



Current and Temperature Ratings

Considerations for Current and Temperature Ratings

Introduction

This application note describes:

- How to interpret Coilcraft inductor current and temperature ratings
- Our current ratings measurement method and performance limit criteria
- Calculations for estimating power performance limits based on current ratings
- How to calculate component temperature from the temperature rating
- How to estimate component DCR at temperatures other than 25°C.
- Detailed rms calculations – Appendix A
- Derivation of temperature rise equation – Appendix B
- Conversion factors for various waveforms – Appendix C

Electrical ratings are interdependent. The current through a component depends on the applied voltage (waveform and duty cycle) and the component impedance. The impedance of a component depends on the DC resistance (DCR), the applied signal frequency (for AC resistance), and the component temperature. The temperature of a component depends on the thermodynamic (heat transfer) characteristics of the component, the circuit board, the solder connection, the surrounding environment, the impedance of the component, and the current through the component. The power dissipation of a component is a function of all of these variables.

The maximum operating rating of a component must be given in terms of a specific measurement method and performance limit. For example, the performance limit could be defined as exceeding a specified temperature rise or as a total breakdown of the insulation or wire. Different measurement methods and performance limit criteria lead to different conclusions. By establishing the method of measurement and the performance limit criteria, a baseline is set for evaluating each application.

Ultimately, circuit designers attempt to determine maximum operating limits for temperature, current, voltage, and power for each component. Each of these is specific to the application environment.

Coilcraft Inductor Current Ratings

Depending on the type of inductor (chip inductor, power inductor) we may specify an I_{sat} , I_{rms} , or I_{DC} current.

- Saturation current (I_{sat}) is the current at which the inductance value drops a specified amount below its measured value with no DC current. The inductance drop is attributed to core saturation.
- I_{rms} is the direct current (DC) that causes the temperature of the part to rise a specific amount above 25°C ambient. The temperature rise is attributed to I^2R losses.
- DC current (I_{DC}) is the current value above which operation is not recommended without testing the component in its intended application.

For some inductors I_{sat} is lower than I_{rms} . The core saturates before the component temperature reaches the performance limit. In this case we may specify only the I_{sat} as it is the limiting factor. For many inductors, I_{sat} is higher than I_{rms} . In these cases we may specify only I_{rms} and the temperature rise above ambient. In many cases, we specify both I_{rms} and I_{sat} current to illustrate which measurement is more critical. I_{DC} is specified typically when I_{rms} greatly exceeds I_{sat} .

Coilcraft Measurement Method and Performance Limit Criteria rms Current – I_{rms}

We determine I_{rms} by measuring the temperature rise above 25°C ambient caused by the current through a representative sample inductor. A low DC bias current is applied to the inductor, and the temperature of the inductor is allowed to stabilize. This process is repeated until the temperature rise reaches the rating limit. The measurements are taken on the top of the part with the sample inductor in still air with no heat sinking. The limit is typically a 15°C rise for chip inductors and a 40°C rise for power inductors.

Therefore, the current rating is based on the data sheet I_{rms} current and temperature rise. The temperature rise of a component due to current depends on the ambient temperature. To determine the component temperature due to rated current at ambient temperatures above the data sheet ambient temperature, see the “Ambient Temperature Range” section of this application note.

Saturation Current – Isat

Isat ratings are established by measuring the inductance of a representative sample at a specific frequency with no DC current. The DC current level is then gradually increased and the inductance is measured.

The Isat rating is the current level at which the inductance value drops a specified amount (in percent) below its measured value with no DC current.

Power Limit Calculations

Total or “apparent” power (P_A) consists of a combination of the average (real) power (P_{avg}) and the reactive (imaginary) power (P_{var}). While the purely reactive portion of power does not consume energy, there is some loss associated with its transmission back and forth in the circuit because transmission lines are not perfect conductors.

Temperature rise due to the heating effect of current through an inductor is related to the average real power dissipated by the inductor. The average real power is a function of the effective series resistance (ESR) of the inductor and the rms current through the inductor, as shown in Equation 1.

$$P_{avg} = (I_{rms})^2 \times ESR \quad (1)$$

where:

P_{avg} = average real power in Watts

I_{rms} = rms current in amps

ESR = effective series resistance in Ohms

Equation 1 estimates the average real power due to losses, assuming ESR accurately represents the ESR at the operating current of the application. This is typically not the case for power applications or higher-power RF applications. ESR from inductor manufacturers is typically measured on an impedance analyzer at very low (all AC) current with no DC bias current. The low-current ESR is also typically used in inductor simulation (SPICE) models, therefore, such models should not be used for loss or efficiency analysis unless the ESR is confirmed to be at the application current.

For the most accurate real power loss estimates of Coilcraft power inductors are given by our online calculation tools (DC-DC Optimizer, Power Inductor Finder and Analyzer). The results are based on actual measurements of loss under a wide range of operating conditions (current, frequency, temperature).

