Voltage Ratings:
Find the Best Power Inductor for Your DC-DC Converter

Engineering ACADEMY

Sponsored by: Coilcraft

Len Crane

Senior Technologist - Coilcraft

Len Crane has more than forty years of inductor design and application experience with Coilcraft, serving as Engineering Manager for nineteen years and Technical Marketing Director since 2005. In his present role, Len focuses on the application of Coilcraft products; developing application notes and web tools for the optimal selection and use of Coilcraft inductors.

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Introduction

Introduction

- **Why now?** What developments are driving the need for greater emphasis on inductor voltage ratings?

- **Inductor voltage capacity.** What are the material and geometry considerations that determine voltage capacity?

- **Voltage Ratings.** How to interpret inductor datasheets.

Introduction

Specifications

Electrical specifications at 25°C. Operating voltage 0 - 80 V

Part number 1	Inductance (µH) 2 *(Tolerance: ±20%)*	DCR (mΩ) 3		SRF typ (MHz) 4	Isat (A) 5			Irms (A) 6	
		typ	max		10% drop	20% drop	30% drop	20°C rise	40°C rise
XGL4030-131MEC	0.13	1.5	1.8	265	12.5	19.5	26.5	21.0	27.0
XGL4030-271MEC	0.27	2.2	2.4	160	9.2	14.4	19.3	17.5	24.2
XGL4030-301MEC	0.30	2.5	2.9	130	8.0	12.5	17.0	17.0	24.0
XGL4030-401MEC	0.40	2.8	3.2	120	7.2	11.5	15.5	15.5	22.5
XGL4030-471MEC	0.47	3.4	3.9	100	6.8	10.6	14.2	15.3	21.2
XGL4030-621MEC	0.62	4.1	4.6	82.0	6.1	9.5	12.7	12.5	15.0
XGL4030-761MEC	0.76	4.9	5.5	72.0	5.6	8.7	11.8	12.3	14.2
XGL4030-102MEC	1.0	6.5	7.2	65.0	4.8	7.6	10.3	10.8	13.0
XGL4030-122MEC	1.2	8.5	9.4	55.0	4.2	6.8	9.2	9.5	12.2
XGL4030-152MEC	1.5	9.5	10.5	50.0	3.8	6.3	8.8	7.0	10.2
XGL4030-222MEC	2.2	13.5	15.0	40.0	3.1	5.0	7.0	5.8	8.7
XGL4030-332MEC	3.3	19.9	21.9	30.0	2.4	3.8	5.3	5.4	7.5
XGL4030-472MEC	4.7	28.5	31.5	26.0	2.1	3.2	4.4	4.8	6.6
XGL4030-562MEC	5.6	31.5	34.7	25.0	2.0	3.1	4.2	4.0	5.5
XGL4030-682MEC	6.8	43.5	47.9	22.0	1.8	2.7	3.7	3.5	4.7
XGL4030-822MEC	8.2	50.6	55.7	20.0	1.7	2.6	3.5	3.1	4.2
XGL4030-103MEC	10	63.0	69.5	18.5	1.4	2.3	3.1	2.9	3.9
XGL4030-123MEC	12	78.5	86.5	17.0	1.4	2.1	2.7	2.5	3.4

Introduction

Specifications

Isat (A) [5]			Irms (A) [6]	
10% drop	20% drop	30% drop	20°C rise	40°C rise
12.5	19.5	26.5	21.0	27.0
9.2	14.4	19.3	17.5	24.2
8.0	12.5	17.0	17.0	24.0
7.2	11.5	15.5	15.5	22.5
6.8	10.6	14.2	15.3	21.2
6.1	9.5	12.7	12.5	15.0
5.6	8.7	11.8	12.3	14.2
4.8	7.6	10.3	10.8	13.0
4.2	6.8	9.2	9.5	12.2
3.8	6.3	8.8	7.0	10.2
3.1	5.0	7.0	5.8	8.7
2.4	3.8	5.3	5.4	7.5
2.1	3.2	4.4	4.8	6.6
2.0	3.1	4.2	4.0	5.5
1.8	2.7	3.7	3.5	4.7
1.7	2.6	3.5	3.1	4.2
1.4	2.3	3.1	2.9	3.9
1.4	2.1	2.7	2.5	3.4

Inductor datasheet dominated by current ratings.

