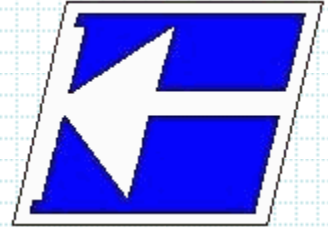


Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina
Departamento Acadêmico de Eletrônica
Curso de Graduação em Engenharia Eletrônica



Projeto de Indutores para Alta Frequência

Prof. Joabel Moia.

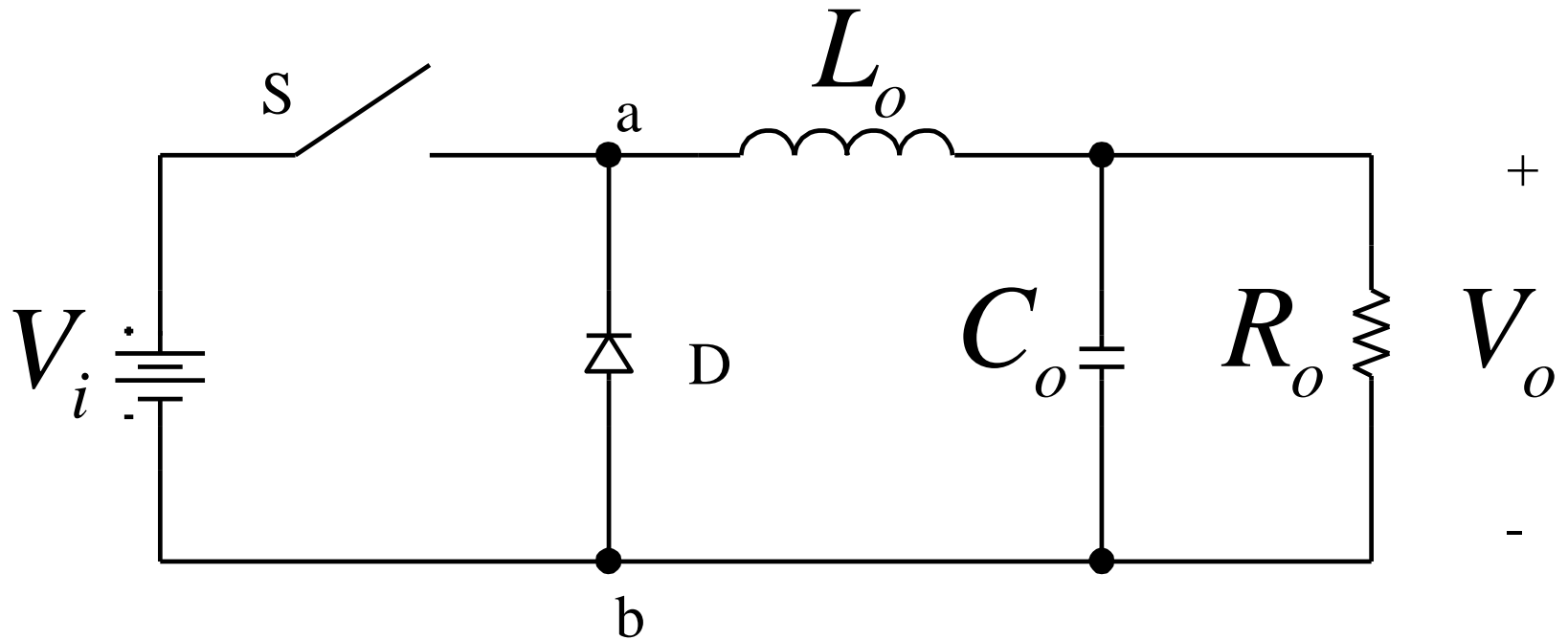
Florianópolis, agosto de 2018.

Introdução comparativa:

