DT0018
Design tip

Use ST Lab Math software to design an effective over-temperature protection circuit for SLLIMM™ IPM

By Giovanni Tomasello

Main Components	
STGIPN3H60T-H	SLLIMM(TM)- nano small low-loss intelligent molded module IPM, 3 A - 600 V 3-phase IGBT inverter bridge
STGIPS10K60A	SLLIMM(TM) small low-loss intelligent molded module) IPM, 3-phase inverter, 600 V short-circuit rugged IGBT
STGIPS10K60T,10K60T,14K60T,14K60T-H	
STGIPL14K60,20K60	
STGIPS30C60T-H,STGIPL30C60-H	
STGIPS35K60L1	SLLIMM(TM) (small low-loss intelligent molded module) IPM, single phase - 35 A, 600 V short-circuit rugged IGBT
STGIPS40W60L1	SLLIMM(TM) (small low-loss intelligent molded module) IPM, single phase - 40 A, 600 V ultra-fast IGBT

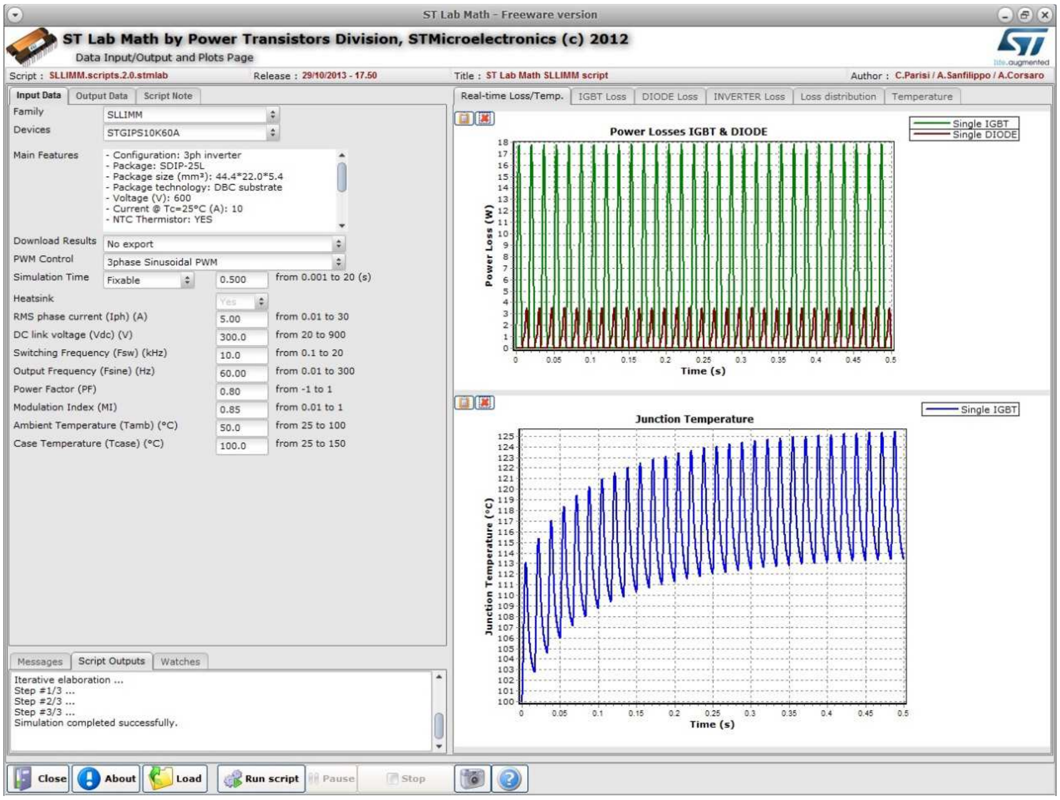
Purpose and benefits

One of the most critical parameters in power electronic devices is the die temperature. Although a direct measurement of the die temperature with a thermal sensor mounted on the chip or an integrated temperature sensor in the device would give the best result, it is not always practical. A viable alternative to estimate the chip's temperature is the calculation of the junction temperature using a thermal model that estimates the power transistors' dissipation and temperature rise and adding that simulated result to the measured case temperature. Designers who use ST SLLIMM™ IPM in motor control applications can use a power losses evaluation tool, ST Lab Math developed by ST, and the module's internal thermistor, also called NTC, to estimate worst case junction temperature under steady state operating conditions and set the over temperature protection threshold based on the simulation results.

