Session 1: June 7th | 10:00 AM CEST | 1:00 AM PDT | 4:00 AM EDT
Session 2: June 7th | 5:00 PM CEST | 8:00 AM PDT | 11:00 AM EDT

Understanding Power Inductor Parameters

Monolithic Power Systems

Codico

June 7, 2022

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Speakers

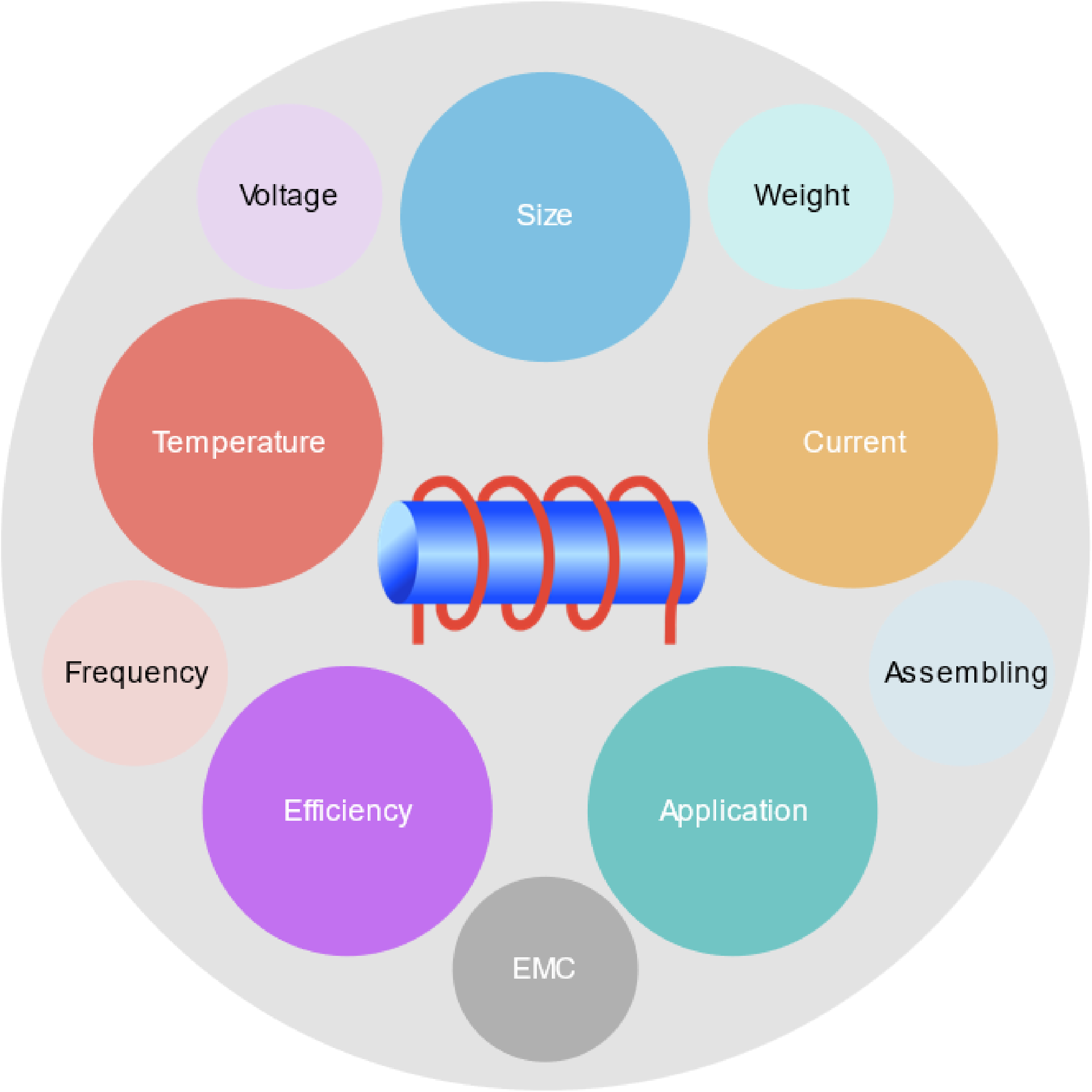
Product Manager, Passive Components
Monolithic Power Systems, Germany
Sven.Spohr@monolithicpower.com
www.monolithicpower.com

Product Line Manager, Passive Components
Codico, Austria
Sebastian.Gebhart@codico.com
www.codico.com

Agenda

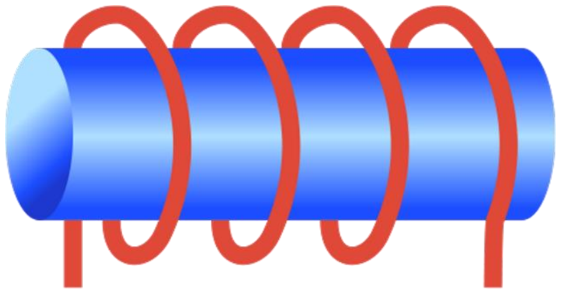
1. What is an Inductor?
2. Technical Characteristics, Electromagnetism Basics
   - Inductance
   - Permeability
   - Inductor Losses
3. Important Parameters when Selecting an Inductor
   - Rated Current
   - Saturation Current
   - Resonance Frequency
   - Start of Winding
4. MPS Inductors Overview
5. Efficiency Comparison
6. Q&A

Selecting an Inductor

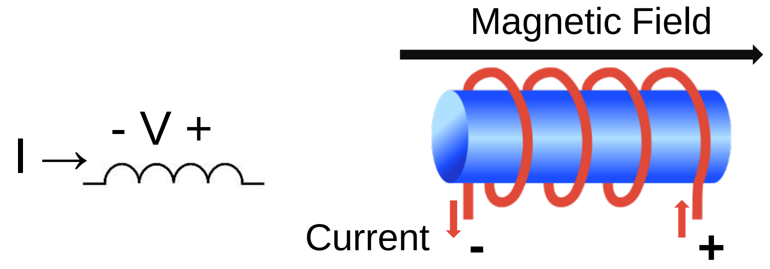


What Is an Inductor?

Wire wounded in coil shape with or without core



- It opposes a change in current from a circuit
  - If current is increasing, inductors try to keep them from increasing

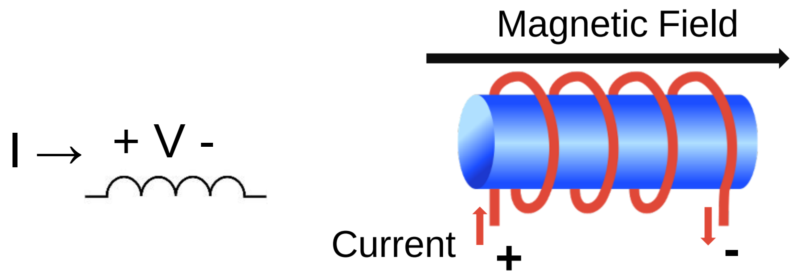


What is the main task of the inductor?

Opposes a change in current

$$V = L\frac{di}{dt}$$

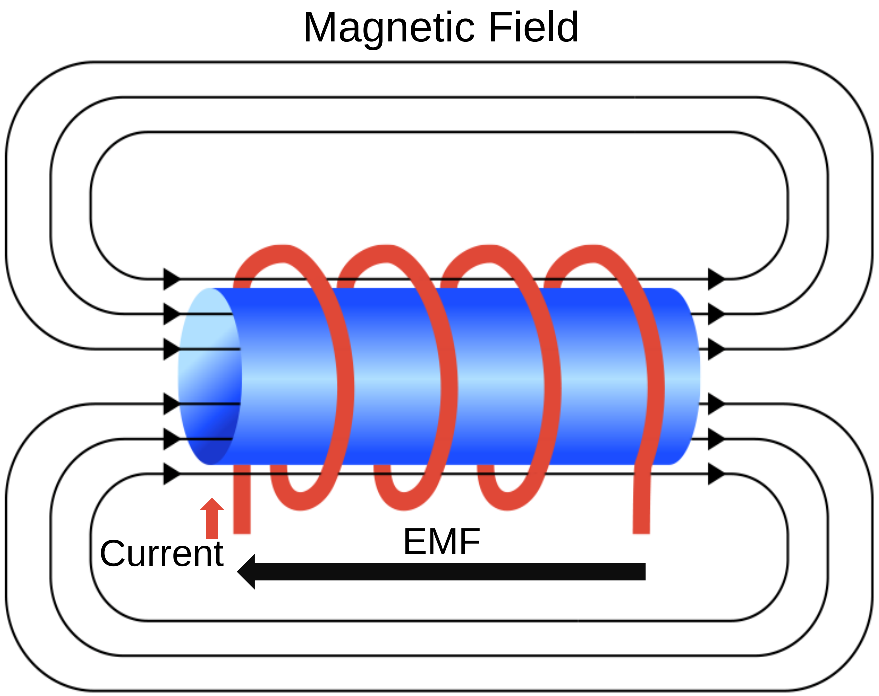
  - If current is decreasing, inductors try to keep them from decreasing



Inductors always have a voltage across them if there is change of current

I = constant V = 0

What Is an Inductor?