1. Conversor Buck;
2. Projeto de indutor com núcleo de ferrite.

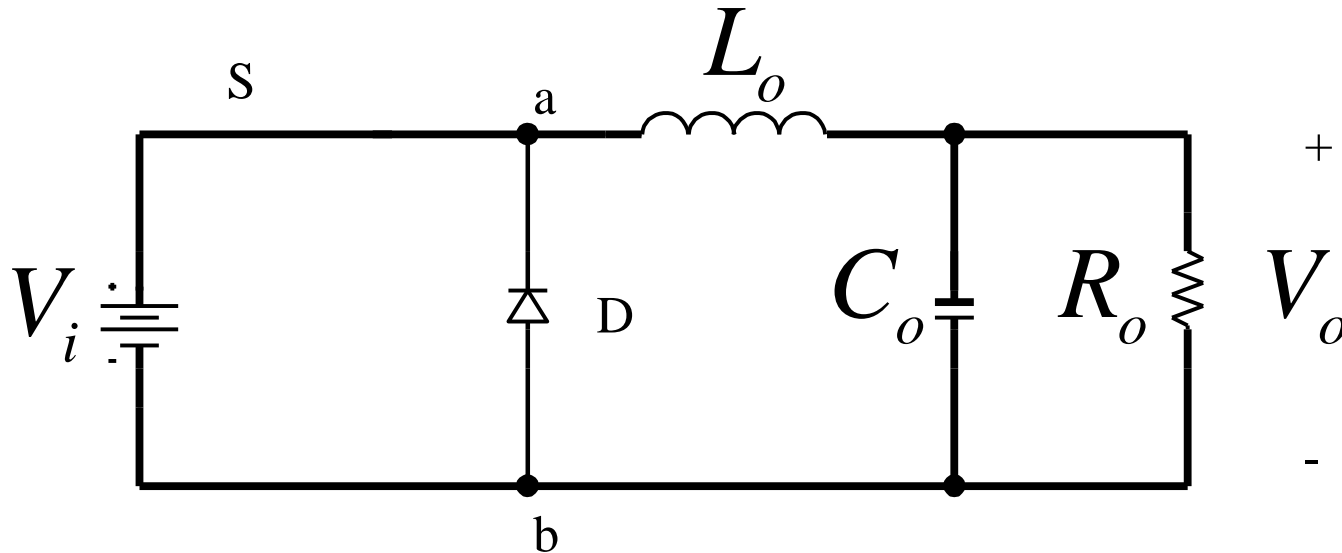


Conversor Buck



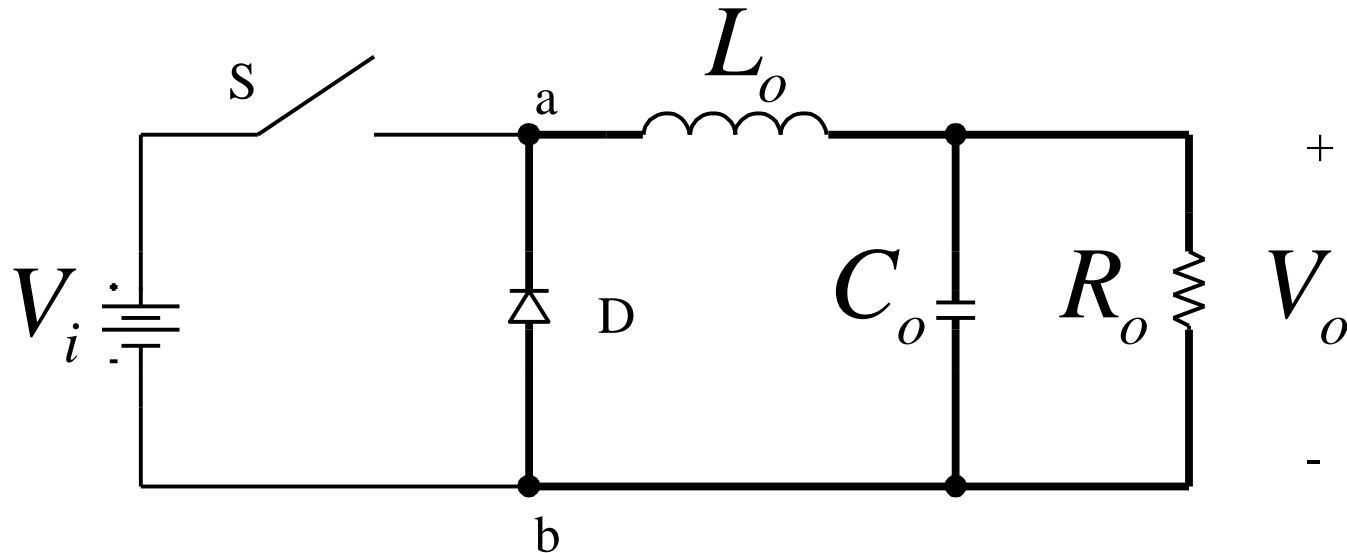
Primeira etapa de funcionamento:

- Interruptor conduzindo;
- Diodo bloqueado;
- Energia sendo armazenada no indutor.



