Determining Ripple Current Capability in Tantalum Hybrid Capacitors

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Introduction

Tantalum Hybrid® capacitors are finding use in applications ranging from radar phased array antennas and laser power supplies to computer and avionics power hold-up. Many of these capacitors suit military and high reliability needs. Hybrid capacitors have very high specific power compared to electrochemical supercapacitors and high specific energy compared to electrolytic capacitors.

A capacitor has internal resistance and its temperature rises when current is present at its terminals. The temperature rise is proportional to the square of the current and is directly related to the power dissipation. The degree of temperature rise is an important design consideration especially where large currents are necessary, such as in power supply filtering and dc pulse forming applications. This is true not only because a certain maximum temperature must not be exceeded but also because the life of a capacitor is strongly related to its operating temperature.

Because of its high specific power, the tantalum Hybrid capacitor fits where other capacitors do not, but its small size is sometimes a disadvantage with respect to heat dissipation. Electrolytic capacitors with similar electrical characteristics compared to Hybrid capacitors have several times the physical size and therefore have much larger surface areas from which to radiate heat. This paper evaluates the relationship between ripple current and temperature rise in tantalum Hybrid capacitors.

Experimental Setup

Hybrid capacitors are polar devices meaning that correct electric polarity must be observed at all times with respect to their terminals. When a Hybrid capacitor is exposed to alternating current, it must be biased to prevent the presence of reverse voltage. In dc applications such as power supply filtering, laser or radar antenna power, this is not a problem because the ac ripple current is usually present in addition to a sizeable dc bias. As our measurements were made without dc bias, this presented a problem which was solved by placing two capacitors of the same capacitance and resistance in back to back series, as shown in Figure 1.

Although almost any frequency ripple current could have been used, these experiments were conducted with 200Hz applied to the capacitors. The selection of 200Hz was justified by two factors. First, and most significantly, there are several important customer applications using a 200Hz repetition rate and second, as can be observed in figure 3, the slope of the curve of resistance (z') over frequency is nearly flat at 200Hz and the phase angle is nearly -45° (z'=z"). The resistance of the capacitor at the ripple current frequency must be known in order to convert the ripple current measurements into power dissipation, as described below, and vice versa.

A 200 Hz sine signal was generated by an Exact model number 605 programmable waveform generator. The frequency range of the instrument was 0.1 mHz to 999 kHz. The amplitude of the output signal was adjusted between 0.3 and 0.7 volts. Output power was delivered by a QSC model number RMX 5050 audio power amplifier. The amplifier had a frequency range of 10 Hz to 50 kHz and a maximum power of 5 kW with adjustable gain controls.

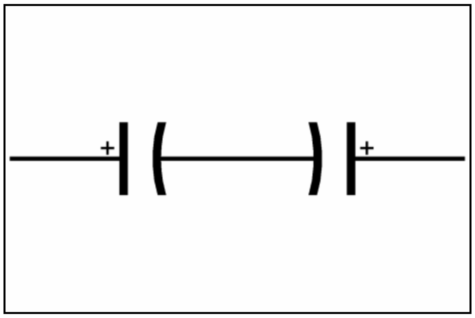
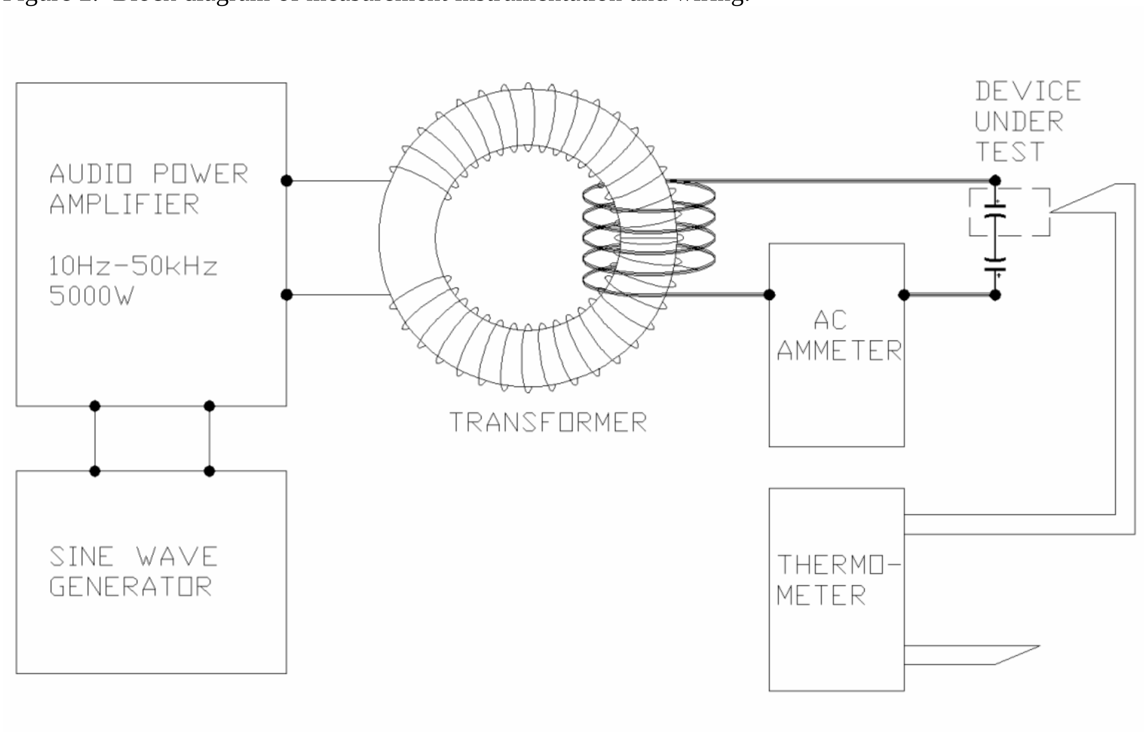


Figure 1. Two polar capacitors were connected in antiseries.