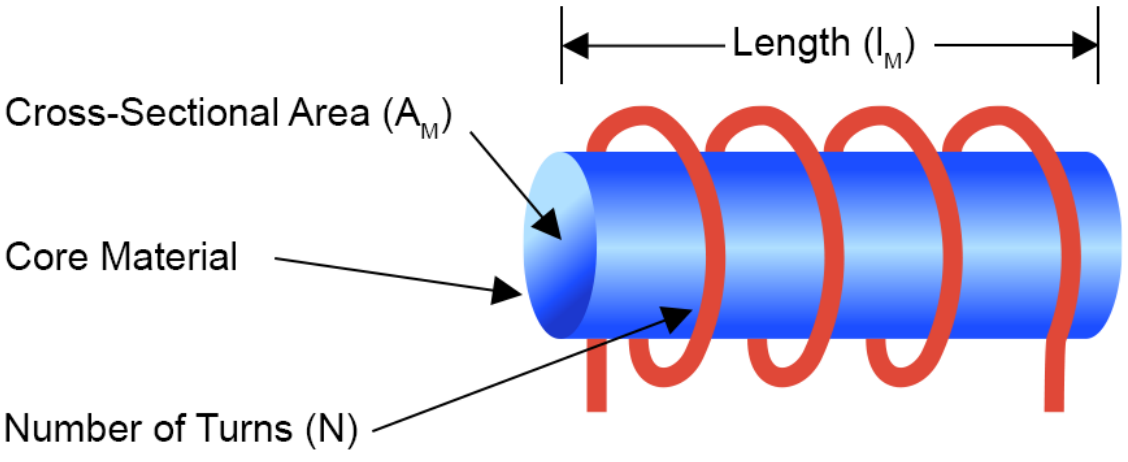
- Inductors have the ability to store induced electric energy as magnetic energy
- With the change of current in time, the induced magnetic energy will change, causing electromotive force

$$e = -\frac{d\varphi}{dt} = -L\frac{di}{dt}$$

e	electromotive force (EMF)
$\frac{d\varphi}{dt}$	change of magnetic flux over the change in time
$\frac{di}{dt}$	change of current over the change in time
L	Inductance unit measured in Henries

Inductance

$$L = \frac{\mu_o \mu_r A}{l} N^2$$



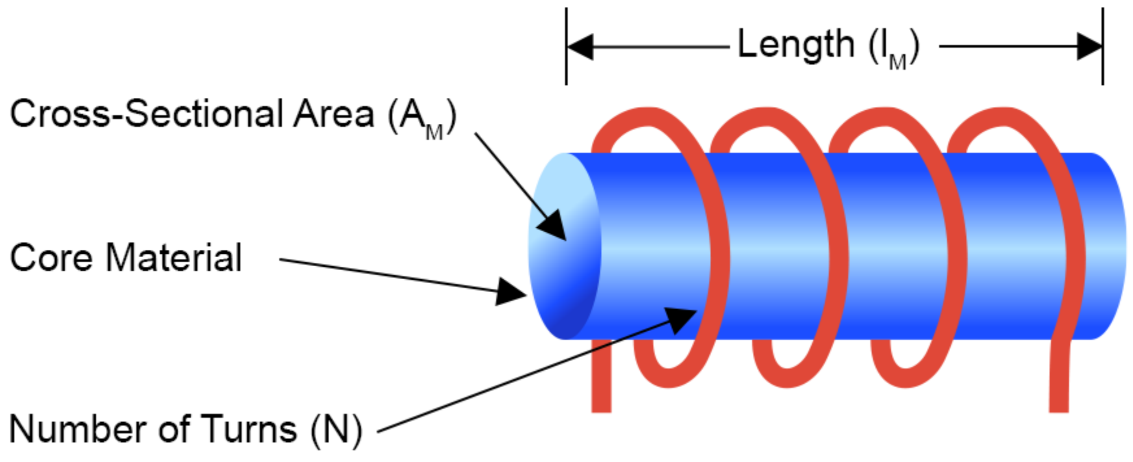
- L Inductance Value Units Henry (H)
- μ_o Constant of Nature $(4\pi 10^{-7})$
- μ_r Relative Permeability
- A_M Area of the Coil
- l_M Length of the Coil
- N Number of Turns

$$L = \frac{\mu_o \mu_r A}{l} N^2 \rightarrow L = A_L N^2$$

Parameters Related to Core Material

Inductance

$$L = \frac{\mu_o \mu_r A}{l} N^2$$



How to Increase Inductance:

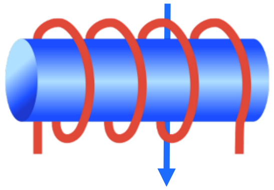
- μ ↑ Higher Permeability Core Material
- l ↓ Reduce Effective Length of Core
- A ↑ Bigger Core Cross Sectional Area
- N^2 ↑ Higher Number of Turns

Balance Between Size, Weight, and Performance
Smallest Package Possible to Reduce Weight
Less Turns Possible to Reduce R_{DC}

Permeability

Ability of a material to concentrate magnetic flux

$$B=\mu_o\mu_r H$$



Concentration of Magnetic
Flux in the Core

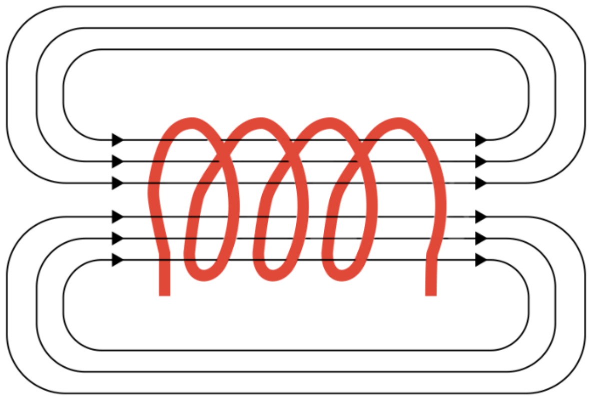
Material
Frequency
Temperature
Current
Pressure

Geometry
Number of Turns
Current

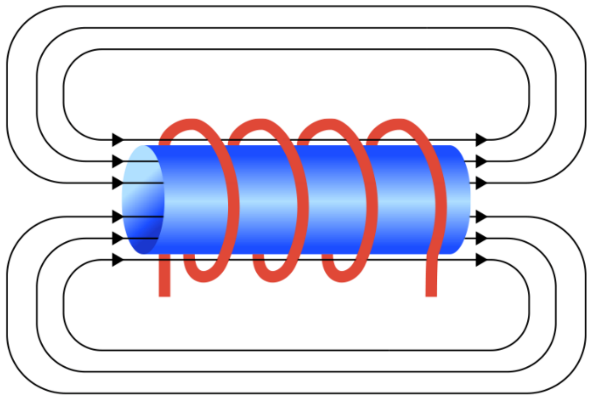
Increasing Permeability ↑ Increases Inductance ↑ Resonance Frequency ↓

Permeability

Material	Relative Permeability μ_r
Air	~1
Iron (FE-Based)	50 to 150
Nickel-Zinc	40 to 1500
Manganese-Zinc	300 to 20000



$$\vec{B} = \mu_o \vec{H}$$



$$\vec{B} = \mu_o \mu_r \vec{H}$$

The magnetic field remains the same

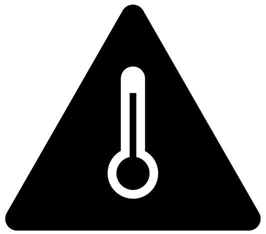
Magnetic flux concentration can intensify by using highly permeable core material