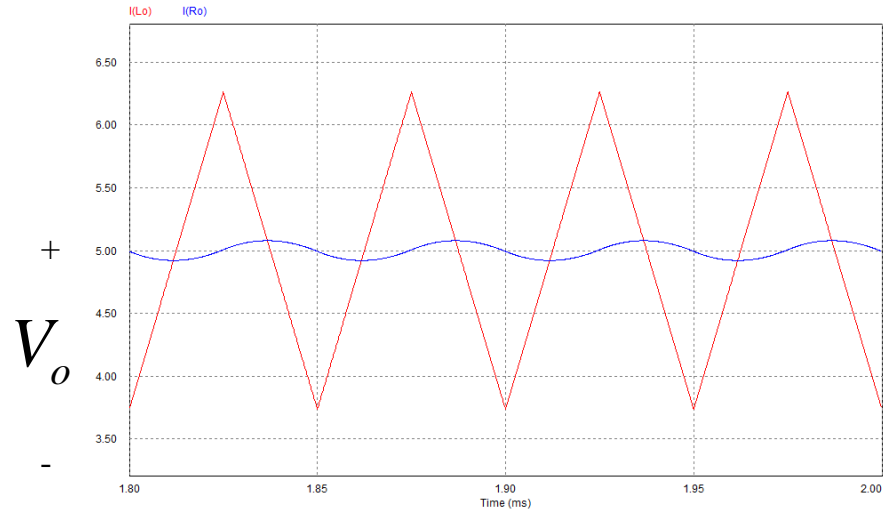
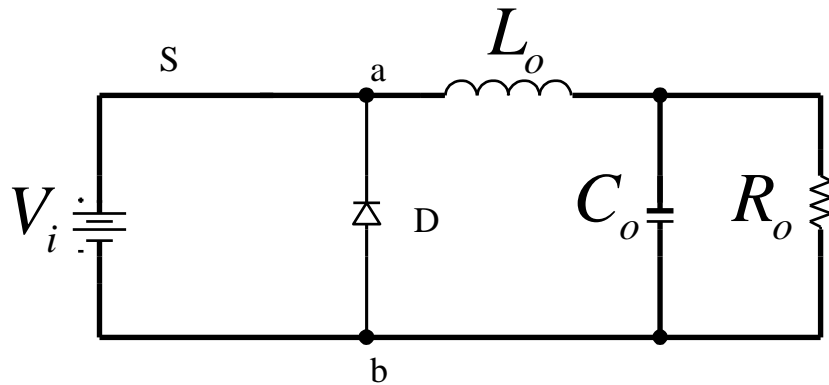
Segunda etapa de funcionamento:

- Interruptor bloqueado;
- Diodo conduzindo;
- Energia armazenada no indutor sendo transferida para saída.



Conversor Buck

Ondulação de corrente em L_o :



$$V_{L_o} = L_o \frac{di_{L_o}}{dt} \approx L_o \frac{\Delta I_{L_o}}{\Delta T}$$

$$\Delta I_{L_o} = \frac{(V_i - V_o) \cdot D \cdot T_s}{L_o}$$

$$\Delta I_{L_o} = \frac{V_{L_o} \cdot \Delta T}{L_o}$$

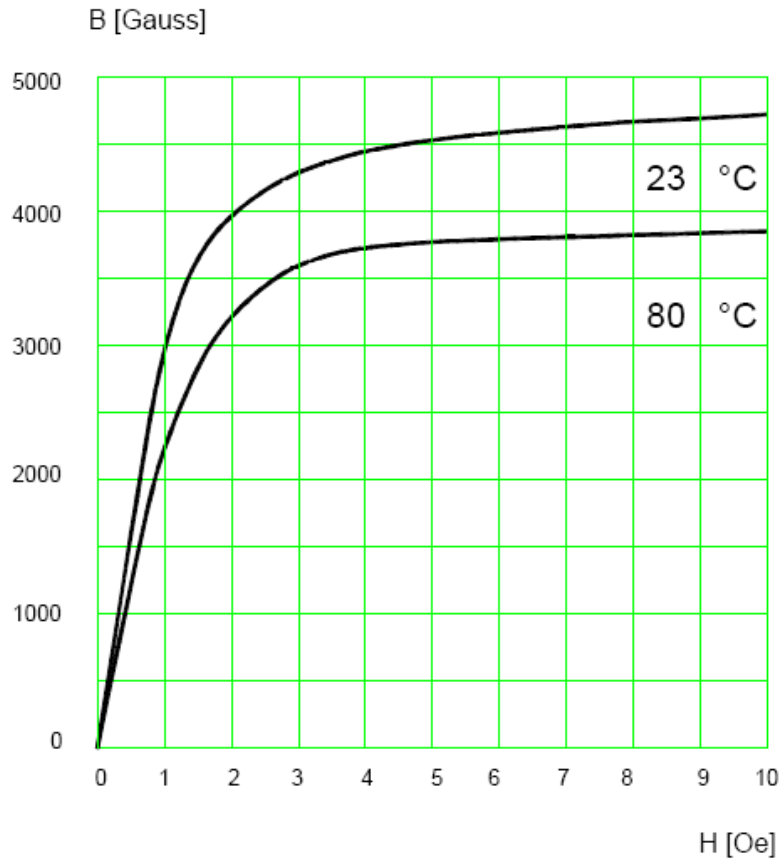
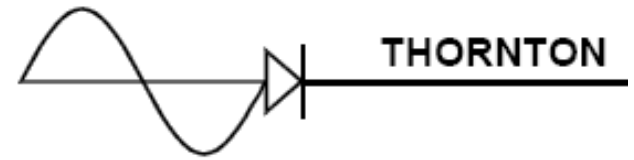
$$\Delta I_{L_o} = \frac{(V_i - D \cdot V_i) \cdot D}{L_o \cdot F_s} = \frac{V_i}{L_o \cdot F_s} D \cdot (1 - D)$$

