Accel-RF Corporation

Thermal Imaging Measurement Services

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1 Introduction

It is a common practice when performing reliability testing on an RF semiconductor product to maintain a constant channel temperature over the course of the test. This type of measurement is useful in predicting product lifetimes and durability in the field. By running a device at an elevated channel temperature, it is possible to extrapolate the expected lifetime of the product at normal operating conditions. In recent years, the industry has moved towards the conclusion that in order to get a truly accurate representation of the durability of the part, these operating conditions should include RF drive.

One issue with using data collected at a certain channel temperature to qualify a product is that calculating a precise and accurate channel temperature is extremely difficult and there is no universally accepted method for doing so. The channel temperature is dependent on the amount of power dissipated in the device, the temperature of the device baseplate, and the thermal resistance of the part. The first two variables are easily determined as they can be measured empirically, but calculating an accurate thermal resistance is more difficult. A common industry-standard method for obtaining the thermal resistance is using a QFI infrared microscope to measure the channel temperature.

If the device operational lifetest is going to include RF drive during the test, it makes sense for the thermal characterization measurements to take place with RF drive as well. This document describes how an Accel-RF Smart Fixture can be used with an infrared camera measurement system to fully characterize the thermal profile of devices provided by PROPRIETARY under RF drive. Included is a description of the test setup and hardware required, and analysis of results that were measured.

2 References

JEDEC, JEP118; “*Guidelines for GaAs MMIC and FET Life Testing”*; January, 1993.

Accel-RF Corp; “Automated Accelerated Reliability Test Set (AARTS) Training Manual”, April 5, 2011.

Accel-RF Corp; “HPS Pulser Standalone Operation Configuration”, April 5, 2011.

3 Required Equipment or Equivalent

Accel-RF Smart Fixture, Model 97385-01, Qty. 1
Accel-RF Smart Fixture Interface Cable, Model 97499-01, Qty. 1
Accel-RF Docking Station, 99249-01, Qty. 1
Quantum Focus Instruments Infrascope II, Qty. 1
Agilent Signal Generator, Model 83752B, Qty. 1
Accel-RF SSPA Module, Model 97671-01, Qty. 1
Agilent Power Meter, Model E4417A, Qty. 1
Agilent Power Sensors, Model E9327A, Qty. 2

4 Reliability Testing Using Elevated Channel Temperatures

In order to characterize the expected lifetime of a product, it is a common practice to run a sample of parts at accelerated levels in order to drive the part to failure. Using the failure time at the elevated levels, it is then possible to extrapolate a lifetime at normal operating conditions. There are a number of different device conditions that can be accelerated in order to increase the stress (voltage, RF drive) and one of the most common is channel temperature.

The channel temperature is defined by the following equation:

$$T_{CH} = P_{DISS} \times R_{TH} + T_{SURF}$$

In this equation, the dissipated power and surface temperature are easily measurable, but determining an accurate thermal resistance is not as straightforward. The thermal resistance is based on the material properties of the device, such as the layer stack-up and device periphery, and is not as easily quantifiable.

If an accurate thermal resistance is not obtained, the precision of the channel temperature measurements can suffer. A small inaccuracy in channel temperature can have a major effect when the measured results are used to extrapolate out to hundreds of thousands of hours. Figure 1 is a plot displaying the relative time to failure of a sample part with an activation energy (E_a) of 2.0.

