Thermal Imaging Measurements Using the Accel-RF Smart Fixture

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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 (also known as junction 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. There are a number of different methods for determining the thermal resistance. One of the more common practices is using an infrared camera to measure the temperature gradient while the device is operating.

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 can prove to be practically difficult, as mounting and fixturing of the device into a suitable test setup where all DC, RF, and temperature levels are controllable is not easily done. 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 a device with a convenient approach. This includes some background on calculating thermal resistance, a description of the test setup and hardware required, and some 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 97390-01, Qty. 1
Accel-RF Smart Fixture Interface Cable, Model 97499-01, Qty. 1
Accel-RF DUT Clamp, Model 99036-01, Qty. 2
Accel-RF Input Matching Circuit, 97948-01, Qty. 1
Accel-RF Output Matching Circuit, 97949-01, Qty. 1
Quantum Focus Instruments Infrascope II, Qty. 1
Agilent Signal Generator, Model 83752B, Qty. 1
Accel-RF SSPA Module, Model 97324-01, 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:

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

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.

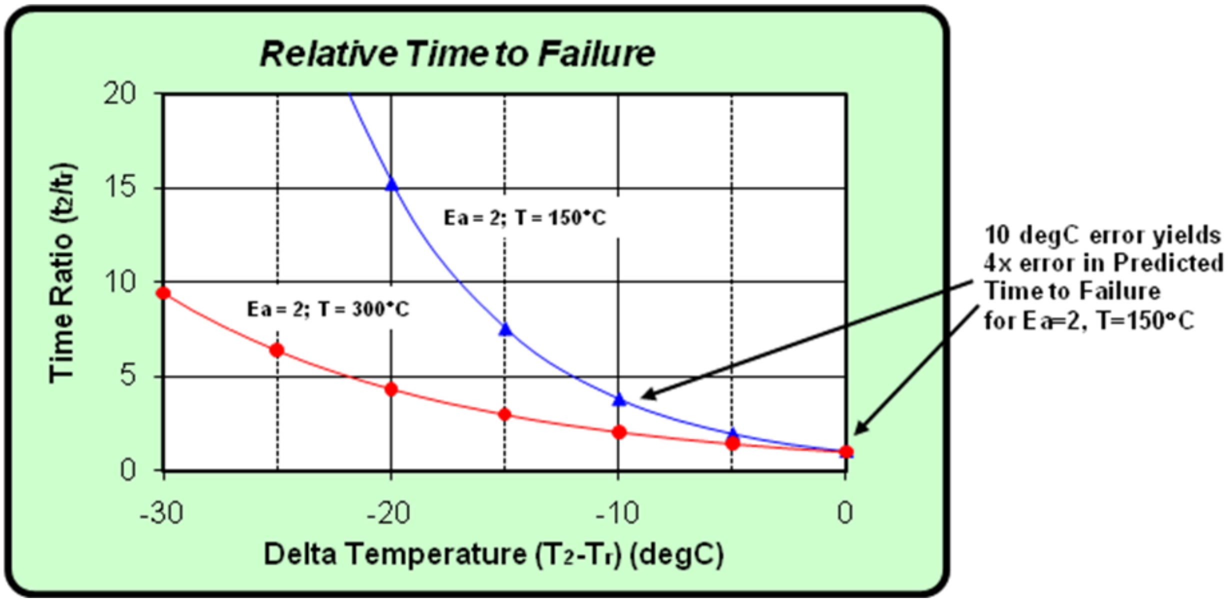


Figure 1 – Effects of Channel Temp. Error on Predicted Time to Failure

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

One of the standard methods of thermally characterizing a device is by using an infrared microscope focused on the channel of the device while it is operating. The infrared measurement system, such as a Quantum Focus Instruments (QFI) Infrascope II, can 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.