$$\Delta I_{L_o_max} = \frac{V_i}{4 \cdot L_o \cdot F_s}$$

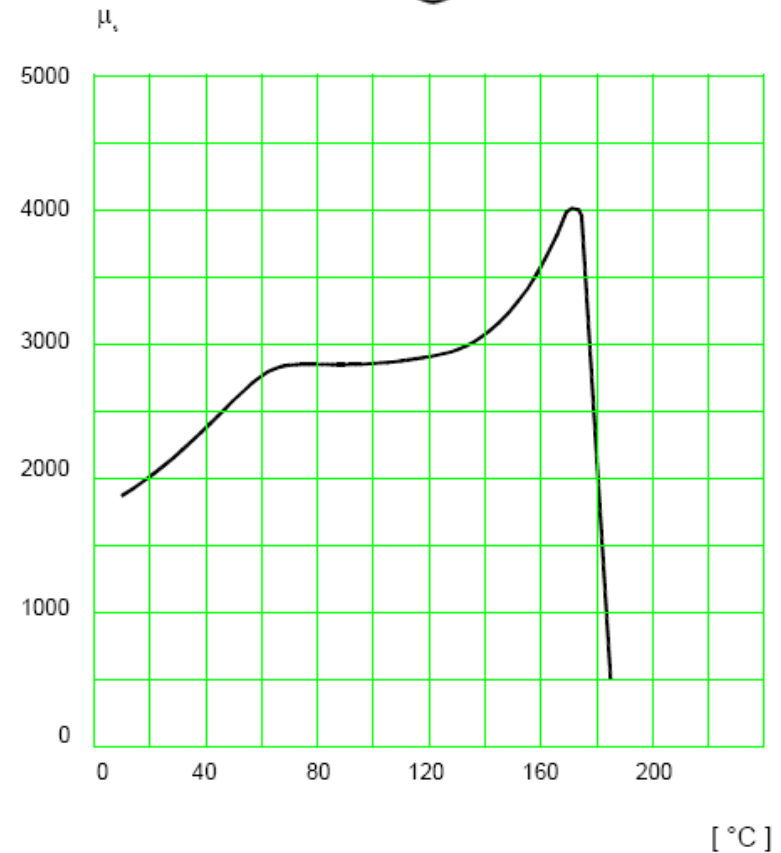
O projeto de um indutor depende:

- Da frequência de operação;
- Da corrente no mesmo;
- Do regime de trabalho;
- Do material utilizado para o núcleo;
- Entre outros....

Características do núcleo:



