# EMV

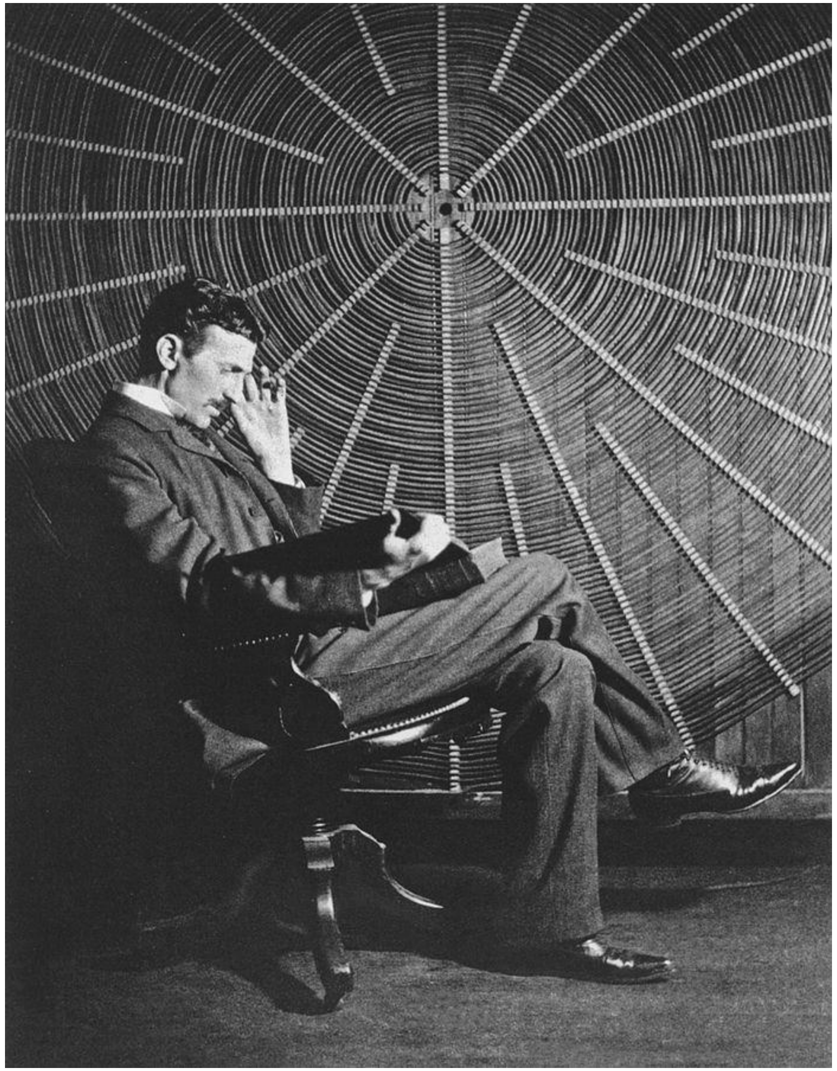
# Filtern und Abblocken

EMV und HF-Technik
Eichstetter
*Verstehen, verbessern,*
*→ bestehen*

Thomas Eichstetter, M.Sc.