Losses

Copper Losses

DC loss

Heat dissipation of the inductor winding's R_{DC}



AC loss

Winding structure loss driven by the frequency

Proximity Effect

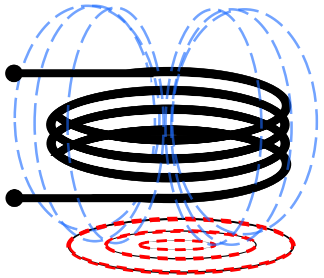
Skin Effect

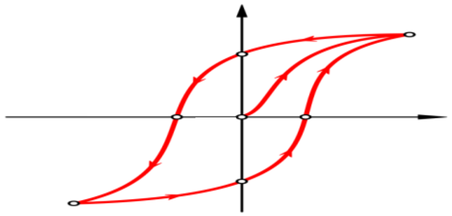
Core Losses

Magnetic material loss

Eddy Currents

Hysteresis Loss





Copper Loss

P_{DC} Copper Loss

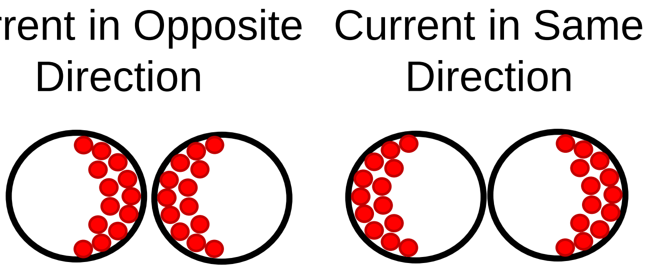
Heat dissipation of the inductor winding's R_{DC}

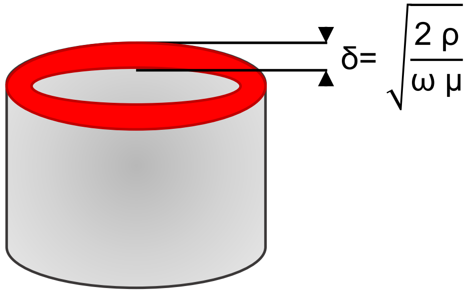
Higher heat dissipated, power loss, and efficiency is reduced
The best winding window shows the lowest R_{DC}
The core material has an impact as well (fewer turns)

P_{AC} Copper Loss

Proximity Effect

Skin Effect





Frequency dependent; the higher the frequency, the higher the P_{AC} loss
Reduce the effective cross-sectional area, which reduces current distribution in the wire

Copper Loss

P_{DC} Copper Loss

Heat dissipation of the inductor winding's R_{DC}

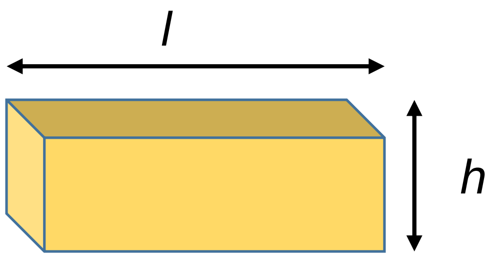
$$P_{DC}=I_{DC}^2\,R_{DC}$$

$$R_{DC}=\rho\,\frac{l}{A}$$

P	Resistivity (Cu)
l	Length
A	Cross-Sectional Area

Round Wire	Flat Wire
Higher inductance	Winding area is limited, maximum inductance is reduced
Higher resistance (R_{DC})	Lower resistance (R_{DC})
Lower cross-section area	Winding window completely used
More turns possible	Fewer turns possible
Lower current	Higher current