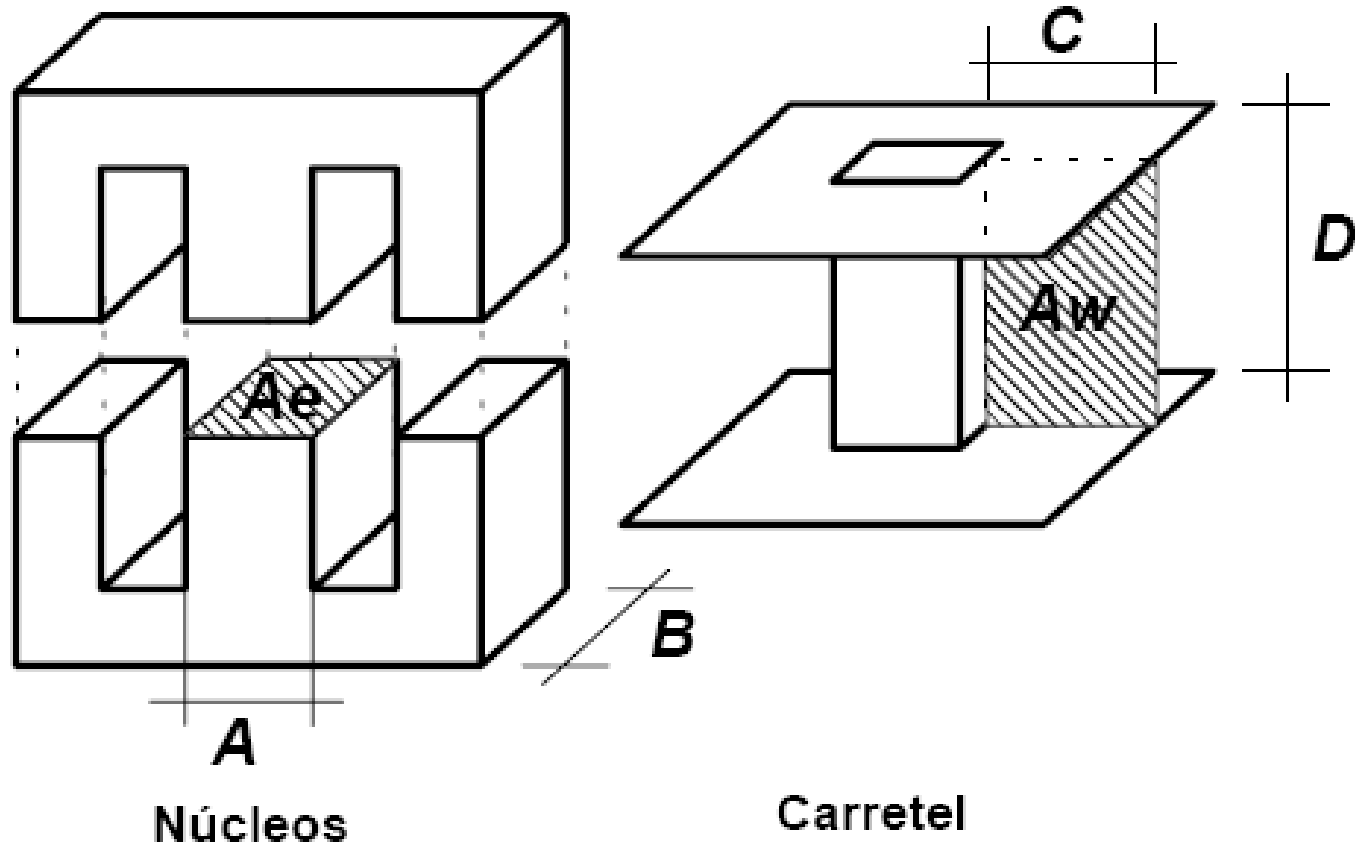
Típico B x H



μ_r x Temperatura

Projeto de indutores com núcleo de ferrite

Montagem do núcleo (com entreferro):



Projeto de indutores com núcleo de ferrite

1) Exemplo: Dados de entrada:

$$L_o = 100 \mu H$$

Indutância do indutor;

$$F_s = 20 kHz$$

Frequência de operação;

$$I_{Lop} = 10 A$$

Corrente de pico;

$$I_{Loef} = 6 A$$

Corrente eficaz;

$$\Delta I_{Lo} = 1 A$$

Ondulação de corrente;

$$k = 0,7$$

Fator de enrolamento;

$$J = 450 A / cm^2$$

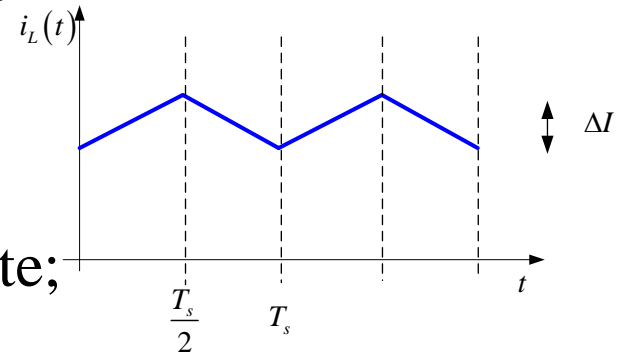
Densidade de corrente;

$$B = 0,35 T$$

Densidade de fluxo máximo;

$$\mu_o = 4\pi \cdot 10^{-7} Wb / A / m$$

Permeabilidade no vácuo.



2) Escolha do núcleo:

$$\Delta B = B \frac{\Delta I_{Lo}}{I_{Lop}} = 0,35 \frac{1}{10} = 0,035 T$$

$$A_e A_w = \frac{L_o \cdot I_{Lop} \cdot I_{Loef} \cdot 10^4}{k \cdot B \cdot J} = \frac{100 \cdot 10^{-6} \cdot 10 \cdot 6 \cdot 10^4}{0,7 \cdot 0,35 \cdot 450} = 0,544 \text{ cm}^4$$

| Núcleo | A _e (cm ²) | A _w (cm ²) | l _e (cm) | l _t (cm) | v _e (cm ³) | A _e A _w (cm ⁴) |
|---------|-----------------------------------|-----------------------------------|---------------------|---------------------|-----------------------------------|--|
| E-20 | 0,312 | 0,26 | 4,28 | 3,8 | 1,34 | 0,08 |
| E-30/7 | 0,60 | 0,80 | 6,7 | 5,6 | 4,00 | 0,48 |
| E-30/14 | 1,20 | 0,85 | 6,7 | 6,7 | 8,00 | 1,02 |
| E-42/15 | 1,81 | 1,57 | 9,7 | 8,7 | 17,10 | 2,84 |
| E-42/20 | 2,40 | 1,57 | 9,7 | 10,5 | 23,30 | 3,77 |
| E-55 | 3,54 | 2,50 | 1,2 | 11,6 | 42,50 | 8,85 |

3) Cálculo do número de espiras:

$$N = \frac{L_o \cdot I_{Lop} \cdot 10^4}{B \cdot A_e} = \frac{100 \cdot 10^{-6} \cdot 10 \cdot 10^4}{0,35 \cdot 1,20} = 24 \text{ espiras}$$

