The Importance of Estimating Power Losses in Consumer Power Supply Magnetic Components

APPLICATION NOTE

SRR1206

SRR1260

INTRODUCTION

At high switching frequencies, inductors can play a significant role affecting the power loss in power supplies used in consumer electronics. While there is no shortage of tools to help engineers design and simulate power supplies, the amount of information available on the performance of an inductor at high frequencies is scarce. This application note presents the importance of identifying the accurate AC resistance of an inductor, and provides a design example for estimating power losses based on the Bourns® Model SRR1206 and SRR1260 inductors. This application note also illustrates that while core losses are still small compared to AC losses in many surface mount power inductors, core losses and thermal effects must be taken into consideration.

THE PROBLEM TO BE SOLVED

The following example provides a guide to all the factors that must be taken into consideration when estimating power losses. The key component to consider is a forward converter, which is the industry-standard name for an isolated buck converter. The basic elements of the open loop section of a single-switch forward converter are shown in figure 1. The control circuit and feedback loop are omitted here for clarity.

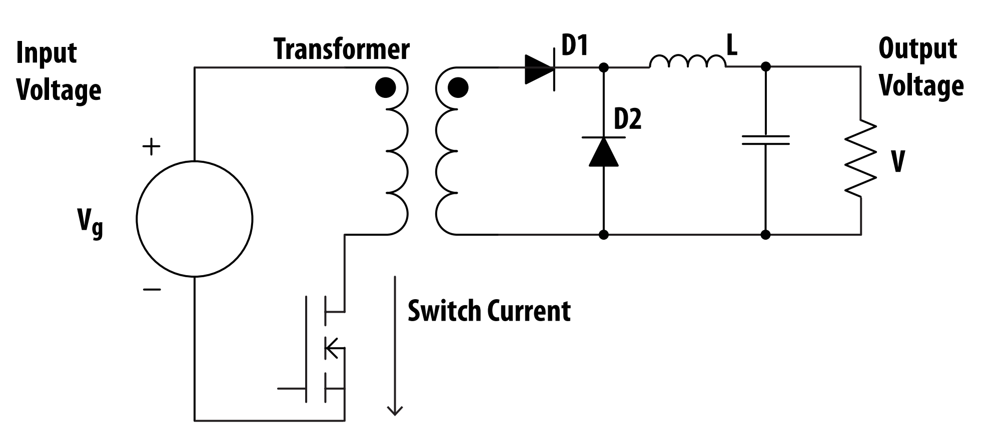

Figure 1. Basic Block Diagram of Forward Converter Power Stage

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THE PROBLEM TO BE SOLVED *(Continued)*

Using an example application, the following are typical design requirements for a power supply that drives a string of lighting LEDs.

Input Voltage	36 V
Switching Frequency	210 KHz
Output Voltage	8 V
Output Current	2 A
Ripple Current	0.75 A pp
Ambient Temperature	40 ˚C
Duty Cycle D	0.65

Table 1. | *Design Requirements for a Power Supply That Drives a String of Lighting LEDs*

Peak voltage at D1 is calculated as:

$$\text{VD1}=\frac{8\text{ V}+0.5\text{ V(diode)}+0.1\text{ V(PCB conduction loss)}}{\text{D}}=13.23\text{ V}$$

The voltage measured across the inductor ΔV during the first interval is, therefore, 5.23 V. The subsequent inductance value is: L =ΔVxDx (1/f)/ ΔI =21.58 µH.

However, 21.58 µH is not a standard inductor value, so for this example, a 22 µH inductor is selected, which is the closest standard inductor available.

A power inductor such as the Bourns® Model SRR1206-220M inductor has a resistance of 62 mΩ and an RMS current of 2.3 A. At an initial glance, it appears that the calculated losses are due to the DC resistance of the winding and the DC current of 2 A. This calculation gives a power loss of 0.248 W. The information on the data sheet shows that the Bourns® Model SRR1206-220R0ML inductor can conduct up to 2.3 A_{rms} giving a total power dissipation of 0.327 W. The temperature rise at full load according to the Bourns' data sheet is 40 °C. If the ambient temperature is 40 °C, then the inductor would be expected to rise in temperature to less than 80 °C at the required current of 2 A. However, the following additional factors must be taken into account.

