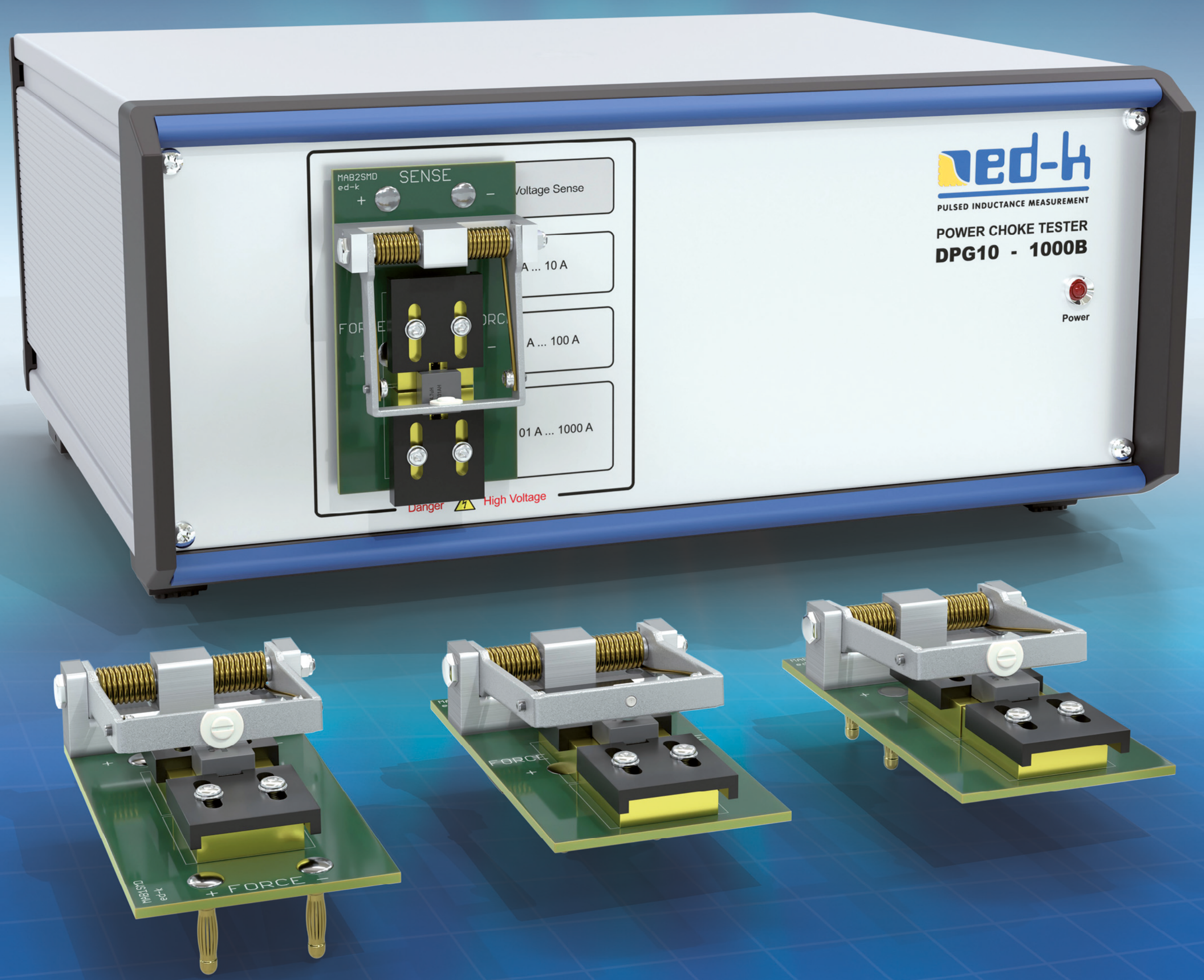
ISSN: 1863-5598

ZKZ 64717
03–24

Bodo´s Power Systems®

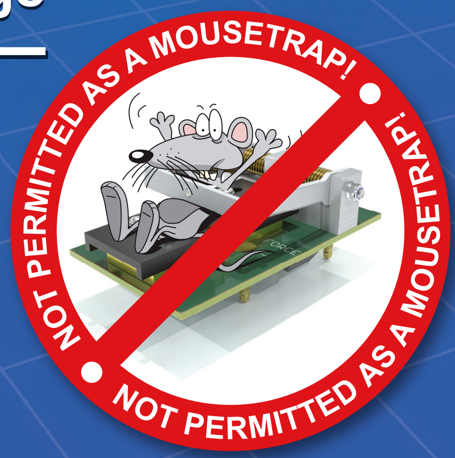
Electronics in Motion and Conversion

March 2024



Pulsed Inductance Measurement on Power Inductors in the nH Range

SMD Test Adapters for the Power Choke Tester DPG10 Series



ed-k
PULSED INDUCTANCE MEASUREMENT

Pulsed Inductance Measurement on Low-inductance, High-current SMD Inductors

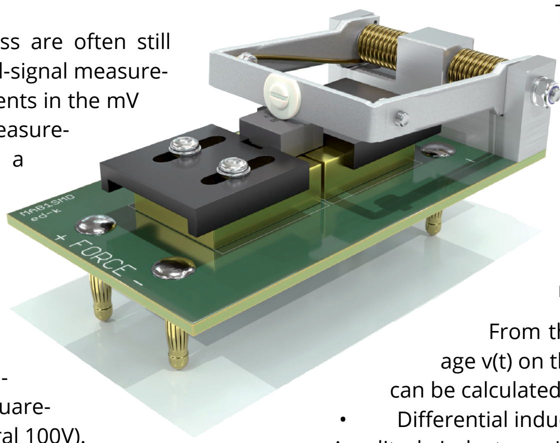
The pulse measurement method of the Power Choke Tester DPG10 series has decisive advantages over other methods of inductance measurement and can be used from small, PCB-mounted inductors to inductors weighing several tonnes. With the help of new test adapters, SMD inductors down to 50nH with currents of up to several 100A can now be tested more easily and more realistically than with LCR meters.

By Hubert Kreis, Chief Executive Officer, ed-k, Germany

Introduction

PCB-mounted SMD and THD inductorss are often still specified in the data sheets with a small-signal measurement with sinusoidal voltages and currents in the mV and µA range (LCR meter). These measurement voltages are superimposed on a direct current in order to characterise the saturation behaviour of the inductance.