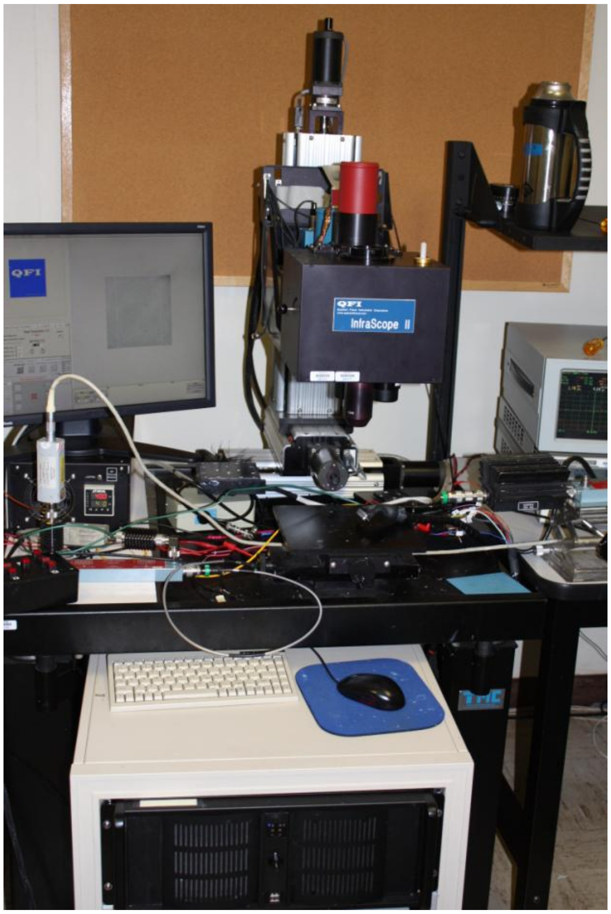


Figure 2- QFI Infrascope II Test Setup with External RF Equipment

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.

The fixture must also be capable of routing the necessary biases needed to power the parts. This can include high power bias if the DUT is a power amplifier with a high power density. It is important that RF operating conditions be included in the testing if the planned lifetest will include RF stimulus. This can be difficult to implement as RF devices often need specific input and output impedance matching conditions to reach their peak operating points. This could consist of 50Ω input and output circuits for an internally matched MMIC or complete custom matching circuits for a discrete FET.

The benefit of using the Accel-RF Smart Fixture is that it allows maximum flexibility for testing a number of different devices under DC and RF conditions while providing precise surface temperature measurements. A picture of a Smart Fixture prepared for thermal imaging measurements is found in Figure 3.

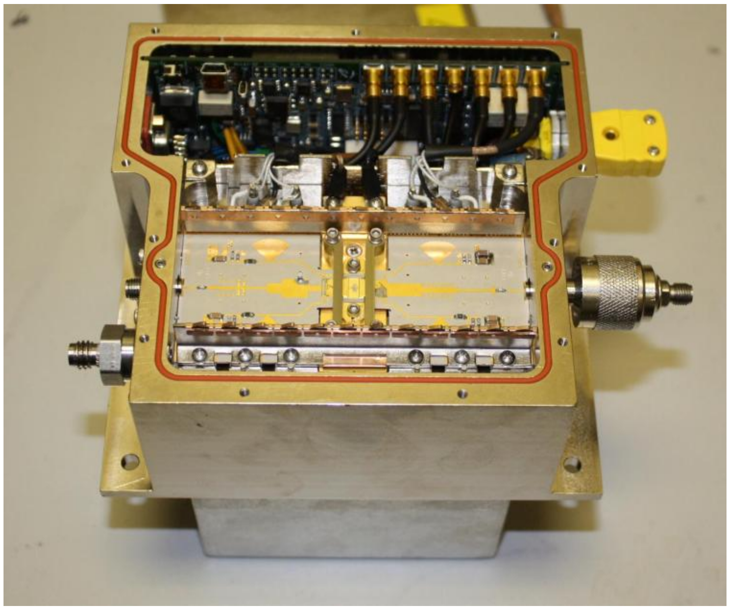


Figure 3- Accel-RF Smart Fixture with Custom Matching Circuits and Open Clamps

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.