4) Cálculo do entreferro:

$$lg = \frac{N^2 \cdot \mu_o \cdot A_e \cdot 10^{-2}}{L_o} = \frac{24^2 \cdot 4\pi \cdot 10^{-7} \cdot 1,20 \cdot 10^{-2}}{100 \cdot 10^{-6}} = 0,087 \text{ cm}$$

5) Perdas no núcleo:

$$K_H = 4 \cdot 10^{-5}$$

$$K_E = 4 \cdot 10^{-10}$$

$$P_{nucleo} = \Delta B^{2,4} \cdot (K_H \cdot F_s + K_E \cdot F_s^2) \cdot V_e$$

$$P_{nucleo} = 0,035^{2,4} \cdot (4 \cdot 10^{-5} \cdot 20000 + 4 \cdot 10^{-10} \cdot 20000^2) \cdot 8$$

$$P_{nucleo} = 2,46 mW$$

6) Profundidade de penetração:

$$\Delta = \frac{7,5}{\sqrt{F_s}} = \frac{7,5}{\sqrt{20000}} = 0,053 \text{ cm}$$

$$D_{\text{fio}_{\max}} = 2 \cdot \Delta = 2 \cdot 0,053 = 0,106 \text{ cm}$$

Não poderá ser utilizado condutor com diâmetro maior que 0,106 cm. Portanto, podem ser utilizados condutores mais finos que o fio 18 AWG. Escolheu-se o condutor 22 AWG.

$$A_{cu22} = 0,003255 \text{ cm}^2$$

$$\rho_{22} = 0,000530 \Omega / \text{cm}$$

7) Escolha da seção dos condutores:

$$S = \frac{I_{Loef}}{J} = \frac{6}{450} = 0,013 \text{ cm}^2 \quad \text{Maior que a área do fio 22 AWG.}$$

$$N_{fios} = \frac{S}{A_{cu22}} = \frac{0,013}{0,003255} = 4 \text{ fios} \rightarrow 5 \text{ fios}$$

8) Cálculo da resistência do fio:

$$R_{fio} = N \cdot \frac{\rho_{22}}{N_{fios}} \cdot l_t = 24 \cdot \frac{0,000530}{5} \cdot 6,7 = 0,017 \Omega$$

9) Perdas no cobre:

$$P_{cobre} = R_{fio} \cdot I_{Loef}^2 = 0,017 \cdot 6^2 = 0,614W$$

10) Perdas totais:

$$P_{totais} = P_{nucleo} + P_{cobre} = 2,46m + 0,614 = 0,616W$$

11) Elevação de temperatura:


$$Rt = 23 \cdot (AeAw)^{-0,37} = 23 \cdot (1,02)^{-0,37} = 22,832^{\circ}C/W$$



$$\Delta T = Rt \cdot P_{total} = 22,832 \cdot 0,616 = 14,066^{\circ}C$$

12) Cálculo do fator de ocupação:

$$Aw_{neces} = \frac{N \cdot N_{fios} \cdot S_{22}}{0,7} = \frac{24 \cdot 5 \cdot 0,004013}{0,7} = 0,688 cm^2$$

$$K_{ocup} = \frac{Aw_{neces}}{Aw} = \frac{0,688}{0,85} = 0,809$$



Keyword Search:  Part # Search: 
Advanced Part Number Finder: >

Home / Design / Design Tools

Design Guides

Design Tools

Inductor Design

Common Mode Filter Design

Current Transformer Design

MagAmp Design

Technical Documents

Datasheet Search

Cross Reference

Selection Guide

Request Samples

Technical Resources

Design Tools

Magnetics® design tools assist engineers in optimizing their Magnetics components. Targeted to specific applications, each software package offers a core selection routine and contains online Help to guide design engineers through the selection and optimization process. Additional references are included to assist with more involved designs.

Select the titles below to run an individual program. If problems arise, please contact a [Magnetics Application Engineer](#) for assistance.sof

Inductor Design

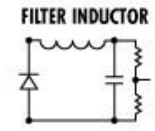
Featuring Magnetics Kool M μ ®, MPP, High Flux, and XFLUX™ powder cores, this design utility aids in core selection for DC output inductors, input chokes, PFC (Power Factor Correction) inductors, high current inductors, and other energy storage devices. Design inputs include DC current, ripple current, full load and no load inductances, and more. Designs are simulated and modeled while providing the designer with complete wound core dimensions, estimated core and copper losses, temperature rise, and more. In addition to toroid shapes, an expanded range of material shapes are included such as Kool M μ E Cores, Kool M μ U Cores, and Kool M μ segmented toroids.

[Features](#)
[Learn More](#)

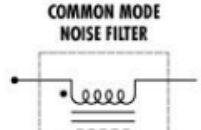
Common Mode Filter Design

This tool allows designers to select an appropriate ferrite toroid material for common mode filtering applications. The program's Help file aims designers to the optimal ferrite material, while still allowing the flexibility to accommodate user-chosen part numbers.

