Switching Regulator Series

Considerations for Power Inductors Used for Buck Converters

No.16027EAY19

A number of inductors used for buck converters are being sold by manufacturers and users are often at a loss as to which of them to select. This application note explains the features and things to consider when shopping for power inductors.

Types of Power Inductors

Power inductors used for buck converters are roughly classified into three types. The wire wound ferrite type is further categorized into an open magnet type in which a wire is simply wound around a drum-type ferrite core, and a closed magnet type (shield type) that covers an open magnet type with a ferrite bobbin. While the open magnet type is small and excellent in performance because inductance saturation is unlikely to occur, its DC resistance is larger than that of the closed magnetic type and magnetic flux leaks out of the inductor, which might adversely affect other circuits. The wire wound ferrite type is most commonly used in boost, buck, inverting and DC/DC converters. Especially, applications that strongly require noise reduction, such as in-vehicle equipment, select the closed magnet type.

The metal composite type of power conductor is manufactured by inserting a coil in a die, charging measured magnetic powders and integrally molding at high pressure. Since the metal composite core features a saturated magnetic flux density that is about twice as much as that of a ferrite core, only a quarter volume is required to accumulate the same amount of energy as that of a ferrite core. However, since its magnetic permeability is generally lower than that of a ferrite core, an increasing number of windings are required to gain the same inductance value. Although the metal composite type is suitable for applications requiring a miniature structure and large current, its inductance value is smaller than that of the wire wound ferrite type. Also, you should pay attention to power inductors that feature a DC withstand voltage as low as 30V.

The multilayer type of power inductor is manufactured by laminating ferrite sheets on which conductor metal is printed to form a coil, and enables extreme miniaturization. Although not suited for applications requiring a large inductance value or large current, the multilayer type can be integrated into DC/DC converters for small currents that control switching operations at high frequency, because of its small inductance value.

Items Described in Catalogs

Besides the inductance value and tolerance, the main electrical characteristics are described in the manufacturer's catalogs. Table 2 shows a wire wound ferrite type inductor manufactured by TAIYO YUDEN.

Item	Wire wound ferrite type	Metal composite type	Multilayer type
Structure	Copper wire wound around a ferrite core	Integrally molded metal powders and wound wire	Laminated ferrite sheets on which conductor metal is printed
Inductance value	High (approx. ≥4.7µH)	Medium (approx. ≤4.7µH)	Low (approx. ≤4.7µH)
DC resistance value DCR	Low	High	High
Q	High	Low	Low
Rated current value	Medium	High	Low
DC superimposing characteristics at saturation	Inductance value is rapidly reduced.	Inductance value is reduced gradually because of difficulty in saturation.	Inductance value is rapidly reduced.
Characteristics at high temperature	Poor	Good	Good
Applications	Buck, Boost, Inverting Medium current Approx. ≤1MHz	Buck Large current, low voltage Approx. ≥1MHz	Buck Small current Approx. ≥3MHz

Table 1. Features of Power Inductors by Type

●NRH2410 Shielded type

Parts number	EHS	Nominal inductance [μH]	Inductance tolerance	Self-resonant frequency [MHz] (min.)	DC Resistance [Ω] (±20%)	Rated current ※) [mA] Saturation current: Idc1 Max.	Rated current ※) [mA] Temperature rise current: Idc2 Max.	Measuring frequency [kHz]
NRH2410T R68NN 4	RoHS	0.68	±30%	120	0.060	2,200	1,570	100
NRH2410T 1R0NN 4	RoHS	1.0	±30%	106	0.070	1,800	1,410	100
NRH2410T 1R5MN	RoHS	1.5	±20%	94	0.110	1,550	1,160	100
NRH2410T 2R2MN	RoHS	2.2	±20%	77	0.150	1,290	970	100
NRH2410T 3R3MN	RoHS	3.3	±20%	56	0.220	1,000	770	100
NRH2410T 4R7MN	RoHS	4.7	±20%	50	0.290	880	670	100
NRH2410T 6R8MN	RoHS	6.8	±20%	43	0.410	750	570	100
NRH2410T 100MN	RoHS	10	±20%	32	0.690	550	450	100
NRH2410T 150MN	RoHS	15	±20%	27	1.02	470	370	100
NRH2410T 220MN	RoHS	22	±20%	22	1.47	390	300	100

Table 2. TAIYO YUDEN Catalog

(Source: TAIYO YUDEN Inductor Catalog in 2016)

DC Resistance

DC resistance is a resistance of a wound wire (copper wire), and affects efficiency at high current. Since heat is generated in the inductor via resistance in proportion to the square of inductor current, a higher resistance value increases the energy loss caused by heat generation and accordingly lowers the conversion efficiency. Since an inductor having a low series resistance is subject to up-sizing and increase in cost, low resistance and high efficiency are in a trade-off relationship. Compared to the wire wound ferrite type of power inductor, the metal composite type requires an increasing number of windings (of copper wire) to gain the same inductance value, which shows a tendency toward large DC resistance.

