Keysight Technologies
Power Semiconductor Device Temperature Characterization with Keysight U5855A and B1506A

Technical Overview

Keysight U5855A TrueIR Thermal Imager

Keysight B1506A Power Device Analyzer
Introduction

Keysight Technologies, Inc. U5855A TrueIR Thermal Imager is an ergonomically designed, easy-to-use handheld infrared thermal imager. As well as being inexpensive, the U5855A delivers 320 x 240 pixels high resolution through fine resolution capability. The U5855A is capable of focusing on objects as close as 10 cm away, demonstrating outstanding performance in thermal characterization of small components as well as predictive maintenance on electrical systems.

Keysight B1506A Power Device Analyzer is superior in evaluating parameters of all power devices including insulated gate bipolar transistors (IGBTs). The B1506A has a wide range of capabilities that help it identify substandard devices under real operating conditions, including a wide voltage and current operating range (3 kV and 1500 A), a wide thermal test capability (-50 to +250 °C), advanced Source Monitor Unit (SMU) technology and sub-nA level current measurements capability.

The power semiconductor market has been experiencing rapid growth in recent years in the fields of power electric equipment, industrial equipment, automobiles and home appliances. Impervious to high voltage, high current and high power consumption, power devices are required to be highly reliable and to operate under harsh environmental conditions. The B1506A allows easy characterization of temperature dependency which can cause a device failure.

This application note describes a measurement method using the U5855A to evaluate temperature characterization of commercially available discrete power MOSFETs and IGBT modules, in tandem with electrical characterization with the B1506A.
Temperature Characterization of Discrete Power MOSFETs

B1506A’s unique plug-in style device test fixture socket adapter is used to determine electrical characteristics of a 3-pin inline discrete power MOSFET, as shown in Figure 1, while the U5855A is used for non-contact temperature measurement of the device surface.

A relationship between power applied to the device with no heatsink and temperature changes caused by self-heating of the device is measured. The measurement procedure starts with applying a set voltage, current, and timing waveforms to the B1506A to lower power Pd that is consumed in the device (Pd = 0.5 W), causing the surface temperature of the device (case temperature) to rise and become stabilized after a while. Then, the temperature, Tc, is measured with the U5855A.

The next step is to stop voltage/current force and application of timing waveforms to the device. Make sure that the device is lowered to the ambient temperature, and reapply them to the device to increase power Pd to 0.75 W. The surface temperature of the device, Tc, is measured once it becomes stabilized.

The relationship between applied power Pd and device surface temperature Tc was measured through repeated procedures. The following shows the observed relationship in the form of “infrared thermal image” and “temperature data.”

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<td>25.5</td>
<td>37.5</td>
<td>33.24</td>
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<td>(208,20)</td>
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<td>54.81</td>
<td>(101,20)</td>
<td>(156,60)</td>
<td>(205,21)</td>
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Figure 3 shows $T_c$ which denotes the maximum surface temperature of the device with respect to applied power $P_d$. Data was obtained when the ambient temperature $T_a$ was 22 °C in the measurement environment.

The data sheet for the device contains an absolute rating of the junction temperature, $T_{j(max)}$, and the device was rated at 150 °C. Thermal resistance between the junction and device surface, $R_{th(j-c)}$, is also in the data sheet, and the device had 0.12 °C/W. The data sheet, however, contains no data on thermal resistance between the junction and ambient temperature, $R_{th(j-a)}$. Thermal resistance between the device surface and ambient temperature, $R_{th(c-a)}$, can be derived from a measurement result of "the relationship between device surface temperature $T_c$ and applied power $P_d$" shown above.
Temperatures measured at 0.5 to 2.5 W are plotted linearly on a graph (Figure 3), giving the gradient of a linear regression line and y-intercept of the line:

\[ T_c = 20.004 \times P_d + 28.778 \]

The gradient given by this expression denotes “thermal resistance between the device surface and ambient temperature, \( R_{th(c-a)} \):

\[ R_{th(c-a)} = 20.004 \, ^\circ C/W \]

**Summary:**

- Thermal resistance between the junction and ambient temperature, \( R_{th(j-a)} \) [No data on the data sheet]
- Thermal resistance between the junction and device surface, \( R_{th(j-c)} = 0.12 \, ^\circ C/W \)
- Thermal resistance between the device surface and ambient temperature, \( R_{th(c-a)} = 20.004 \, ^\circ C/W \)

At this time, a relationship of \( R_{th(j-a)} = R_{th(j-c)} + R_{th(c-a)} \) holds, allowing \( R_{th(j-a)} = 0.12 + 20.004 = 20.124 \, ^\circ C/W \) to be determined from this measurement result.

Equation 1 provides a relationship among junction temperature \( (T_j) \), thermal resistance between the junction and ambient temperature \( (R_{th(j-a)}) \), applied power \( (P_d) \) and ambient temperature \( (T_a) \):

\[ T_j = R_{th(j-a)} \times P_d + T_a \] (1)

In this measurement, thermal resistance between the junction and ambient temperature \( (R_{th(j-a)}) \) was found with no heatsink in the device, which enables the junction temperature to be derived from applied power and ambient temperature. The device was rated at 150 °C for an absolute maximum rating of the junction temperature \( (T_j(max)) \), determining a relationship between the maximum power applied to the device and ambient temperature, shown in Figure 4.

