DIGITAL WE DAYS 2024

OPERATING VOLTAGE OF MOLDED POWER INDUCTORS

Jens Kehl

AGENDA

- **Introduction**
  - Market Trends
  - Molded Inductor production process and materials
  - Molded Inductor phenomenons
- **Effects in Applications**
- **WE Operating Voltage Definition**
  - Detection Method
  - Datasheets, Application Note

INTRODUCTION

Market Trends
Molded Inductor production process and materials
Molded Inductor phenomenons

INTRODUCTION

Market Trends

- **Design-In of Molded Power Inductors**
  - Compact Design
  - Power Density
  - Temperature stability
  - Soft Saturation
- **Switching Frequencies**
- **Input Voltages**
- **Duty Cycles**
  - Previously 48 V to 12 V, to 5 V, to 1,8 V
  - Today 48 V directly to 1,8 V

Example: WE-PD2

Example: WE-MAPI

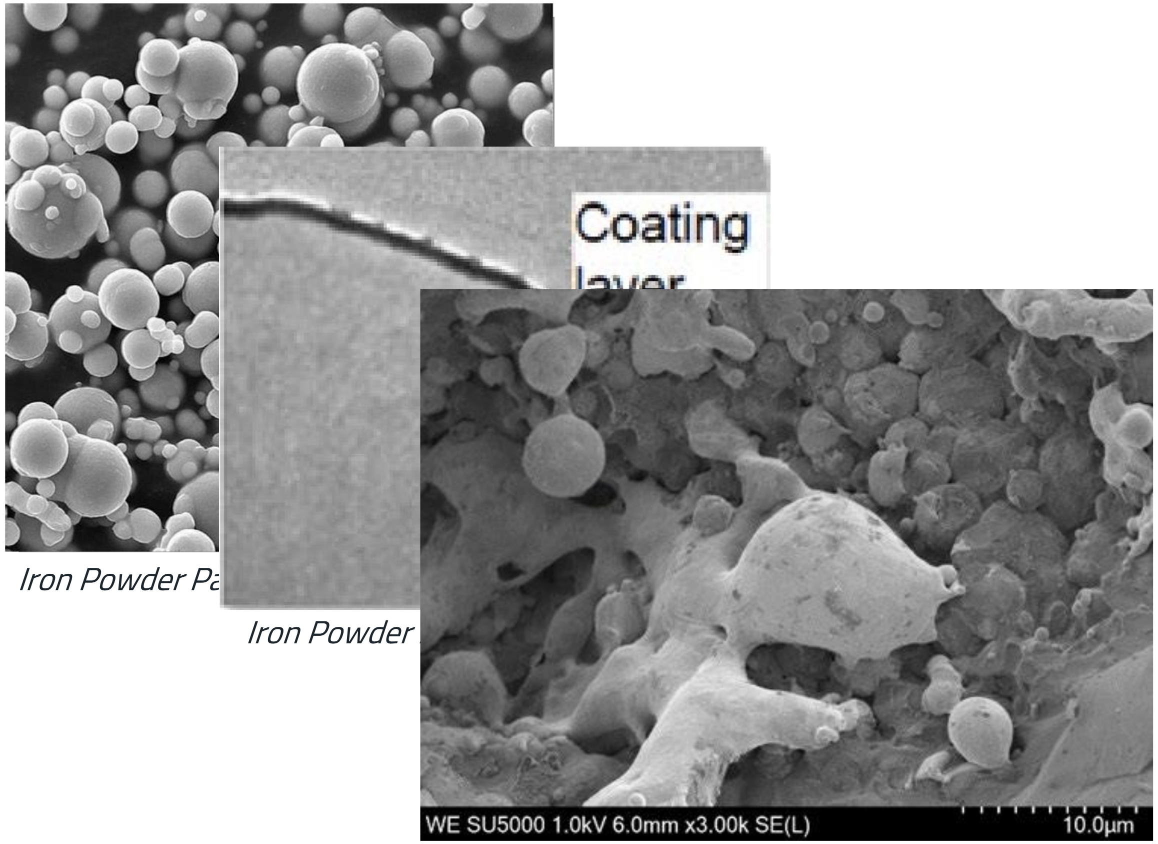
Example: WE-XHMI

INTRODUCTION

Molded Inductor production process and materials

- Production Process (simplified)
  - Wound insulated copper wire
  - Material mixed containing Iron Powder and Binder
  - Pressed in mold
  - Cured in Oven
- Core Material
  - Mostly contain Iron Particles
  - Iron is conductive
  - Particles are coated
  - Binder used as „glue“