DC Superimposed Allowable Current

DC superimposed allowable current represents how the inductance value changes against the current flowing in the inductor. Table 2 shows a list of DC current values when the inductance value reduces by 30% from the initial value. This condition varies depending on the manufacturer and inductor series. Therefore, due consideration must be taken when comparing with other inductors.

Figure 2 shows an example of characteristics. When DC current flows in the inductor, magnetic saturation starts in the ferrite in response to the increase in current, and the inductance value lowers due to deterioration of magnetic permeability. Since the saturated magnetic density of the metal composite type is higher than that of the wire wound ferrite type, the inductance value gradually decreases as shown in Figure 3 regardless of the increase in current.

The DC superimposed allowable current value is judged as to whether or not the specification satisfies the inductor current peak current value shown in Figure 1. You should select an inductor having a sufficient leeway in the inductor specification.

Temperature Rise Allowable Current

Temperature rise allowable current is a current value that represents how the inductor generates heat against current flowing to the inductor. Figure 4 shows an example of characteristics. The example in Table 2 lists the DC values when the inductor temperature rises by 40°C. This condition varies depending on the manufacturer and inductor series, as well as the difference in heat radiation characteristics of the measurement board and the difference in measurement position. Therefore, due consideration must be taken when comparing with other inductors.

The temperature rise allowable current value is judged as to whether or not the specification satisfies the inductor current average value shown in Figure 1. You should select an inductor having a sufficient leeway in the maximum value of the inductor specification.

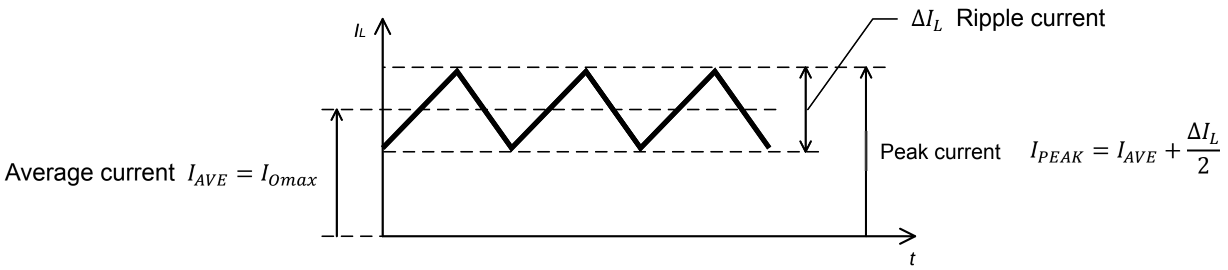

Figure 1. Inductor Current

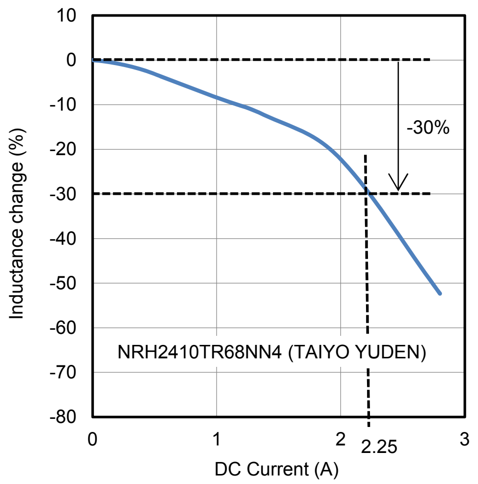

Figure 2. Example of DC Superimposed Characteristics in Table 2

(Source: TAIYO YUDEN Engineering Data in 2015)

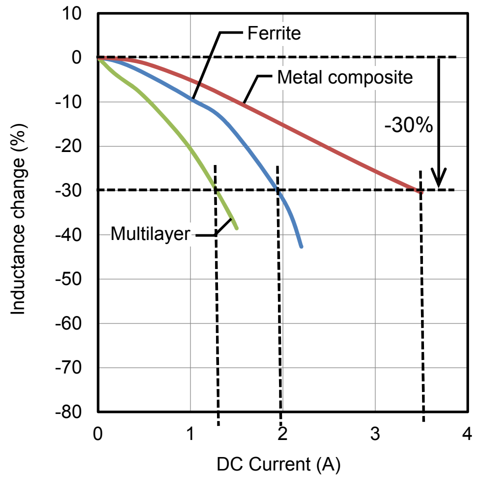

Figure 3. DC Superimposed Characteristics by Structure

Wire wound ferrite type: NRH2410T1R0 (TAIYO YUDEN)
Metal composite type: MAKK2520T1R0 (TAIYO YUDEN)
Multilayer type: CKP25201R0-T (TAIYO YUDEN)