Figure 2. Block diagram of measurement instrumentation and wiring.



The output impedance of the power amplifier was matched to the capacitor using a toroidal transformer manufactured by Toroid Corporation, model number 402-140. It had 162 turns on the primary winding and 20 turns on the secondary, resulting in a step down ratio of 8.1:1.   A Fluke model number189 portable true RMS multimeter was used to measure capacitor alternating current. The frequency range of the meter is 0.5 Hz to 1 MHz. The meter current is rated at a maximum of 10A continuous. A Fluke model number 54II dual input electronic thermometer was used for temperature measurements. Two type K thermocouples were used. One thermocouple was attached to the bottom end of the test capacitor using adhesive tape; the other thermocouple was placed about a foot away, exposed to the air. The thermometer was set to display the difference between the two temperatures and thus directly indicated the rise in temperature of the capacitor.

The capacitors were placed bottom end up on 1” diameter X 1” long hollow cardboard tubes. They were positioned about 1 foot from each other. Heat was dissipated by natural convection. No mechanical means were applied for air circulation.

Capacitor current was varied by steps, from a current of 1A or less to the maximum current of 10A, rms. Current was changed by adjusting either the amplitude of the sine wave generator or the gain of the power amplifier. At least two hours were allowed for temperature readings to stabilize between measurements.

Analysis

The ability of a component to dissipate heat by natural convection is governed by its exterior mechanical characteristics including housing size and shape, and materials of construction. Heat dissipation is not related to the internal contents or configuration of a component. Therefore, measurements of temperature rise from a single rating can be generalized to a family of capacitors that share only a common housing. Since capacitors of different capacitance and voltage rating have different values of internal resistance, generalization across a family of devices needs to account for this. Finally, as resistance changes across temperature and frequency, these variables should also be considered.

The value of the power dissipated was calculated according to the relationship,

$$P = I^2 \cdot R,$$

where I is the ac ripple current and R is the resistance of the capacitor.

To find the temperature rise at a specific ripple current value, first determine the resistance of the capacitor in question at the frequency of the application [1]. Initially, guess at the temperature and determine resistance. Then, using the above formula, calculate power. Use one of the charts below to look up temperature rise or plug the value of power into the linear fit provided and calculate temperature rise. Depending on your initial guess for temperature, an iterative approach could be used to refine the result.
Heat transfer by a surface at constant temperature in convection is proportional to the difference in temperature between the air and the heated surface and follows the formula,

$$?T = q/h$$

where ?T is the temperature difference, q is the heat flux, and h is a free-convection heat transfer coefficient. Therefore, one would predict that the charts for temperature rise vs. ripple power would fit a zero intercept, straight-line function with a slope of 1/h.

This is not the case, as a second-order polynomial better fits these data. The explanation for this is that the value of h is not constant but varies with temperature difference. The larger the difference in temperature between the heated surface and the air, the greater is the value of h. The heat transfer coefficient can be approximated by

$$h= 1.42(?T/L)^{1/4}, \text{ W/m°C for vertical surfaces, and}$$
$$h=1.32(?T/L)^{1/4} \text{ for horizontal surfaces. [2]}$$

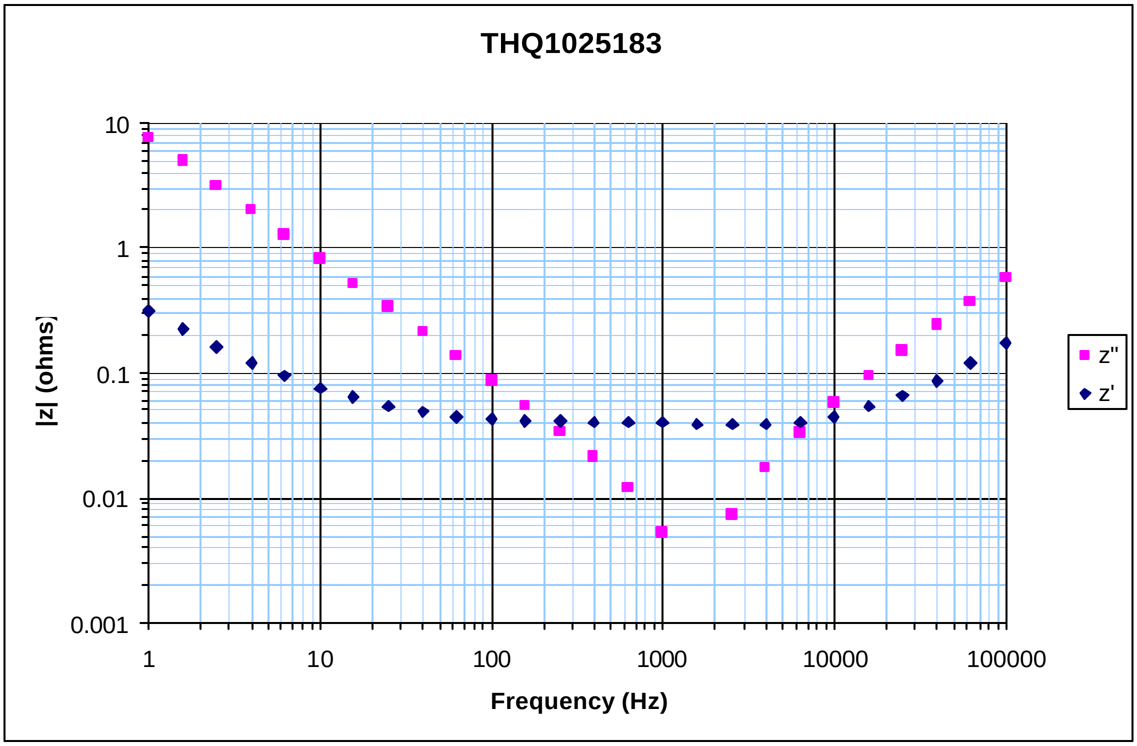
Conclusion

We tested the assumption that temperature rise was not related to the internal components of a capacitor but only to the external mechanical housing and dissipated power by running the same experiment in THQ1 capacitors of different voltage rating. These capacitors differed in resistance, capacitance, and frequency response from the THQ1025 results shown, but they followed an identical temperature rise vs. dissipated power function. We also ran the experiment at different frequencies and got similar results. Therefore, the generalization of this work to other capacitors at different frequencies and applications appears to make sense.