➔ Too high voltage can cause a short circuit over the material



Iron Powder Pa

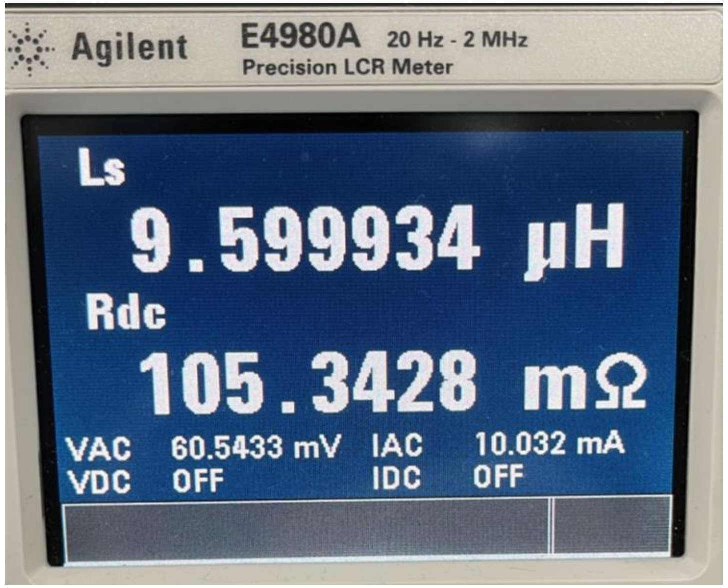
Iron Powder

Melted powder structure of a molded Power Inductor

INTRODUCTION

Molded Inductor phenomenon

- Material degradation not detectable during standard qualification testing



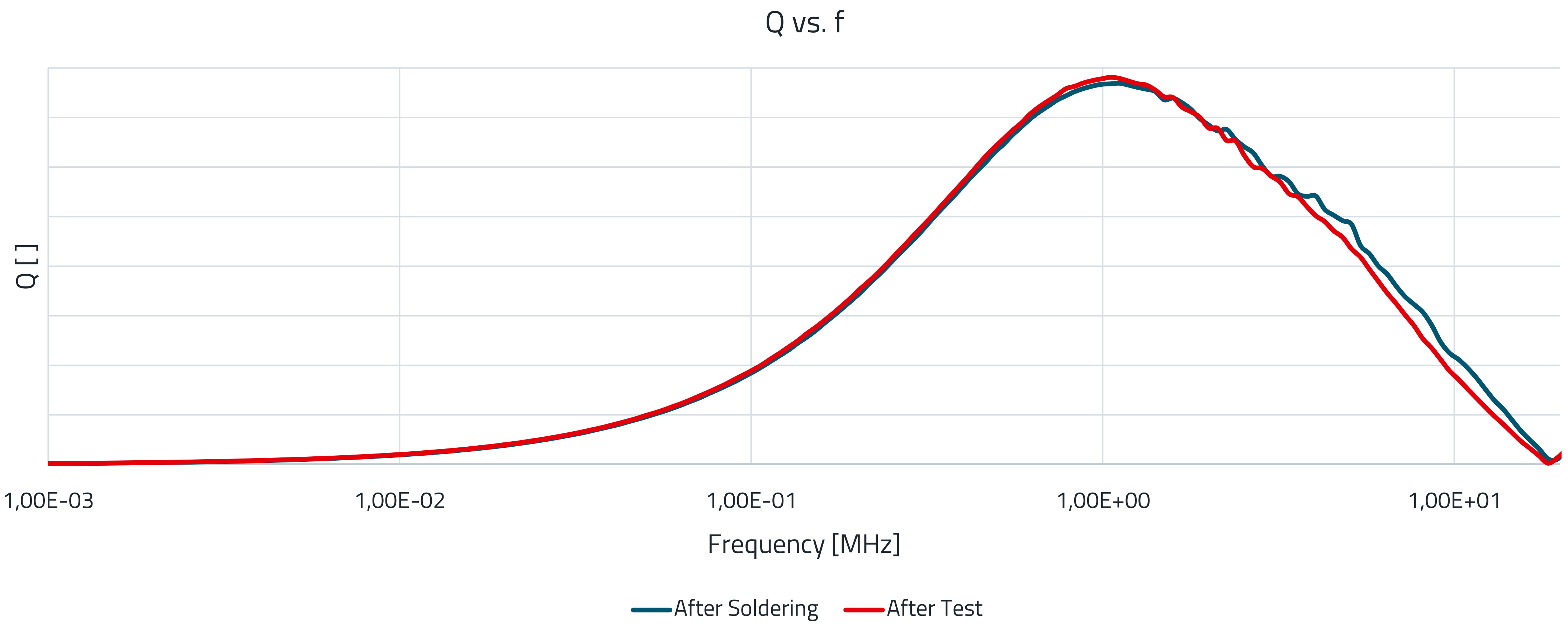
Good part

Compromised part

- Change in Q is the main driver of this phenomenon!

