Tech Notes

How to Use Power Inductors

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As electronic devices become more advanced, the power supply voltage of LSIs used in them is lowered, so their power consumption can be reduced and their speed increased. However, a decrease in the power supply voltage also causes the requirements regarding voltage fluctuations to become more severe, creating a need for high-performance DC-DC converters to fulfill these characteristic requirements, and power inductors are important components that greatly affect their performance. TDK has a widely varied lineup of power inductor products, and this article describes and explains effective methods for using power inductors, and key points for selecting them, according to the required characteristics of DC-DC converters.

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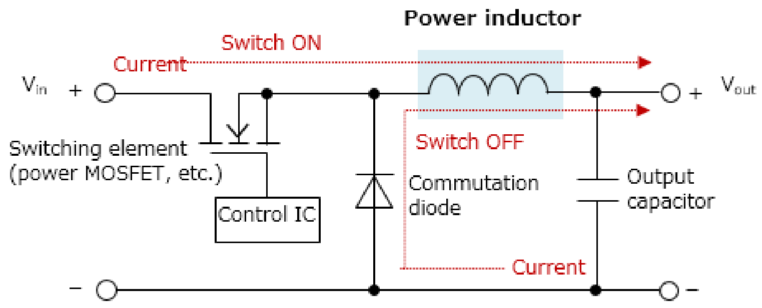
Power inductors are important components that largely affect DC-DC converter performance

Although inductors (coils) are capable of transmitting direct current smoothly, if the current varies they will generate electromotive force to obstruct those fluctuations. This is known as **self-induction**, and with alternating current it has the property of obstructing transmission to the point where it can appears at higher frequencies. Therefore, if a current is passed through an inductor it will be accumulated as energy, and if the current is interrupted this energy will be discharged. **Power inductors** are components which effectively apply this property and are used primarily in power supply circuits for equipment such as DC-DC converters.
Figure 1 shows a basic circuit for a **step-down DC-DC converter** (diode rectification type). Power inductors are important components that largely affect its performance.

Figure 1: Basic Circuit of Step-down DC-DC Converter (Diode Rectification Type)



When the switching element is ON, the power inductor accumulates energy, and when it turns OFF the energy is discharged and the current is transmitted. The voltage can be decreased to the required value by setting the duty ratio (ratio of ON time to switching cycle).

Vout = Vin × Duty

Parameters related to power inductor characteristics have a complex trade-off relationship with each other

The difficulty in designing a power inductor stems from the variability of its characteristics according to factors such as temperature and current magnitude. For example, **inductance** (L) has the property of decreasing as the current becomes larger (**DC superimposition characteristics**), and temperature rises caused by increase of current can cause the inductor core **magnetic permeability** (μ) and **saturation magnetic flux density** (Bs) to change as well. Even with the same inductance value, the **DC resistance** (Rdc) will change depending on the winding thickness and the number of windings, causing variations in the degree of heat generation, and differences in the magnetic shield structure can also affect the noise characteristics.
These parameters have a complex, mutual trade-off relationship with each other, making it critical to select the best power inductor for an application from an overall perspective, with consideration for the efficiencies, sizes, and costs of DC-DC converters.

Key Point Magnetic cores of power inductors are broadly classified into ferrite and metal types

Power inductors can be broadly classified into **wire-wound**, **multilayer**, and **thin-film** types, according to differences in their production methods, with ferrite or metallic magnetic materials used in their cores. Ferrite cores have a high μ value and high inductance, while metallic magnetic cores have excellent saturation magnetic flux density, making them well-suited to larger currents.

Key Point There are two types of rated currents for power inductors: allowed current for DC superimposition, and allowed current for temperature rise