References

1. The impedance data used to compute power values are found at www.evanscap.com.
2. J. P. Holman, “Heat Transfer, Fourth Edition”, p. 249, McGraw-Hill. (1976)

Figure 3. Resistance varies with frequency…



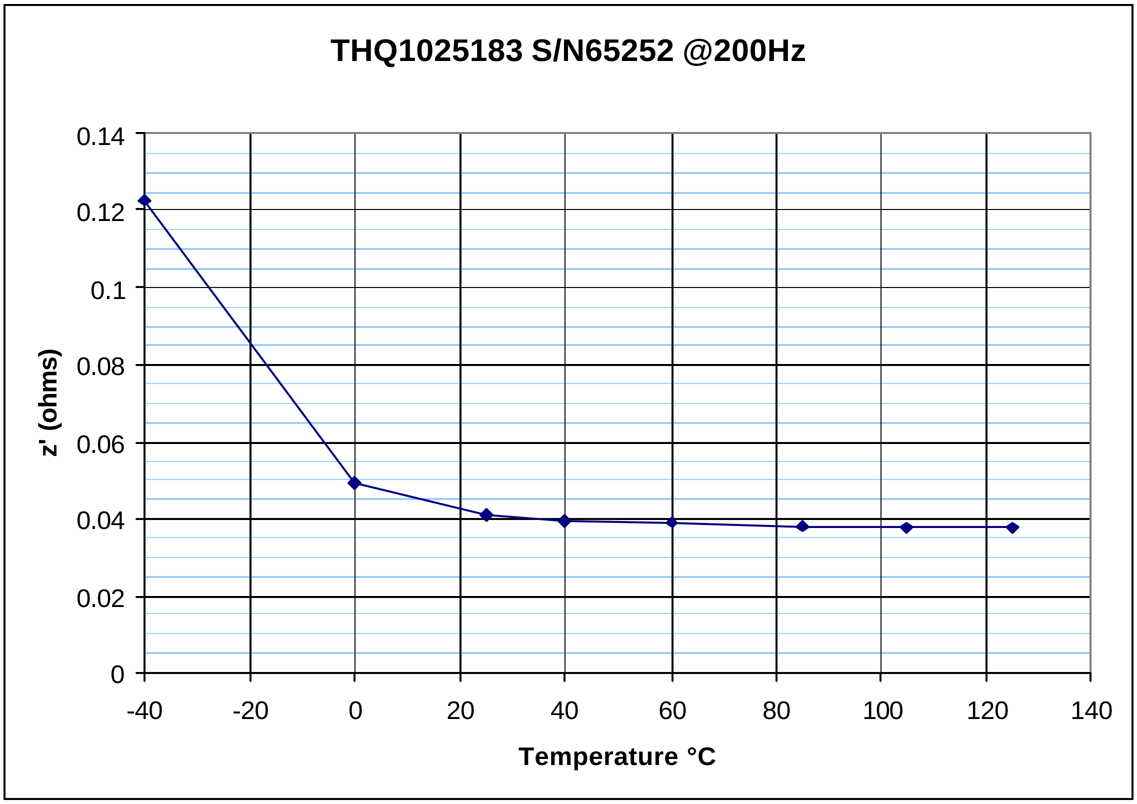
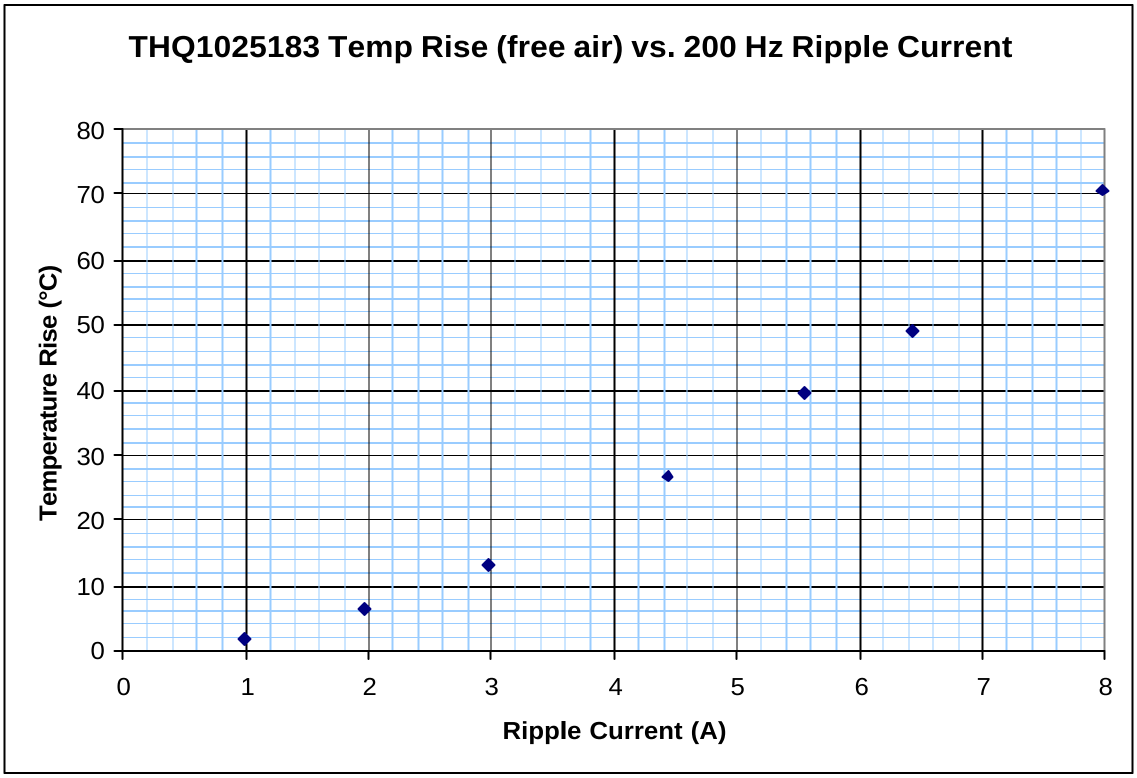


