How Current and Power Relates to Losses and Temperature Rise

Losses and Temperature Rise for Inductors and Transformers

Core and winding losses in inductors and transformers cause a temperature rise whenever current flows through a winding. These losses are limited either by the allowed total loss for the application (power budget) or the maximum allowable temperature rise.

For example, many Coilcraft products are designed for an 85°C ambient environment and a 40°C temperature rise implying a maximum part temperature of +125°C. In general, the maximum allowed part temperature is the maximum ambient temperature plus temperature rise. If the losses that result in the maximum allowed part temperature meet the power budget limits, the component is considered acceptable for the application.

The temperature rise created by core and winding losses is related to the thermal dissipation characteristics of the specific component. For example, 100 mW of loss might create a temperature rise of 40°C in one inductor but may result in only a 30°C rise in another inductor that has better thermal dissipation (thermal resistance) properties.

Thermal resistance is not specified for Coilcraft inductors or transformers because they are mostly open frame style and not solid, homogenous bodies like molded IC packages. These body styles have a variety of thermal flow paths and multiple heat sources (winding and core) as opposed to an IC that may generate heat in a specific junction and conduct heat consistently throughout the solid body.

From the datasheet specifications for DCR and Irms, an approximate thermal resistance (Rth) can calculated. Dividing the temperature rise due to Irms current (e.g. 40°C rise) by the power required to generate that rise (Power = DCR × $Irms^2$):

$Rth\ (in\ °C/W) = 40°C \div (DCR \times Irms^2)$

where DCR is in Ohms and Irms is in Amps.

Once a thermal resistance is calculated for a specific component, it is assumed that it is a fixed property of the materials and construction and does not vary at other operating conditions (temperature, current, frequency, etc.). Under this assumption, the temperature rise resulting from any specific power dissipation can be estimated from:

$Trise = Rth \times P$

where:
Trise is the temperature rise
Rth is the thermal resistance in °C/W and
P is the dissipated power in Watts

Irms Ratings and Temperature Rise

Coilcraft's current ratings specify a temperature rise that results from applying the rated (Irms) current. The specified temperature rise is allowable at or below the maximum ambient temperature rating.

The Irms rating is the effective DC (or low-frequency AC) current that causes the specified temperature rise. The actual temperature rise will be higher when core and winding losses are involved. Lower current must be applied as operation approaches the maximum ambient temperature rating. At lower ambient temperatures, the allowable temperature rise is that which results in the maximum allowed (ambient + temperature rise) part temperature. Core and winding losses depend on current and frequency, and the specific component material and construction. Therefore, current derating (based on temperature rise) depends on the specific losses resulting from the amplitude and frequency of the AC ripple current.

Core and winding losses, and an estimate of the resulting temperature rise, can be calculated for Coilcraft's power inductors using the web tool at this link:
http://www.coilcraft.com/apps/loss/loss_1.cfm

RF Chip and Air Core Inductors

Note: The following estimate does not account for current-dependent losses or other large-signal loss mechanisms at higher frequency that are not part of the small-signal ESR measurement, such as with ferrite, iron powder or composite core constructions.

Frequency-dependent small signal losses for our RF chip and air core spring inductors can be estimated based on the effective series resistance (ESR).

The ESR of our RF chip and air core spring inductors can be found using the graphing web tool at this link:
http://www.coilcraft.com/apps/lqz/lqz.cfm

Given the ESR at a specific frequency and the datasheet ratings, the maximum current the inductor can theoretically handle at that frequency (at maximum ambient temperature) can be estimated.

Example: An 1812CS-102XJL (1 µH) chip inductor has an Irms rating of 480 mA and a DCR maximum rating of 1.2 Ohms. The Irms rating corresponds to a 15°C temperature rise from ambient. The maximum allowed ambient temperature is 125°C, so the 15°C temperature rise allows for a maximum part temperature of ~140°C (125 + 15).

To estimate the power capability at maximum ambient temperature, calculate:

$Irms^2 \times DCR = (0.48\ A)^2 \times (0.8 \times 1.2\ \ Ohms)$
$= 0.221\ W = 221\ mW.$

Note that this assumes the nominal DCR to be 80% of the maximum specification. So, approximately 221 mW of power will cause the temperature of this inductor to rise ~15°C.

At RF frequencies, the ESR may be much higher than the DCR, therefore the amount of current that causes the same temperature rise will be significantly reduced. For example, if the RF signal is 100 MHz, the ESR of the 1812CS inductor in the example above is 8.14 Ohms (almost seven times the DC resistance) so the Irms AC current that corresponds to the same power (and thus temperature rise) is only 161 mA versus the 480 mA Irms rating.

If the application ambient temperature maximum is lower than the component data sheet maximum ambient temperature rating, it may be possible to operate at higher than rated current. Again, as long as the total (application maximum ambient + application component temperature rise) component temperature does not exceed the data sheet total (maximum ambient + component temperature rise due to Irms current) the part can be operated within safe limits.

To estimate the temperature rise due to current, use the power and thermal resistance calculations as described in the section above.

Ferrite, Iron Powder, or Composite Core Components

The performance of wideband chokes and transformers is obtained by using high permeability core materials such as powdered iron or ferrite. As RF signals travel through the inductor, frequency-dependent and current-dependent core losses contribute additional heat to the total produced by the inductor. The ESR measurement (typically made at very low current) does not capture these losses. Therefore the above estimation method is not applicable and will incorrectly predict a lower temperature rise than actually results. The component will get hotter than expected. This is true for any component that has a high permeability (ferrite, powdered iron, composite) core. In these cases, we suggest taking a temperature rise measurement of the inductor under all conditions of frequency and current that may result in your application to determine the worst-case temperature rise.

Duty Cycle

The above discussion applies to continuous current waveforms. For pulsed waveforms, the allowable equivalent currents can be estimated using the equations described in the Pulsed Waveforms section of Coilcraft Document 361 (Current and Temperature ratings) found at:

http://www.coilcraft.com/pdf_viewer/showpdf.cfm?f=pdf_store:Doc361_Current_Temp.pdf

References:

Current and Temperature Ratings, Coilcraft, Inc., Document 361, October 22, 2008