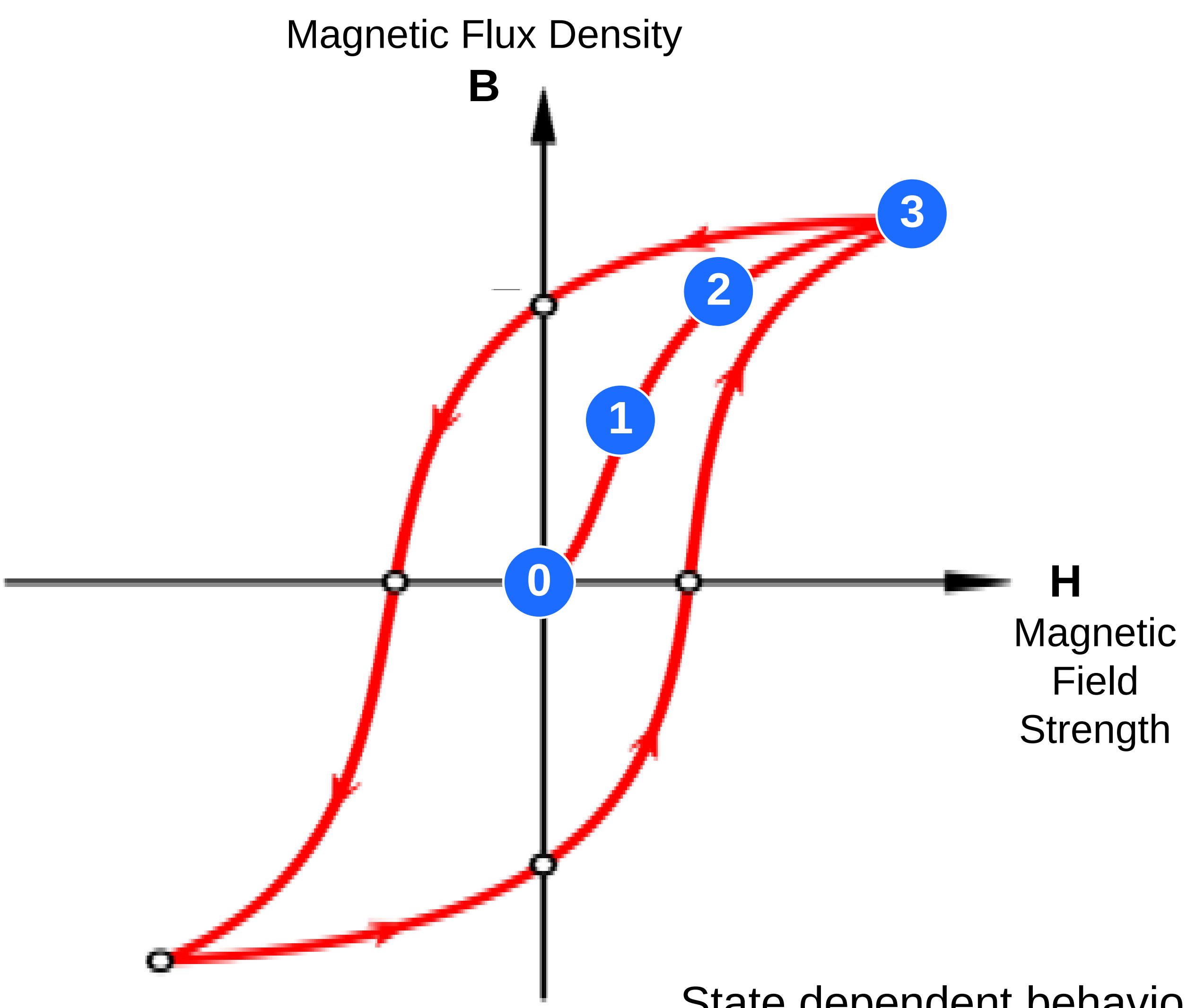
$$A = \pi r^2$$
$$= 0.785 mm^2$$



$$A = length\ x\ height$$
$$= 1\ mm^2$$

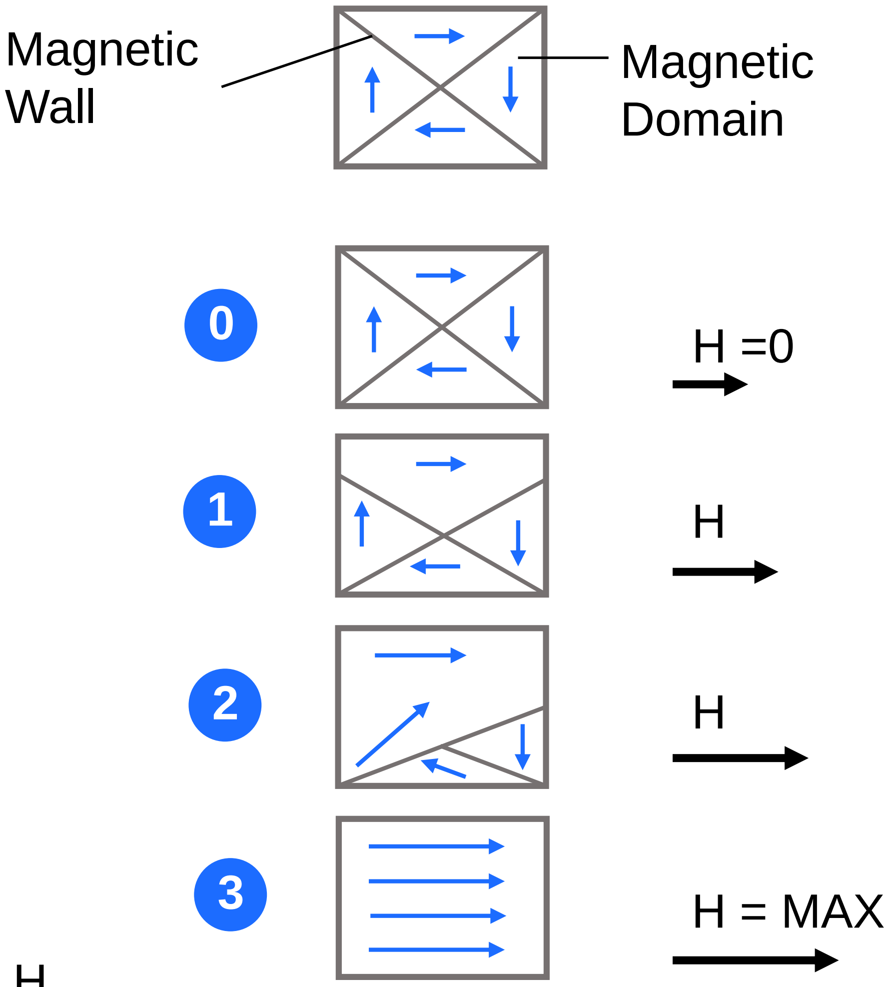
Lower R_{DC} to Get Higher Efficiency and Better Thermal Dissipation in the System

Core Loss – Hysteresis Loss



State dependent behavior B,H

Domain Structure



Rated Current

Self-heating of the component caused by the wire's R_{DC}.

The temperature rise is not standard, and varies from manufacturer to manufacturer.

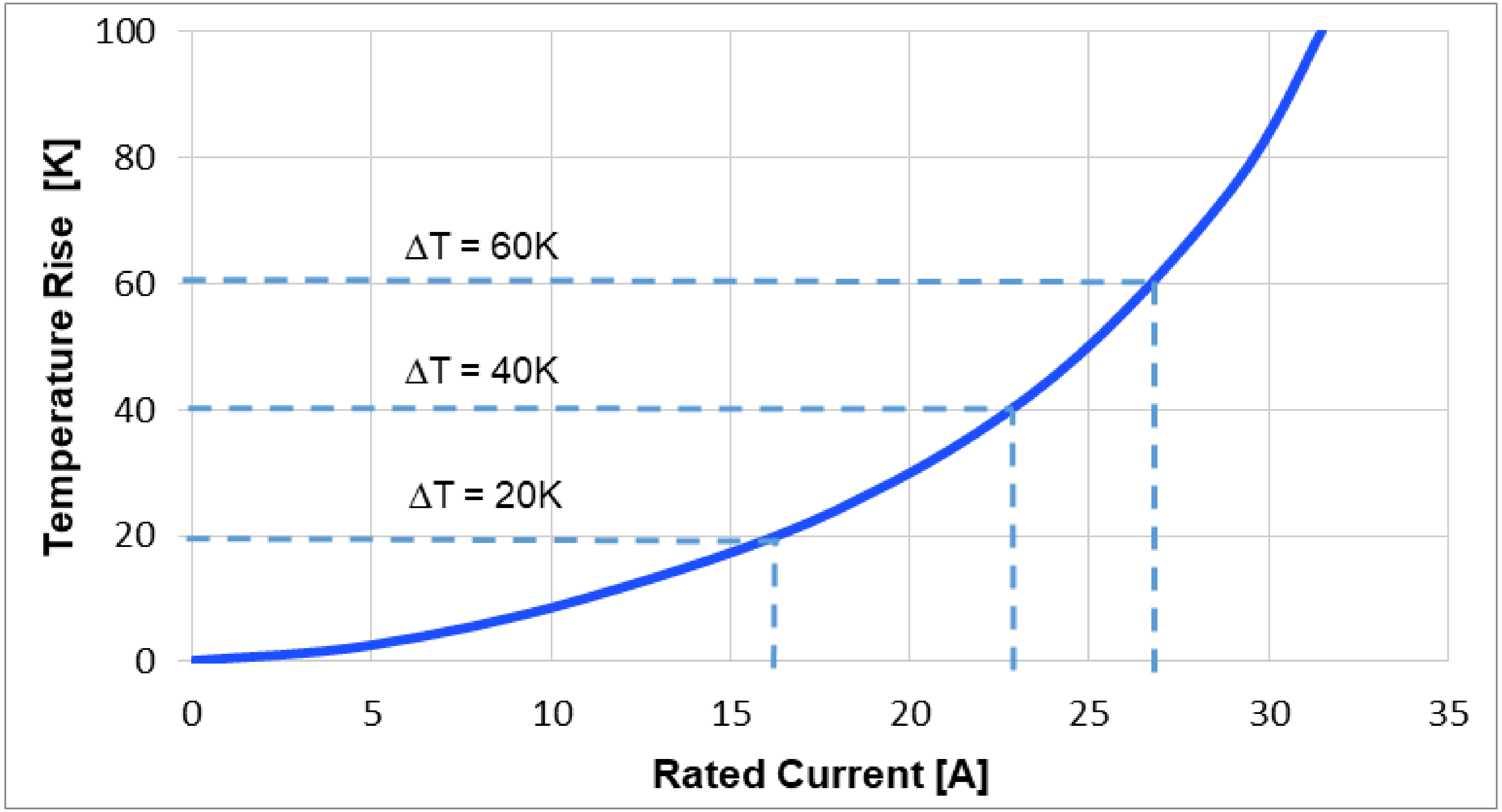
$$T_{OP} = T_{AMB} + \Delta T$$

T_{AMB}	Ambient Temp	-40 to 85°C / -40 to ?°C
ΔT	Temperature Rise (Self-Heating)	20K / 30K / 40K / ?K
T_{OP}	Operating Temperature	Max. Value Given in Datasheet

Don't exceed the maximum operating temperature T_{OP}

- At higher ambient temperatures, the ΔT (self-heating) should be adjusted
- Larger-sized component

Rated Current



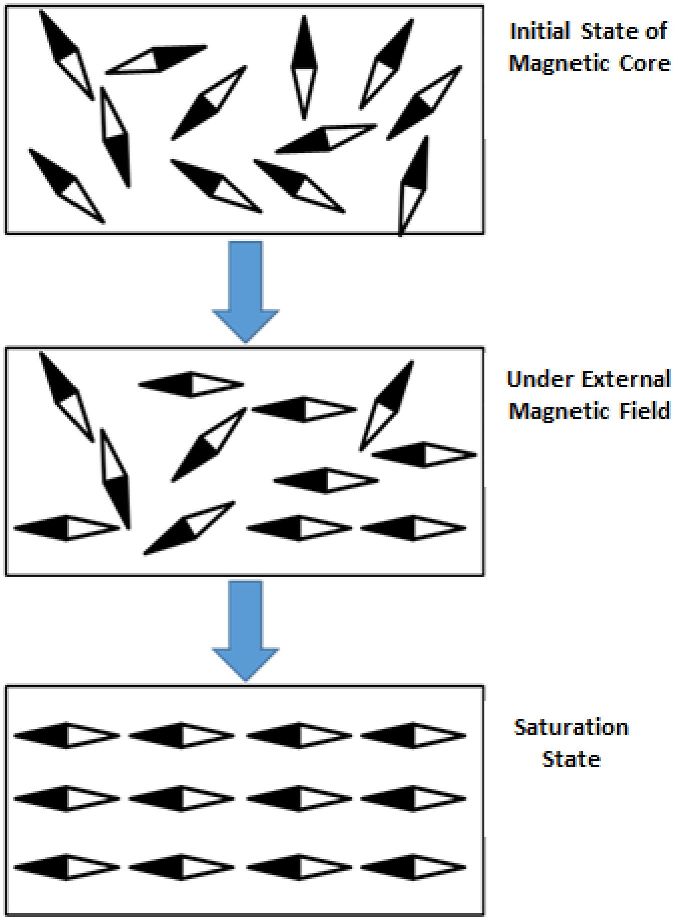
Pay attention to the maximum operating temperature conditions. The ambient temperature must be considered as well.

Saturation Current

When the current is passed through the coil, the coil generates a magnetic field.