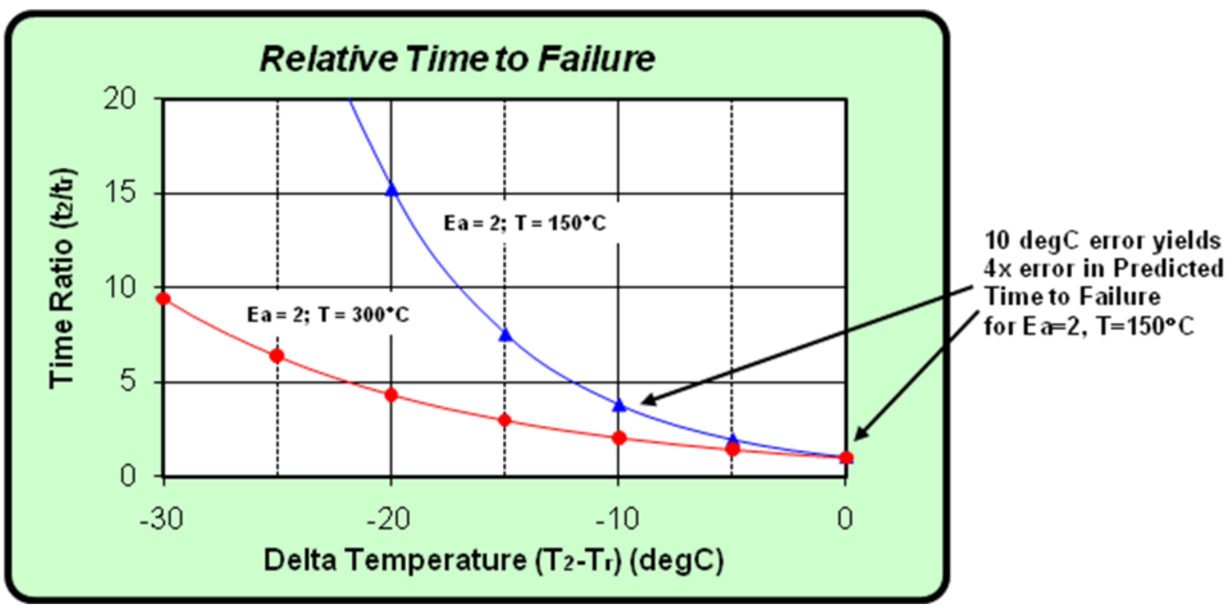

Figure 1 – Effects of Channel Temp. Error on Predicted Time to Failure

When the determined E_a is used to extrapolate to a normal operating channel temperature of 150°C, any inaccuracy in channel temperature can have a dramatic impact on the predicted life. For example, if there is a miscalculation in channel temperature of 10°C, this corresponds to a 4x error in predicted lifetime. This shows that having as precise a channel temperature as possible is vital to predicting accurate lifetimes, and the key to having an accurate channel temperature relies on the thermal resistance estimation.

5 Test Methodology

5.1 QFI Measurement System

For this test, a Quantum Focus Instruments (QFI) Infrascope II, is used to measure the temperature gradient in the device channel at different power dissipations. The QFI system measures the emissivity of the device and creates a color-coded map of the locations and values of the different temperatures. Using the measured channel temperature, the thermal resistance can be calculated as long as the power dissipation and surface temperature are accurately measured. Since the measurement is visual, the device must be de-lidded and have suitable clearance for the lens.

A picture of a QFI system can be found in Figure 2.