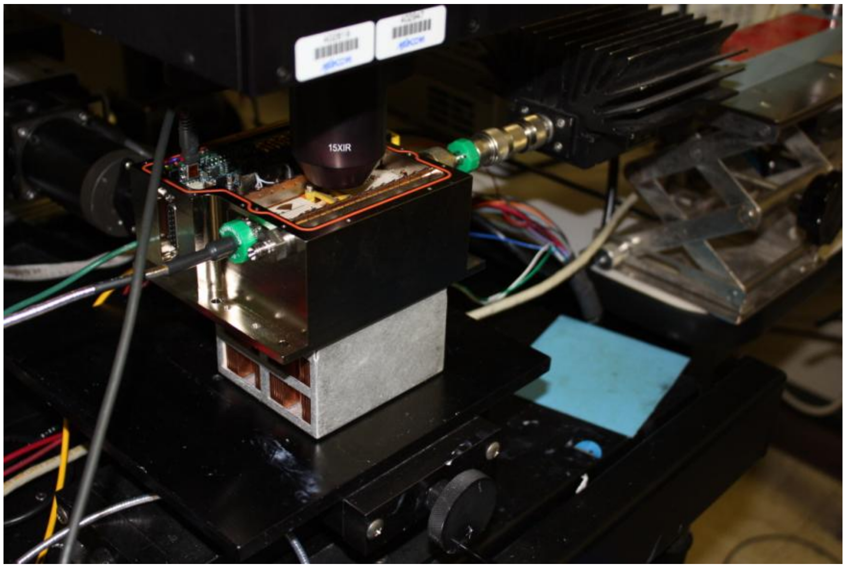


Figure 4- QFI 15x Scope Measuring a Device a Smart Fixture

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.

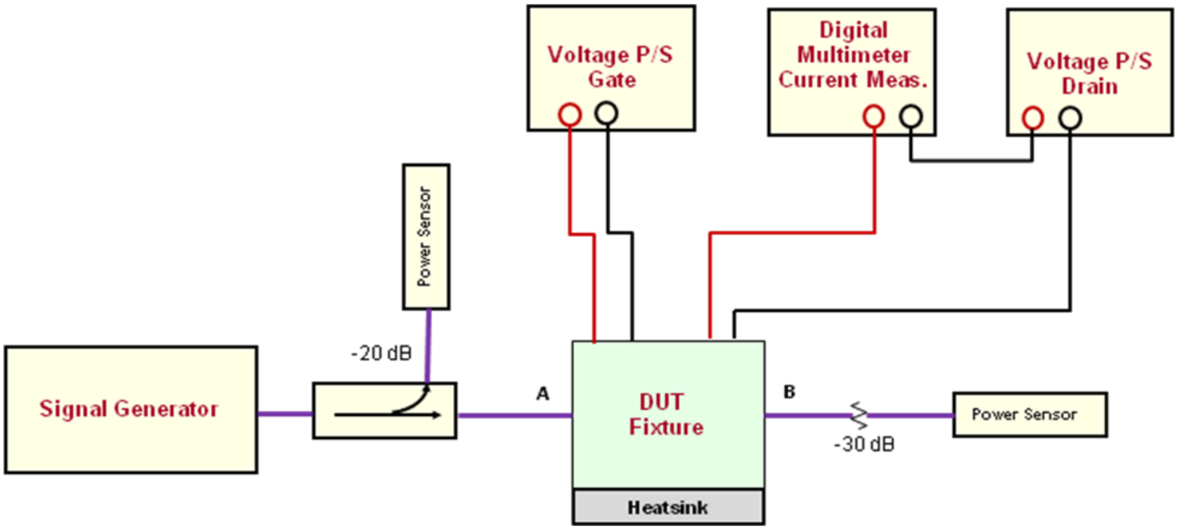


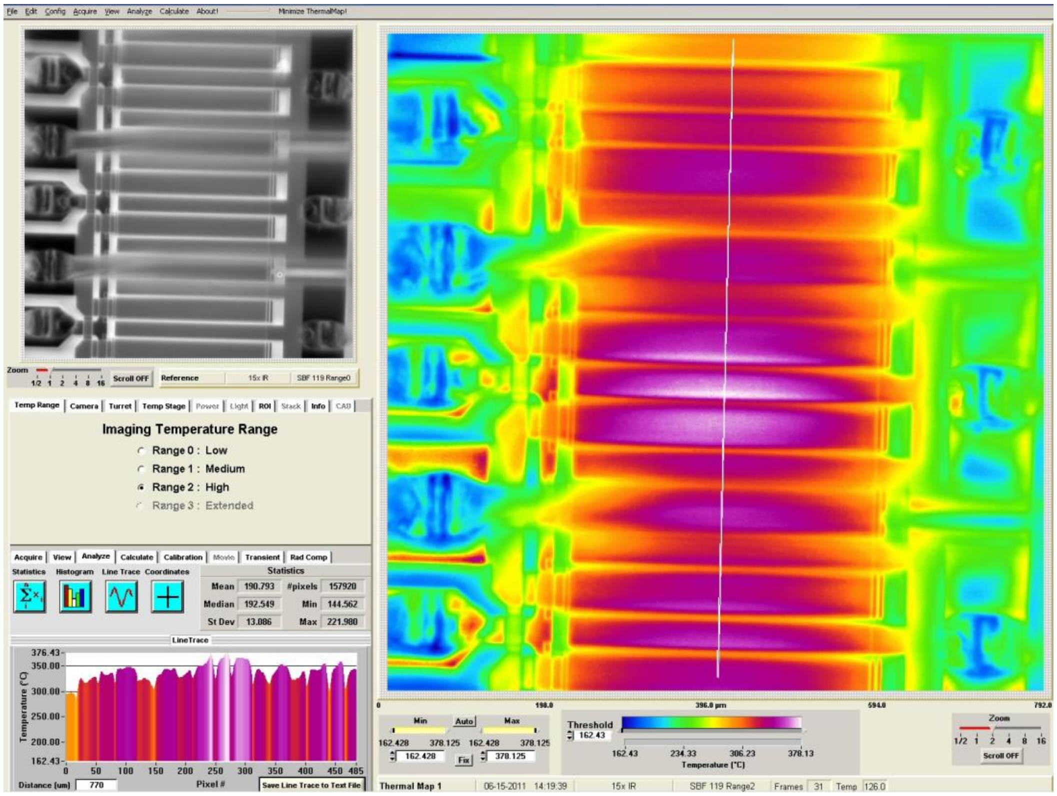
Figure 5- Hardware Block Diagram for RF Measurements