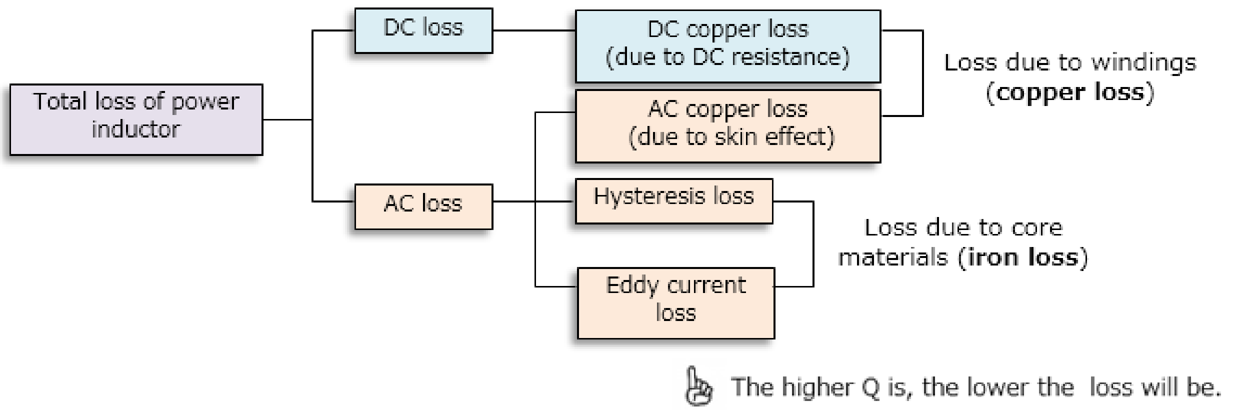
If the core of a power inductor becomes **magnetically saturated**, its inductance value will drop. The guideline for the maximum current that can be transmitted without reaching magnetic saturation is the **allowed current for DC superimposition** (example: drop of 40% from initial inductance value). The current defined by the heat generation according to the electrical resistance of the windings is the **allowed current for temperature rise** (example: temperature rise of 40℃ due to self-heat generation). The **rated current** is generally considered to be the smaller of these two types of allowed currents.

The conditions of loss will change depending on the sizes and frequencies of loads

Key Point The main types of loss which can cause rises in temperature are copper loss due to windings, and iron loss due to core materials

Loss which occurs due to windings is known as **copper loss**, while that due to core materials is known as **iron loss**. The main copper loss is caused by the DC resistance (Rdc) of the windings (DC copper loss), and increase proportionally to the square of the current. Also, as the frequency of AC current becomes higher, there is a tendency for the current flow to become concentrated in the area near the conductor surface and for the effective resistance value to increase (**skin effect**). In high frequency regions, copper loss resulting from the AC current (AC copper loss) will be added as well.
The main iron loss are hysteresis loss and eddy current loss. Eddy current loss is proportional to the square of the frequency, so in high frequency regions the core loss caused by eddy current loss becomes larger. One key point for improving efficiency is selecting core materials which have low core loss even in high-frequency regions.

Figure 2: Factors Contributing to Power Inductor Loss



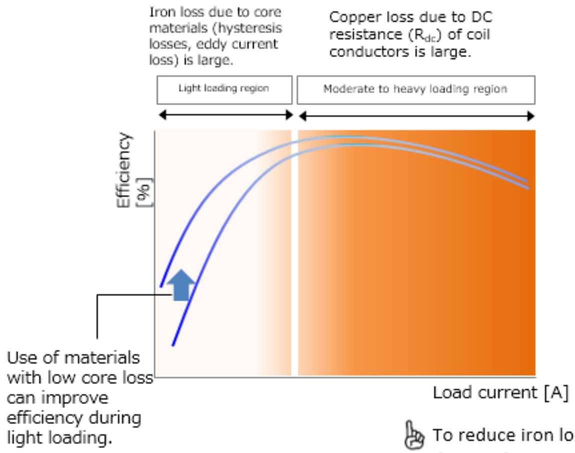
The higher Q is, the lower the loss will be.

Key Point

Copper loss becomes dominant during moderate to heavy loading, while iron loss becomes dominant during light loading

Power inductor loss also changes depending on the size of loads. For currents flowing through inductors during moderate to heavy loading, the DC bias current is large so the copper loss occurring due to the DC resistance (Rdc) of the windings becomes dominant. On the other hand, during light loading there is almost no DC bias current flow so the copper loss is reduced, but since constant-frequency switching operation is performed even during standby status, the iron loss due to the core materials becomes dominant and the efficiency decreases significantly (Figure 3).

Figure 3: Differences in DC-DC Converter Load Sizes and Power Inductor Loss



To reduce iron losses, lower the driving magnetic flux density during use (A higher inductance value is favorable, however this will cause the Rdc to become larger.)

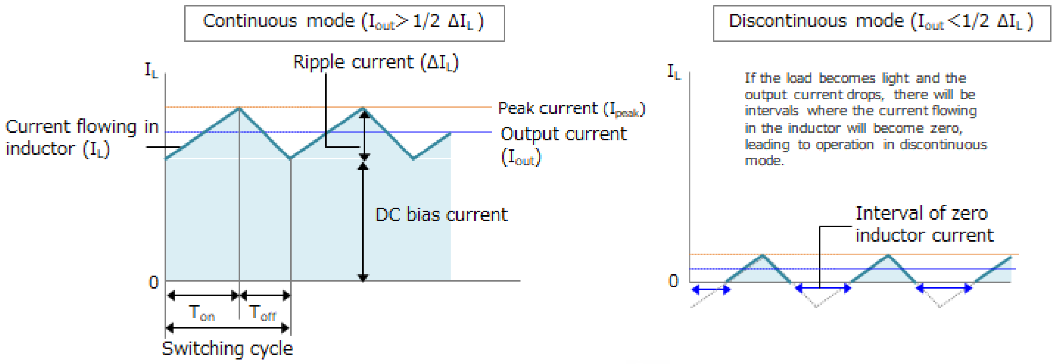
It is essential to specify appropriate inductance values by considering factors such as ripple current

