METHOD FOR EVALUATING THERMAL PERFORMANCE OF ALLEGRO CURRENT SENSORS IN APPLICATION

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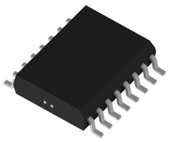
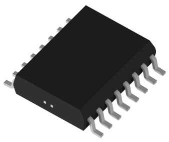
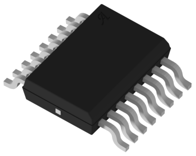
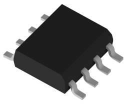
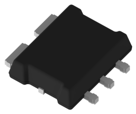
INTRODUCTION

When designing with Allegro integrated conductor current sensors, it is important to characterize thermal performance of the Allegro device once it is incorporated into the application. One key parameter to monitor during thermal characterization is the junction temperature (T_J) of the device. Each datasheet specifies a maximum junction temperature (T_{JMAX}) that should not be exceeded to avoid permanently damaging the circuitry. One typical method in determining the junction temperature of a device is to perform a calculation using the package junction-to-ambient thermal resistance ($R_{\Theta JA}$). However, with Allegro current sensors, the current primary path is the main heat source rather than the package's internal silicon die. Because of this, the calculations of junction temperature using $R_{\Theta JA}$ are no longer accurate and a different method is required. Experimental data is available using an Allegro standard demo board[1], but thermal performance in application can vary from these results due to different PCB layouts and heatsinking properties. If a more accurate thermal characterization is required, this note proposes a method for determining the junction temperature through experimental data using a correlation between the package case temperature (T_C) and the junction temperature, allowing for the case temperature to be measured and used to estimate the junction temperature. Table 1 below shows the five packages that were tested in this application note.

Table 1: Description of Allegro Current Sensor Packages

Package Type	SOICW-16 (LA)	SOICW-16 (MA)	SOICW-16 (MC)	SOIC-8 (LC)	7-pin PSOF (LR)
Appearance					
Dimensions (mm)	10.3 × 10.3 × 2.65	10.3 × 10.3 × 2.65	11.3 × 13 × 3.01	4.9 × 6 × 1.62	6.4 × 6.4 × 1.5
Resistance (mΩ)	0.85	0.85	0.27	1.2	0.2
Work Voltage for Basic Isolation according to UL 60950-1 (edition 2) (V_{DC})	870	1550	1618	420	100

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[1] https://www.allegromicro.com/-/media/allegro/allegromicro/files/application-notes/an296190-current-sensor-thermals.ashx

$R_{\theta JA}$, AND ITS APPLICABILITY TO ALLEGRO CURRENT SENSORS

$R_{\Theta JA}$, or junction-to-ambient thermal resistance, is commonly used when designing electronic systems with integrated circuits and is a measure of how effectively a device can dissipate heat from the surface of the die to the ambient environment. $R_{\Theta JA}$ calculations assume heat is generated from operation of the package's internal silicon die and that the part is only surrounded by air, i.e., not soldered to a PCB or attached to any other heat sinking elements. This characteristic is defined in terms of °C/W. This translates to how much the junction temperature will increase as a function of device power consumption. Junction temperature is defined as the peak temperature on the die of a semiconductor device. This is not accurate for Allegro current sensors because the main heat source is the current primary path (IP loop) instead of the silicon die as shown in Figure 1.