In contrast, the pulse method of the Power Choke Tester DPG10 series has significant advantages, as the measurement method uses an application-related voltage curve shape (square-wave) and amplitude (several V to several 100V).



This article presents and compares both measurement methods. The problems with measuring small inductance values (< 1µH) are then explained and the new test adapters for SMD inductors down to 50nH are presented.

Principle of pulse measurement of the Power Choke Tester DPG10/20 series

The pulse measurement principle of the DPG10 series works with a single square-wave voltage pulse. The amplitude can be set in a wide range from < 10V to 400V. It should be selected so that it corresponds approximately to the voltage at the inductor in the real application.

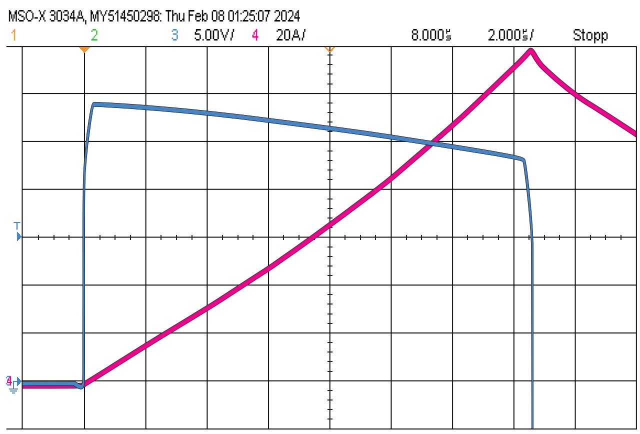


Figure 2: Test pulse of the Power Choke Tester DPG10
CH3: 5V/div
CH4: 20A/div
Time base: 2µs/div

This results in a ramp-shaped current curve in the test specimen. The current-dependent differential inductance $L_{diff}(i)$ and several other variables can then be calculated from the slew rate di/dt, taking the ohmic resistance R into account.

When the preset maximum current or a preset pulse duration is reached, the measuring pulse is switched off again.