Key Point

Use in discontinuous mode will affect power supply stability

In power inductors for step-down DC-DC converters, there will be a flow of ripple current (ΔIL) with a waveform of continuous triangular waves, in association with the ON/OFF operation of its switching elements (Figure 4). During moderate to heavy loading, the ripple current will be superimposed on the DC bias current, so there will be no interruption in the inductor current, a state known as **continuous mode**(Iout> 1/2ΔIL). However, in diode rectification DC-DC converters, during light loading where Iout<1/2ΔIL, there will be intervals where the inductor current will become zero. In this state, known as **discontinuous mode**, the inductor current will be interrupted intermittently and the stability of the power supply will therefore be affected. If the inductor operates in discontinuous mode, acoustic noise will also occur and ringing will be generated in the pulsed voltage waveform as a result of switching, which will contribute to the generation of noise.

Figure 4: Continuous and Discontinuous Mode of Diode Rectification DC-DC Converters



If the load becomes light and the output current drops, there will be intervals where the current flowing in the inductor will become zero, leading to operation in discontinuous mode.

Using synchronous rectification can allow the current to always flow continuously.

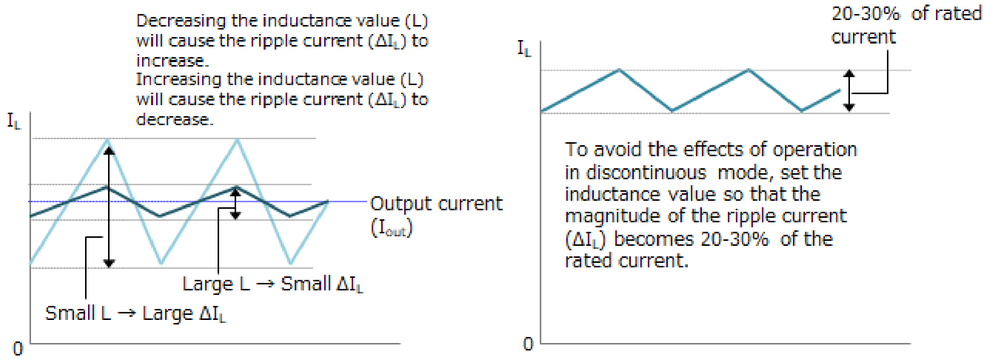
Key Point Choose the inductance value such that the ripple current becomes 20-30% of the rated current

The magnitude of the ripple current is related to the inductance of the power inductor. Diode rectification DC-DC converters should therefore be designed to avoid problems associated with operation in discontinuous mode, by restricting the ripple current. The inductance value L required for a power inductor can be determined by the following formula.

Inductance value L = (Voltage applied to inductor/Ripple current) x Ton

It can be seen from this formula that there is a trade-off relationship between the magnitudes of the inductance and the ripple current. If it is desired to use a power inductor with small inductance due to issues of size or cost, the ripple current will become larger. Conversely, if it is desired to reduce the ripple current, a large inductance will be required, which could lead to drawbacks from the viewpoint of size or cost, or could cause the **transient response characteristics** to worsen during sudden load changes, as will be explained later. Therefore, it is normally considered best to specify the inductance value so that the ripple current becomes 20-30% of the rated (it will be discontinuous at roughly 10% of the rated current) (Figure 5).

Figure 5: Relationship between Ripple Current and Inductance



Decreasing the inductance value (L) will cause the ripple current (ΔI_L) to increase.
Increasing the inductance value (L) will cause the ripple current (ΔI_L) to decrease.

To avoid the effects of operation in discontinuous mode, set the inductance value so that the magnitude of the ripple current (ΔI_L) becomes 20-30% of the rated current.