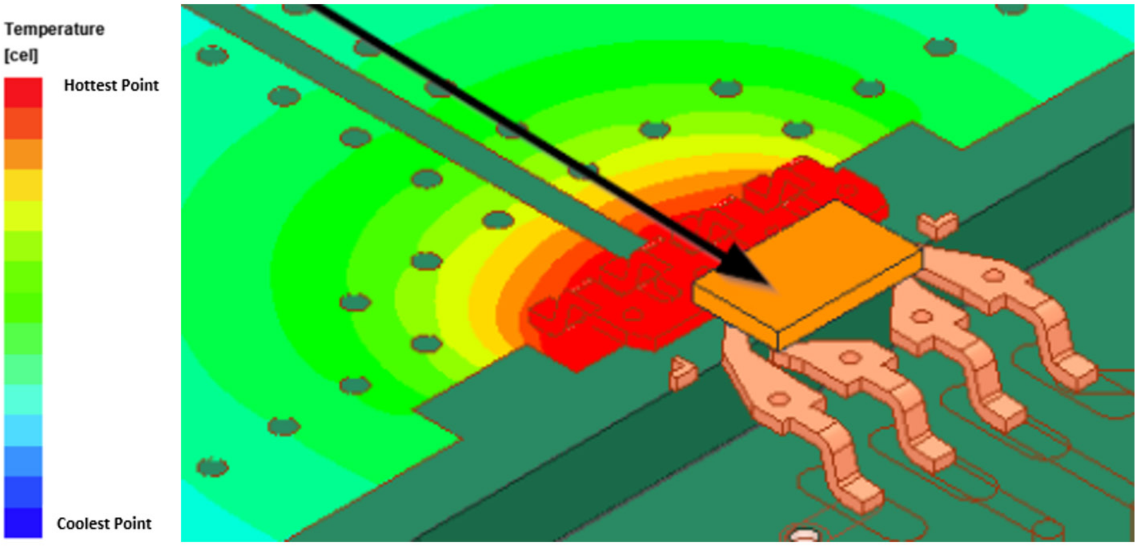

Figure 1: Current primary path through the leads causes the die to heat up.

MEASURING CASE TEMPERATURE

Case temperature is commonly used as an approximation for junction temperature as it is much easier to measure. However, the case temperature will be less than the junction temperature when current flowing through the device is causing self-heating. Case temperature can be measured many ways such as with an IR camera, thermistor, temperature IC, or thermocouple. This report will focus on the K type thermocouple due to its prevalence in most labs and ease of use.

Rest the end of the thermocouple probe on the center of the device package. For the thermocouple to make good contact with the device case, thermal glue/paste must be used. A minimal amount of thermal glue should be applied to help minimize the heat sinking effects of the thermal glue.

EXPERIMENTAL DATA COLLECTION

For each package, two devices were used for data collection. All testing was conducted at three different ambient temperatures, 25°C, 85°C, and 125°C. Each device was put in a thermal chamber and allowed time to reach the desired ambient level. Junction and case temperature were measured with 0 A flowing through the device. Next, using a current source, a known current was forced through the IP leads of the device. The current source was increased in 5 A steps while measuring case and junction temperature at each interval. The current applied was increased until junction temperature was measured at a maximum specified limit of 165°C. Junction temperature and case temperature, each normalized to ambient temperature, were plotted against each another to show the correlation and to run linear regression. This relates to a relationship in the form of $T_J - T_A = A (T_C - T_A) \pm B$, where A and B are unique for each package.

CORRELATION RESULTS BETWEEN JUNCTION AND CASE TEMPERATURE

While the relationship of T_J to current applied depends on layout conditions, the relationship between $T_J - T_A$ and $T_C - T_A$ for each package holds true across all layout variations. When testing thermal performance of an Allegro current sensor in an application, the equations derived from the regression, summarized in Table 2 below, can be used to calculate T_J. The three standard error was calculated by finding the root mean square of the measurement error from the regression line and multiplying the result by three to represent 3-sigma or 99.7% of the population.