The magnetic core is magnetized by the field, and its internal magnetic domain rotates slowly.

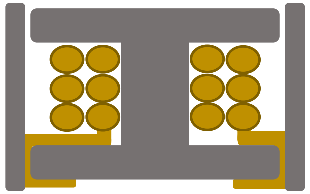
When the magnetic core is completely magnetized, the direction of the magnetic domains becomes consistent with the magnetic field.

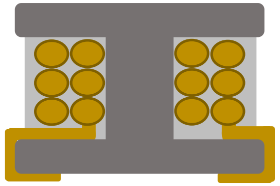


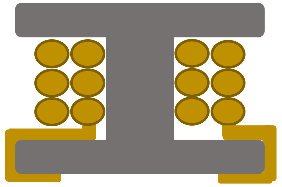
The higher the H-field, the higher the B-flux
The airgap determinates the saturation level

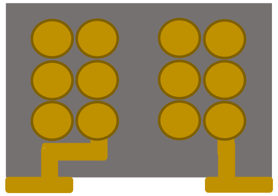
Saturation Current

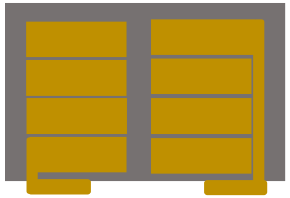
Drum Core Shielding Ring Type	Lowest Saturation
Semi-Shielded Type	Low – Medium Saturation
Drum Core Unshielded Type	Medium Saturation
Molded Type	Highest Saturation







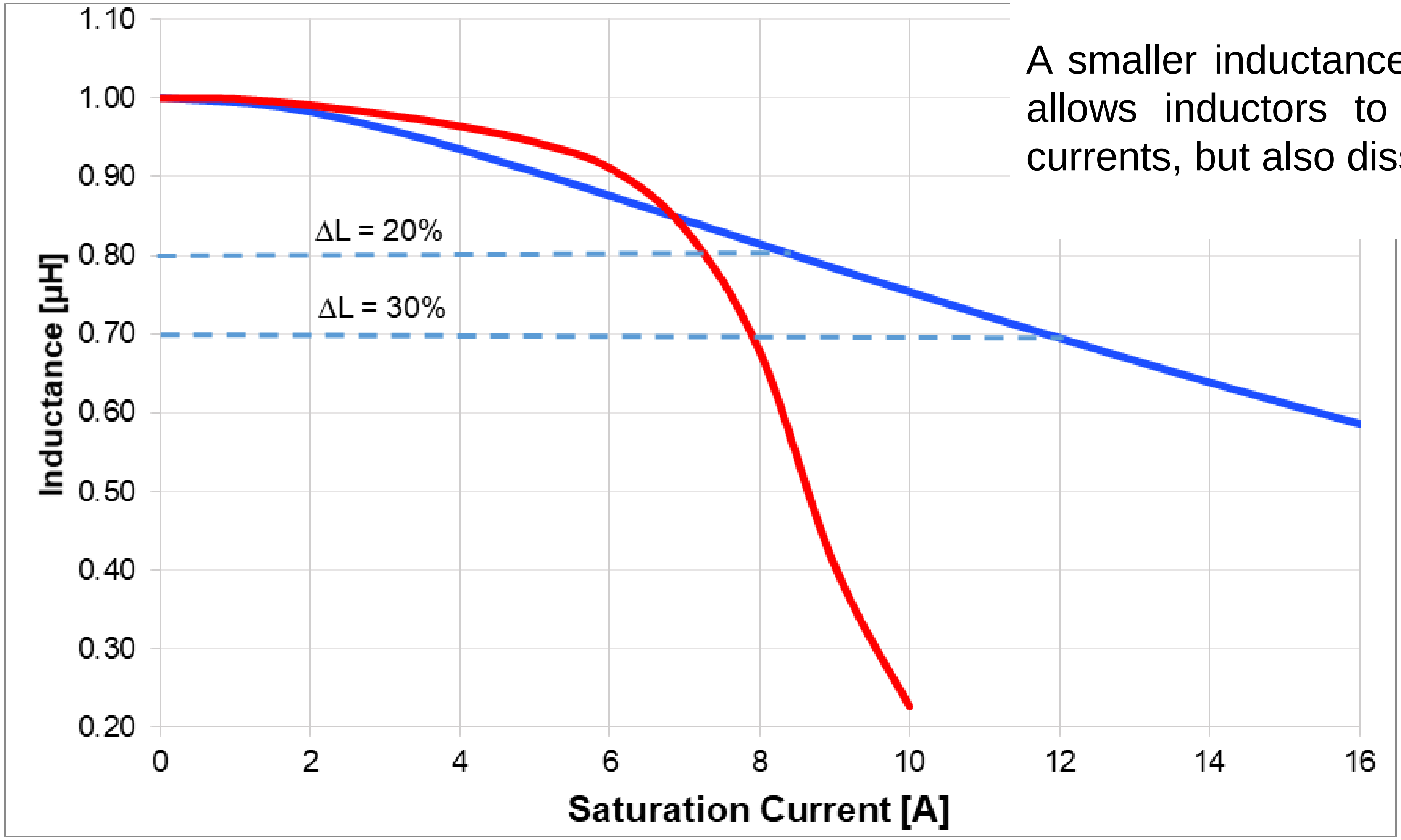




The saturation current point extends when increasing the airgap
Distributed airgap on molded inductors