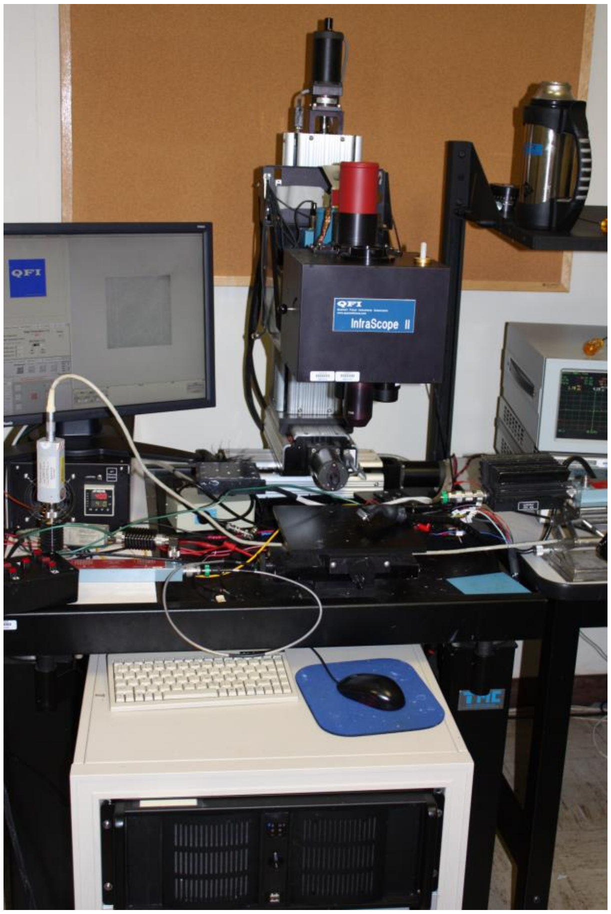

Figure 2- QFI Infrascope II Test Setup with External RF Equipment

5.2 Accel-RF Smart Fixture

The test vehicle for the device under test (DUT) is a critical part of the testing. For one, it is vital for the device baseplate temperature to be controlled and monitored. The QFI system is first calibrated using a baseline temperature of at least 70°C with no power dissipation. Using this baseline, it creates the color map to quantify the rise in temperature. It is often necessary to raise the baseplate to temperatures of greater than 200°C during the thermal characterization testing.

A picture of a Smart Fixture prepared for thermal imaging measurements is found in Figure 3.

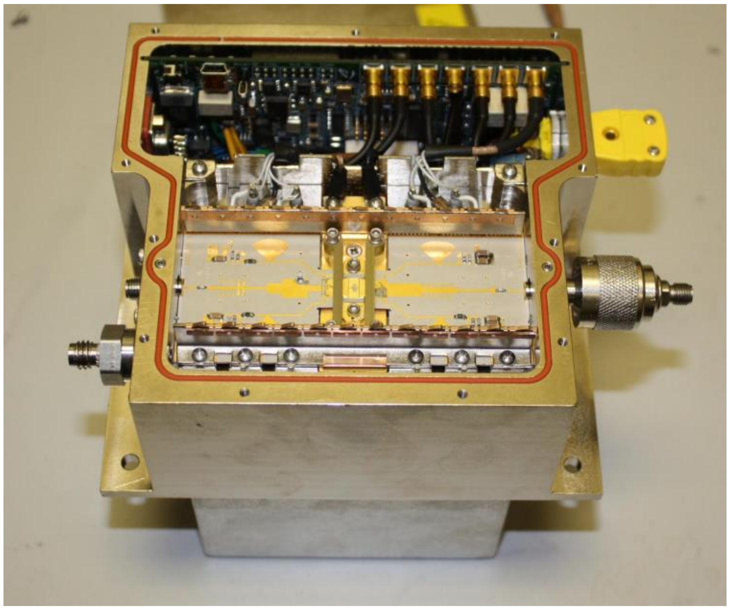

Figure 3- Accel-RF Smart Fixture with Custom Matching Circuits and Open Clamps

The DUT is mounted on a central heater block whose temperature is precisely controlled by interfacing through a USB connection with the Accel-RF USBControl software. The fixture also has DC and RF pulsing capabilities which are controlled through the software as well. The top section of the heater block is a removable adapter plate, which is customizable to fit a number of different package types. After the DUT is screwed down to the adapter plate, the package leads are held down using separate torlon clamp bars. This clamping approach allows full access for the scope and high magnification of the channel. Figure 4 shows the Smart Fixture in use with the 15x magnification lens of the QFI system.