Table 2: Summary of T_J equations and error for each package

Package Type	SOICW-16 (LA)	SOICW-16 (MA)	SOICW-16 (MC)	SOIC-8 (LC1)	7-pin PSOF (LR)
Junction Temperature (T_J) (°C)	$1.514 (T_C – T_A) – 1.402 + T_A$	$2.188 (T_C – T_A) – 2.009 + T_A$	$1.554 (T_C – T_A) – 0.586 + T_A$	$1.588 (T_C – T_A) + 1.485 + T_A$	$1.854 (T_C – T_A) + 1.531 + T_A$
Three Standard Error	5.02C	7.22C	6.22C	12.31C	11.00C

Worst-case conditions, such as DC or transients, can be applied to the system at the maximum ambient temperature while measuring T_C and calculating T_J. After adding a margin of error to T_J, such as the three standard error from Table 2, it can be ensured that T_J is not exceeded in worst-case conditions.

$T_J – T_A$ VS. $T_C – T_A$ CORRELATION

LA Package Results

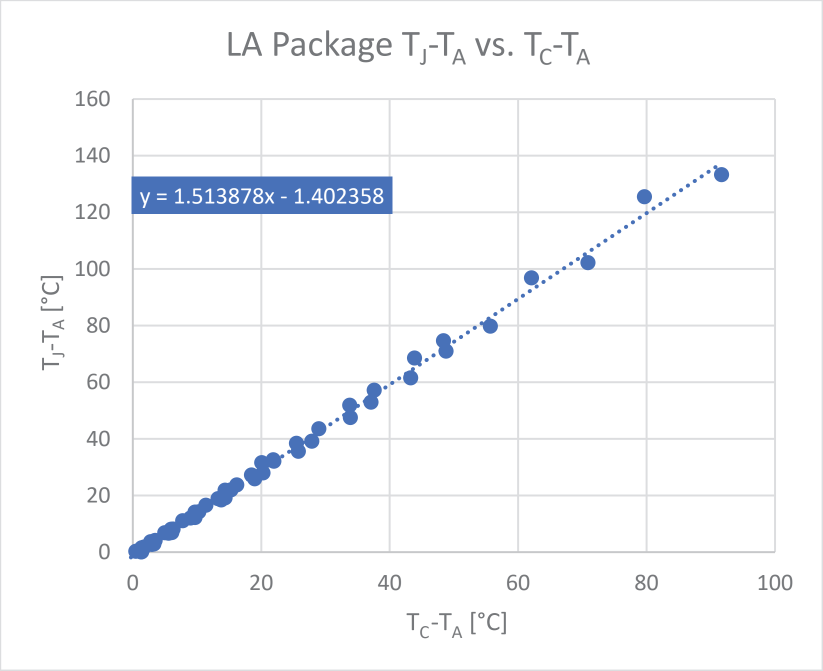

Figure 2: LA package, $T_J – T_A$ vs. $T_C – T_A$. This yields a junction estimation of $T_J = 1.514 (T_C – T_A) – 1.402 + T_A$.