Figure 4. …and with temperature. It is very important to use the proper resistance value in computing ripple power, and conversely when using the power function to find temperature rise vs. current.

Figure 5. Raw data from temperature rise vs. current measurements.



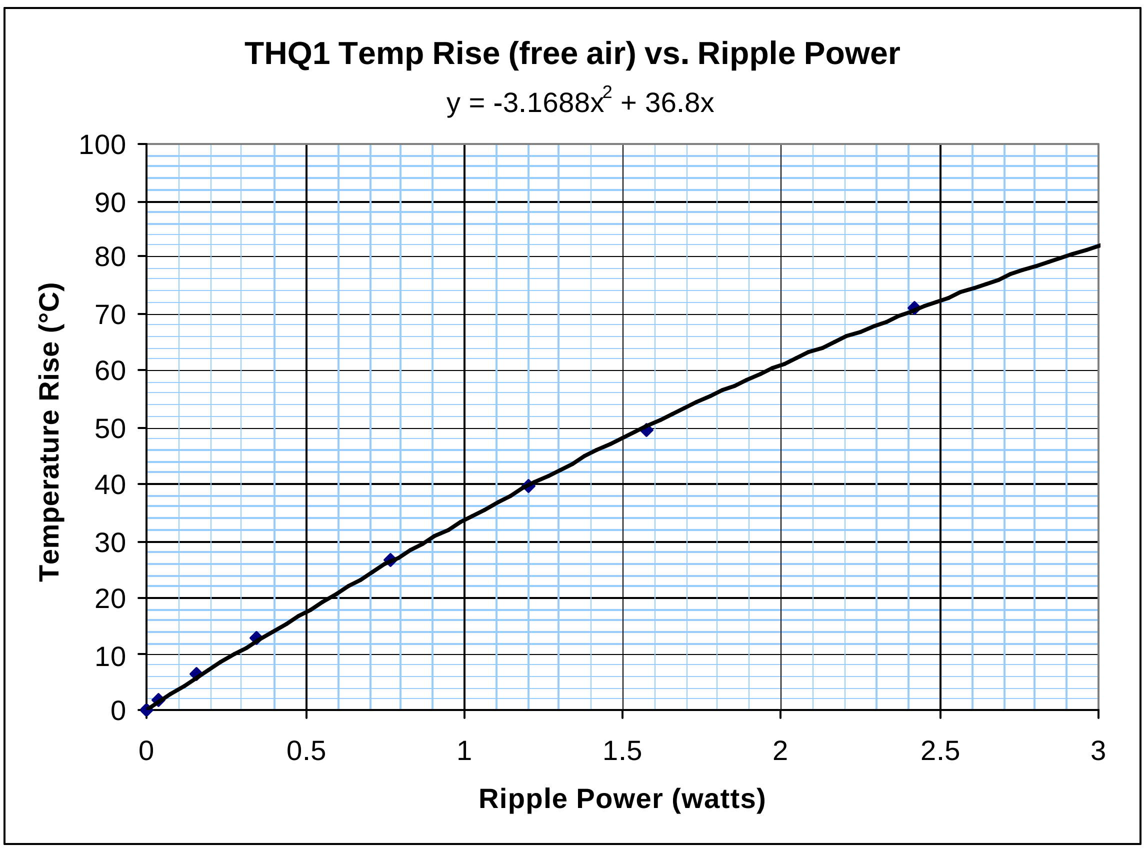
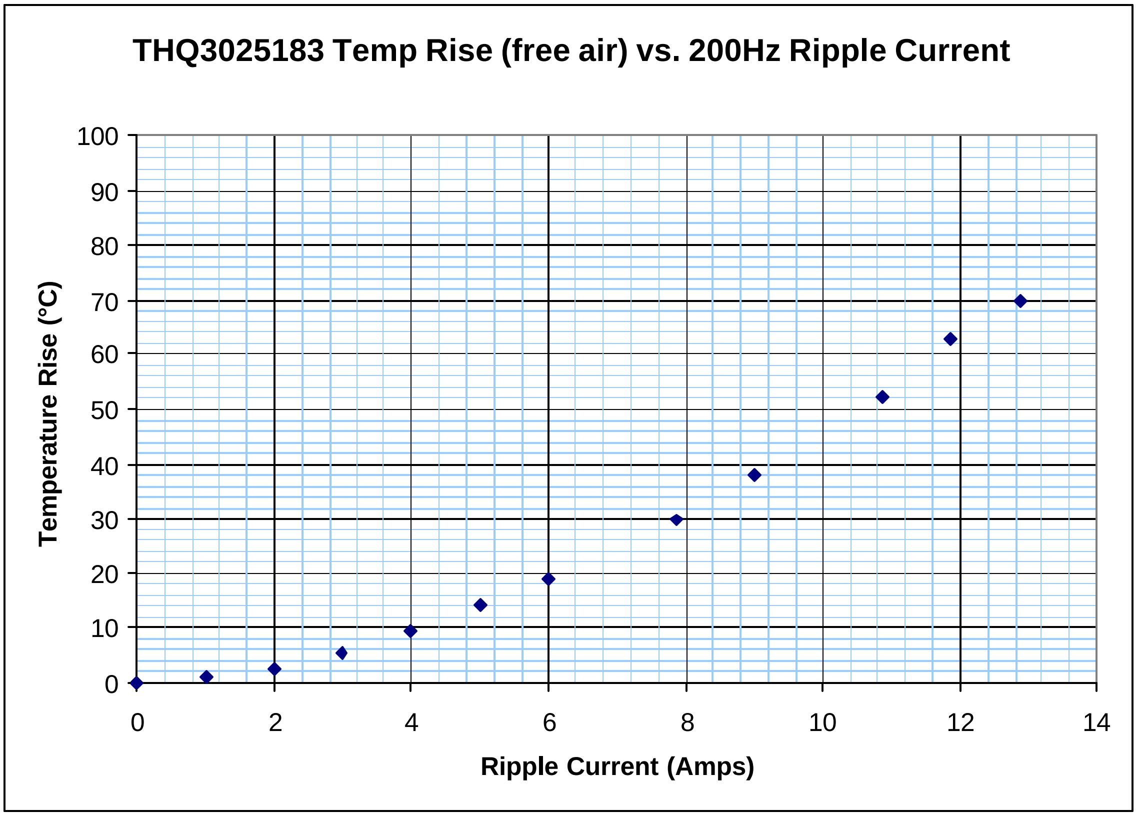