From the curve of the current i(t) and the voltage v(t) on the test specimen, the following variables can be calculated with a single test pulse:

- Differential inductance $L_{diff}(i)$ and $L_{diff}(\int Udt)$
- Amplitude inductance $L_{amp}(i)$ and $L_{amp}(\int Udt)$
- Linked flux ψ(i)
- Magnetic co-energy $W_{co}(i)$
- Flux density B(i), if the core cross-section and number of turns are known

The behaviour of all core materials is more or less dependent on frequency and amplitude. Since the test pulse has the same rectangular curve shape as in most power electronics applications and the same amplitude and frequency or pulse width as in the real application, the most realistic measurement results are obtained. The small-signal measurement of LCR meters, on the other hand, is based on measurement signals that often have nothing to do with real conditions. In these cases, the results are not very meaningful.

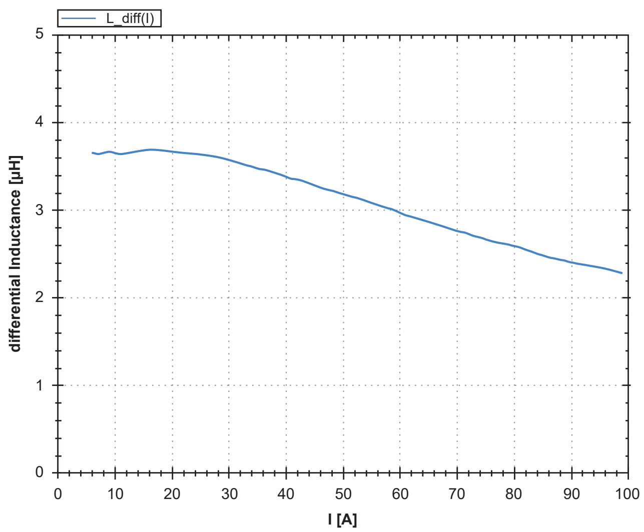


Figure 3: Diagram of the differential inductance Ldiff(i)

The pulse voltage source takes the pulse energy from a capacitor bank charged to the desired measurement voltage. Its energy content is usually significantly higher than the energy withdrawn during the pulse. The voltage of the test pulse is then roughly constant, although this is not a necessary condition. Due to the principle, there is no upper limit for the capacitance of the capacitor bank, regardless of the type of test specimen. That is one of the reasons for the extremely wide application range of the Power Choke Tester DPG10/20 series for virtually all inductive power components, from small PCB-mounted inductors to inductors weighing several tonnes in the MVA range.

Advantages of the DPG10/20 measurement principle:

- Enormously wide range of applications
- Very wide current range, available from 10mA to 10kA
- Pulse energy available from several µJ to 15kJ
- Suitable for all core materials from 1MHz to < 0.5Hz
- Small, light and relatively inexpensive despite the very high test currents
- Very easy to use, measurement results within seconds
- No thermal influence on the test specimen

Application examples:

- Storage chokes for switch mode power supplies, DC/DC converters, etc.
- Filter chokes for UPS, inverters, etc.
- Mains chokes for PFC, etc. and commutation inductors
- Suppressor chokes and current-compensated chokes
- Coils of electromagnets, valve actuators, etc.
- Transformers for flyback converters
- Other transformers and motors
- Many other inductive power components

Small-signal measurement principle of LCR meters with DC bias

LCR meters use sinusoidal voltages and currents with selectable frequency in the mV to µV and mA to µA range, which are superimposed on an adjustable direct current. The inductance, resistance and Q factor can then be calculated from the amplitude and phase angle of the voltage and the current through the test specimen.

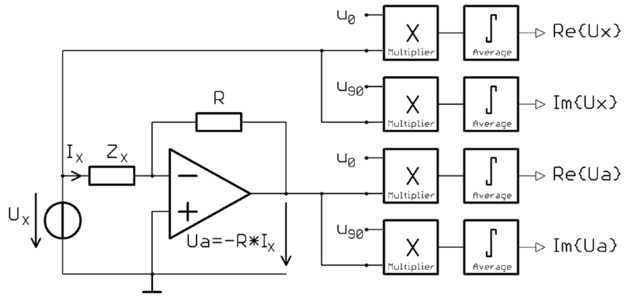


Figure 4: Small-signal measurement of LCR meters (auto balancing method)

Such a modulation of the core material with tiny hysteresis curves around an operating point cannot be found in switch mode power electronics applications. The test result of such a small-signal measurement is accordingly not very meaningful. The difference between these measurement results and those of the DPG10/20 pulse measurement method depend a great deal on the core material and cannot generally be stated for an entire group of materials. In some cases, the differences are relatively small, while in other cases they can be considerable.