(Source: TAIYO YUDEN Engineering Data in 2015)

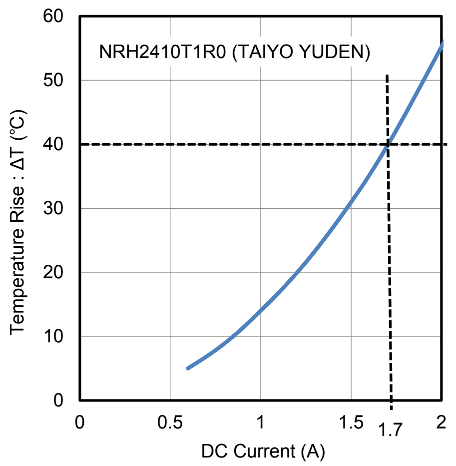

Figure 4. Example of Temperature Rise Characteristics in Table 2

(Source: TAIYO YUDEN Engineering Data in 2015)

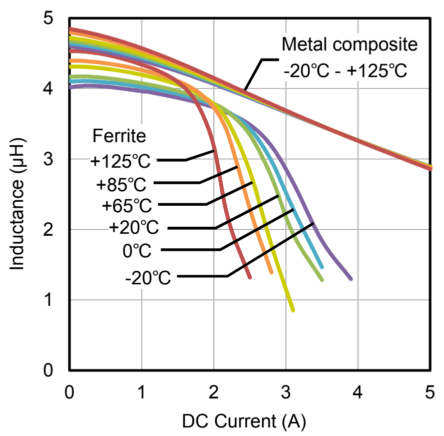

Figure 5. Temperature Characteristics

Wire wound ferrite type: NRS5014T4R7 (TAIYO YUDEN)
Metal composite type: MDPK5050T4R7 (TAIYO YUDEN)

(Source: TAIYO YUDEN Engineering Data in 2015)

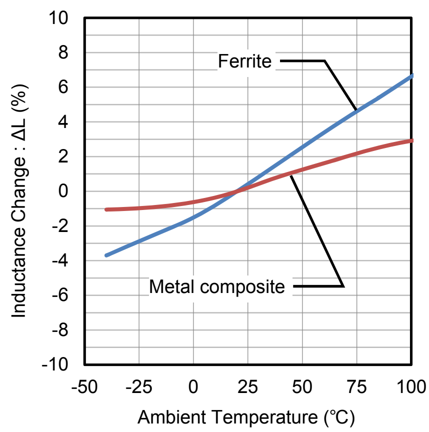

Figure 6. Temperature Characteristics

Wire wound ferrite type: NRS5014T4R7 (TAIYO YUDEN)
Metal composite type: MDPK5050T4R7 (TAIYO YUDEN)

(Source: TAIYO YUDEN Engineering Data in 2015)

Temperature Characteristics

As the inductance value of the buck converter circuit changes, so does the ripple value. Figures 5 and 6 show the temperature characteristics of the wire wound ferrite type and the metal composite type of power inductors. The wire wound ferrite type features significant temperature characteristics of magnetic materials and, therefore, deterioration of DC superimposed characteristics especially at high temperature. The metal composite type incurs minimal change in inductance value due to temperature changes because it uses magnetic metal materials that are excellent in both magnetic saturation and temperature characteristics. The wire wound ferrite type is subject to a vicious spiral where the current peak value increases, temperature further rises and, accordingly, the inductance value further decreases, through the decrease in inductance value is caused by temperature rise from self-heating.

Occurrence of Problems Due to Decrease in Inductance Value

As mentioned above, when DC flows into the inductor, the inductance value decreases due to magnetic saturation. However, if the operating allowable current has no leeway against the peak current value actually flowing, a rapid increase in current may destabilize control.

If the inductor allowable current has sufficient leeway against the peak current, the degree of decrease in inductance value is small, which will enable control as designed.

If no leeway is provided, the inductance value decreases due to magnetic saturation in response to the increase in current, and peak current further increases due to the decrease in the inductance value as shown in Figure 7. This phenomenon may activate the overcurrent protection circuit and stop output. If current increases too rapidly, the overcurrent protection operation may not keep up with this rapid increase, resulting in IC damage.