MA Package Results

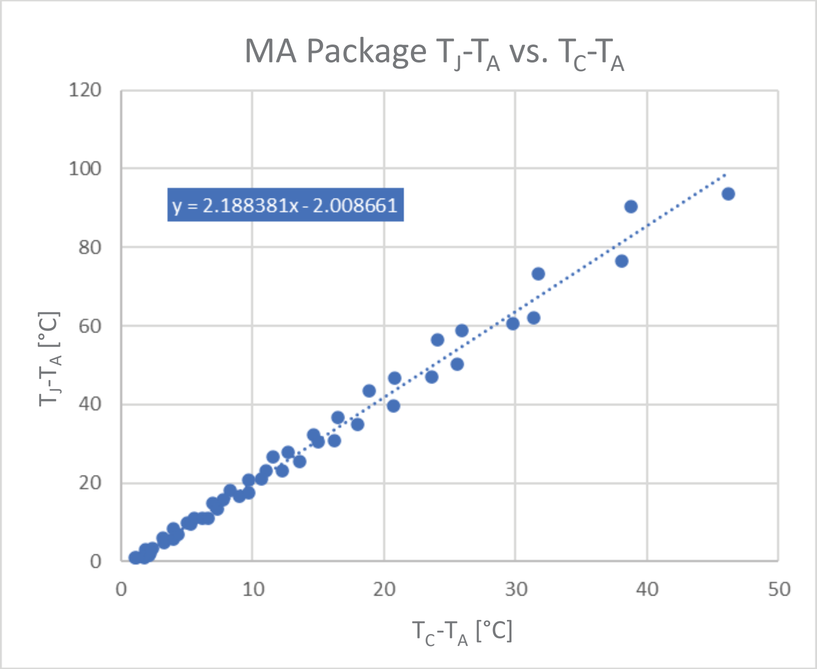

Figure 3: MA package, $T_J - T_A$ vs. $T_C - T_A$. This yields a junction estimation of $T_J = 2.188\ (T_C - T_A) - 2.009 + T_A$.

MC Package Results

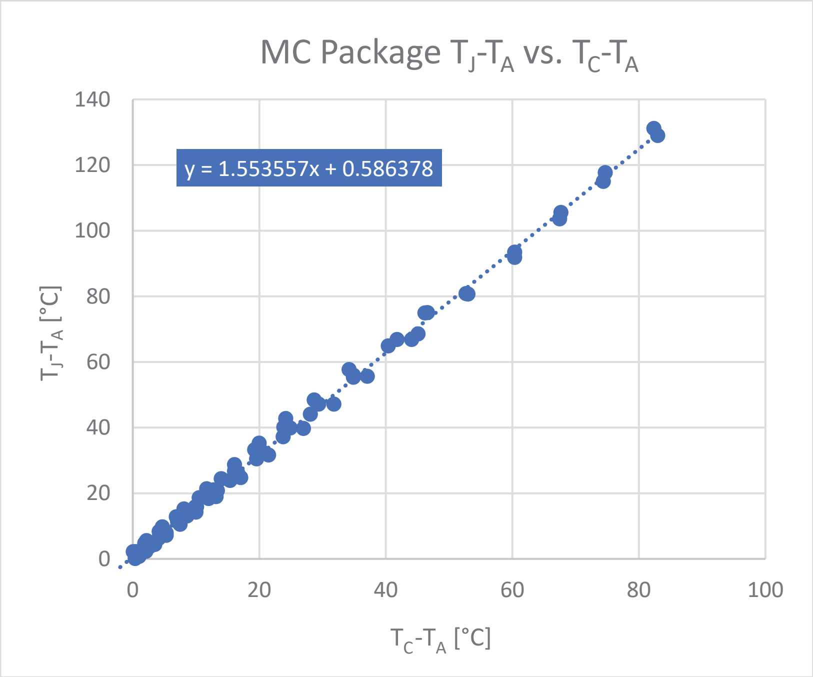

Figure 4: MC package, $T_J - T_A$ vs. $T_C - T_A$. This yields a junction estimation of $T_J = 1.554\ (T_C - T_A) - 0.586 + T_A$.