Additional amplification of the signal generator might be required as well using an SSPA if the signal generator cannot drive the DUT into compression. The biases and all other necessary DC signals are routed through the fixture interface cable that plugs into the back of the Smart Fixture.

6 Thermal Characterization of a Discrete FET

After completing the setup described in Section 5, it is possible to do a complete thermal profile of a discrete transistor under DC and RF conditions in order to compare the differences. Once the package is mounted and the system is calibrated, the next step is to turn the device baseplate up to 70°C using USBControl to make the baseline temperature measurement. After the temperature has stabilized and the initial QFI calibration is complete, the device is biased up and the characterization begins.

In this case, the device was biased up to a DC-only power dissipation of 35W and the surface temperature was increased to 125°C. As this is done, the QFI system monitors the increase in channel temperature from the baseline measurement with no power dissipation. The color map indicates the temperature values as well as any hot spots on the device. A screen shot of this condition is found in Figure 6.



Reference | 15x IR | SBF 119 Range0

Imaging Temperature Range

○ Range 0 : Low
○ Range 1 : Medium
● Range 2 : High
○ Range 3 : Extended

Statistics

Mean	190.793	#pixels	157920
Median	192.549	Min	144.562
St Dev	13.086	Max	221.980

Distance (um) 770

Min 162.428 378.125 162.428

Max 162.428 378.125 378.125

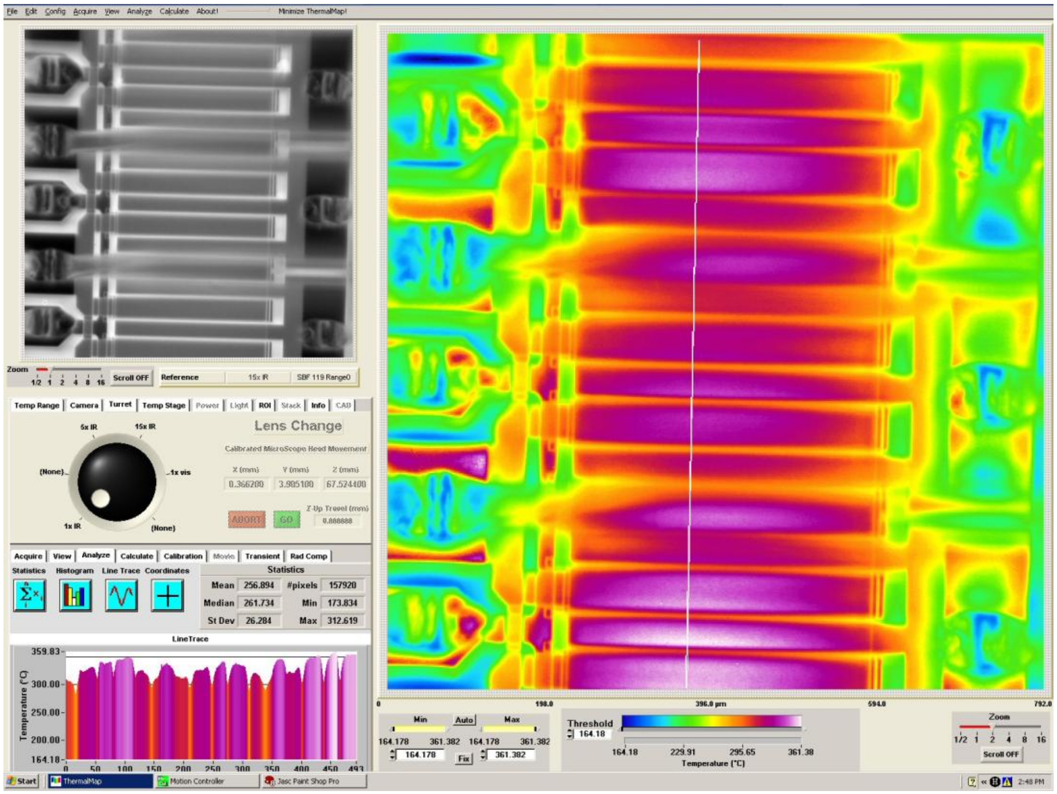
Threshold 162.43

Thermal Map 1 | 06-15-2011 14:19:39 | 15x IR | SBF 119 Range2 | Frames 31 | Temp 126.0

Figure 6- QFI Measured Results at 35W DC, 125°C Baseplate

The results show that the greatest amount of heat radiates out from the center of the device under DC conditions. This is marked by the white section of the color scale. The measured peak channel temperature here was 376°C. Using the DC bias conditions and the measured temperatures, the thermal resistance is calculated to be 7.1°C/W.

Next, RF drive was introduced in order to compare what thermal resistance is found under otherwise similar conditions. The device was first biased up to its quiescent point and then driven into compression (2.5 dB compressed) in order to reach 35W power dissipated (including RF). It was found that in order to reach as high as channel temperature as previously measured in the DC only condition, it was necessary to raise the baseplate temperature to a higher level. This already shows a variance in the thermal resistance between the two conditions. A screen shot of the RF test condition is found in Figure 7.



Reference: 15x IR, SBF 119 Range0