To prevent a rapid decrease in the inductance value in response to the increase in peak current, it is necessary to select inductance in consideration of the inductor allowable current characteristics.

Power Inductor Loss

Serial resistance R_{dc} is given in catalogs as an inductor loss that will influence the efficiency in the large current region. When switching frequency becomes as high as several MHz, resistance R_{ac} against AC will also be an important element, as it will influence the efficiency in the entire current region. Since this data is hardly opened to the public, you have to obtain it from inductor suppliers.

Figure 8 shows a power inductor equivalent circuit model. The AC resistance data (Figure 9) is provided in the form of a composite value of R_{dc} and R_{ac}. When the frequency is low, R_{dc} is dominant because the value of R_{ac} is small. As frequency increases, R_{ac} also increases.

As shown in Figure 10, loss against AC is generated by copper loss of the wound wire (skin effect, proximity effect) and iron loss of the magnetic materials (hysteresis loss, eddy current loss and net loss).

Wire wound resistance is a loss due to DC. The resistance component of wound wire (copper) adversely affects loss and takes up most of inductor loss at a large current.

Skin effect is a phenomenon in which current density becomes high on the surface of the conductor and becomes low in its center when high frequency current flows through the conductor. As frequency becomes high, current concentrates on the surface more. (Example: Copper wire: 100 kHz and surface skin depth: 0.21mm, copper wire: 1MHz and surface skin depth: 0.066mm, and copper wire: 10MHz and surface skin depth: 0.021mm).

Proximity effect is a phenomenon in which the repulsive force created by AC flowing through adjacent conductors in the same direction or the suction force created by AC flowing through adjacent conductors in the reverse direction deviates current in the conductors.

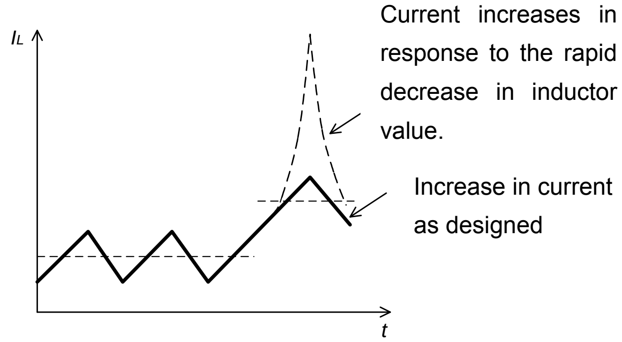

Figure 7. Increase in Current in Response to Decrease in Inductance Value

Hysteresis loss is generated when the core changes the magnetic field direction. It is represented by a hysteresis loop and its volume is proportional to the area surrounded by the loop. For AC, the potential energy loss is proportional to the number of turns in the loop. The resultant loss is proportional to the frequency.

$$P_h = k_h f B_m^{1.6}$$

P_h: Hysteresis loss
f: Frequency
B_m: Maximum magnetic flux density
k_n: Constant of proportionality

By flowing AC in a coil wound around a conductive core, eddy current corresponding to change in magnetic flux flows. This current generates heat due to the electric resistance of the core material. The resultant loss is proportional to the square of the frequency.

$$P_e = k_e \frac{(tfB_m)^2}{\rho}$$

P_e: Eddy current loss
t: Iron plate thickness
f: Frequency
B_m: Maximum magnetic flux density
ρ: Resistivity of magnetic substance
k_e: Constant of proportionality

Net loss is a loss other than hysteresis loss and eddy current loss. Inductor manufacturers promote development of products that reduce copper loss and iron loss.

Inductor Selection Procedures

Select several types of inductors. Table 1 shows the features of inductors and Figure 11 shows the numeric values in details. Since these figures are provided merely as selection tools, you may use them as reference when selecting products.

Calculate the inductance value by referring to the calculation method, and make sure that the calculated value is specified in the IC data sheet.

Find the one in manufacturer catalogs that meets the required electrical characteristics and dimensions.