Due to the large DC bias units required, this method is restricted to low measuring currents of up to 250A and requires very expensive test equipment.

Many individual measurements must be carried out to create a complete measurement curve L(i). This takes a relatively long time and places a thermal load on the test specimen. In the overload range, this can make the measurement of the saturation behaviour impossible due to excessive heating. At least the behaviour cannot simply be measured at defined temperatures, because the temperature is determined by the self-heating.

The pulse measurement method, on the other hand, does not lead to any measurable heating of the test specimen on account of the short pulse duration. The behaviour can thus be determined at any desired temperature, for example, in the climate cabinet.

Advantages of the pulse measurement principle compared to small-signal measurement with DC bias unit

- Realistic measurement principle
- Significantly higher test currents possible
- Significantly lower equipment costs
- No thermal influence on the test specimen, as the measuring pulse is very short (µs to ms)

Measurement adapter for measuring low-inductance SMD components up to 50nH

Precise inductance measurement of low-inductance components < 1µH is fundamentally problematic, error-prone and metrologically demanding, regardless of which measuring device and which measurement principle is used. In the pulse measurement principle of the Power Choke Tester DPG10 series, it is above all the parasitic inductances, the inductive coupling between the force leads and the sense leads, as well as the maximum sampling rate that are important for an accurate measurement result.

Together with the test specimen, the parasitic inductance of the test leads as well as the device's parasitic internal inductances form an inductive voltage divider. If these parasitic inductances are larger or even much larger than the inductance of the test specimen, then only a small part of the voltage of the test pulse is dropped across the test specimen. Most of it is then dropped across the parasitic inductances. Although a 4-wire measurement is always carried out, this reduces the measuring accuracy. In the 4-wire measurement, the voltage is tapped directly on the test specimen via separate sense leads.

To prevent the display of incorrect or inaccurate measurement results, measurements must be discarded if too much of the pulse voltage drops across the parasitic inductances. In order to be able to measure the smallest possible inductance values, the parasitic inductances must therefore be minimised.

The test leads play a significant role in the parasitic inductances. An ideal test lead made of highly flexible measuring litz wire with a 6mm² copper cross-section and a length of 0.6m already has an inductance of over 700nH. In conjunction with further parasitic inductances for the crocodile clips on the test specimen and the device's internal inductances, this limits the measurement to values of 500nH at best.

In order to extend the area of use of the DPG10 series down to 50nH, ed-k has developed new solderless Kelvin test adapters for SMD components that can be plugged directly into the sockets on the front panel of the devices without the use of test leads. The influence of the test leads can thus be completely eliminated. These test adapters are optimised for minimum parasitic inductances. In conjunction with the optimum internal design of the DPG10 series and the associated extremely low parasitic inductances, measurement can be performed in some cases down to 50nH!

The Kelvin test adapters MABxSMD are plugged directly into the front panel. There is a separate test adapter (MAB1SMD, MAB2SMD or MAB3SMD) for each of the three measuring ranges of the DPG10 series. The test adapters can accommodate SMD components contacted on the underside with a width of 5-25 mm, a length of 5-25 mm and a height of up to 25 mm. After positioning, the test specimen is held in place by a spring-loaded bracket, which makes handling easy.

Measurement examples

Figures 5-8 show measurement examples of SMD inductors from the catalogue range of various manufacturers.

