

$$t_w = 0.001 \cdot \left(\frac{\frac{T_{ch(Max)} - T_a}{0.473 \cdot BV_{DSS} \cdot I_{AS}}}{r_{th(ch-a)\_1ms}}\right)^2 = 0.00447 \cdot \left(\frac{T_{ch(Max)} - T_a}{BV_{DSS} \cdot I_{AS} \cdot r_{th(ch-a)\_1ms}}\right)^2 \quad \text{-- Formula 2-5}$$

From this formula, avalanche period t_w can be calculated with measured value and datasheet parameter.

Next step is to replace the unknown parameter “L” with measured value and datasheet parameter. Figure 2.1 shows avalanche test circuit. From this circuit, avalanche waveform is shaped like figure 2.2 and avalanche period “t_w” can be calculated from formula 2-6 also.

$$t_w = L\frac{I_{AS}}{BV_{DSS}-V_{DD}} \quad \text{-- Formula 2-6}$$

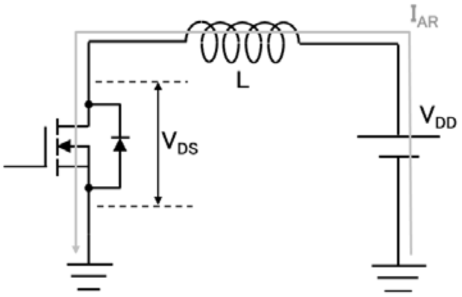

Figure 2.1 Avalanche test circuit

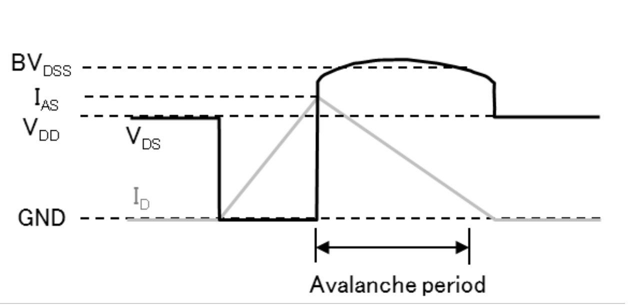

Figure 2.2 Avalanche waveform

From formula 2-6, the unknown parameter “L” can be shown as following:

$$L = t_w\frac{BV_{DSS}-V_{DD}}{I_{AS}} \quad \text{-- Formula 2-7}$$

To remove parameter “L”, substituting formula 2-7 in formula 1-1 as following:

$$E_{AS} = \frac{1}{2}\cdot t_w\cdot\frac{BV_{DSS}-V_{DD}}{I_{AS}}\cdot I_{AS}^2\cdot\frac{BV_{DSS}}{BV_{DSS}-V_{DD}}$$
$$= \frac{1}{2}\cdot t_w\cdot BV_{DSS}\cdot I_{AS} \quad \text{-- Formula 2-8}$$

Finally, “t_w” can be remove from substituting formula 2-5 in formula 2-8 as following:

$$E_{AS} = \frac{1}{2}\cdot 0.00447\cdot\left(\frac{T_{ch(Max)}-T_a}{BV_{DSS}\cdot I_{AS}\cdot r_{th(ch-a)\_1ms}}\right)^2\cdot BV_{DSS}\cdot I_{AS}$$
$$= \frac{1}{I_{AS}}\cdot\underbrace{\frac{0.00224}{BV_{DSS}}\left(\frac{T_{ch(Max)}-T_a}{r_{th(ch-a)\_1ms}}\right)^2}_{\text{Fixed value}} \quad \text{-- Formula 2-9}$$

There is inverse promotion between I_{AS} and E_{AS} in the short length period (<1ms) condition. If the single pulse avalanche current “I_{AS}“ is under maximum rating value, larger avalanche energy “E_{AS}“ is allowed under the condition that channel temperature ”T_{ch}” is less than maximum rating.

The avalanche energy “E_{AS}“ value under avalanche current “I_{AS}“ condition is shown on datasheet of each product. So the fixed value in formula 2-9 can be calculated easily from these 2 values.

3. Calculation example

TPH3R704PL(V_{DSS} = 40V) is selected for calculating example. Picking up each values following formula 2-9 from datasheet. Only thermal resistance of 1ms "$r_{th(ch-a)\_1ms}$" should be read by graph.

BV_{DSS} : 52V *BV_{DSS} of low voltage MOSFET (loser than 250V) is estimated by 1.3 x V_{DSS}.
$T_{ch(Max)}$: 175 ℃
T_a : 25 ℃ (Initial temperature)
$r_{th(ch-a)\_1ms}$: 0.85 ℃/W

From these values and Formula 2-9, avalanche energy "E_{AS}" of TPH3R704PL can be shown as following:

$$E_{AS} = \frac{1}{I_{AS}} \cdot \frac{0.00224}{52} \left(\frac{175-25}{0.85}\right)^2 = \frac{1.34}{I_{AS}} \quad *$$

*The datasheet value of E_{AS} and I_{AS} are calculated and rounded down. Therefore, datasheet value will be smaller than calculated value from formula 2-9.

This calculation can be used only for the pulse of 1ms and less than 1ms. The next step is to calculate the avalanche current at t_w=1ms. The avalanche current "I_{AS}" is calculated from changing formula 2-3 as following:

$$I_{AS} = \frac{T_{ch(Max)} - T_a}{0.473 \cdot BV_{DSS} \cdot r_{th(ch-a)\_tw(=1ms)}}$$

$$= \frac{175-25}{0.473 \cdot 52 \cdot 0.85} = 7.2A$$

Figure 3-1 shows relation between single pulse avalanche energy and single pulse avalanche current of TPH3R704PL. This device can be applied energy same as and smaller than this line.

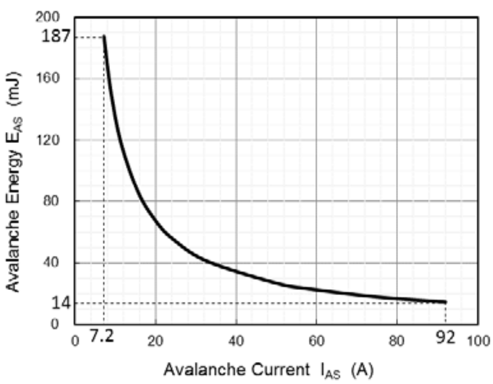

Figure 3.1 Avalanche energy – current characteristics

"E_{AS}" has relation with "I_{AS}". Please calculate "E_{AS}" from the current that goes to avalanche mode on you application when design for safety.

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