Calibrated MicroScope Head Movement

X (mm): 0.366200
Y (mm): 3.905100
Z (mm): 67.524400
Z-Up Travel (mm): 0.000000

Statistics

Mean	256.894	#pixels	157920
Median	261.734	Min	173.834
St Dev	26.284	Max	312.619

Min: 164.178 – 361.382, 164.178
Max: 164.178 – 361.382, 361.382
Threshold: 164.18

Figure 7 - QFI Measured Results at 35W DC and RF, 145°C Baseplate

This measurement returned a peak channel temperature of 360°C. There are two immediately noticeable differences from the DC-only measurements. The first is that the heat is not distributed in the same way under RF conditions, which is obvious by looking at the color map. In this case, the hot spots were consistently located towards either the top or bottom sections of the die, as opposed to the middle. This proved to be the case across a number of parts that were tested.

The second difference is that a significantly different thermal resistance is calculated under RF drive but with the same power dissipation. In this case, the thermal resistance was found to be 6.3°C/W. In order to verify this difference between DC and RF conditions, a second DUT was measured in identical scenarios: 100°C baseplate and 35W power dissipation. The recorded data from those measurements is found in Table 1.

Table 1- Measured Thermal Resistance Difference Between DC and RF Operation

Condition	**P_{DISS} (W)**	**T_{BP} (°C)**	**T_{CH} (°C)**	**ΔT (°C)**	**Rth (°C/W)**
DC	35.0	103	325	222	**6.3**
RF (2.5 dB Compressed)	35.8	102	269	167	**4.7**

This set of data shows an even greater variance in thermal resistance between the DC and RF operating states. With identical power dissipation and baseplate temperature (T_{BP}), there is a difference in T_{CH} measurements of over 55°C.

7 Conclusions

The measurements outlined in Section 6 show how potentially important the presence of RF drive is to thermal characterization measurements if the purpose of the testing is to determine a thermal resistance for an RF lifetest. The results shared here show that the difference between DC and RF operation can result in a variation in thermal resistance of greater than 1°C/W, which correlates to a difference in channel temperature of greater than 50°C. This would have a huge impact on the predicted lifetime of the device if it was incorrectly extrapolated.

Fortunately, making the necessary RF thermal characterization measurements is completely possible when using the techniques described within this paper. By utilizing an Accel-RF Smart Fixture along with an infrared or Micro-Raman measurement system, accurate thermal resistance measurements can be made in both DC and RF conditions. These results can then be used for performing an RF lifetest with the highest confidence in the calculated channel temperatures.