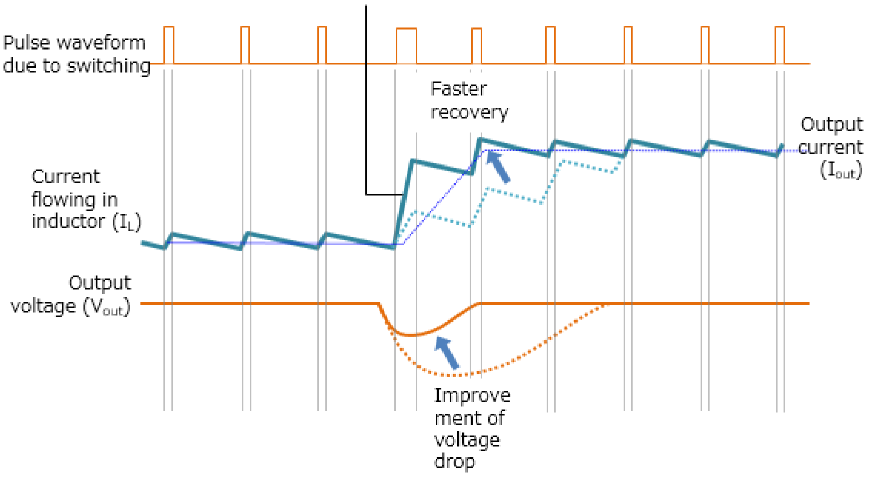
There is a relationship between the magnitudes of the ripple current and the output ripple voltage, but the ripple voltage can be reduced by using a low-ESR output smoothing capacitor.

Key Point Properly lowering the inductance value can improve the load response characteristics

At times such as when the load has increased suddenly, there will be a drop in output voltage, and to recover from it, an abnormally large peak current may flow through the power inductor over a short time to charge the output capacitor, along with the load current. If the ripple current has been set to a small value, however, it will not be possible to obtain the transient response characteristics required to recover quickly from a sudden drop in output voltage. One method of addressing this situation would be to reduce the inductance value and thereby increase the ripple current. As shown in Figure 6, the output voltage drops substantially if the load response characteristics are poor, but if the inductance value is lowered appropriately and the ripple current is increased, the change in the inductor current will become larger, causing the drop in voltage to be reduced and allowing faster recovery. However, when lowering the inductance value it will be important to use a setting that takes sufficient consideration for overall balance.

Figure 6: Improvement in Transient Response Characteristics when Inductance is Lowered

If the load response characteristic is poor, the output voltage will drop substantially. However, by lowering the inductance value appropriately and thereby increasing the ripple current, the change in the inductor current will become larger, reducing the output voltage drop and allowing faster recovery.

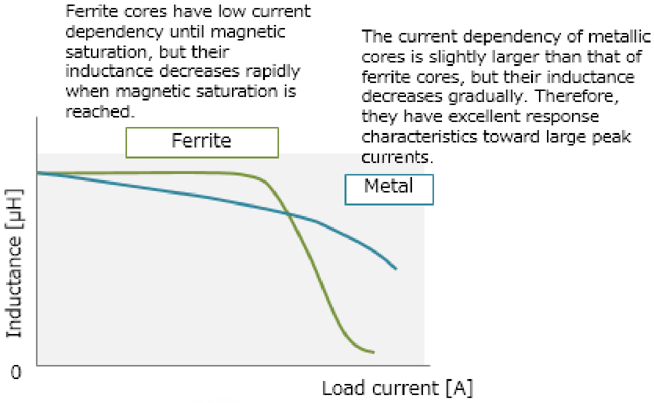


The voltage drop can be suppressed by increasing the capacity of the smoothing capacitor, but this will cause the time required until recovery of the voltage to become longer.

Key Point **To respond to the peak current generated during sudden load changes, set the current peak value to be 110-130% of the overcurrent setting.**

Power supply ICs with modular switching elements, control circuits, or other such components are equipped with internal **overcurrent protection circuits**. Although the overcurrent setting values and detection methods may vary widely, overcurrent protection circuits must also be considered when selecting an externally-mounted power inductor. If there is insufficient leeway in the allowed current of a power inductor with respect to peak current, it may cause the overcurrent protection circuit to operate and stop the output. In general, the peak value of current flowing in a power inductor should be set to be roughly 110-130% of the overcurrent setting value. Also, as indicated by the DC superimposition characteristics graph in Figure 7, in situations where a flow of excessive peak current could occur, it would be suitable to use a metallic inductor whose core has gradual magnetic saturation characteristics (**soft saturation**) and which will not cause sudden drops in inductance.

Figure 7: Comparison of DC Superimposition Characteristics for Ferrite and Metallic Cores



Ferrite cores have low current dependency until magnetic saturation, but their inductance decreases rapidly when magnetic saturation is reached.