[Features](#)



FILTER INDUCTOR



COMMON MODE NOISE FILTER

<http://www.mag-inc.com/design/design-tools>

Output Inductor Design Tool

The OUTPUT INDUCTOR Design Tool was created as a Design Tool, to assist you in your application Designs of:

Flyback Transformer Design, Forward Converter output Filter Design, Half Bridge Converter output filter Design , Full Bridge Converter output filter Design, VRM Inductor Design, Voltage regulation module design, synchronis rectification output inductor design

[Download the .EXE file](#)

[Download the ZIP File](#)

AC Reactor Design Tool

The AC Reactor Design Tool was created as a Design Tool, to assist you in your application Designs of:

Harmonic Filter Design, UPS Harmonic Filter Design, dv/dt Inductor Design, Harmonic Filter for Distributed Power Generation, Solar Cell Harmonic Filter Design, Wind Power Harmonic Filter Design, Wind Power Harmonic Filter Design.

[Download the .EXE file](#)

[Download the ZIP File](#)

DC Reactor Design Tool

The DC Reactor Design Tool was created as a Design Tool, to assist you in your application Designs of:

Choke Design, High Power Harmonic Filter Design, Power Factor Harmonic Filter Design, Input Inductor Design, DC Link Reactor Design, DC Link Filter.

[Download the .EXE file](#)

[Download the ZIP File](#)

<http://hitachimetals.metglas.com/>

Projeto de indutores

Excel interface showing the 'Projeto de indutores' (Inductor Design) spreadsheet. The spreadsheet is divided into four main steps:

STEP 1: Design Input

| Parameter | Value | Unit |
|-------------------|--------|---------------------|
| DC Current | 8,4133 | Amps |
| Ripple Current | 0,16 | Amps (peak to peak) |
| Frequency | 100 | KHz |
| Full Load L | 0,5 | mH |
| Stack Cores | 1 | |
| Specified Current | 8,333 | Amps |
| Temp Rise | 63 | °C |

STEP 2: Calculated LI² value

Calculated LI² value: 36,07

Based on the LI² value choose a part number to fill in STEP 3.

STEP 3: Input a Part Number

Input a Part Number: 00K4022E060

Input a Wire Size: 14

| Parameter | Value |
|-----------------------|-------|
| AWG | 14 |
| Material | |
| Kool Mu | |
| Core A Dimension (mm) | 42,85 |
| Core B Dimension (mm) | 21,1 |
| Core C Dimension (mm) | 20 |
| Core Perm | |
| | 60 |
| Core Al | 194 |

STEP 4: Inductor Specifications

| Parameter | Value | Unit |
|------------------------------|-------|------|
| Inductance at Full Load | 0,569 | mH |
| Inductance at No Load | 1,09 | mH |
| Specified Current Inductance | 0,58 | mH |
| Core Loss (W) | 0,01 | W |
| Copper Loss (W) | 4,00 | W |
| Total Loss | 4,01 | W |
| Temp Rise | 29,1 | °C |
| Number of Turns | 75 | |
| Winding Factor | 89,3% | |
| DC Resistance of Winding | 56,50 | mΩ |

INSTRUCTIONS:

- Enter the input parameters in STEP 1.
- Full Load DC Current is the full load or peak bias current. Enter zero if there is no bias current.

Navigation tabs: Toroid Design, Toroid LI² Chart, E Core Design, E Core LI² Chart, Wire Table

Planilha no Excel: Fabricante Magnetics

Projeto de indutores

PEprt - [Buck1]

File Libraries Calculations Modeler Reports FEA Link Options View Window Help

Property Value

Waveforms Design Inputs Modeling Options

Input Voltage: 24 V

Switching Frequency: 100 kHz

Inductor Current Ripple: Ripple Value: 833.33 mA, 20 % of laverage

Output Values: Voltage: 12 V, Current: 4.17 A, Power: 50 W, Load: 2.88 ohm

Inductor Average Current: 4.17 A

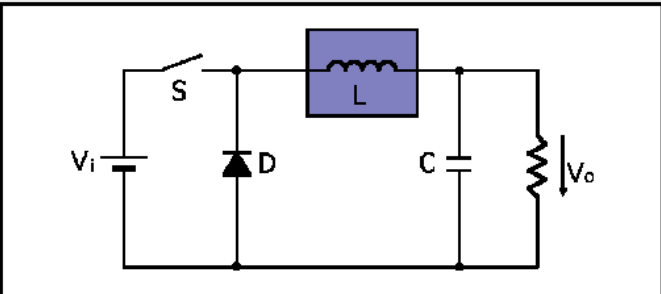
Inductance: 72.00 uH

Conduction Mode: Continuous

Duty Cycle: 50.0%

Cores Bobbins Wires Material

Stock Libraries: AVX, Electrical steel, Epcos, Ferroxcube, Magnetics, Metglas, Micrometals, Steward, TDK, Design Library



Voltage

Graph showing Voltage (V) vs Time (us). The voltage is a square wave switching between 0V and 12V.