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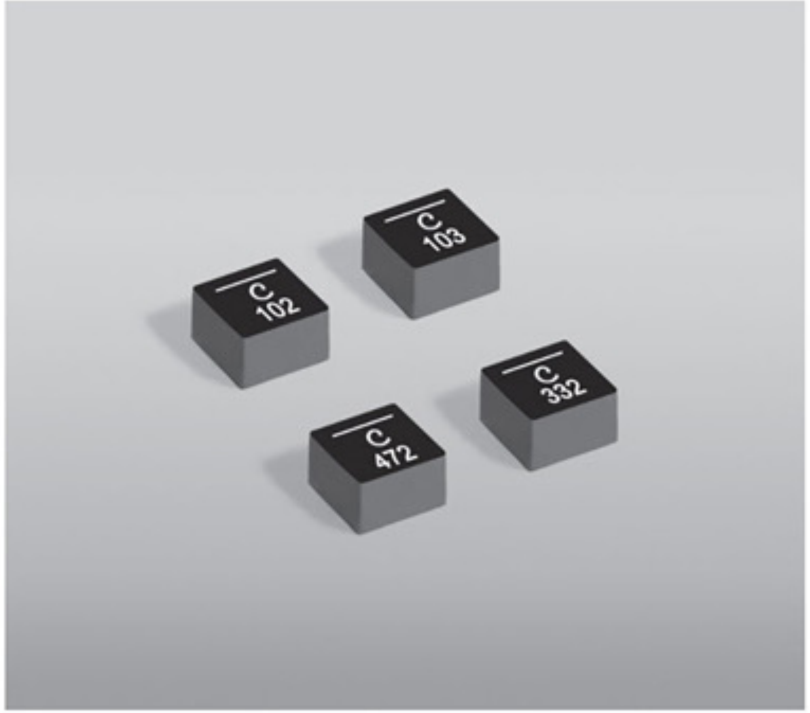
Introduction



Operating voltage: 0 – 80 V

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Part 1: Why now?
What developments are driving the need for a greater emphasis on inductor voltage ratings?

Part 1: Why Now?

- Wide band-gap devices like silicon carbide (SiC) and gallium nitride (GaN) are more suitable for higher voltage operation than traditional silicon MOSFETs.

e.g. SiC transistors = 650 volts

- Wide Vin applications
  - Automotive batteries (12 v, 400 v, 800 v)
  - Telecomm voltage (-36 v to -57 v)

- Converter topologies
  - 48 to 1 volt direct conversion for data center

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- Wide band-gap devices like silicon carbide (SiC) and gallium nitride (GaN) are more suitable for higher voltage operation than traditional silicon MOSFETs.

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Higher voltage operation

- Wide Vin applications
  - Automotive batteries
  - Telecomm voltage (-36 v to -57 v)

DC-DC converter operation over a wide range of duty cycles

- Converter topologies
  - 48 to 1 volt direct conversion for data center

DC-DC converter operates at higher voltage and extreme duty cycle

Part 1: Why Now?

- New inductor types are often optimized for efficient high-current performance.
- New voltage ratings needed to ensure suitability for high application working voltage.

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Part 1: Why Now?

Why don't we usually have voltage breakdown problems with inductors?

- From Faraday's law of induction:

$$v = -L\left(\frac{di}{dt}\right)$$

- High inductor voltage drives high di/dt.
- Most designs historically use a large inductance for high voltage applications to limit di/dt. Why/how does high inductance help with voltage stress?

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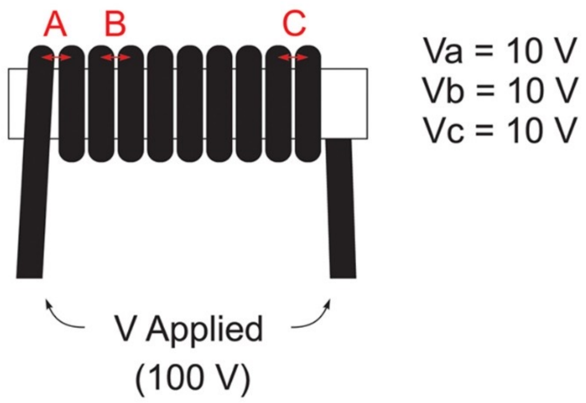
Part 2: Inductor physics. Material and geometry determine voltage capacity.