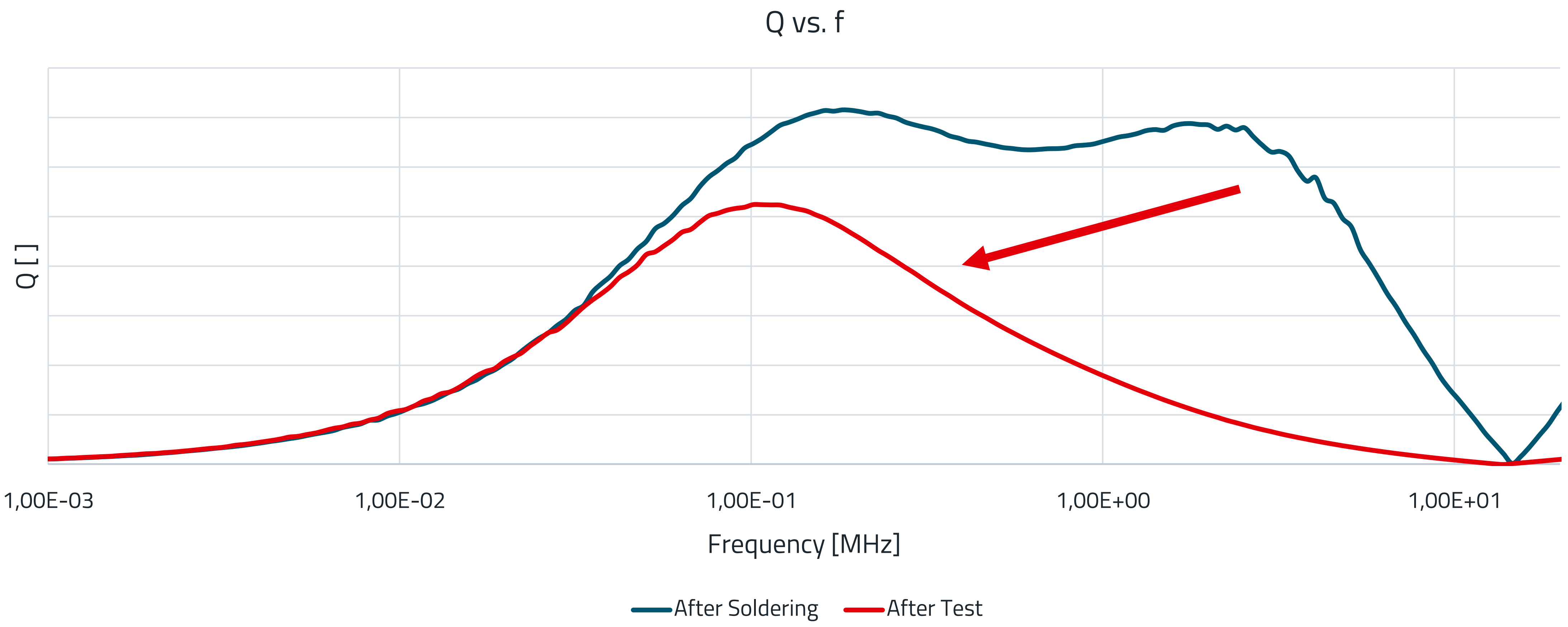
INTRODUCTION

Molded Inductor phenomenon



INTRODUCTION

Molded Inductor phenomenon



EFFECTS IN APPLICATIONS

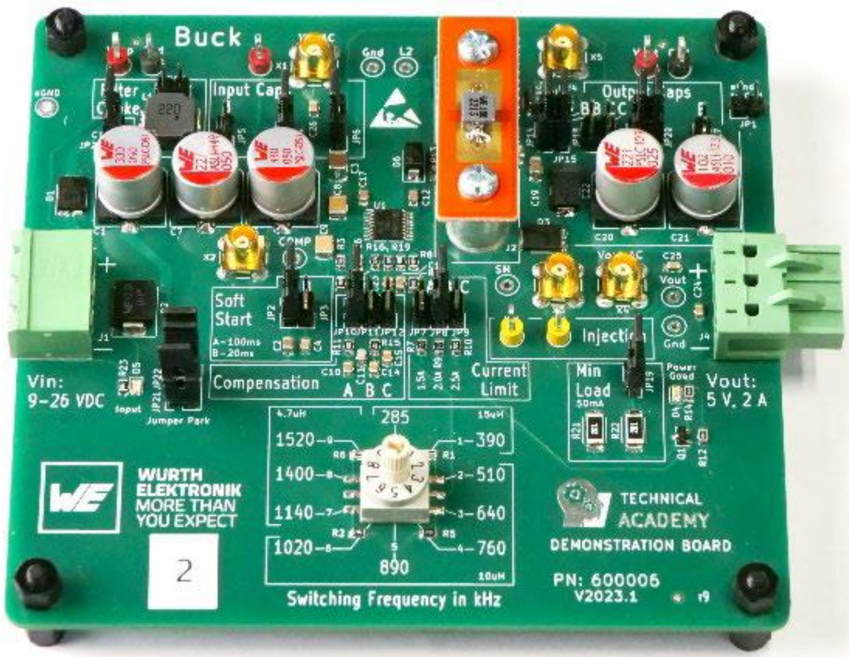
EFFECTS IN APPLICATIONS

Application Parameters

- **Buck Converter Application**
  - Input Voltage: 18 Vdc
  - Output Voltage: 5 Vdc
  - Switching Frequency: 510 kHz
  - Output Current: 1 A