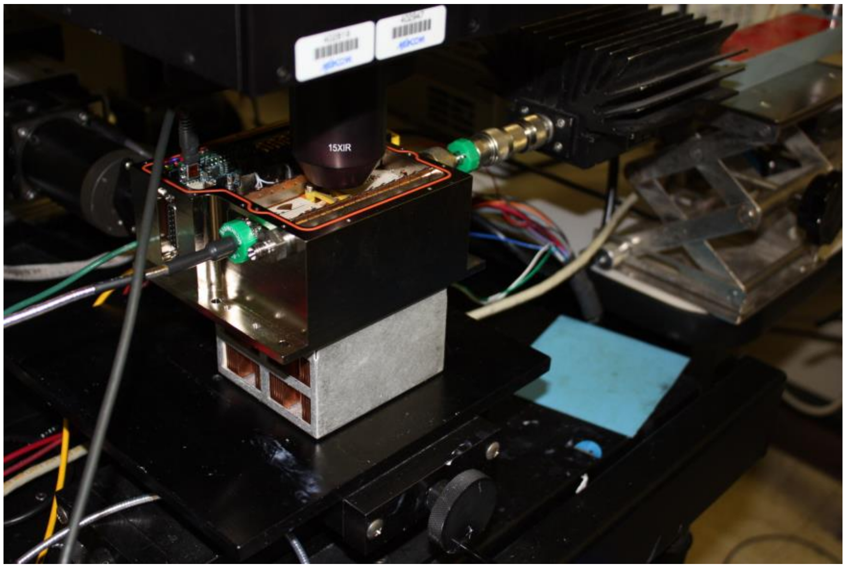

Figure 4- QFI 15x Scope Measuring a Device a Smart Fixture

5.3 Additional Hardware Setup

A standard RF power bench is also required in conjunction with the thermal imaging and fixture setup. This consists of an RF signal generator, RF power meter and sensors, and DC supplies. An example test setup is found in Figure 5.

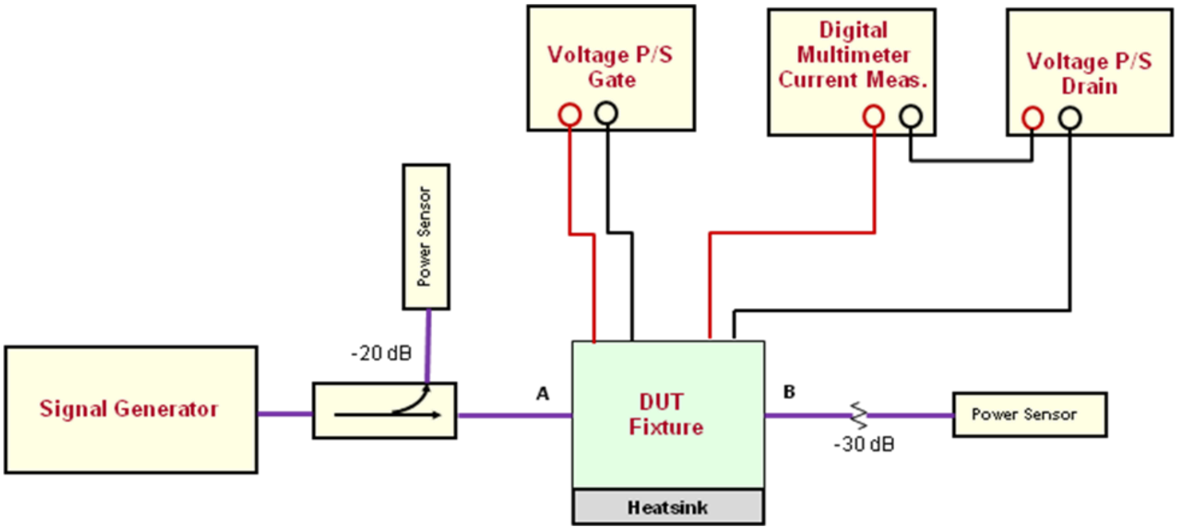

Figure 5- Hardware Block Diagram for RF Measurements

In addition to the signal generator, a 10GHz SSPA module was used to achieve the necessary drive levels. The biases and all other necessary DC signals are routed through the fixture interface cable that plugs into the back of the Smart Fixture.

The test setup was calibrated to the fixture input and output connectors (marked A and B in Figure 5). An additional offset was then added to account for the input and output insertion loss of the fixture RF circuit boards. This offset was measured to be 1dB per side.