Part 2: Material and geometry determine voltage capacity.

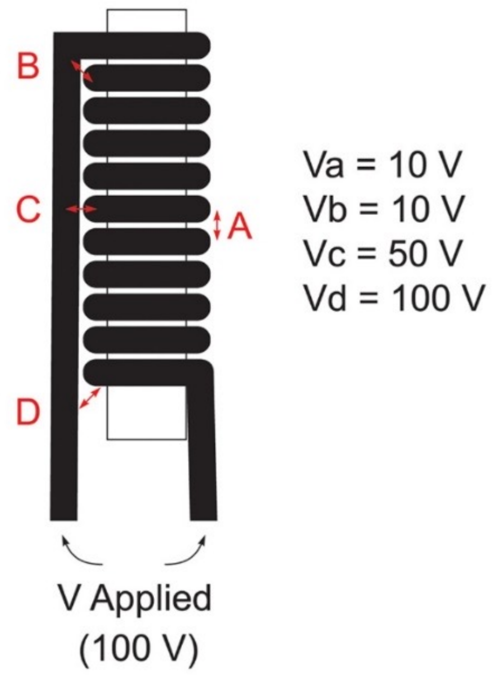
- Inductor impedance consists of the series sum of impedances of each turn.
- Inductor voltage divides between the turns.



- Higher inductance parts have higher number of turns. Voltage capacity of the inductor to resist breakdown depends on the wire insulation to withstand turn-to-turn voltage stress.

Part 2: Material and geometry determine voltage capacity.

- Inductor turns are not always evenly spaced.
- Voltage stress on the wire insulation is not always simply the voltage divided by the number of turns.



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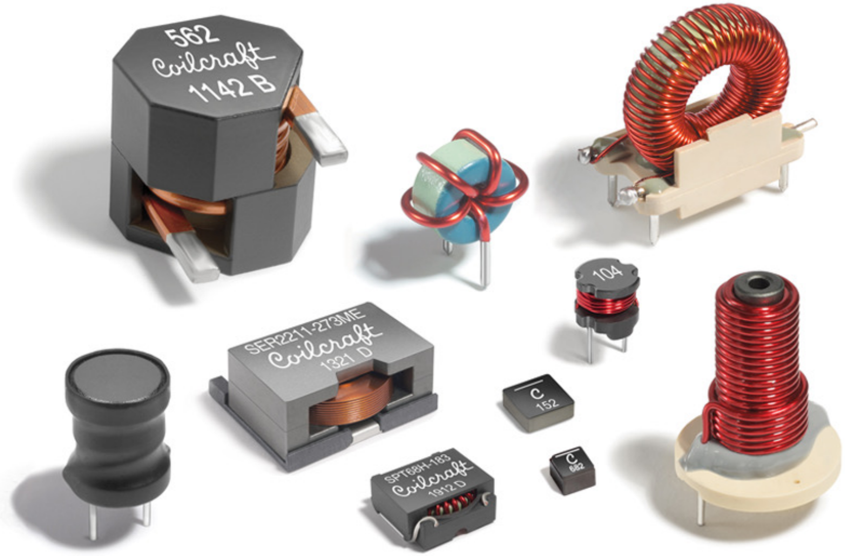
Part 2: Material and geometry determine voltage capacity.

- Inductor turns are not always evenly spaced.
- Voltage stress on the wire insulation is not always simply the voltage divided by the number of turns.
- Nevertheless, many traditional inductors similar to that shown are suitable for 100’s or 1,000’s of volts.

Part 2: Material and geometry determine voltage capacity.

- Inductors are made in a huge variety of shapes and sizes.



- It is very difficult to make assumptions about the voltage stress inside the inductor.
- Voltage ratings are necessary

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Part 2: Material and geometry determine voltage capacity.

- Many of the most popular, powerful (high current) and efficient dc-dc inductors are made in a different way.

- Many inductors are made by molding the core material over/around the windings.