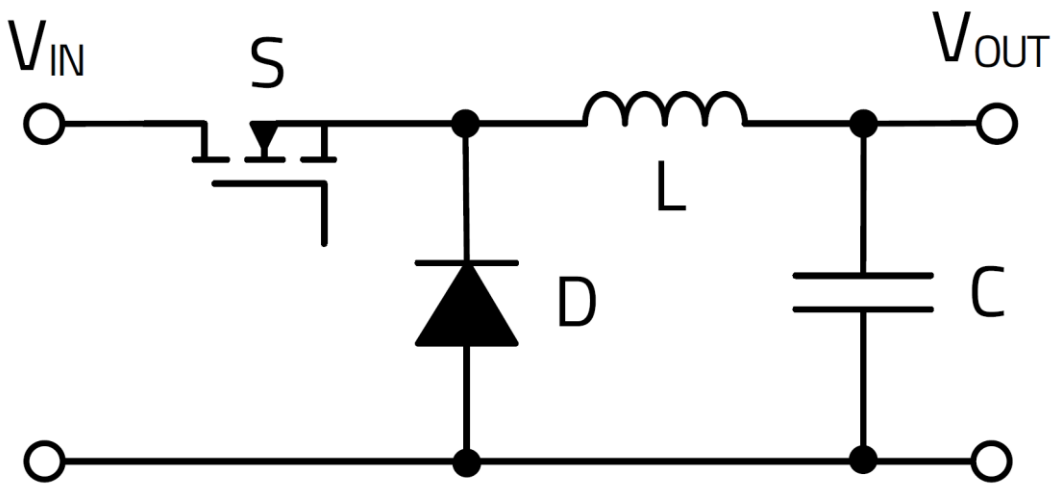
- **Inductors are interchangeable**
  - Part fresh from production
  - Compromised part by multiple voltage pulses > 200 V