Figure 6. Temperature rise vs. dissipated ripple power in THQ1.

Figure 7. Raw data for THQ3025183 temperature rise vs. ripple current at 200Hz.



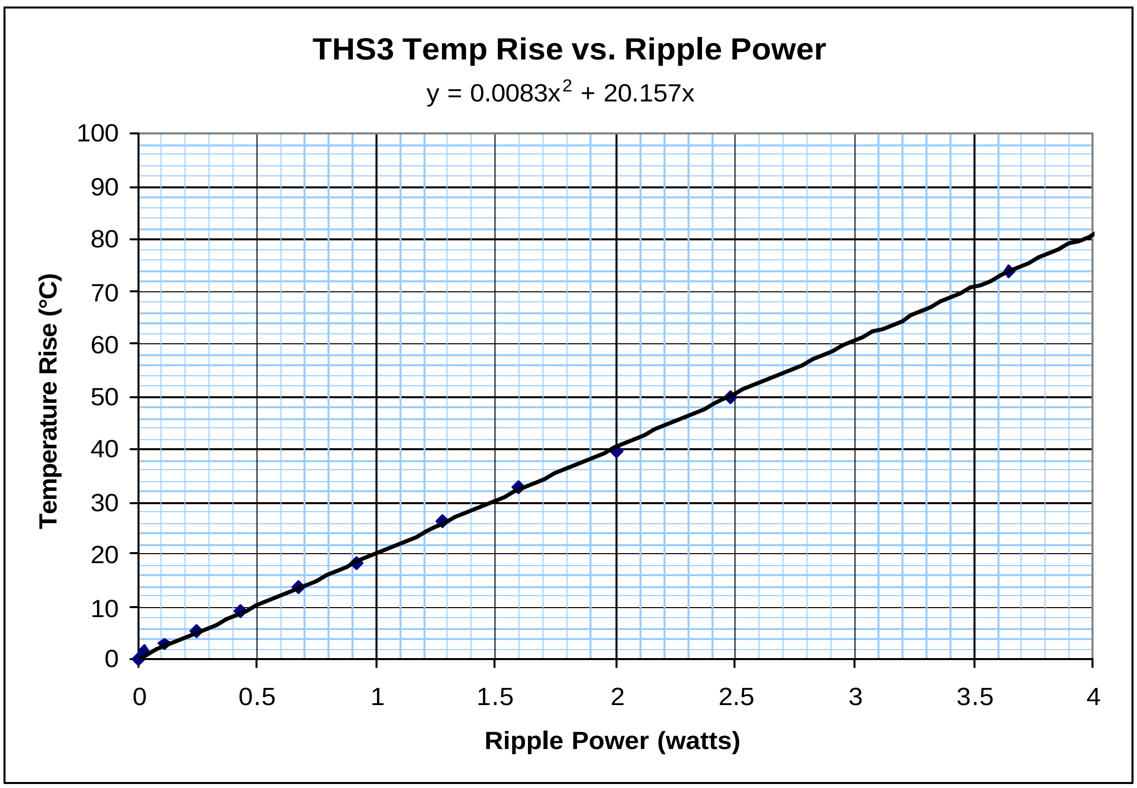
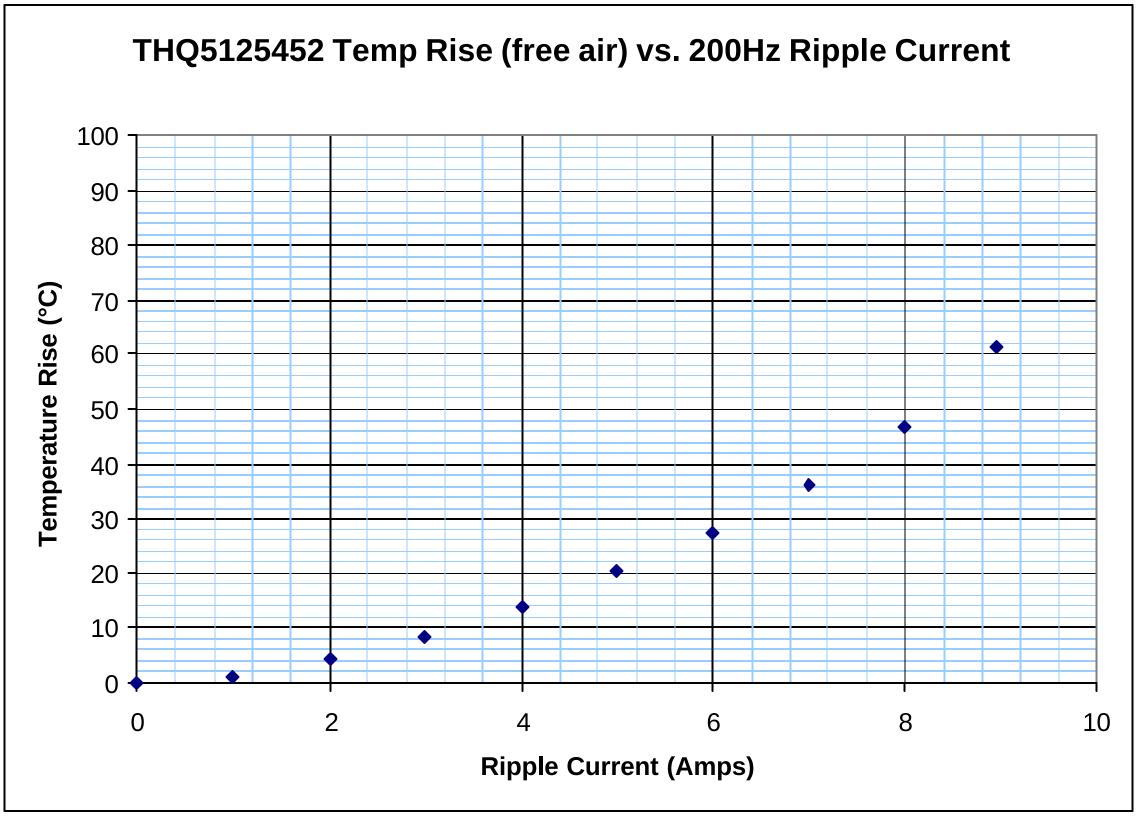