Description

ST Lab Math for SLLIMM™ is a powerful simulation tool, able to simulate the conduction and switching power losses of the power devices inside the IPM and estimate the junction temperature swing for the internal IGBTs and free-wheeling diodes. The tool is set up specifically for motor control applications based on 3-phase inverter sinusoidal modulation, under the assumption of sinusoidal output currents at inductive loads.

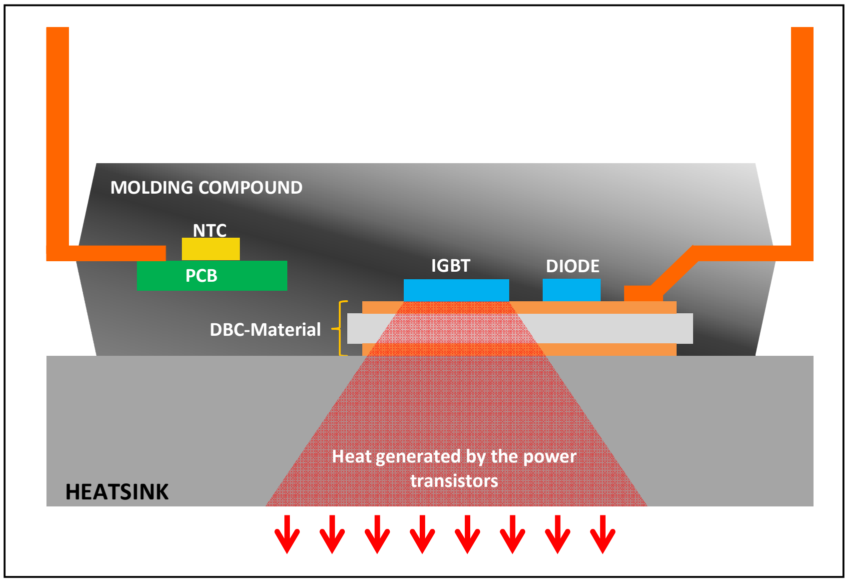
Figure 1. ST Lab Math user interface



A very intuitive user interface, shown in figure 1, will guide the designer through the simulation process. The interface is clearly designed to separate the input data from the output one. Designers can choose between several SLLIMM part numbers (new ones are added regularly), can simulate several working conditions and can analyze the power losses and temperature results, with the possibility to create a simulation report from the tool itself. The first step, to design proper over-temperature protection circuitry, is to simulate the nominal working conditions of the final application. Parameters such as switching frequency, output current, case temperature and ambient temperature are needed as inputs to the simulation tool. The tool will give an estimation of the peak junction temperature, average power losses and an approximate heat-sink thermal resistance value. Based on the simulation results, designers can fix the maximum acceptable case temperature (to guarantee that the IGBT will always work inside its SOA). Please consider that due to the simplicity of the simulation model, additional safety margins must be adopted and that STMicroelectronics will not be liable in any manner for possible drawbacks derived by the inadequate use of this tool.

Knowing what the maximum case temperature (T_{CASE_MAX}) is that can be allowed, designers can use the internal NTC resistance value to properly set-up over-temperature protection. It is very important, at this point, to explain how the IGBTs, the NTC and the case temperature are thermally connected, as shown in figure 2.

Figure 2. SLLIMM™ diagram showing the flow of the thermal energy



Almost all the heat generated in the chips flows directly to the heat-sink, as represented by the red area in picture 2, from where it is dissipated to the environment. As a consequence, there is basically no thermal energy flowing directly from the power silicon to the NTC. Therefore, the thermistor is only suitable to represent the case temperature in steady-state points of operation. Due to the thermal impedance of the module and its own thermal time constant, the NTC thermistor is not able to detect rapid junction temperature variations. Transient phenomena, like heat generated in short circuit condition, cannot be monitored or detected.

The resistance versus temperature characteristic of an NTC is non-linear and is described by the following expression:

$$R(T) = R_{25} * e^{B(\frac{1}{T} - \frac{1}{298})}$$

Where T is the temperature in Kelvin, B and R_{25}, respectively, are a constant value in the SLLIMM™ working range and the resistance value at 25 °C. Please refer to the relevant datasheets to find the correct parameters.