The current dependency of metallic cores is slightly larger than that of ferrite cores, but their inductance decreases gradually. Therefore, they have excellent response characteristics toward large peak currents.

Metallic materials have a small μ and require more windings to attain a high inductance

Care must also be taken regarding leakage flux and acoustic noise

Key Point **Leakage flux from power inductors can affect their surroundings and cause noise**

If the leakage flux from power inductor is large, it could affect their surroundings and cause noise. Power inductors with magnetic shield structures are available as a measure to reduce leakage flux, so it is important to select the most appropriate product type for application. For details, refer to the following article.
[Related Page] Application Guide: "Selection Guide for Power Inductors in Consideration of Leakage Flux"

Key Point **Use of the PFM method during light loading could create problems with "acoustic noise" in power inductors**

One method used to improve the efficiency of DC-DC converters is switching from PWM mode, which performs switching at constant frequency and controls the pulse width under light-load conditions, to **PFM** (**pulse frequency modulation**) mode, which keeps the pulse width constant and controls the frequency. However, if the switching frequency becomes 20kHz or lower, caution will be required since a problem may occur in which the vibrations resulting from the core's magnetostrictive effects and magnetic attraction will become audible as what is known as "**acoustic noise**". This problem may also be caused by excessive fluctuations in load current.
[Related Page] Solution Guide: "Measures against Acoustic Noise in Power Inductors"

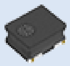
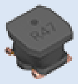
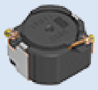
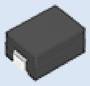
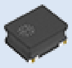
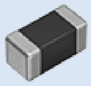
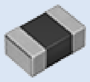
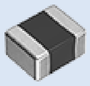
Required characteristics of DC-DC converters and power inductors

Table 1 shows the required characteristics of DC-DC converters and the related characteristics of power inductors, and Table 2 summarizes the main types of power inductors offered by TDK. For details on their characteristics and specifications, please use the Product Information pages and Selection Guides from the TDK Product Center, or our tools such as functions to search by characteristic values.

Table 1: Required Characteristics of DC-DC Converters and Power Inductors

Required Characteristics of DC-DC Converters	Technology and Measures for Response by Power Inductors
High efficiency	Low-loss inductors (reduction of copper losses and iron losses)
Small sizes and low profiles	Application of multilayer technology and thin-film technology, adoption of metal composite types, etc.
Large currents	Adoption of metallic cores, adoption of rectangular wires, etc.
Improvement of output stability	Improvement of DC superimposition characteristics, improvement of temperature characteristics, measures using circuits, etc.
Improvement of transient response characteristics	Optimization of inductance values, optimization of ripple current, etc.
Response to peak current	Appropriate current peak settings, linkage with overcurrent protection circuits, soft saturation by adopting metallic inductors, etc.
Low noise	Reduction of leakage flux, measures against discontinuous mode, etc.
Measures against acoustic noise	Vibration damping structures, adoption of multilayer, thin-film, and metal composite types

Table 2: TDK's Main Types of Power Inductors

Type	Wire-wound Inductors							Multilayer Inductors		Thin-film Power Supply Inductors
Product	Ferrite					Metal		Ferrite	Metal	Metal
										
Series Name	NLCV	VLS-CX	VLS-EX	CLF SLF LTF	VLB VLBU VLBS	VLS-HBX	SPM	MLP MLD	MLS (Under development)	TFM
Shielding	No shield	Resin shield	Resin shield	Shield	Shield	Resin shield	Shield	Shield	Shield	Shield
Size	Small size	Small size	Middle size	Middle size Large size	Middle size	Small size	Middle size ~Large size	Thin type Small size	Small size	Small size
Features	Resin mold	Low Rdc	Wide inductance range	Wide inductance range, 150°C	Low L, large currents	Large currents	Large currents	High Q	Large currents high efficiency	Large currents high efficiency 150°C

Contact Information

Inquiries on products, sales, or technical matters

Related Links

Product Portal

Inductors (Coils) product informaton
A comprehensive guide to information on Inductors (Coils) from the TDK Group.

Selection Guides

Selection Guide
Inductors for Power Circuits (Commercial Grade)

Selection Guide
Inductors for Power Circuits (Automotive Grade)

Products & Technologies

Product Overview
Ferrite Shield-Type Automotive Power Inductors

Product Overview
Power Inductor SPM Series

Product Overview
Power Inductor TFM Series

Product Overview
Power Inductor VLS Series

Applications & Cases

Application Note
Selection Guide for Power Inductors in Consideration of Leakage Flux

Solution Guide

Solutions for silencing DC-DC converters
Measures Against Acoustic Noise in Power Inductors