Figure 8. Temperature rise vs. ripple power dissipation for THQ3.

Figure 9. Raw data for THQ5125452 temperature rise vs. ripple current at 200Hz.



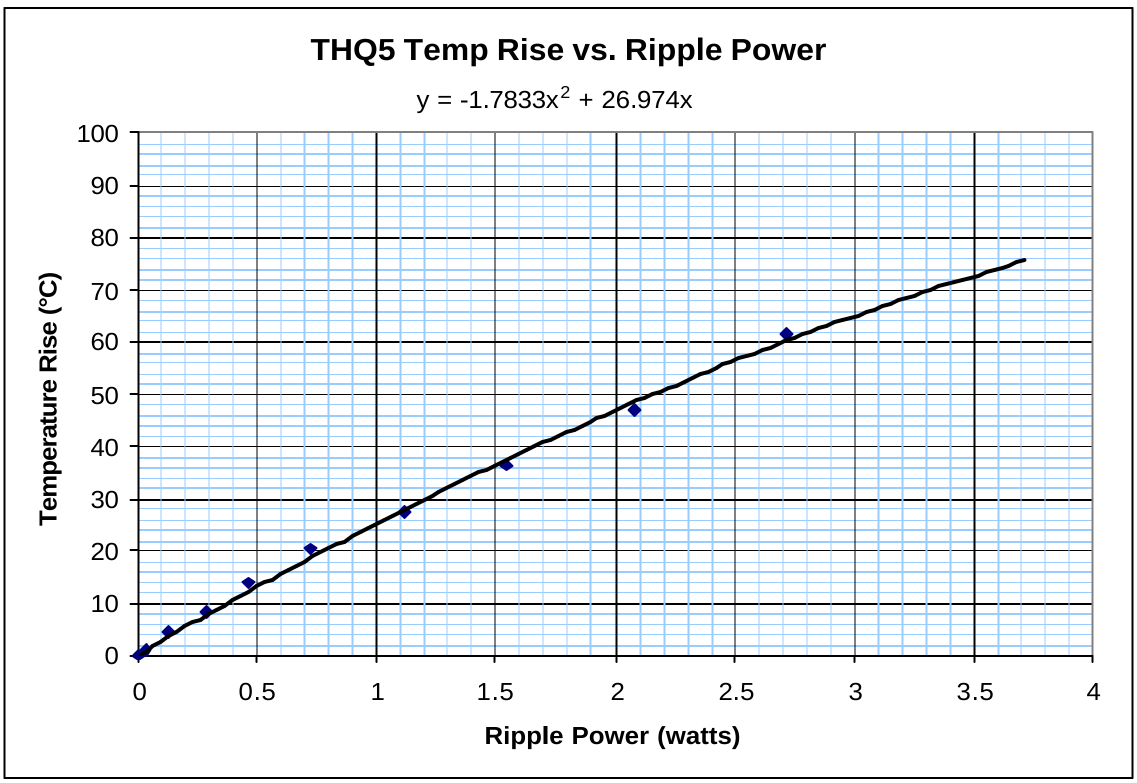
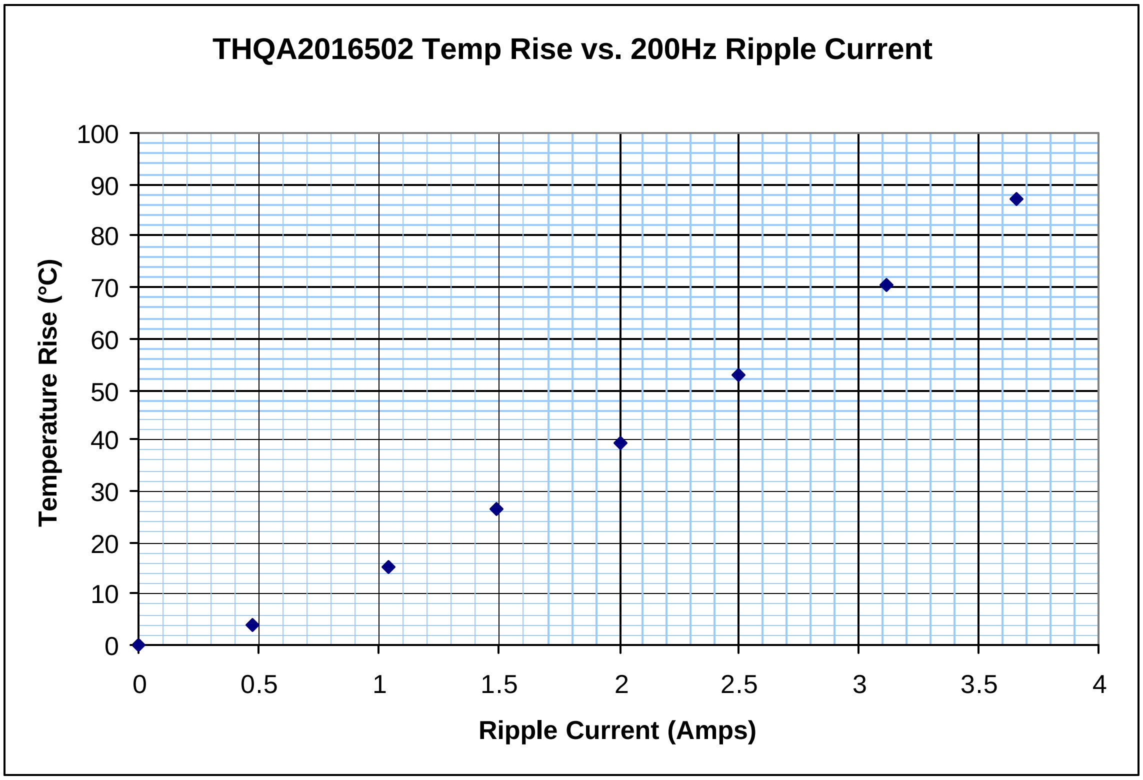