Knowing T_{CASE_MAX} (coming from the simulation tool ST Lab Math) and the resistance vs. temperature characteristic of the NTC, it will be easy to calculate R (T_{CASE_MAX}):

$$R_{NTC}(T_{CASE-MAX}) = R_{25} * e^{B(\frac{1}{T_{CASE-MAX}} - \frac{1}{298})}$$

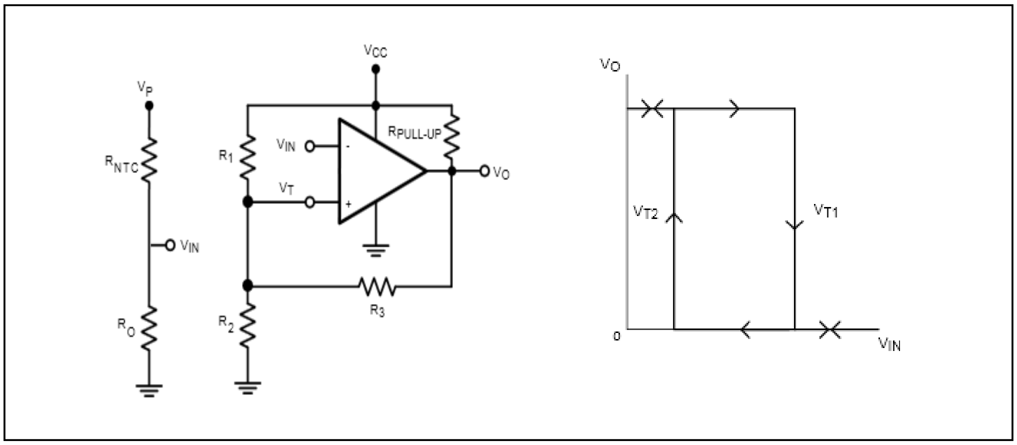
Please remember that T is expressed in Kelvin.

The maximum power dissipation in the thermistor should not exceed 50 mW over the full operating range in order to guarantee a safe working condition and avoid its internal power dissipation affecting the temperature measurement through self-heating. Therefore, it must be always verified that:

$$R_{NTC} * I^2{}_{NTC} \leq 50mW$$

At this point, we can use a simple circuit, like a Schmitt trigger represented in figure 3, to realize an effective over-temperature protection. Please refer to the following equations:

Figure 3. Simple Over-Temperature protection based on a Schmitt's trigger



$$V_{IN}(T_{CASE-MAX}) = \frac{R_0}{R_0 + R_{NTC}(T_{CASE-MAX})} * V_P$$

$$V_{T1} = (\frac{V_{CC} * R_2}{\left(\frac{R_1 * R_3}{R_1 + R_3}\right) + R_2})$$

$$V_{T2} = V_{CC} * (\frac{R_2 * R_3}{R_2 + R_3})/(R_1 + \left(\frac{R_2 * R_3}{R_2 + R_3}\right))$$

The comparator output can be used to shut-down the SLLIMM™ module (using a microcontroller or the /SD pin of the SLLIMM™ itself, where available) as soon as a critical temperature is reached. The designer can also fine-tune the hysteresis of the comparator, which is the region defined by V_{T1} and V_{T2} in figure 3, to inhibit the IPM until a safer temperature is detected.

Support material

Related design support material
ST Lab Math for SLLIMM™ Motor control ((please contact your local sale representative to get a copy of the software): • Simulation tool that is able to analyze the conduction and switching power losses, the junction temperature's swing for IGBTs and free-wheeling diodes of the SLLIMM product family.
Documentation
Datasheet: • **STGIPN3H60T-H** SLLIMM(TM)-nano small low-loss intelligent molded module IPM, 3 A - 600 V 3-phase IGBT inverter bridge • **[STGIPS10K60A,STGIPS10K60T,10K60T,14K60T,14K60T-H,STGIPL14K60,20K60, STGIPS30C60T-H,STGIPL30C60-H]** SLLIMM(TM) small low-loss intelligent molded module) IPM, 3-phase inverter, 600 V short-circuit rugged IGBT • **STGIPS35K60L1** SLLIMM(TM) (small low-loss intelligent molded module) IPM, single phase - 35 A, 600 V short-circuit rugged IGBT • **STGIPS40W60L1** SLLIMM(TM) (small low-loss intelligent molded module) IPM, single phase - 40 A, 600 V ultra-fast IGBT
Application note: • **AN3338:** SLLIMM™ small low-loss intelligent molded module
User manual: • **ST Lab Math** for SLLIMM™ Motor control user manual

Revision history

Date	Version	Changes
16-May-2014	1	Initial release

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