Demonstrator Board



EFFECTS IN APPLICATIONS

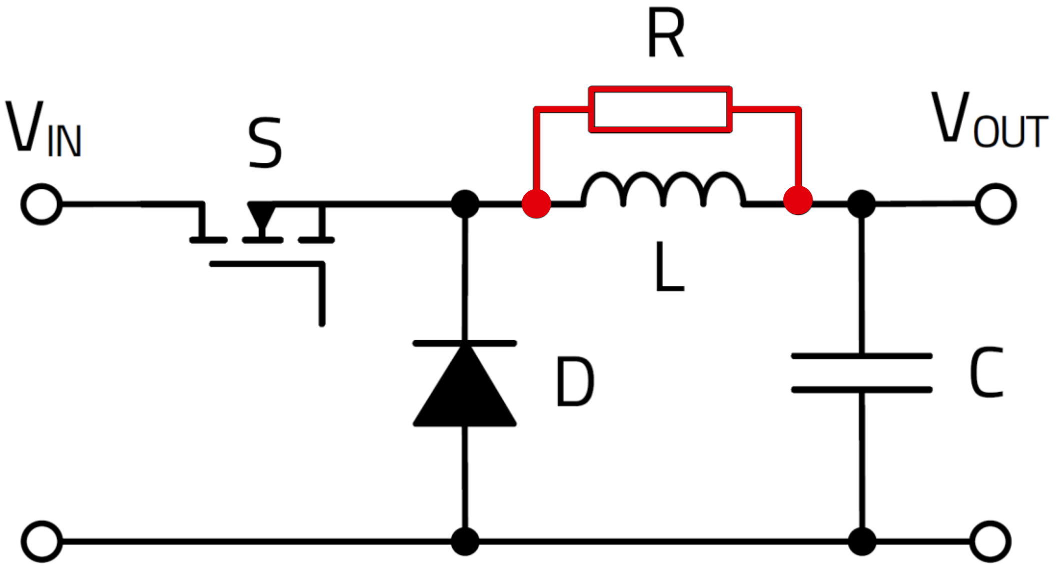
Simplified Buck Converter



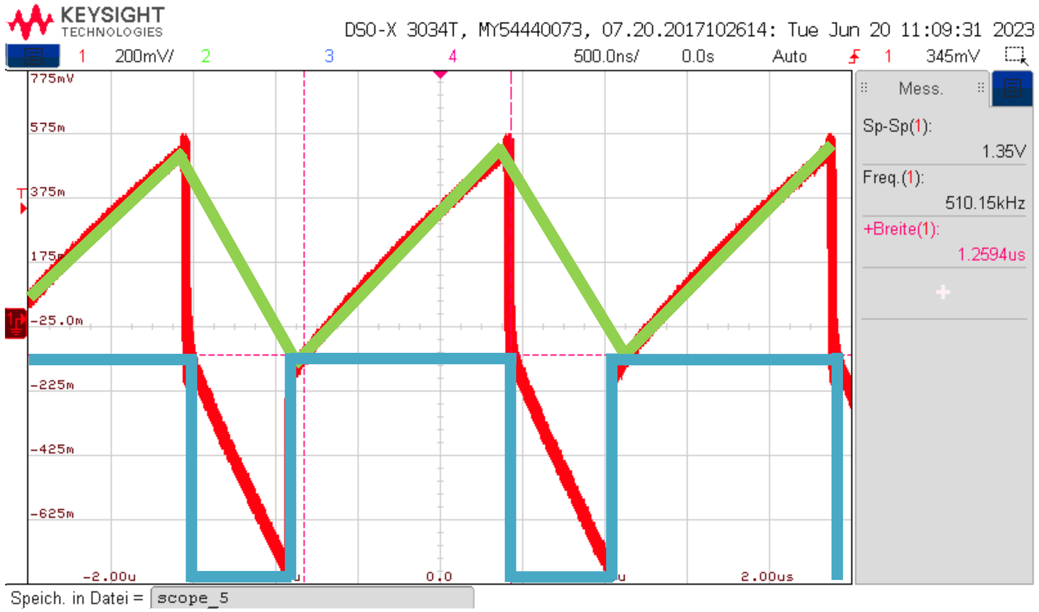
Buck Converter Current Waveform

EFFECTS IN APPLICATIONS

Simplified Buck Converter with parallel Resistor R



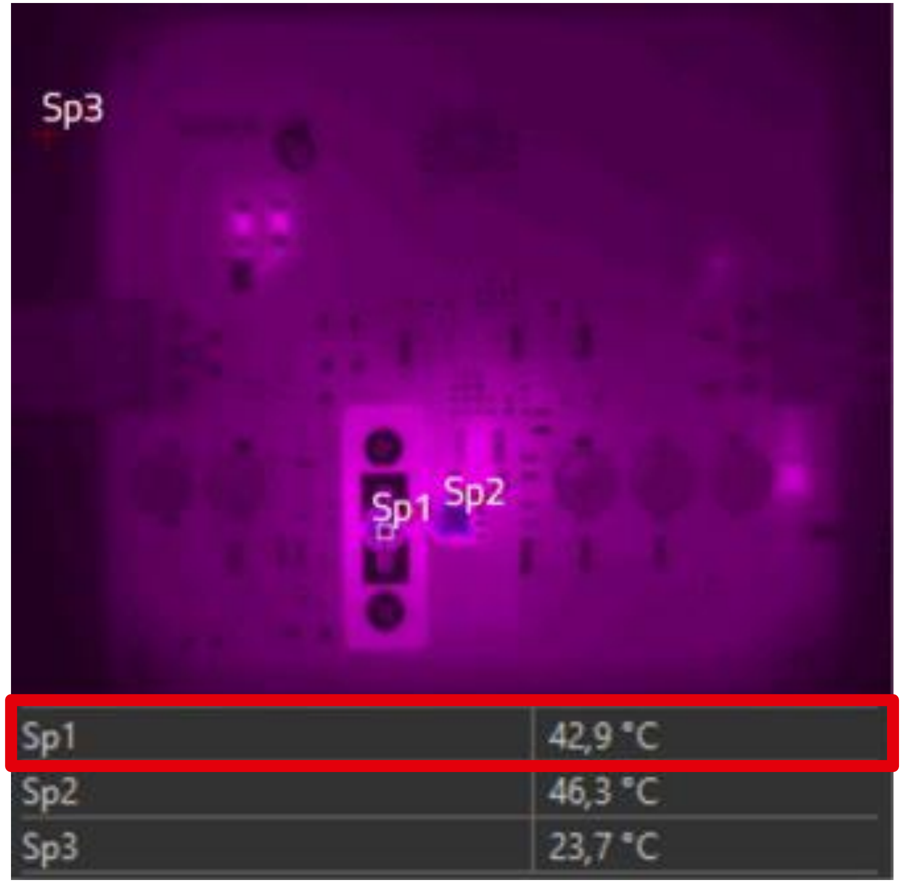
Buck Converter Current Waveform with Resistor R



EFFECTS IN APPLICATIONS

Temperature Rise – What do you think?