Figure 10. Temperature rise vs. ripple power dissipation for THQ5.

Figure 11. THQA2016502 temperature rise vs. ripple current at 200Hz



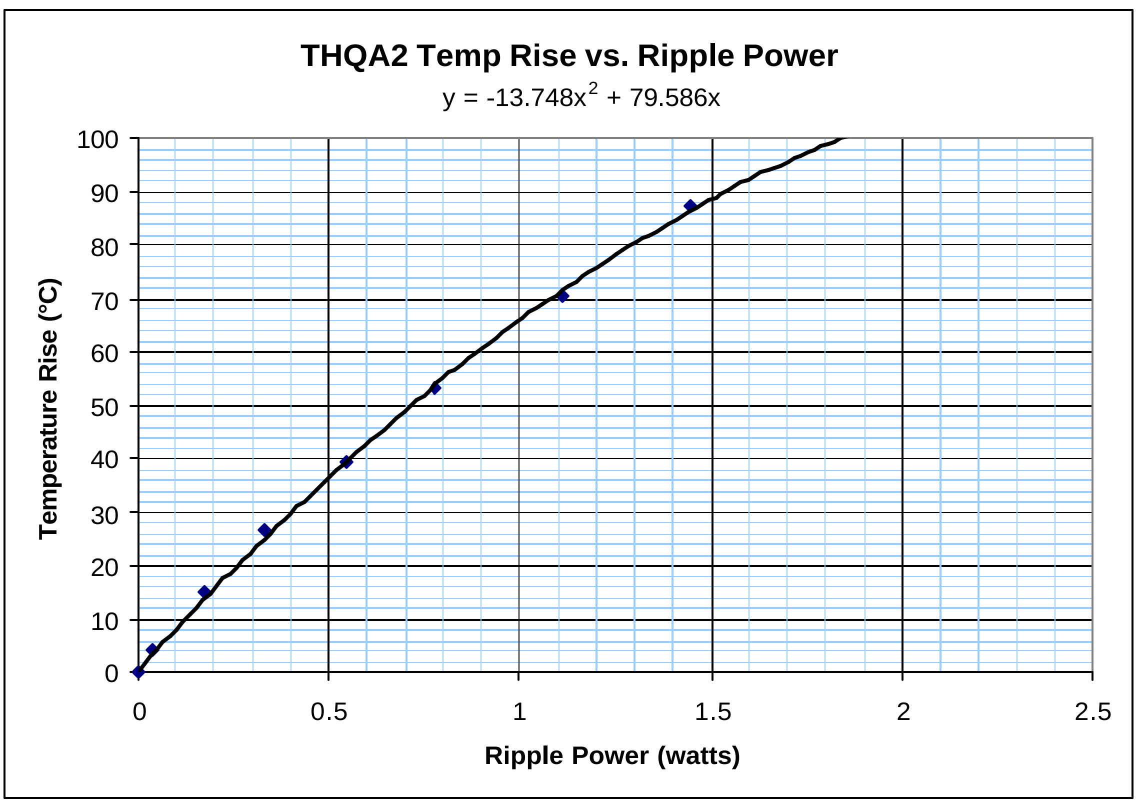
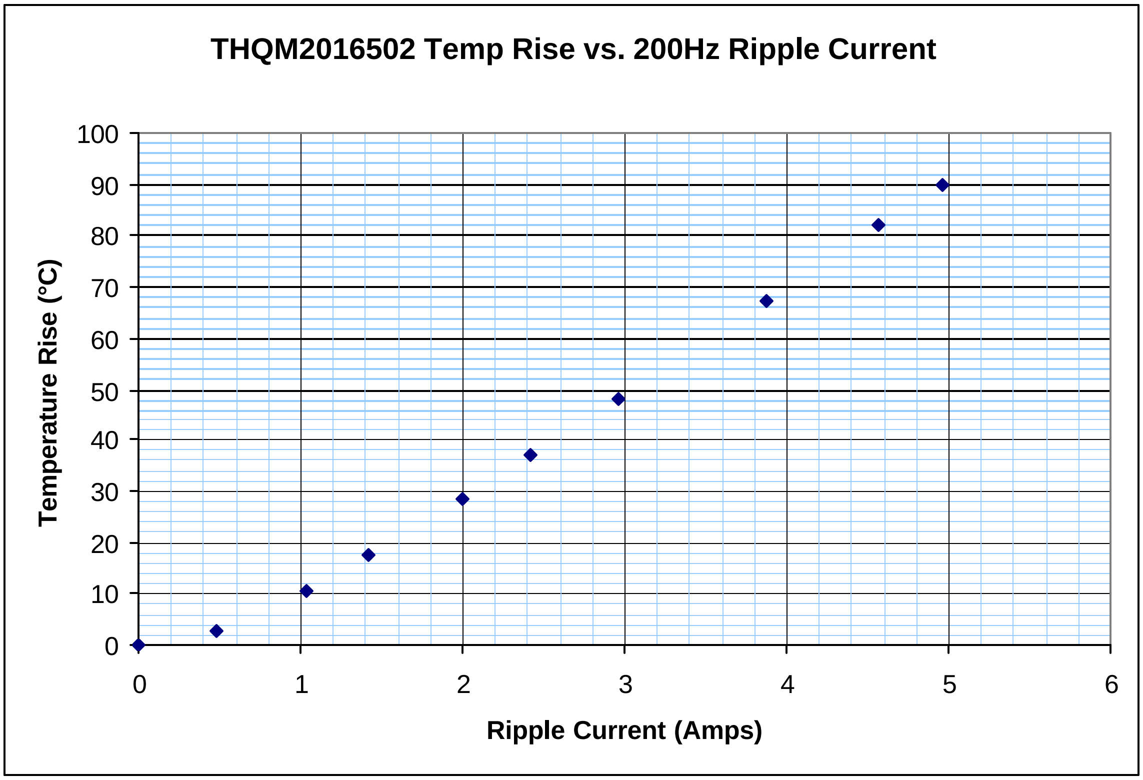