![Figure 4. Relationship between maximum applied power \( P_d(max) \) and ambient temperature \( T_a \)](image)

A relationship between the junction temperature and maximum applied power was considered based on a relationship between applied power and temperature changes caused by self-heating of the device that was measured with use of the B1506A and U5855A.
Considering temperature changes of the measured device is very critical to electrical characterization of a power semiconductor device. Figure 5 shows the example of electrical characteristics when the junction is at normal and high temperatures.

With no heatsink in the device, the junction temperature fluctuates greatly even with small power. The importance of characterization solutions allowing for temperature fluctuation is discussed above. But characterization solutions sometimes require the application of larger power. Larger power can be applied if a measurement is performed with the B1506A and U5855A while the device is forcefully cooled with the heatsink in the device. This may, however, raise problems such as “characterization solutions require heatsinking” and “characterization solutions are confused with heatsinking design evaluation.”

A relationship between applied power and junction temperature is given by Equation 1. The power applying time and thermal resistance of the device possess “transient thermal resistive characteristic” as shown in Figure 6.
The B1506A enables a device measurement with low transient thermal resistance while shortening the pulse width and adjusting the duty ratio applied to the device. It also allows a measurement while curbing the rise in the junction temperature and characterization solutions through the application of larger power.

**Temperature Characterization of IGBT Module**

B1506A’s test fixture enables simple and safe electrical characterization of large devices such as the IGBT module, as shown in Figure 7. Temperatures in the device often have an uneven distribution, which requires the U5855A for measuring the two-dimensional distribution of the device temperature with non-contact.

The U5855A is capable of thermal imaging objects as close as 10 cm away in 320 x 240 pixel high resolutions, with approximately 2.1 mrad spatial resolution. With temperature measurement range of -20 to 350 °C, the U5855A achieves high thermal sensitivity of up to 0.07 °C. Coupled with its high sensitivity, the U5855A delivers outstanding performance in measuring the temperature distribution of semiconductor components with non-contact.

Figures 8-1 and 8-2 show the thermal and visible images of the terminal and radiating surfaces of the IGBT module which were captured with the U5855A after the device showed a rise in temperature upon electrical characterization with the B1506A. With the single pull of the trigger, the U5855A captures a thermal image and visible image at a time. Capable of fusion (picture-in-picture and blend) display of captured thermal and visible images, it gives an at-a-glance picture of where temperature is measured. Keysight TrueIR Analysis and Reporting Tool (free downloadable software) realizes the analysis of a captured thermal image on the computer. The software also enables users to change color display settings of temperature distribution and automatically create reports on available results as compared with an visible image.

Figures 9-1 to 11-2 provide reports generated on analyzed IGBT module measured data that is retrieved into Keysight TrueIR Analysis and Reporting Tool. The figures suggest that the terminal surface of the IGBT module has an uneven distribution of temperatures in the component, displaying differential temperatures in color mode and the distribution in two-dimensional data. They show that a mostly even temperature distribution is observed on the radiating surface of the IGBT module.
Measurements

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<tr>
<th>Line</th>
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<th>Min</th>
<th>Max</th>
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Figure 9-1. Analysis data on IGBT module terminal surface (Line L1, L2, Box B1)

Figure 10-1. Profile of IGBT module terminal surface (Line L1, L2)

Figure 11-1. Histogram of IGBT module terminal surface (Box B1)
### Measurements

<table>
<thead>
<tr>
<th>Line Name</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
<th>Start coordinates</th>
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Figure 8-2. Thermal image and visible image of IGBT module radiating surface captured with U5855A

Figure 9-2. Analysis data on IGBT module radiating surface (Line L1, L2, Box B1)

Figure 10-2. Profile of IGBT module radiating surface (Line L1, L2)

Figure 11-2. Histogram of IGBT module radiating surface (Box B1)
Conclusion

Power semiconductor devices are required to operate under harsh environmental conditions, from low to high temperatures, and be highly reliable.

Endowed with various features such as wide voltage and current ranges, wide thermal test capability, high resolution measurement capability and simplified interface architecture, Keysight B1506A Power Device Analyzer is a powerful, critical tool for power device characterization.

Coupled with Keysight U5855A True/IR Thermal Imager that delivers outstanding performance in device temperature characterization with non-contact, the B1506A maximizes its ability to perform not only temperature characterization under the user’s operating condition which is not contained in the data sheet and with the device under high stress but thermal design.

Current temperature characterization employs a thermocouple, which is effective but only available for a limited measurement point. It also requires consideration of placement of the thermocouple at the point, the way of placing it, and temperature changes by contact. An infrared radiation spot thermometer is also used for temperature measurement but only permits a single measurement point. Displacement can often occur between measured point and indicated point by laser on the object, leading to poor data reliability.

The U5855A offers non-contact measurement, easy acquisition of two-dimensional data on temperature characteristics, and real-time image processing. True/IR Analysis and Reporting Tool expands capability of analyzing and reporting. Keysight B1506A Power Device Analyzer and Keysight U5855A True/IR Thermal Imager deliver an excellent solution to your temperature characterization and reliability evaluation of power devices.
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