Good Part

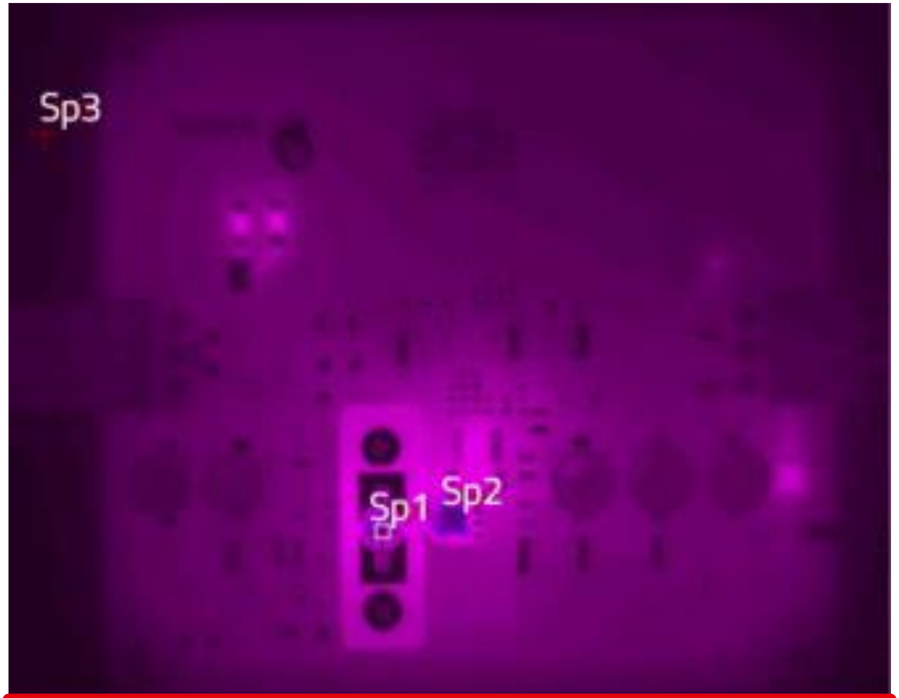


Compromised Part

EFFECTS IN APPLICATIONS

Temperature Rise

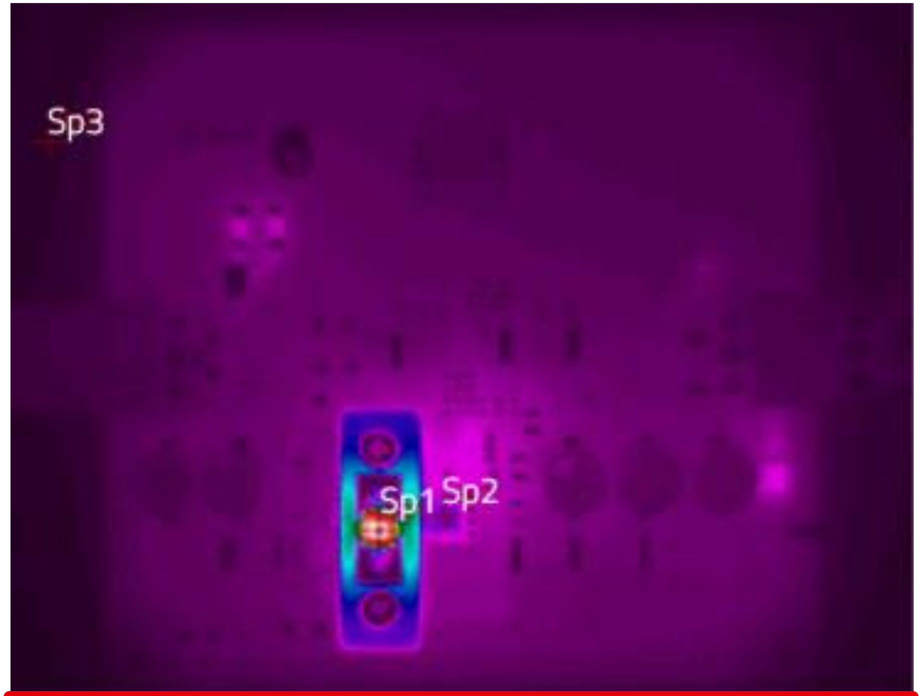
Good Part



Sp1	42,9 °C
Sp2	46,3 °C
Sp3	23,7 °C

+ 276 %

Compromised Part



Sp1	118,3 °C
Sp2	44,9 °C
Sp3	23,9 °C

WE OPERATING VOLTAGE DEFINITION

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Detection method

- No test standard available from IEC or equivalent
- Own developed measurement procedure
- Custom developed measurement equipment with partner MinDCet NV
- Very close to end application use
- Completely different approach to any competitor