Figure 12. Temperature rise vs. ripple power dissipation for THQA2

Figure 13. THQM2016502 temperature rise vs. ripple current at 200Hz



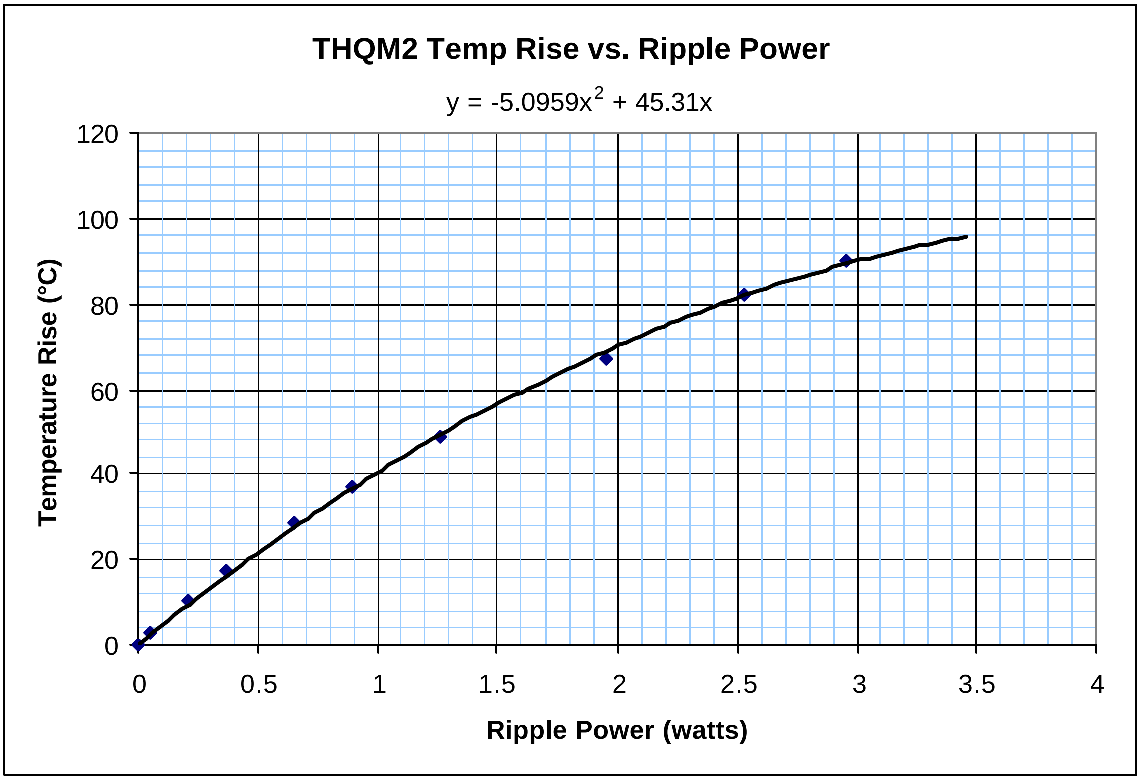


Figure 14. Temperature rise vs. ripple power dissipation for THQM2