The apparent (total) power required by an inductor is a function of the rms current through the inductor, the rms voltage across the inductor, and the phase angle difference between the voltage and current. Equation 2 can be used to estimate the apparent power required for the inductor.

$$P_A = I_{rms} \times V_{rms} \times \cos(\theta) \quad (2)$$

where:

P_A = apparent power in Watts

I_{rms} = rms current in amps

V_{rms} = rms potential across inductor in Volts

θ = phase angle in degrees

Since the AC behavior of an inductor is frequency-dependent, and V_{rms} is application-specific, we recommend using our simulation models to determine the apparent power requirements for your specific application voltage and frequency.

Ambient Temperature Range

Ambient temperature is described as a range, such as “–40°C to +85°C.” The range describes the recommended ambient (surrounding environment) temperature range of operation. It does not describe the temperature of the component (inductor). The component temperature is given by Equation 3:

$$T_c = T_a + T_r \times 0.00385 \times (229.5 + T_a) \quad (3)$$

where:

T_c is the component temperature

T_a is the ambient (surrounding environment) temperature

T_r is the data sheet temperature rise due to rated current through the inductor

Refer to Appendix B for the derivation of this equation.

Example: The ambient temperature range for a power inductor is stated as –40°C to +85°C, and the I_{rms} is rated for a 40°C rise above 25°C ambient.

The worst-case component temperature would be (85°C + 49.4°C) = 134.4°C at the I_{rms} current.

DC Resistance vs. Temperature

Equation 4 can be used to calculate the approximate DC resistance of a component within the operating temperature range:

$$DCR_{T2} = DCR_{25} \times ((1 + 0.00385(T2 - 25))) \quad (4)$$

where:

DCR_{T2} is the DC resistance at the temperature $T2$

DCR_{25} is the data sheet value of DC resistance at 25°C

$T2$ is the temperature in °C at which the DC resistance is being calculated

Appendix A – rms Calculations

Figure 2 shows a typical sinusoidal waveform of alternating current (AC) illustrating the peak and peak-to-peak values. The horizontal axis is the phase angle in degrees. The vertical axis is the amplitude. Note that the average value of a sinusoidal waveform over one full 360° cycle is zero.

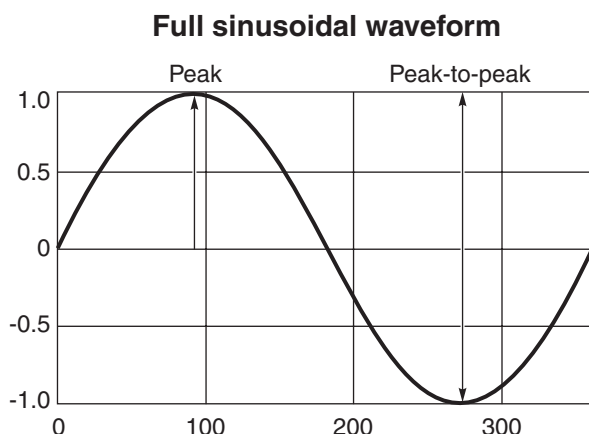


Figure 2

Figure 3 shows the same full sinusoidal waveform of Figure 2, full-wave rectified. The average rectified and rms values are illustrated for comparison.

Calculate the root-mean-square (rms) value by the following sequence of calculations: square each amplitude

Rectified sinusoidal waveform

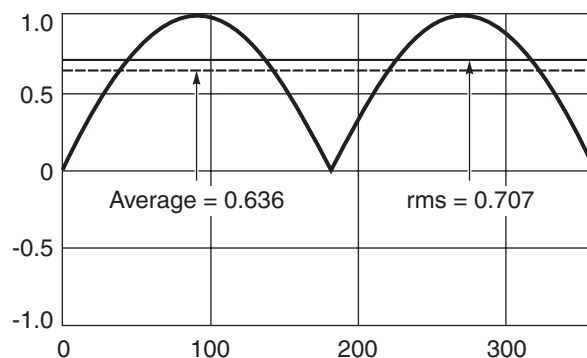


Figure 3

value to obtain all positive values; take the mean value; and then take the square root.

The rms value, sometimes called the “effective” value, is the value that results in the same power dissipation (heating) effect as a comparable DC value. This is true of any rms value, including square, triangular, and sawtooth waveforms.

Some AC meters read average rectified values, and others read “true” rms values. As seen from the conversion equation in Appendix B, the rms value is approximately 11% higher than the average value for a sinusoidal waveform.