Thermal

Copper has a very high temperature coefficient. The resistance at 43 °C ambient will increase to 67 mΩ. The DC loss in the winding will, therefore, be 0.268 W at a current of 2 A.

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THE PROBLEM TO BE SOLVED *(Continued)*

AC Resistance

The distribution of current in each layer of a multilayered wound inductive component will be unevenly distributed depending on the frequency of the current. The magnetic fields generated by the multiple layers are responsible for this effect and are known as “proximity”. The illustration in figure 2 shows how the current is pushed towards the core. There is a one-dimensional solution to the complex differential equations describing the ratio of the AC resistance to the DC resistance, which is called the Dowell equation. This equation enables us to calculate losses in the inductive component due to proximity.

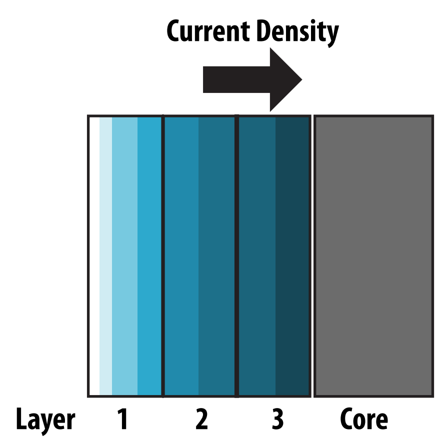

Figure 2. | *Distribution of Current in a Multilayer Inductor*

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THE PROBLEM TO BE SOLVED *(Continued)*

AC Resistance *(Continued)*

Using Dowell's equation, the AC resistance plot of the Bourns® Model® SRR1206-220R0ML inductor against frequency is shown in figure 3.

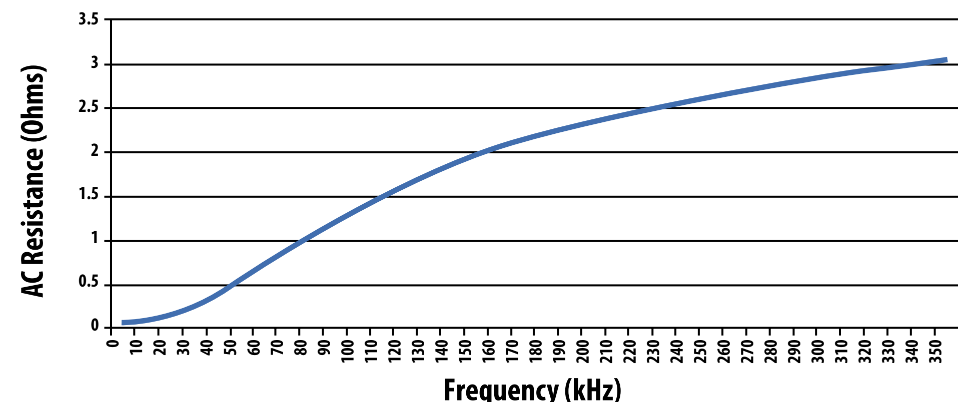

Figure 3. | *Dowell Equation Applied to the Bourns® Model SRR1206-22R0ML Inductor*

The AC current in the inductor is a sawtooth waveform, and can be written as $I_{rms} = I\sqrt{(1/3)}$. For this device, the RMS value is calculated at 0.22 A, given that the current in the inductor is 0.75 A peak-to-peak.

From figure 3, the AC resistance at the switching frequency is 2.4 Ω. This generates a loss due to proximity of 0.112 W in the inductor.