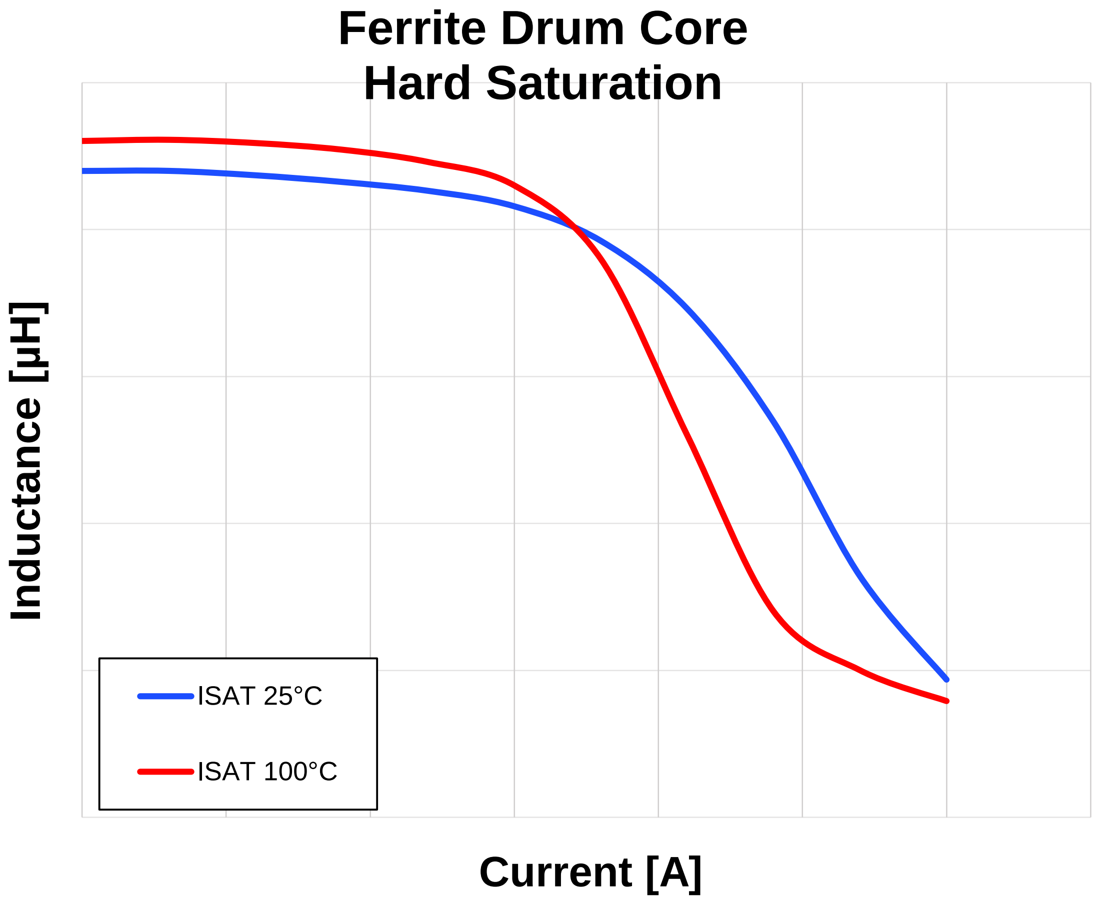
Saturation Current

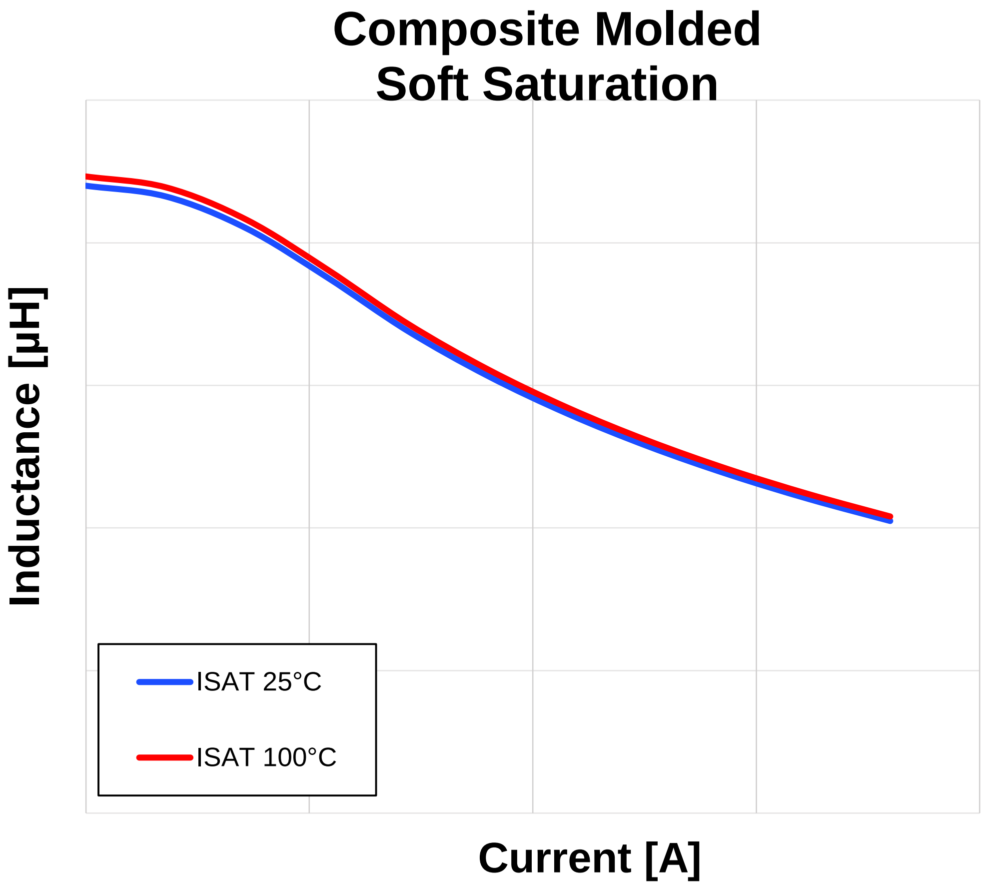
Inductance drops by 30% at the given current



A smaller inductance or a larger package size allows inductors to handle higher saturation currents, but also dissipates more heat

Saturation Current





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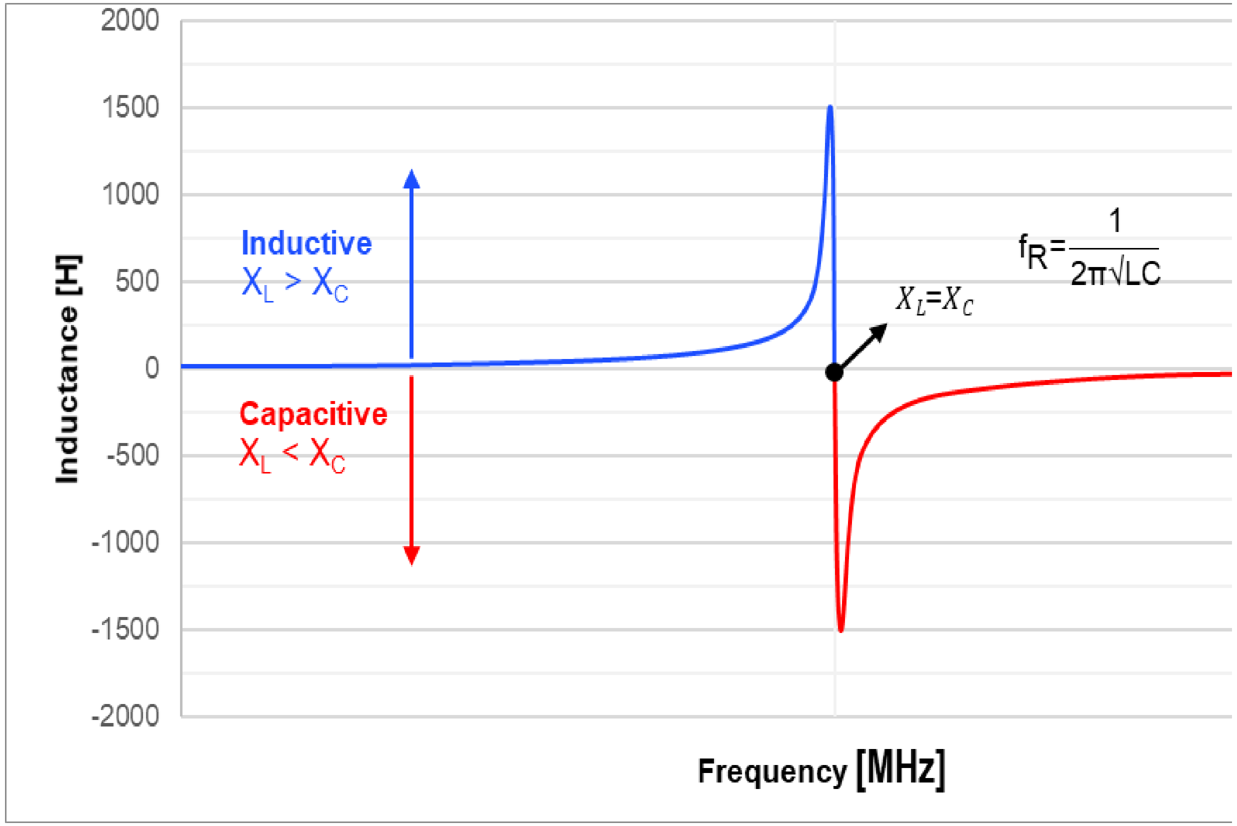
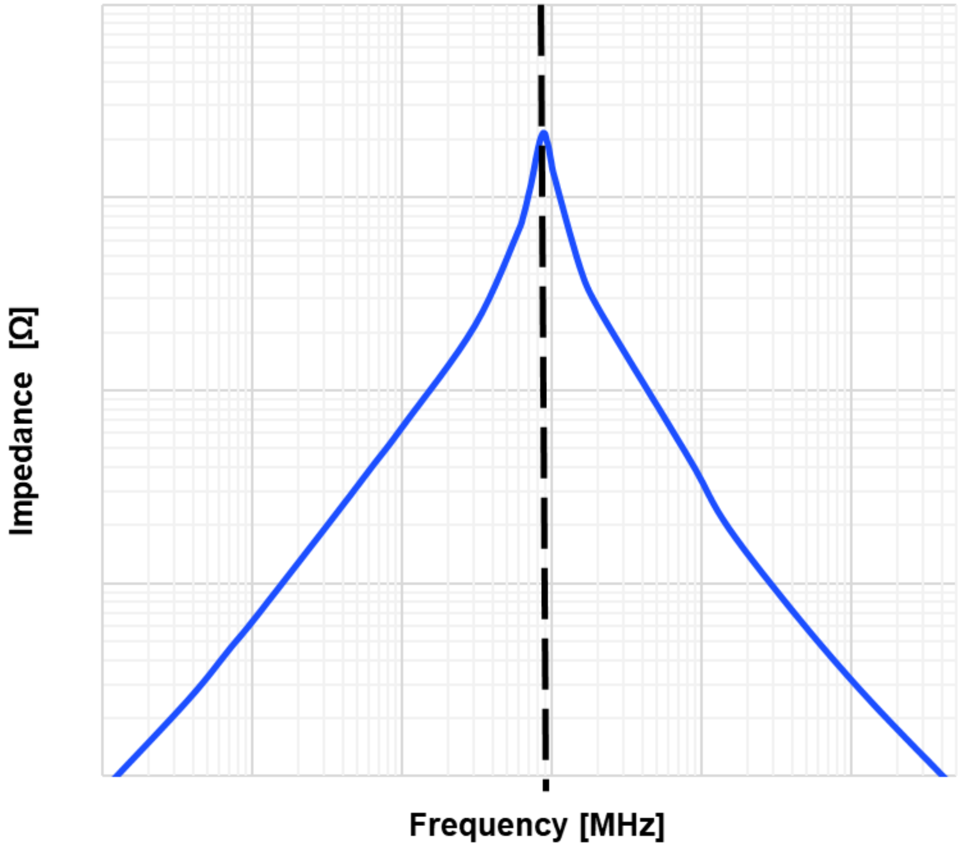
Resonant Frequency