LC Package Results

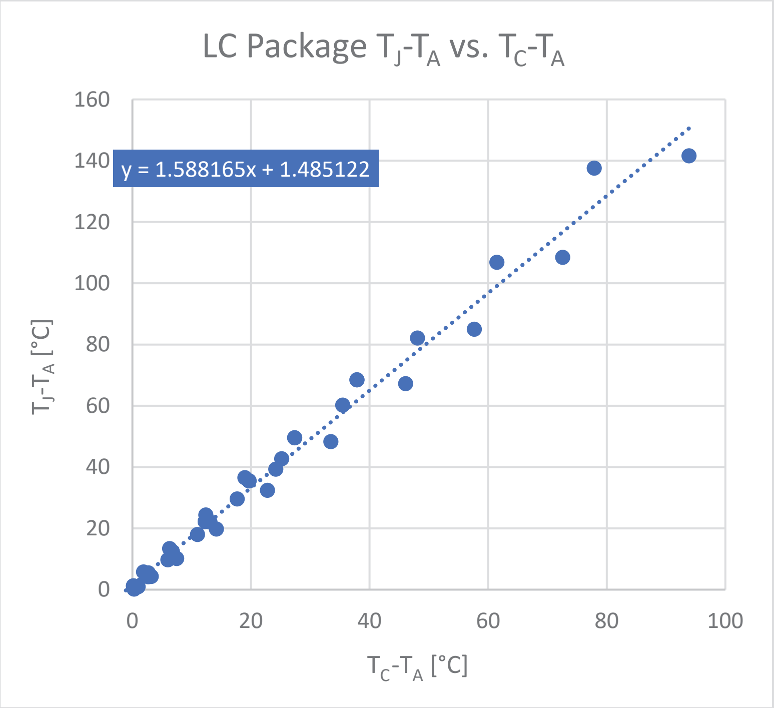

Figure 5: LC package, $T_J - T_A$ vs. $T_C - T_A$. This yields a junction estimation of $T_J = 1.588\ (T_C - T_A) + 1.485 + T_A$.

LR Package Results

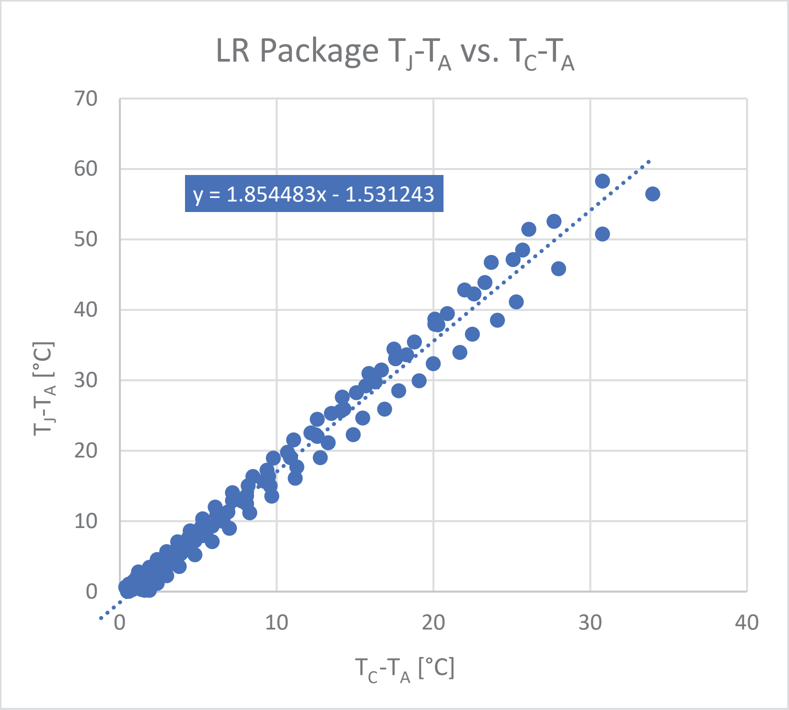

Figure 6: LR package, $T_J - T_A$ vs. $T_C - T_A$. This yields a junction estimation of $T_J = 1.854\ (T_C - T_A) + 1.531 + T_A$.

CONCLUSION

This application note discusses the industry standard of using $R_{\Theta JA}$ to design for maximum junction temperature and why it does not apply to Allegro MicroSystems integrated conductor current sensors. It then proposes an experimental method for characterizing the thermal performance of an Allegro current sensor in application using a correlation between the package case temperature and the junction temperature. This relates to a relationship in the form of $T_J - T_A = A\ (T_C - T_A) \pm B$, where A and B are unique for each package and given in Table 2. Experimental results acquired using this method can ensure that the maximum junction temperature is never reached, as well as help to define a maximum allowable current at various ambient temperatures in application.

Revision History

Number	Date	Description	Responsibility
–	May 19, 2021	Initial release	Sam Locke

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