Common Issues with Power Supply Design: Part 2

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Introduction

This is the continuation of a series of white papers on the common problems seen with power supply designs, with a focus on inductors.

Selecting Off The Shelf Inductors

Selecting off the shelf inductors is not as simple as it seems. It requires understanding of the vendor specification and how it compares to your actual application. Vendors not only specify inductance but they usually give

- DCR (DC Resistance)
- Maximum DC Current Due to Heating
- Saturation current

in their datasheet to further characterize their devices. However, there are issues when selecting inductors based on these parameters:

DCR

This is the DC resistance of the winding. If this inductor is used in a switching power supply application, the inductor will most likely be running at an elevated temperature. Therefore you like to use the DCR value that is at the higher temperature than at 25C that is usually specified. If the DCR is only given at room temperature, you can use the temperature coefficient of copper to calculate the DCR at higher temperatures.

Maximum DC Current Due to Heating

The maximum DC current due to heating is related simply to I^2_{DC} x DCR which is the power loss due to the winding. For switching power supplies, usually the current through the inductor will have both a DC and AC component. Therefore, to calculate the total power loss due to the winding you will need to calculate both DC and AC losses. The AC resistance will be due to the skin effect and will be based on the geometry of the winding, relation to the core gap and frequency of the AC portion of the waveform. This resistance will always be higher than the DC resistance. If you want to maintain the same temperature rise, you will need to reduce the DC loss to compensate for the AC losses or reduce the current. Usually this will not be a problem for output inductors used in BUCK topologies because the AC current is relatively low. However, for discontinuous BOOST PFC circuits, the AC winding losses will be significant.

Another issue that does not show up with DC current but with AC current is core loss in the ferrite. Core loss is proportional to the volt-time applied to the inductor. This is an additional power loss in the inductor but it will be due to the core and it's not affected by DC current. Some vendors do give you this data in the form of curve fit equations.

Since the AC resistance and core loss is not known, you'll need to rely on measuring the temperature of the inductor to determine the actual temperature rise. If the temperature rise is an issue, try selecting another inductor but a lower DCR part may not be better. For example, if the AC losses are higher because of fields induced in the winding from the gap, cutting back the winding from the gap decreases significantly the AC resistance while only slightly increasing the DC resistance. Therefore it's possible to have a part with a higher DCR but with a much lower AC resistance which could have a total loss less than the lower DCR part.

Saturation Current

As the H field increases for magnetic materials such as ferrite, the flux density, B will increase linearly with the H field. The ratio of B/H is the effective permeability, μ of the material. However, there will be a point where the ratio of B/H starts to decrease because the flux density can no longer increase linearly with the H field. The start of this point is called the saturation current which is related to the applied H field. Ferrite material does not have a hard saturation curve but instead it gradually enters saturation which makes the saturation current subjective. This is why ferrite is classified as "soft" magnetic material.

Since the saturation current is not a "hard" number, most vendors spec the saturation current when the inductance drops by 10%. Since inductance is a function of the permeability μ, using the drop in inductance is a good indicator that the flux density, B is no longer increasing linearly.

For switching power supplies, the saturation current is important for three reasons:

1. If the saturation current is exceeded, the inductance decreases. This causes the peak current to increase. For example for a BUCK topology, $I_{PK} = I_{LOAD} + ½ \times I_{RIP}$ where $I_{RIP} = (V_{IN}-V_{OUT}) \times (V_{IN} / V_{OUT})\ 1 / (F_{SW} \times L)$. If the inductance, L decreases, the ripple current, I_{RIP} increases and the peak current, I_{PK} then also increases. As the peak current increases and the inductance drops, there will be a point where the current is so high that it will damage components in the power supply. Winding loss will increase since the RMS current is now effectively higher.

2. Earlier it was discussed that core loss is proportional to the volt-time that is applied to the core. That assumes that the inductor is operating in the linear part of the B-H curve. When saturating, the core loss increases considerably because significant energy is required to reset the core. This will increase the temperature rise in the core.

3. Certain control schemes like peak current mode rely on the inductor current during the on time as a linear ramp signal to compare the error voltage with. If the inductance is changing the inductor current may not look like a ramp but as an exponential function or a lower inductance value which either way can affect the behavior of the control loop

You would like to select an inductor with a saturation current that is high enough that your inductance is not changing at the peak current. Most vendors spec the saturation current where the inductance has dropped by a specified amount. Rule of thumb is that if the inductance drops by a certain amount, decrease the saturation current by the same percentage. For example if the saturation current is defined by 20% drop in inductance, then do not allow the peak current in the inductor to exceed 80% of the saturation current.

You will note there was no mention of DC versus AC current component. Saturation current is independent of whether it's DC or an AC waveform. This just depends on the peak value of the current.

You can see that selecting an inductor is not as straight forward as it appears. The data vendors give is for DC operation but for switching power supplies you will have an AC component to the current. This will result in a higher temperature rise than expected. Then there is the issue of saturating the inductor which also can cause a temperature rise in the inductor and even possibly damage to the power supply.