Self-resonant frequency needs to be much higher than the switching frequency

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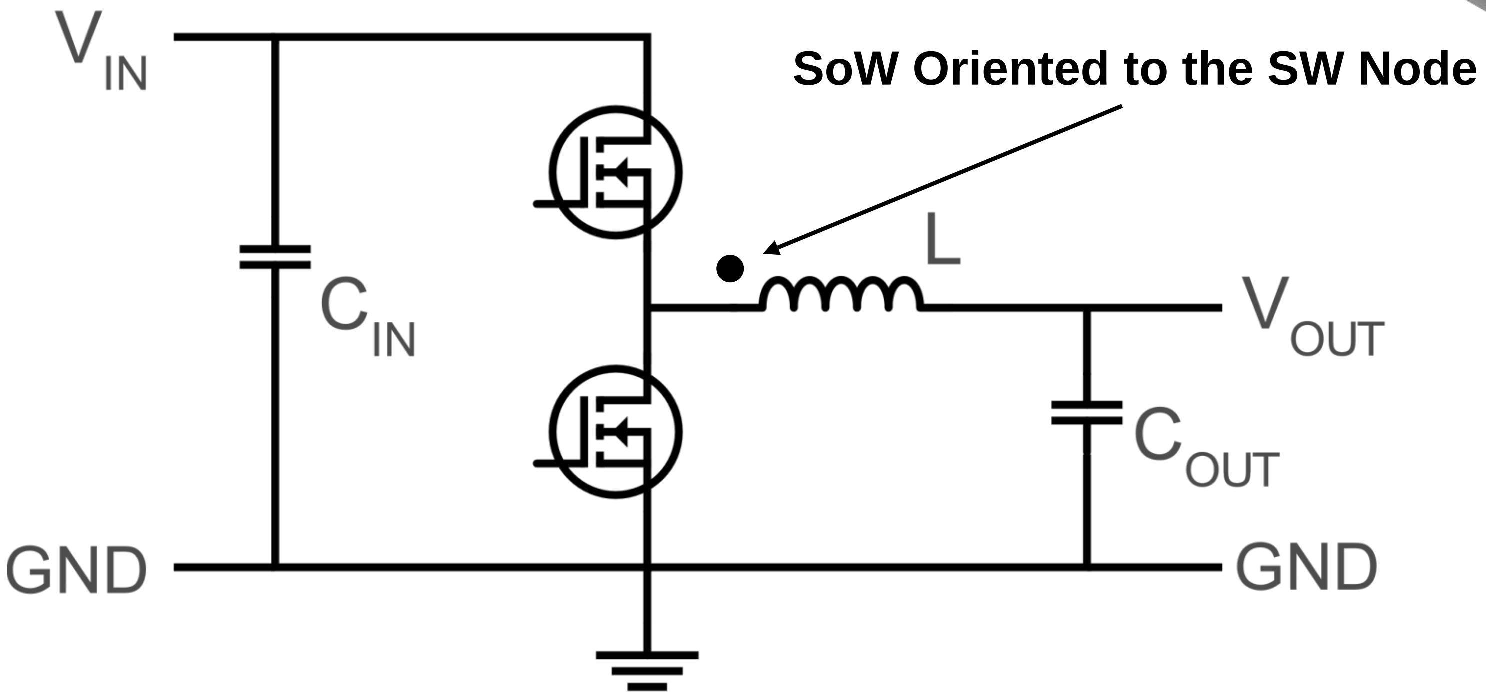
Start of Winding

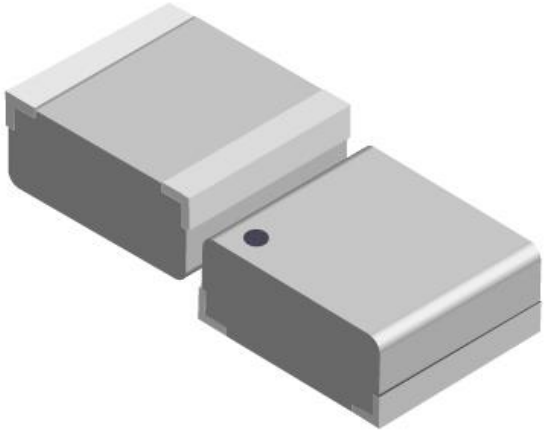
The converter switch node is close to the start of winding side



- Avoids audible noise from harmonics
- Reduces emissions caused by the inductor

MPL-AT Series

- **MPL-AT (Tiny Molded Inductors)**
  - **Start of Winding Indication**
  - Low-Profile Inductors
  - Low DCR
  - High Saturation Current
  - Soft Saturation
  - Stable over Temperature
  - Max Operating Temperature: 125°C
  - Sizes: 2010 / 2512 / 2514



MPL-AY Series

- **MPL-AY (Molded Inductors)**
  - **Start of Winding Indication**
  - Low DCR
  - High Saturation Current
  - Soft Saturation
  - Stable over Temperature
  - Max Operating Temperature: 125°C/155°C
  - Sizes: 3020 / 4020 / 1050 / 1265

MPL-AL Series

- **MPL-AL (Low-Resistance Molded Inductors)**
  - **Start of Winding Indication**
  - **Flat Wire Construction**
  - Lowest DCR
  - High Performance
  - High Saturation Current
  - Soft Saturation
  - Stable over Temperature
  - Max Operating Temperature: 155°C
  - Sizes: 4020 / 5030 / 5050 / 6050 / 6060