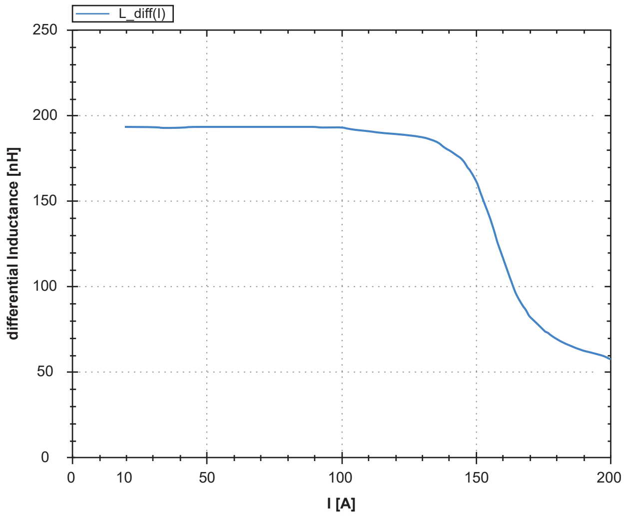


Figure 5: Rated inductance 200nH, thermally rated current 92A$_{RMS}$

Figure 5 shows the differential inductance L_{diff}(i) of an inductor with EP ferrite core and air gap determined with the Power Choke Tester DPG10-1000B and the Kelvin test adapter MAB1SMD. According to the data sheet, the saturation current with a 20% drop in inductance is 113A and the thermally permissible RMS current is 92A. The rated inductance of 200nH according to the data sheet is not quite achieved (194nH). However, the saturation current is significantly higher than specified (approx. 150A).

There are several reasons for these differences.

Firstly, there are the different measurement methods. As previously explained, the Power Choke Tester DPG10 series uses application-oriented square-wave large-signal measuring pulses with the same amplitude as in the real application. The small-signal modulation of the core material with sinusoidal voltages in the µV or mV range and currents in the µA or mA range provides more or less different results depending on the core material.

However, with such extremely small inductance values, even the smallest differences in the geometry of the test setup play a role that cannot be neglected. Even small deviations in the test point on the component or the type of current feed (e.g. planar or punctiform) can lead to different measurement results. In order to obtain reproducible test results, the geometry of the test setup must always be exactly the same. This can hardly be guaranteed without special test adapters and applies not only to the pulse measurement principle, but also in the same way to small-signal measurement with LCR meters.

Last but not least, specimen scatter of up to 10% must of course also be taken into account.

The inductor in Figure 6 in a 5050 package consists of a powder core material with a distributed air gap. The nominal value of 220nH is clearly exceeded at the beginning (280nH). The thermally permissible RMS current is specified at 66A, and the saturation current with a 20% drop in inductance is specified at 68A.

With regard to the differences between the pulse measurement and the data sheet specifications, the same reasons apply here as in the previous example. The data sheet specification for L_0 (220nH @ 100kHz, 0.25 V) cannot be reproduced at all with an LCR meter without a special test adapter. This is difficult even with a carefully calibrated test adapter. The actual initial inductance L_0 appears to be systematically greater than specified, which is confirmed by the measurement with the Power Choke Tester DPG10.

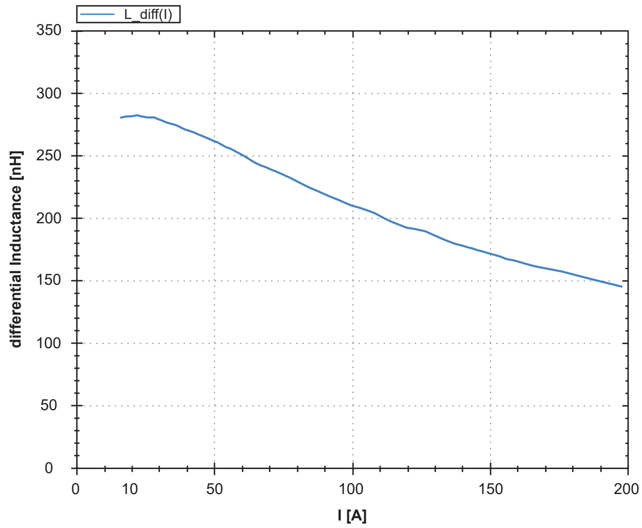


Figure 6: Rated inductance 220nH, thermally rated current 66A$_{RMS}$, 5050 package

The saturation curve of the powder core material is much softer than that of ferrite cores with an air gap. As a result, this core material is less problematic when used in switch mode applications if the current rises far above the rated current in the event of a fault. Even at 200A, this specimen still has an inductance of over 140nH.

These statements also apply analogously to the inductor in Figure 7. It has a rated inductance of 470nH with a thermally permissible RMS current of 30ARMS in the 4040 package (10 x 10 x 4 mm³) and consists of the same core material.