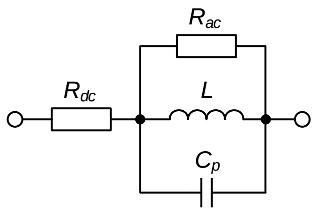

Figure 8. Power Inductor Equivalent Circuit Model

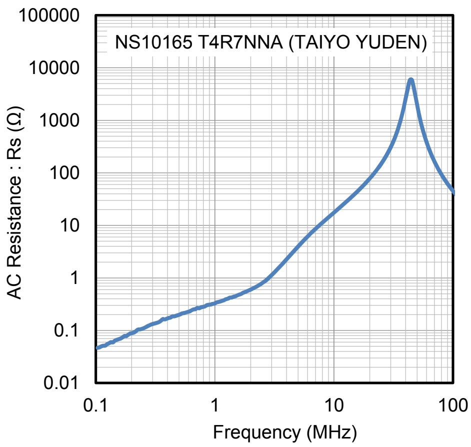

Figure 9. AC Resistance Frequency Characteristics

(Source: TAIYO YUDEN Engineering Data in 2015)

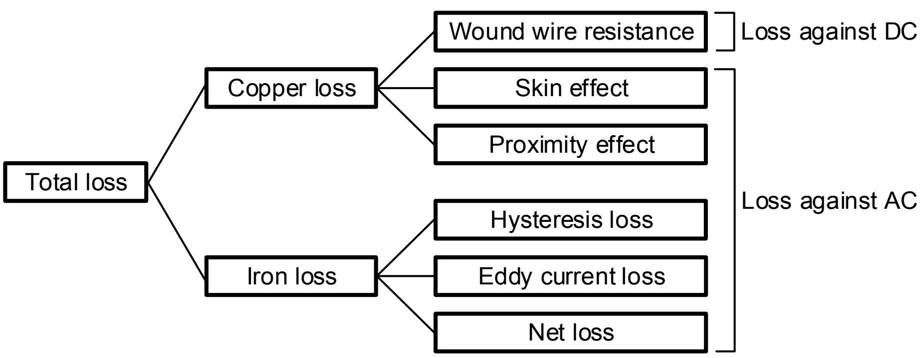

Figure 10. Inductor Loss

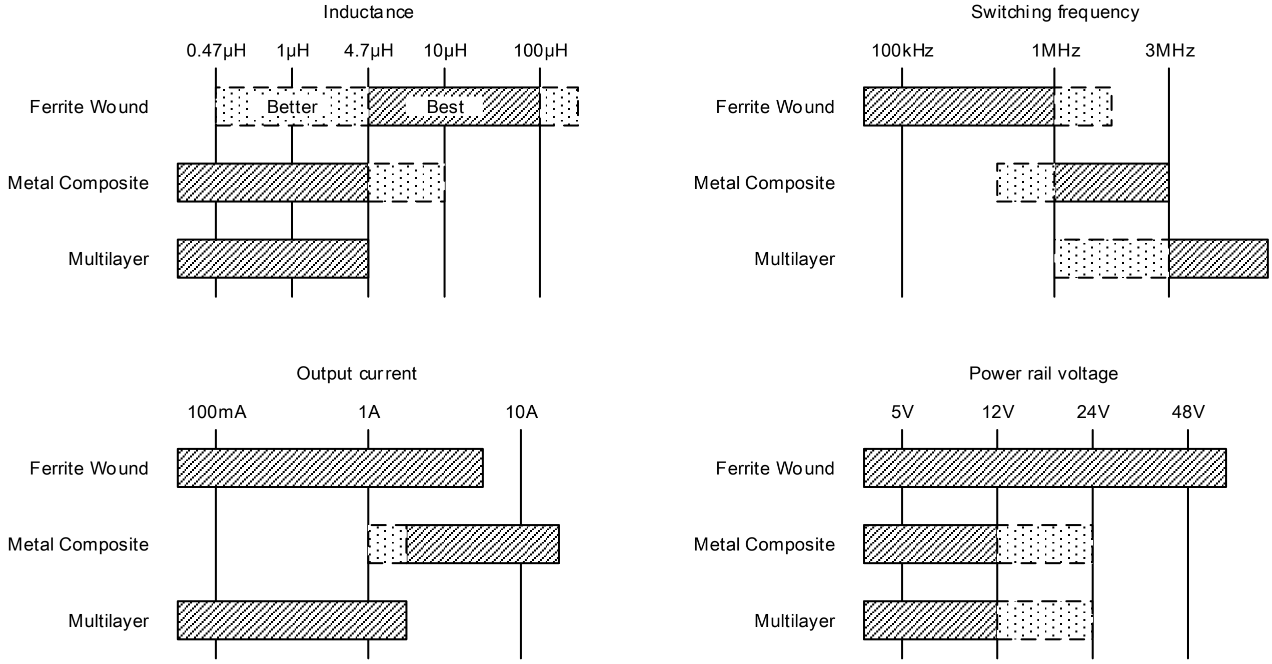

Figure 11. Conceptual View of Inductor Type Selection Process

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