6 Thermal Characterization Measurements

After completing the setup and calibration described in Section 5, a series of measurements were made to establish a complete thermal profile of a packaged MMIC under DC and RF conditions. The first step was to set the device baseplate to 70°C to make the baseline temperature measurement. This sets a 'zero level' for the emissivity level. After the temperature has stabilized and the initial QFI calibration is complete, the device is biased up and the characterization begins.

Due to time constraints on the measurement system, two devices were characterized at various bias conditions and surface temperatures. The first device (wafer G872, device 5149) was measured at RF compression levels of 2dB, 3dB and 4dB, and Drain-Source voltages of 12V, 14V, and 16V. A DC-only condition was measured on this device as well (constant DC power dissipation) in order to compare the differences in RF versus DC characterization. A second device (wafer G871, device 5150) was measured at RF compression levels of 2dB, 3dB, and 4dB. For each instance, the device was biased to a quiescent level of 200mA and then the gate and drain voltages were held constant. All the raw data along with some plots can be found in Appendix I.

An example of the measured results from the QFI system is found in Figure 6. The peak channel temperatures measured in the channel are used for all thermal resistance calculations.

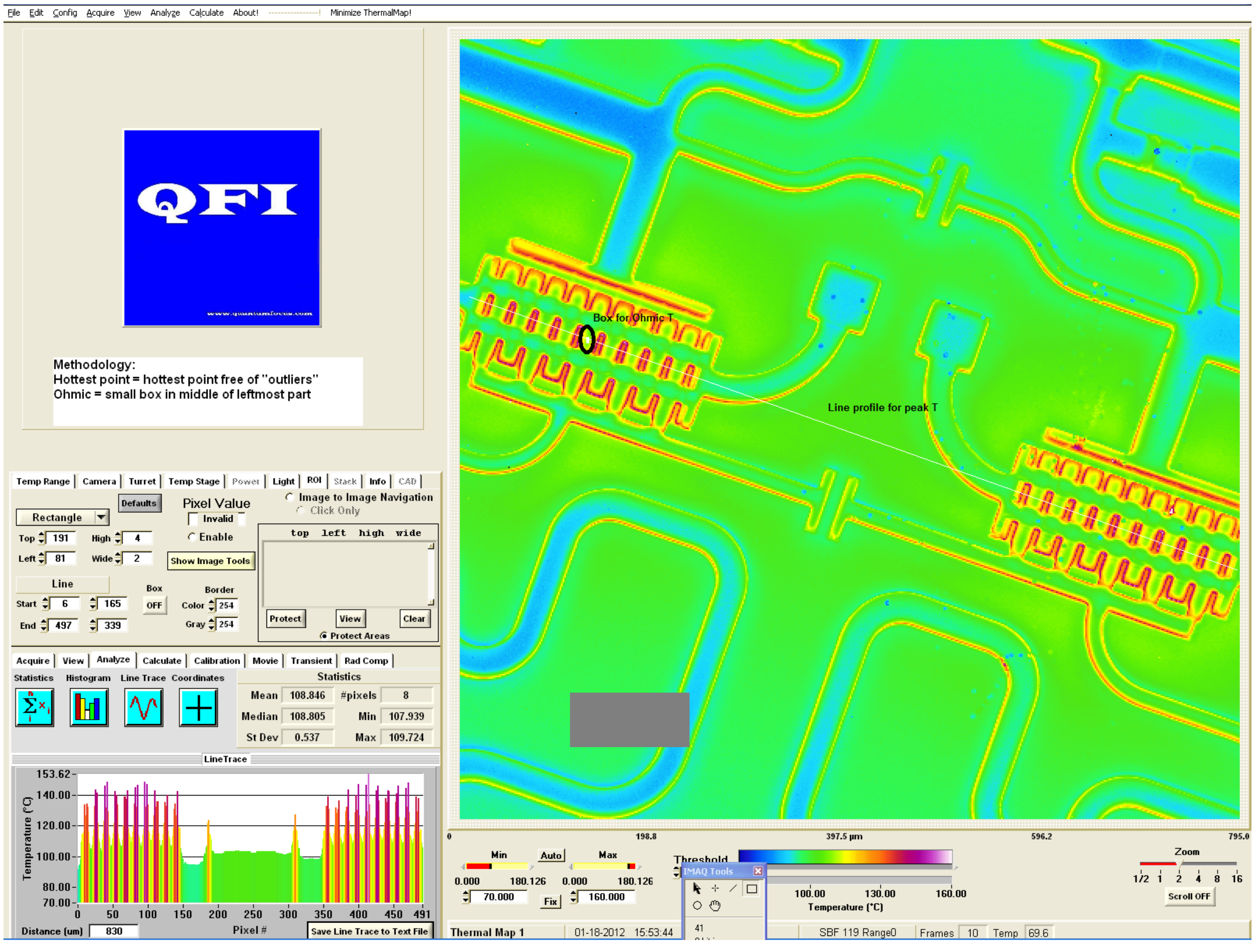