HV-MADMIX; MinDCet Website

MINDCET.
Custom
Integrated Power
Management
Solutions

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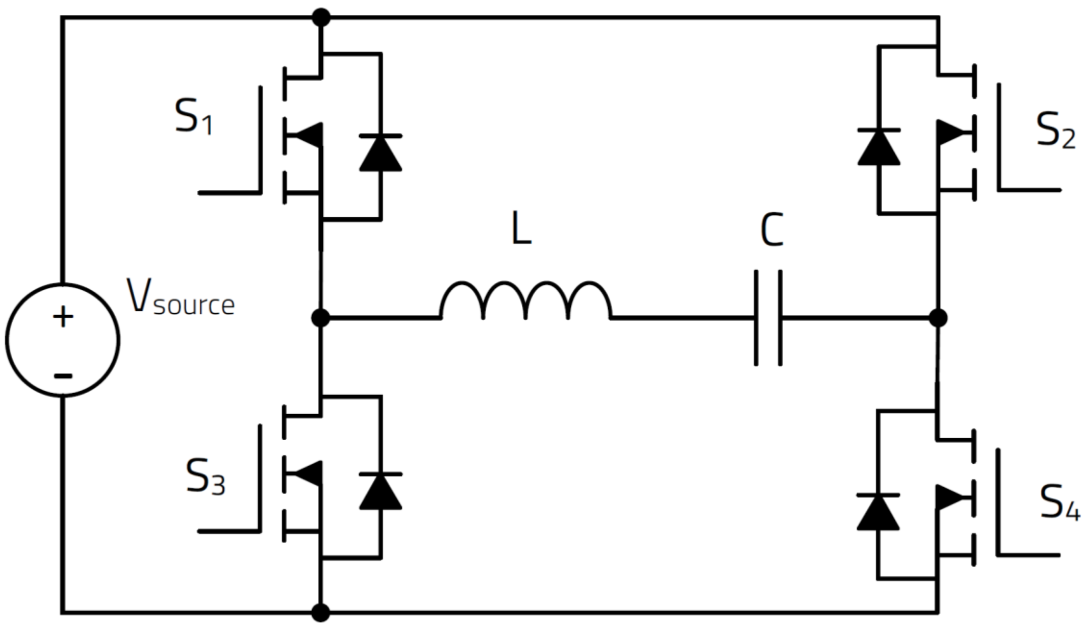
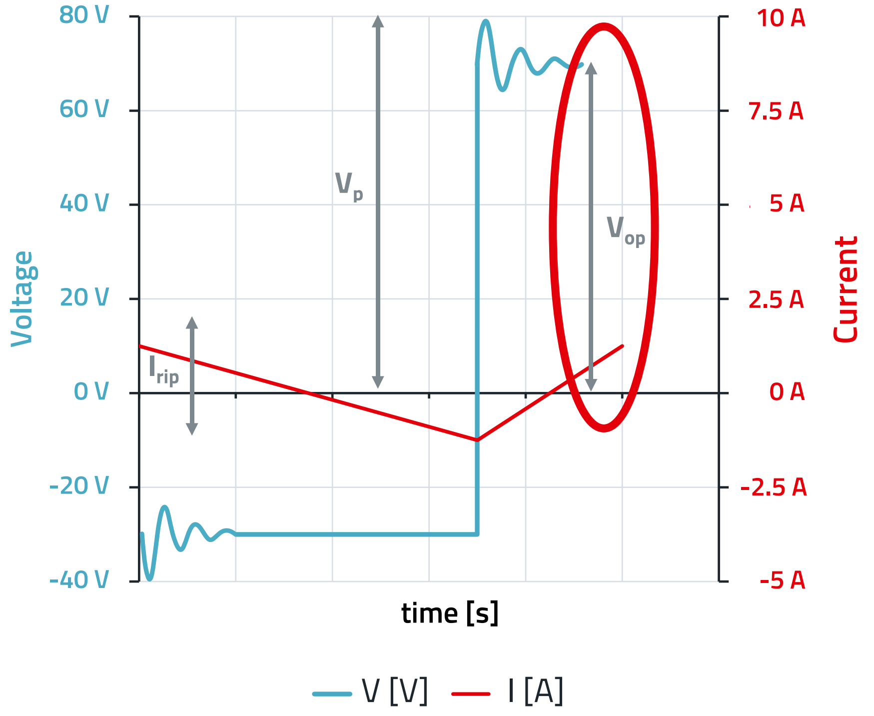
Detection method

Full Bridge DC-to-DC Converter



Inductor Voltage and Current Waveform



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Datasheet: WE-MAPI Size 4020

Electrical Properties:

Properties		Test conditions	Value	Unit	Tol.
Inductance	L	100 kHz/ 10 mA	1	µH	±20%
Performance Rated Current [1)]	$I_{RP,40K}$	$\Delta T = 40K$	10.1	A	max.
Saturation Current @ 10%	$I_{SAT, 10\%}$	$\|\Delta L/L\| < 10\ \%$	5.3	A	typ.
Saturation Current @ 30%	$I_{SAT,30\%}$	$\|\Delta L/L\| < 30\ \%$	11.5	A	typ.
DC Resistance	R_{DC}	@ 20 °C	12	mΩ	typ.
DC Resistance	R_{DC}	@ 20 °C	15	mΩ	max.
Self Resonant Frequency	f_{res}		55	MHz	typ.
Operating Voltage	V	DC	80	V	max.

[1)] refer to IEC 62024-2-2020

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Application Note ANP126

APPLICATION NOTE

ANP126 | Voltage specification for molded inductors

Annika Frankemölle, Alexander Lang

01. INTRODUCTION

1.1 Voltage and inductances

Inductors play a decisive role influencing the current rise in electrical circuits. In this process, the current resulting from the applied voltage induces a magnetic field, which opposes the current thus creating a controlled increase and can be limited as required. Therefore, when selecting the right inductor for an application, the inductance value and the maximum current rating needs to be considered, as they play a central role in the desired function of a switching regulator.

Historically inductors in electrical circuits have used iron powder-based alloys or ferrite cores. For shaped cores, a coil former was used to secure the wire windings. The windings can be applied directly to toroids as the external epoxy coating serves as insulation in addition to protection against corrosion and moisture.. The selection of the insulation coating on enameled copper wire was primary based on temperature class rather than dielectric strength since the wire usually withstands several thousands of volts and had no direct contact with the core.

This has changed in recent years with the increasing popularity of molded inductors based on fine iron powder with a distributed air gap where their design allows a wide range of sizes to be realized. The powder used for the core material consists of pure iron or iron powder-based alloys containing nickel, silicon or molybdenum, which are compressed under high pressure around the enameled copper winding using insulating synthetic resin as a binder.

By constantly optimizing the production process and the material composition, it is possible to achieve the greatest possible permeability, in order to realize large inductance values in the smallest possible installation space. This must be combined with the maximum possible current carrying capacity. As a result, the power density per volume can be continuously increased.

To constantly increase the power handling of the inductors in the smallest possible volume, the percentage of insulation binder in relation to the iron powder has been continuously reduced so that, consequently, the distance between the individual grain sizes has continuously decreased.