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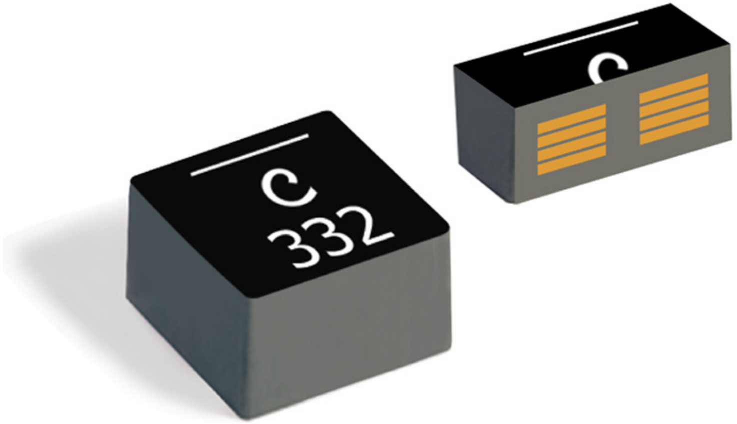
Part 2: Material and geometry determine voltage capacity.

- The core materials are iron-based and therefore are more or less conductive.



- The core material is in direct contact with more of the winding wire than traditional winding types.
- The core material creates lower resistance paths between inductor turns and lowers overall voltage capacity.

Part 2: Material and geometry determine voltage capacity.

Coilcraft General rule of thumb:

<u>Traditional Wire-on-core:</u>

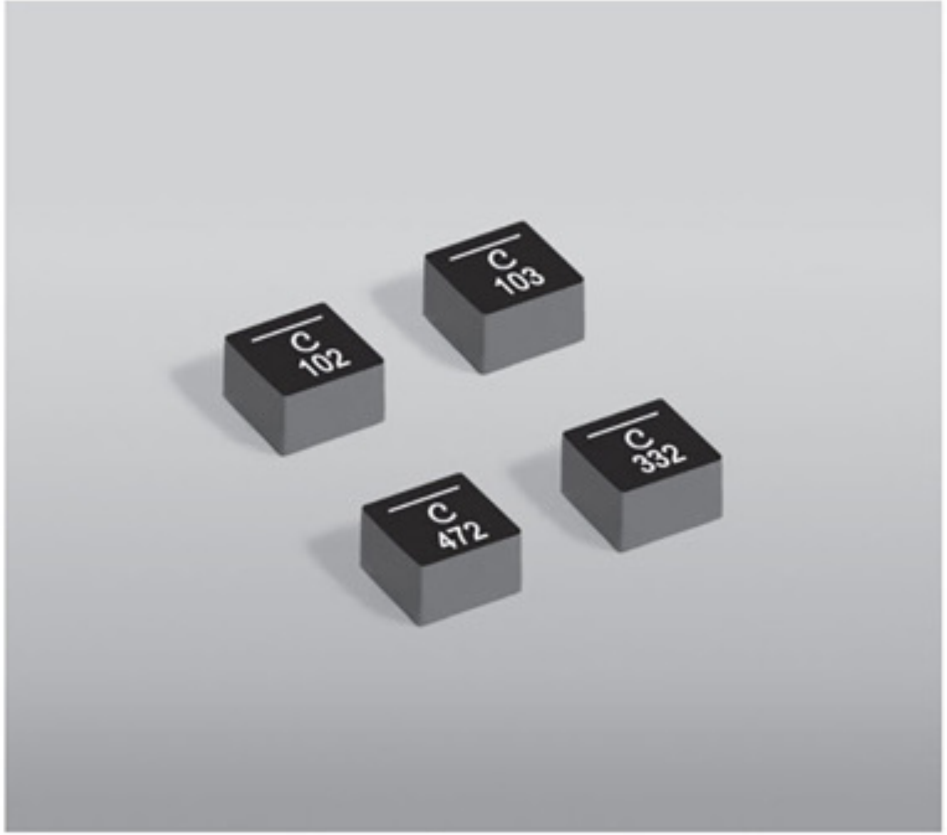
- At least 100 volts
- Typically 400 volts or more