Currents

Graph showing Currents (A) vs Time (us). The current is a red line showing ripple around an average value (green line). The average current is approximately 4.17 A.

PEprt™ Version 2015.0.0. © 2015 Universidad Politécnica de Madrid (UPM) and SAS IP, Inc.

Software PExprt - ANSYS

Especificações

- Indutância
- Corrente média
- Frequência de operação
- Máxima elevação de temperatura
- Temperatura ambiente
- Fator de utilização da janela

Seleção do núcleo

- Material do núcleo
- Máxima densidade de campo magnético
- Produto de área do núcleo

Enrolamentos

- Número de voltas
- Densidade de corrente
- Seleção dos condutores

Perdas

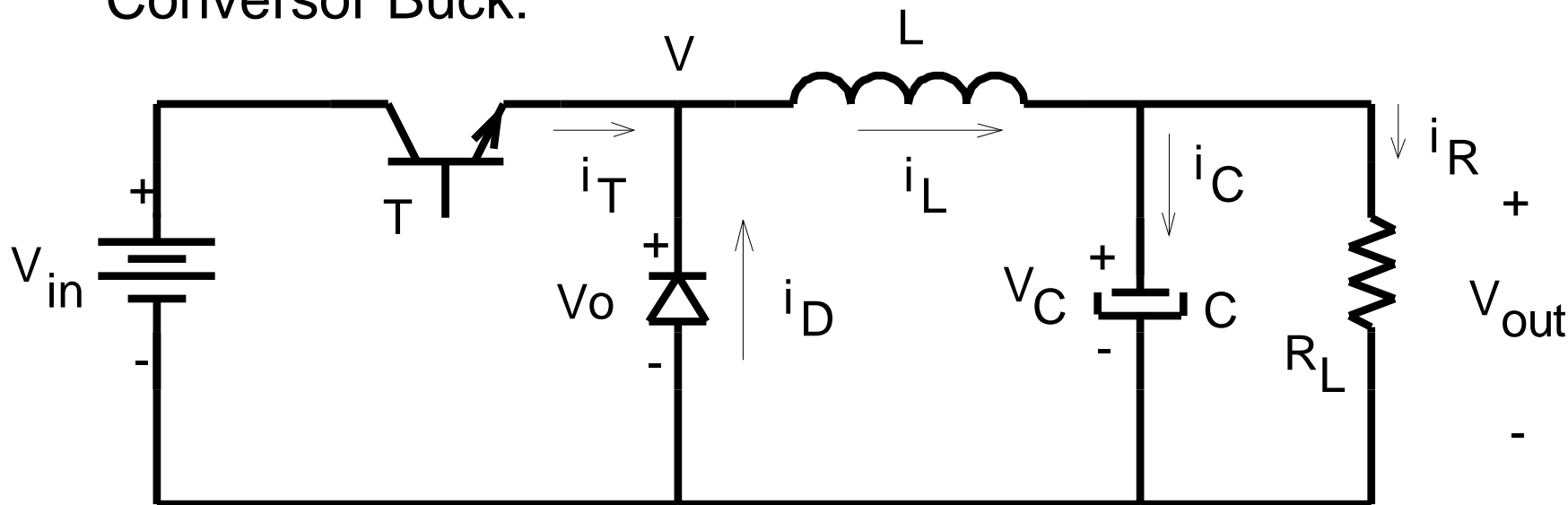
- Perdas no cobre
- Perdas nos enrolamentos se necessário

Passos para projetar elementos magnéticos em alta frequência:

- Calcular os esforços de corrente e tensão em tal elemento;
- Calcular a variação do fluxo magnético;
- Definir qual material e fabricante será empregado;
- Calcular o tamanho do núcleo mínimo:
 - Definir um núcleo comercial;
- Calcular o número de espiras;
- Calcular a área de seção transversal (bitola) do fio:
 - Calcular a quantidade de fio em paralelo, devido ao efeito pelicular;
- Calcular a possibilidade de execução;
- Calcular as perdas magnéticas e do fio;
- Calcular a elevação de temperatura;

Tarefa 3 para entregar até a próxima aula

Conversor Buck:



Especificação:

Tensão de Entrada: 36 V

Tensão de Saída: 12 V

Frequência de comutação: 100 kHz;

Indutância L: $\Delta I = 10\%$ da corrente média

Capacitância C: 100 μF ;

Potência: 100 W;

Apresentar:

- Projetar o Indutor L:
 - Utilizar a planilha desenvolvida no Smath e as aulas e definir um núcleo da Thornton;
 - Utilizar a planilha da Magnetics e definir um núcleo de tal fabricante