This reduction has resulted in the fact that today, the applied voltages to an inductor within a DC-DC converter should be considered when selecting an inductor for an application, as the reduced insulating material content in the powder core limits the dielectric strength of the material and thus a high operating voltage can lead to failure of the entire application.

1.2 Trends and changes

As an example of the changing market conditions of electronics, the voltage drop across an inductor in a buck converter (Figure 1) will be considered below.

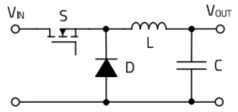

Figure 1: Reference schematic buck converter V_{in} = 24 V; V_{out}=5 V

At the moment of switching on, there is between 24 and 36 V at the input. The insulation of the powder particles must therefore be able to withstand 36 V permanently.

With the continuous technological advancement in the semiconductor industry, MOSFETs today can achieve high power densities and fast switching speeds. As a result, it is now possible to reduce the output voltage in DC-DC converters in ever larger steps.

**An example: In the past, an input voltage of 48 V was gradually stepped down to 12 V, to 5 V and finally to 1.8 V. However, by using GaN MOSFETs in the application, it is possible to step down the voltage from 48 V directly to 1.8 V with enormously low switching losses (efficiency > 90%). With additional consideration of possible tolerances of the input voltage, up to 60 V can be applied to the inductor in the application at times. A value that high was rather usual in the past.*

By using highly efficient MOSFETs, the designer thus has the advantage of being able to dispense with stage-by-stage regulation of the voltage, resulting in high-power density in a

compact form. This allows the entire application to be further miniaturized and, as a result, costs can be saved.

For this reason, the question of the dielectric strength of inductors has become very important in recent years when selecting the right inductor and will continue to be a requirement to be considered in the future.

To ensure the necessary transparency, Würth Elektronik has decided to integrate the new operating voltage property for all powder-based storage inductors into the data sheets. For this purpose, a state-of-the-art testing concept was developed, which will be explained in more detail shortly.

02. DEFINITION OF THE OPERATING VOLTAGE

Würth Elektronik defines the maximum operating voltage V_{op} in their datasheets at which an inductor can be operated continuously during the application, without affecting the performance, risking damage, or overheating of the component. The operating voltage is therefore a limit value for the input voltage to which the inductor can be reliably used without irreversible damage in an application. The maximum operating voltage of a molded inductor can be influenced by various factors. For example, the inductance value of an inductor, ambient conditions, or the material composition. In addition, the design of the component can play a decisive role. For example, the arrangement of the winding layers of the coil and the insulation materials on the copper wire can have an impact on the maximum operating voltage.

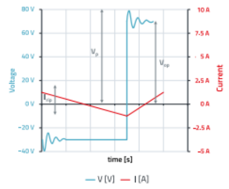

Figure 2: Inductor waveform – Delimitation V_p and V_{op}

In contrast to the operating voltage V_{op}, the parameter of peak voltage V_p refers to the maximum voltage across the inductor without causing damage. The peak voltage can be applied across the inductor for a short period compared to the total "switch on-time". During the switching operations in a buck converter for example, the voltage across the inductor exceeds the max operating voltage value for a short time (Figure 2). Parasitic effects of the MOSFETs and the inductor mainly cause this. An inductor used in this application needs to be able to withstand these short-term voltage peaks without taking damage or affecting the reliability of the circuit.

03. EFFECTS OF EXCEEDING THE OPERATING VOLTAGE

3.1 Influencing factors

As previously described, a steady optimization of the ratio between the powder and insulation binder led to a reduction of the dielectric strength. But what happens if the voltage is too high? To better understand this, the structure of a powder inductor is analyzed in more detail.

Ferrite materials are ceramic compounds consisting of iron oxide (Fe_2O_3) in combination with other metal oxides such as manganese, nickel or zinc. After firing, these materials have a crystalline structure in which the iron and other metal ions are arranged in a specific lattice form. This crystalline structure inherently prevents the free movement of electrons, resulting in non-conductive behavior.

Pressed powder or powder alloys consist for the most part of iron powder, which has very good electrical conductivity. Unlike traditional cores which have an external coating protecting them from the environment, the pressed core material is exposed (Figure 3).

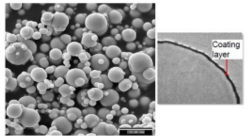

Figure 3: Microscopic analyze of a powder structure of a molded inductor [Zoom: 5µm]

Therefore, the particle coating needs to insulate electrically and protect against environmental influences because iron begins to rust as soon as it encounters atmospheric moisture and the electrical properties of the inductor would be lost. There are different types of coating for the desired area of application, such as resistance to chemical influences, temperature, or humidity. The thickness and the material of

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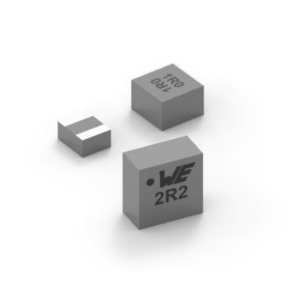
Defined Product Series

	Product Series	Operating Voltage
	WE-MAPI	80 V
	WE-LHMI	120 V
	WE-XHMI	120 V

Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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