Appendix B – Derivation of Temperature Rise Equation

Our current ratings are typically based on a specific temperature rise (T_r) above 25°C ambient, resulting from the rated current. When a component is used in a higher ambient temperature environment, the resistance of the component wire is higher in proportion to the temperature difference between the higher ambient (T_a) and 25°C. The increase in resistance depends on the thermal coefficient of resistance (TCR) of the wire (α). For copper wire, $\alpha \approx 0.00385$. When full rated current is applied to the component at a higher ambient temperature, the increased wire resistance results in increased I^2R losses. The increased losses are assumed to be converted to heat, resulting in a temperature rise that is proportional to the increase in resistance of the wire.

The derivation of the equation for determining the component temperature (T_c) when operating at a higher ambient temperature (T_a) follows. We begin with the definition of the temperature coefficient of resistance, using 25°C as our reference temperature.

$$\alpha = \frac{\Delta R}{R_{25}} / (T_a - 25) = \frac{R_a - R_{25}}{R_{25}} / (T_a - 25)$$

$$\frac{\Delta R}{R_{25}} = \alpha(T_a - 25)$$

The increase in temperature due to the increased resistance = $\frac{\Delta R}{R_{25}} \times T_r$

$$T_c = T_a + T_r + \frac{\Delta R}{R_{25}} \times T_r$$

$$T_c = T_a + T_r \left(1 + \frac{\Delta R}{R_{25}}\right)$$

$$T_c = T_a + T_r (1 + \alpha(T_a - 25))$$

$$T_c = T_a + \alpha T_r \left(\frac{1}{\alpha} + (T_a - 25)\right)$$

For $\alpha = 0.00385$

$$T_c = T_a + 0.00385 \times T_r (229.5 + T_a)$$

Definitions:

ΔR = Increase in resistance due to higher ambient temperature T_a

T_a = Ambient temperature (assumed to be >25°C)

R_a = Resistance of copper wire at ambient temperature (T_a)

R_{25} = Resistance of copper wire at 25°C ambient

T_r = Data sheet temperature rise due to rated current

T_c = Component temperature due to rated current at ambient temperature (T_a)

Appendix C – Conversion Factors for Various Waveforms

Use the following equations to convert between average, rms, peak, and peak-to-peak values of various waveforms of current or voltage.

Sinusoidal Waveforms

Given an Average Value:

$$\text{rms} = 1.112 \times \text{Average}$$

$$\text{Peak} = 1.572 \times \text{Average}$$

$$\text{Peak-to-Peak} = 3.144 \times \text{Average}$$

Given an rms Value:

$$\text{Average} = 0.899 \times \text{rms}$$

$$\text{Peak} = \sqrt{2} \times \text{rms} (\approx 1.414 \times \text{rms})$$

$$\text{Peak-to-Peak} = 2 \times \sqrt{2} \times \text{rms} (\approx 2.828 \times \text{rms})$$

Given a Peak Value:

$$\text{Average} = 0.636 \times \text{Peak}$$

$$\text{rms} = 1/\sqrt{2} \times \text{Peak} (\approx 0.707 \times \text{Peak})$$

$$\text{Peak-to-Peak} = 2 \times \text{Peak}$$

Given a Peak-to-Peak Value:

$$\text{Average} = 0.318 \times \text{Peak-to-Peak}$$

$$\text{rms} = 1/(2 \times \sqrt{2}) \times \text{Peak-to-Peak} (\approx 0.354 \times \text{Peak-to-Peak})$$

$$\text{Peak} = 0.5 \times \text{Peak-to-Peak}$$

Squarewave Waveforms

$$\text{Average} = \text{rms} = \text{Peak}$$

$$\text{Peak-to-Peak} = 2 \times \text{Peak}$$

Triangular or Sawtooth Waveforms

Given an Average Value:

$$\text{rms} = 1.15 \times \text{Average}$$

$$\text{Peak} = 2 \times \text{Average}$$

$$\text{Peak-to-Peak} = 4 \times \text{Average}$$

Given an rms Value:

$$\text{Average} = 0.87 \times \text{rms}$$

$$\text{Peak} = \sqrt{3} \times \text{rms} (\approx 1.73 \times \text{rms})$$

$$\text{Peak-to-Peak} = 2 \times \sqrt{3} \times \text{rms} (\approx 3.46 \times \text{rms})$$

Given a Peak Value:

$$\text{Average} = 0.5 \times \text{Peak}$$

$$\text{rms} = 1/\sqrt{3} \times \text{Peak} (\approx 0.578 \times \text{Peak})$$

$$\text{Peak-to-Peak} = 2 \times \text{Peak}$$

Given a Peak-to-Peak Value:

$$\text{Average} = 0.25 \times \text{Peak-to-Peak}$$

$$\text{rms} = 1/(2 \times \sqrt{3}) \times \text{Peak-to-Peak} (\approx 0.289 \times \text{Peak-to-Peak})$$

$$\text{Peak} = 0.5 \times \text{Peak-to-Peak}$$