Figure 6- Example of QFI Measured Results

7 Analysis

The measured results show similar trends in thermal resistance for both devices, which is a promising sign. One of the most common reasons for performing these measurements is to fit an equation for thermal resistance to the data under the bias conditions expected for a life test. For example, if the testing will be performed at 12V and 2dB compression, the equation and plot show in Figure 7 could be used to calculate thermal resistance.

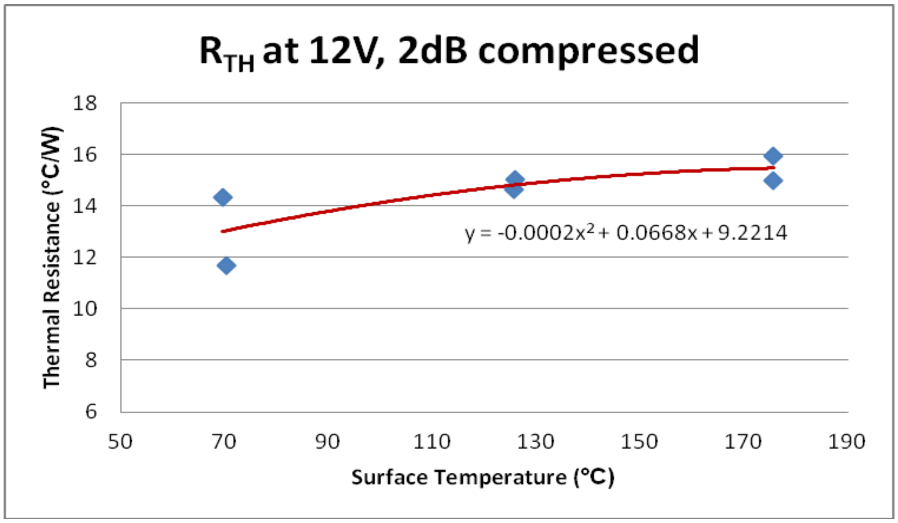

Figure 7- Variation of Thermal Resistance with Surface Temperature at 12V, 2dB Compression

The equation:

$$R_{TH} = -0.0002 \times T_{SURF}^2 + 0.0668 \times T_{SURF} + 9.2214$$

can be inserted into the equation for T_{CH} (found on page 2) so that a constant channel temperature can be maintained using empirically measured results.

Analyzing the plot in Figure 7, it is clear that there is more of a variation in results at the lowest surface temperatures and then the results converge at higher temperatures. Unfortunately, this is an artifact of the QFI system at levels when the emissivity is very low. At these low temperatures, more error is introduced for this reason.

By using the measured values at different bias conditions, it is possible to observe the effects of different stimulus levels on the thermal resistance. Figures 8 and 9 show the resulting thermal resistance values based on different compression levels and drain voltages, respectively.