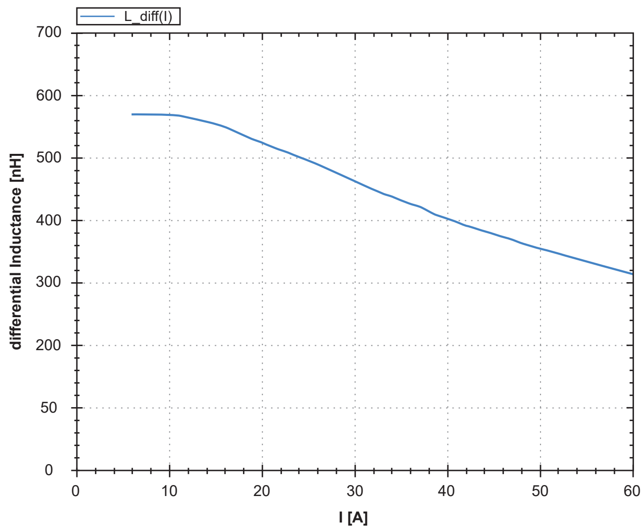


Figure 7: Rated inductance 470nH, thermally rated current 30A$_{RMS}$, 4040 package

The last measurement example in Figure 8 is a small SMD inductor with dimensions of 8 x 8 x 4 mm³. It is also a powder core with a distributed air gap. In this case, the measured values slightly deviate from the data sheet specifications due to component scatter (inductance at 3.2 A 28.6 µH, data sheet specification 26.4 µH). The measurement of such large inductance values is much less critical and less prone to error.

Correct choice of measurement parameters

At very low inductance values, both measurement parameters – test current and test voltage – can no longer be freely selected. This is due to the minimum pulse duration of 3µs of the Power Choke Tester DPG10 series. The test pulse duration can be roughly estimated using the following formula:

$\Delta t = L_{diff} * \Delta i / V$

The formula states that the smaller the inductance, the smaller the test current and the greater the measurement voltage, the shorter the pulse duration. At very low inductance values, the test voltage must therefore be as low as possible and the test current as high as possible! The smallest presettable test voltage is 10V, although the effective test voltage can be as low as 6-8V due to parasitic voltage drops at higher current.

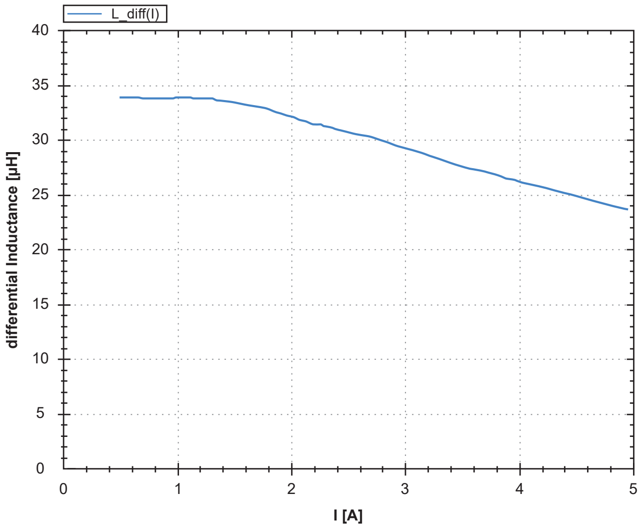


Figure 8: Rated inductance 33µH, thermally rated current 3.1A_{RMS}, 3232 package

This results in the following minimum required test currents for a given inductance:

100nH => approx. 150A
1µH => approx. 20A
10µH => approx. 3A

However, components with a significantly lower rated current can usually also be measured by simply selecting a correspondingly higher test current until a measurement is possible. As the test pulse is extremely short, a multiple of the rated current does not lead to any heating or damage to the component.

Summary

- Precise inductance measurement of low-inductance components < 1µH is fundamentally problematic, error-prone and metrologically demanding.
- With the new test adapters, the inductance L(i) of SMD inductors down to 50nH can be measured more easily and realistically than with LCR meters.
- The pulse measurement method also enables significantly cheaper measuring equipment, especially for currents above 20A.
- Hopefully, the small-signal measurement method that is still often used for PCB-mounted inductors will be replaced by a more realistic specification using the pulse measurement method, which uses square-wave pulses with an amplitude close to that of the application.

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