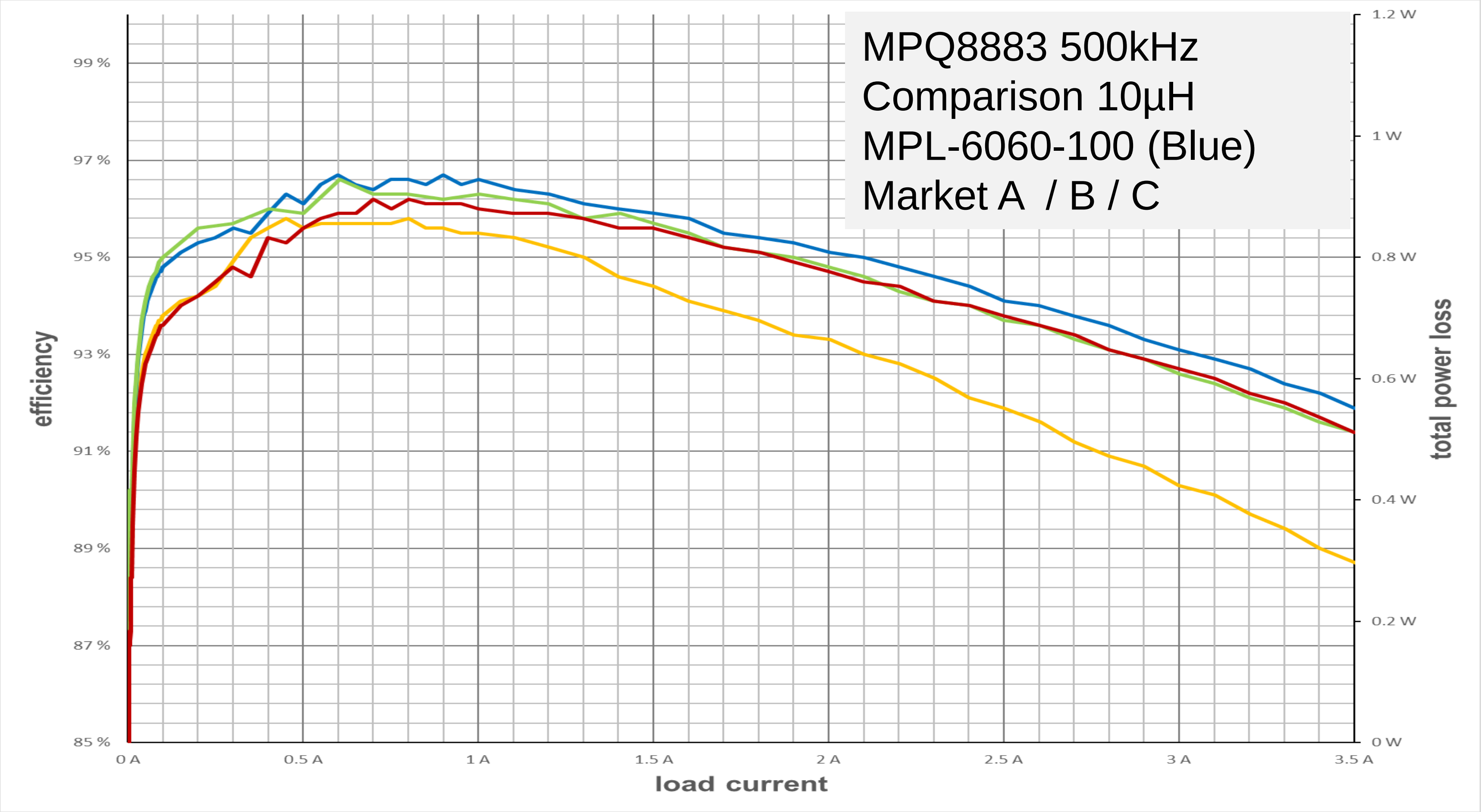
Flat Wire, Low DCR, High Efficiency

MPL-SE Series

- **MPL-SE (Semi-Shielded Inductors)**
    - External Epoxy Resin for Better Magnetic Characteristics
    - Magnetically Shielded
    - Low DCR
    - High Current
    - Max Operating Temperature: 125°C
    - Sizes: 2512 / 4030 / 5040 / 6040

Efficiency

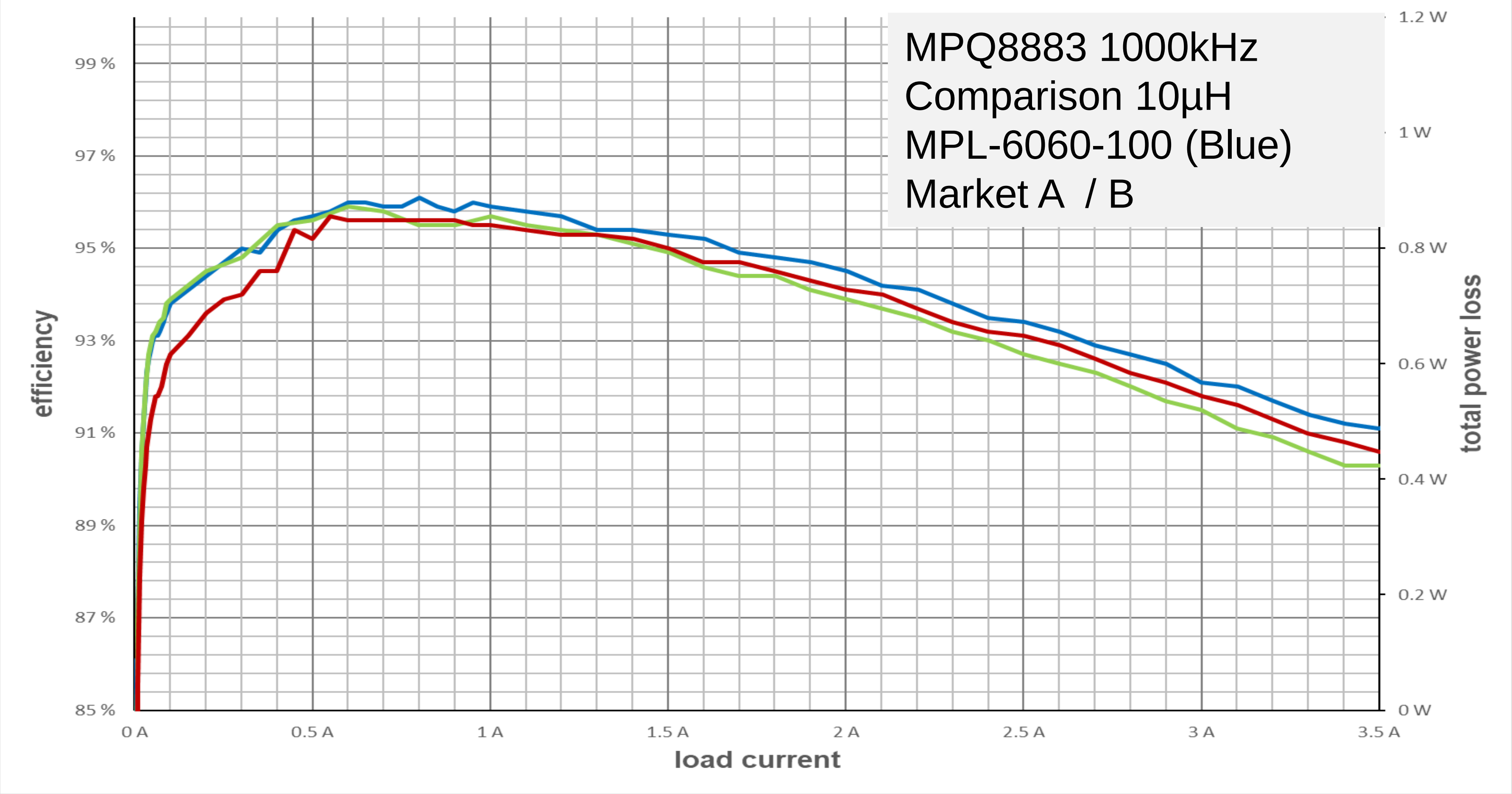
Part Number	L	R_{DC}	I_{DC}	I_{SAT}
MPL-AL6060-100	10µH	24mΩ	6.9A	6.6A



A / B / C	MPS

Efficiency

Part Number	L	R_{DC}	I_{DC}	I_{SAT}
MPL-AL6060-100	10µH	24mΩ	6.9A	6.6A



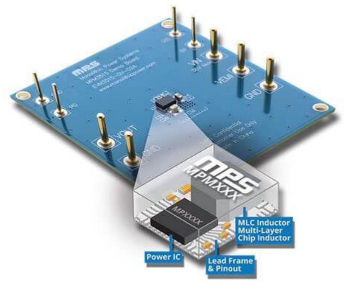
A / B	MPS

Summary

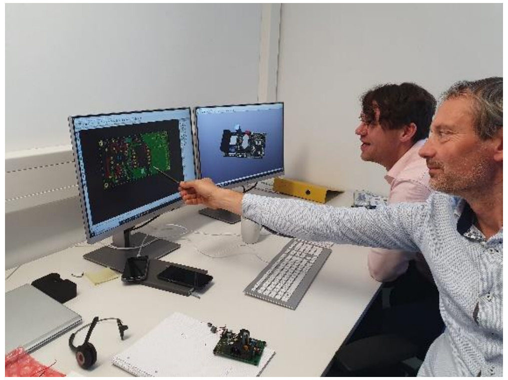
- An Inductor Reacts to Current Changes
- Stores Induced Electric Energy as Magnetic Energy
- Inductance Depends on the Core Material Characteristics and Number of Turns
- Magnetic Flux Density Can Be Intensified by Highly Permeable Core Material
- Losses
- Rated Current
- Saturation Current
- Layout SoW on SW Node
- High-Efficiency MPS Inductors
    - MPS Reference Designs Including Inductors Available
    - MPS Converters Matching with MPS Inductors
- Inductor Calculator Tool

Summary Codico

The COmponent Design In COmpany, better known as CODICO, incorporates the sales and support for high-quality active and passive components as well as connection technology products



In a close cooperation with MPS since 2008 we offer following support:



- Selection of parts according to customers design specifications
- Samples and Evaluation boards with short leadtimes
- Schematic and layout design-proposals
- Layout- and PCB-reviews of customers design
- Troubleshooting
- Competitive pricing and logistic services

For reviews and design support we have FAEs working in 2 Labs, one in Munich/Germany and one in Perchtoldsdorf/Austria

Q&A

Contact

PowerMagnetics@monolithicpower.com

Power Inductors Page and Inductor Selector Tool

https://www.monolithicpower.com/en/products/inductor.html

MPS Flyer – Power Inductors Brochure

https://www.monolithicpower.com/en/support/product-literature.html