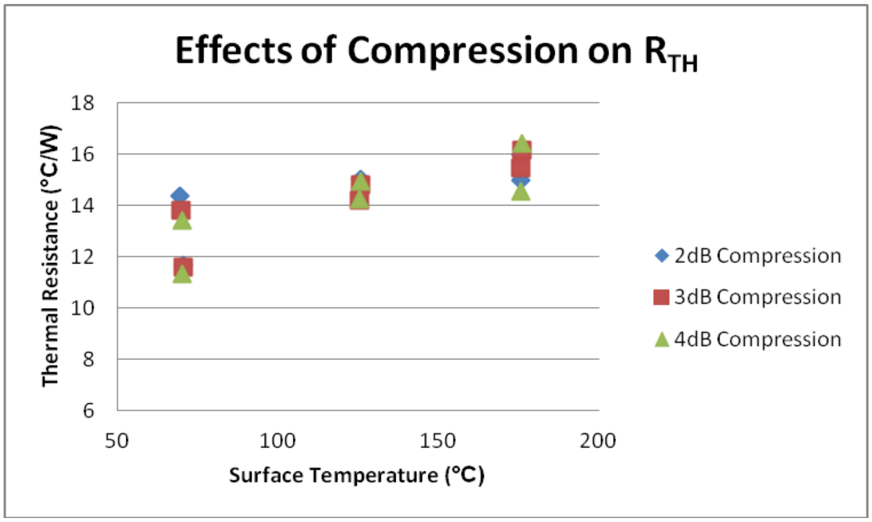

Figure 8 - of Thermal Resistance with Surface Temperature Different Compression Levels

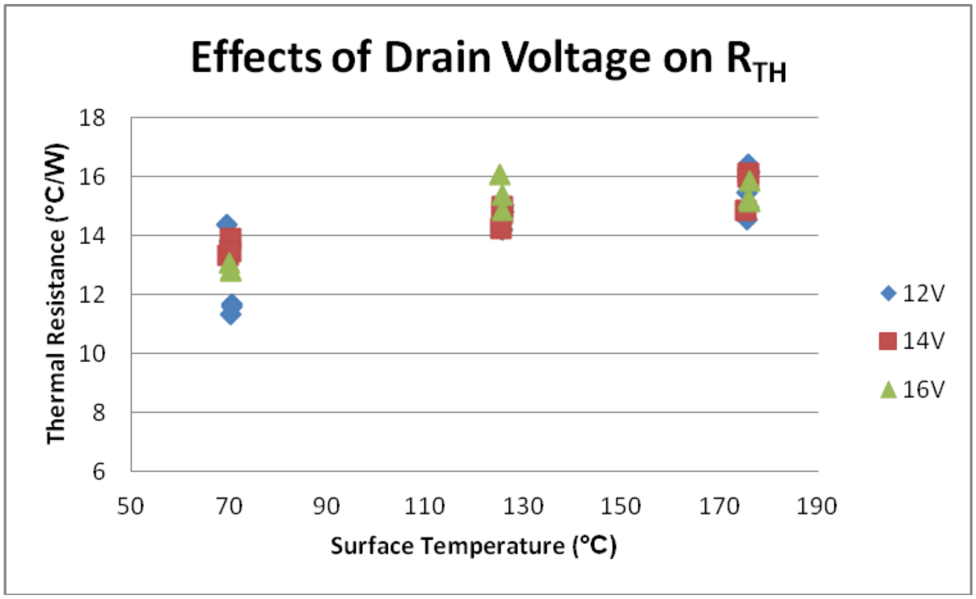

Figure 9 – of Thermal Resistance with Surface Temperature Different Compression Levels

Both plots reflect that varying these bias conditions does not have a significant effect on the thermal resistance, as most of the data points at each surface temperature overlay each other. This reinforces the idea that surface temperature variation has the most significant impact on the thermal resistance.

These are just a few examples of how the data can be interpreted. There are other variables which can be analyzed as well, such as power dissipation versus surface temperature, in order to obtain a complete understanding of the thermal performance of this MMIC.