<u>Molded core style:</u>

- 20 volts to 120 volts

Part 3: Voltage Ratings. Inductor Datasheets and Supplier Guidance

Voltage Ratings

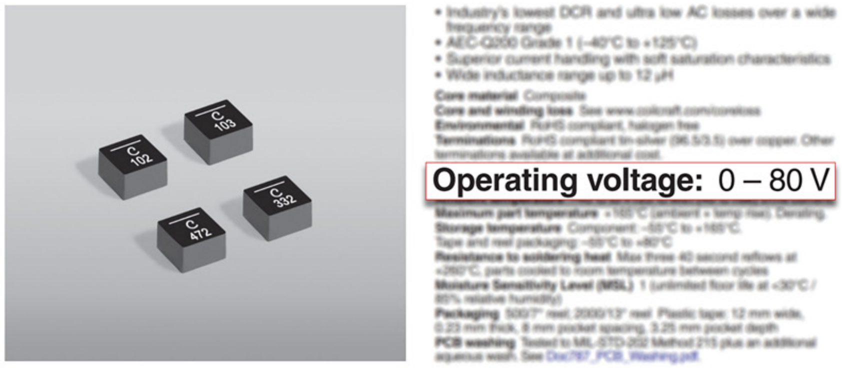


- Industry's lowest DCR and ultra low AC losses over a wide frequency range
- AEC-Q200 Grade 1 (–40°C to +125°C)
- Superior current handling with soft saturation characteristics
- Wide inductance range up to 12 µH

Core material Composite
Core and winding loss See www.coilcraft.com/coreloss
Environmental RoHS compliant, halogen free
Terminations RoHS compliant tin-silver (96.5/3.5) over copper. Other terminations available at additional cost.

Operating voltage: 0 – 80 V

Voltage Ratings



- The voltage rating of an inductor is **the maximum voltage that can be applied to the terminals without causing arcing or insulation breakdown**.
- Voltage above the maximum rating may cause short circuits between turns, through the insulation, or from the windings to core or frame.

Voltage Rating = Working Voltage = Operating Voltage

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Voltage Ratings

From Faraday's law of induction:

$$v = -L\left(\frac{di}{dt}\right)$$

- Inductor voltage rating is <u>not a performance parameter</u>
- Inductor voltage <u>does not change the performance</u> or change inductor parameters like inductor saturation current
- Inductor voltage <u>does change</u> $\frac{di}{dt}$
- Inductor voltage <u>does change</u> i_{peak}

Part 4: Summary & FAQ

Questions

Q. What is the difference between a Voltage Rating and a HiPot test?

A. Both measure insulation ability to withstand high voltage without breakdown.

Voltage rating = working voltage for lifetime of use.

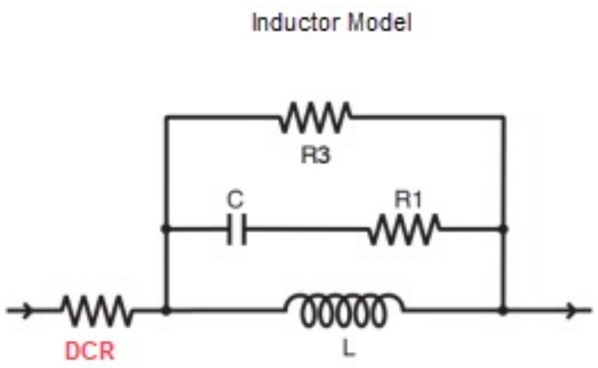
HiPot = many times higher than working voltage. Not expected during use.

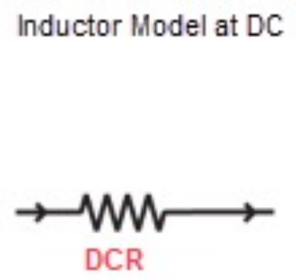
Questions

Q. What is the difference between a Voltage Rating and a HiPot test?

A. HiPot can be directly measured across the insulation with ac or dc voltage, with a HiPot tester.

Working voltage only appears across impedances of the winding turns, which only exist when energized by ac or changing voltage.





To test for working voltage, the inductor must be energized and insulation integrity detected. This is typically done with a surge tester.

Questions

Q. Is the voltage rating DC or RMS or Peak?

A. It's the peak voltage. The voltage rating is the maximum voltage that will not damage the insulation integrity. Therefore the RMS or average does not apply, and DC voltage does not apply to inductors.

Summary

- New devices, new circuits, new inductor types, and new applications put increasing voltage stress concerns on power converter inductors.

- Voltage withstanding capability depends on insulating material properties as well as the winding geometry, which makes it impossible for a user to properly judge the voltage capacity of an inductor.

- Voltage ratings on datasheets or direct guidance from the inductor manufacturer are crucial tools for selecting a suitable dc-dc converter inductor.

Thank you!