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THE PROBLEM TO BE SOLVED *(Continued)*

Core Losses

The ferrite core also generates some losses due to the eddy currents generated by the swings in flux as current rises and falls in the coils of the inductor. These are known as core losses. Faraday's Law is used to calculate the flux density B in the wound core.

$B = 1/NA * \int e\,dt$: Faraday's Law

Using this calculation, the peak flux in this application is 26 mT. By convention, the change in flux density or ΔB is taken as one half the peak flux or 13 mT. By checking the core data, it is known that the loss at 210 kHz at a ΔB of 13 mT is 50 mW.

The total dissipation in the inductor is now 0.438 W (0.268 W + 0.12 W+0.05 W). The original calculation was an erroneous 0.248 W with the new measurement indicating that the device is now actually above the rated full power of the inductor at 0.325 W.

This information can save significant time for a designer in the component selection process. Having AC resistance curves at hand can be very useful when selecting the right magnetic component along with the understanding that AC losses are more significant than core losses.

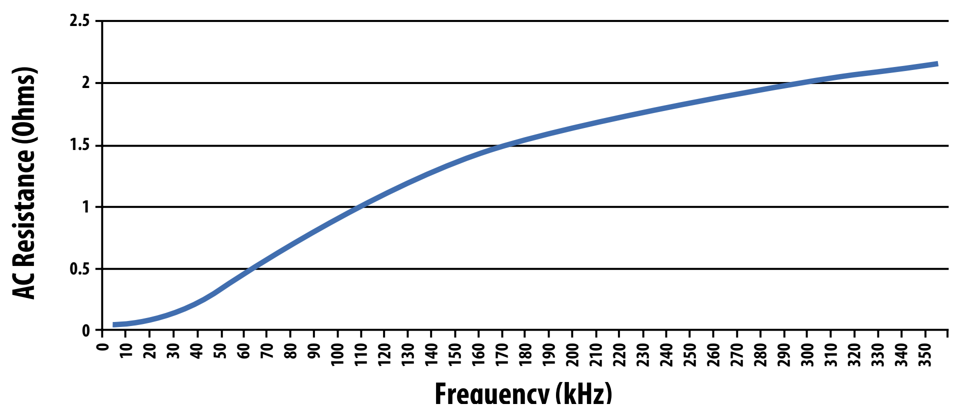

Figure 4. | *AC Resistance of the Bourns® Model SRR1260-220R0ML Inductor at 40 °C*

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FINDING THE OPTIMAL SOLUTION

From the power loss estimates in the example provided, the optimal solution for designers is to select an inductor with the same dimensions as the Bourns® Model SRR1206 inductor but with a lower DC resistance. Therefore, the Bourns® Model SRR1260 is the right inductor for this application example. It features the same core as the Bourns® Model SRR1206, as well as the exact footprint (12.5 x 12.5 x 6 mm). It also has the identical number of winding layers, which means that the ratio of AC to DC resistance is unchanged. Applying Dowell's equation to the Bourns® Model SRR1260 inductor gives an AC resistance as shown in figure 3. At 210 kHz, the AC resistance is 1.7 ohms. The total losses including core losses are 0.3 W (0.170 W + 0.082 W+0.05 W), which is well below the rated maximum DC power of 0.688 W.

ACHIEVING ENHANCED POWER SUPPLY RELIABILITY

For the highest operational reliability, care should be taken when selecting an inductor for a power supply application. As demonstrated in this application note, choosing an inductor by relying purely on the rated DC current as written in the data sheet could lead to complications such as overheating and premature failures in the field. While core losses are often mentioned as being a problematic source, AC resistance can be much more detrimental to the application and is often overlooked. If the information on AC resistance is not available, designers may be forced to "over-specify" the inductor to give them enough margin to accommodate any additional losses. Bourns developed the curve charts in figures 3 and 4 to benefit design engineers in estimating power losses to determine the optimal inductor for their next power supply design.

ADDITIONAL RESOURCES

For more information on Bourns® Magnetic Components,
visit Bourns online at:

www.bourns.com

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