2024-10-23

# Übersicht



1 **Gleich- und Gegentaktstörung**

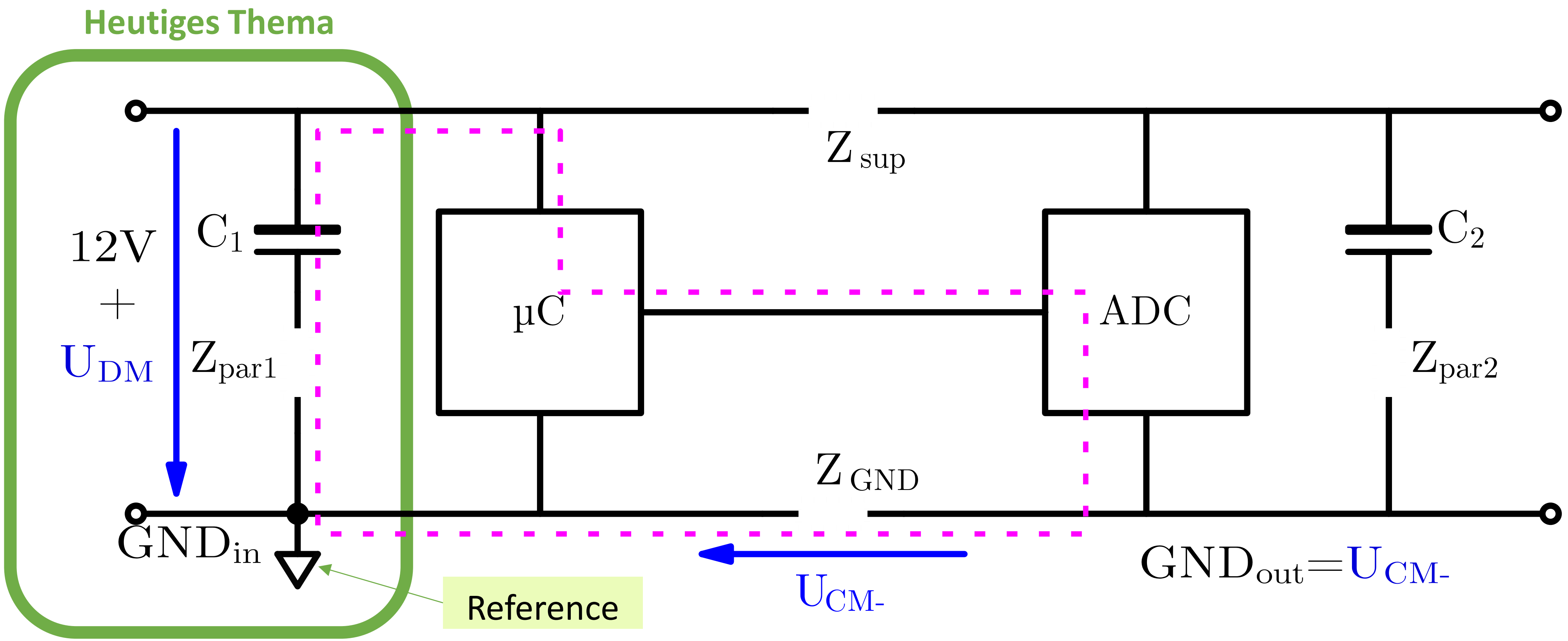
2 **Filterentwurf mit der HF-Tapete**

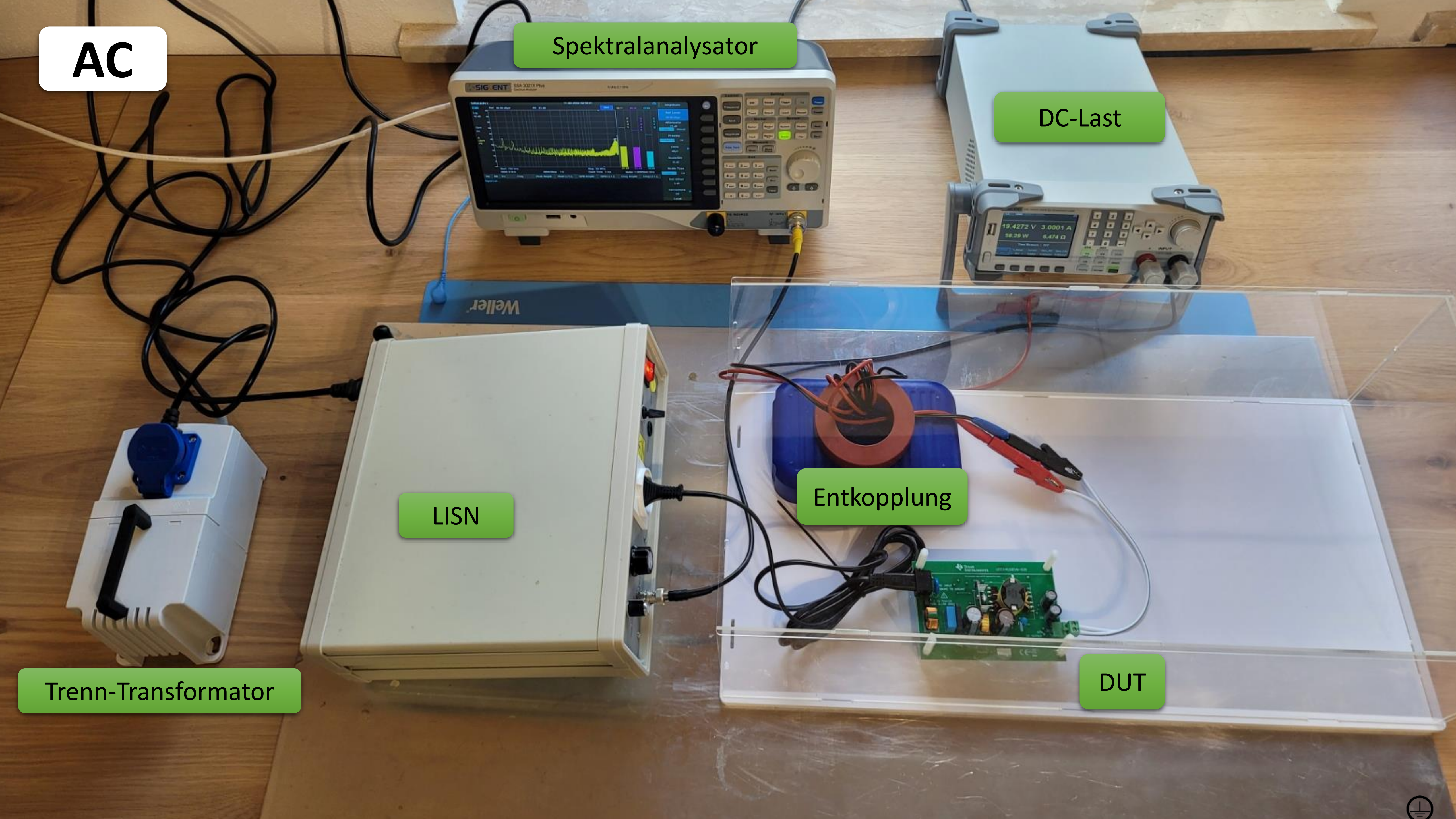
3 **Snubber-Design**

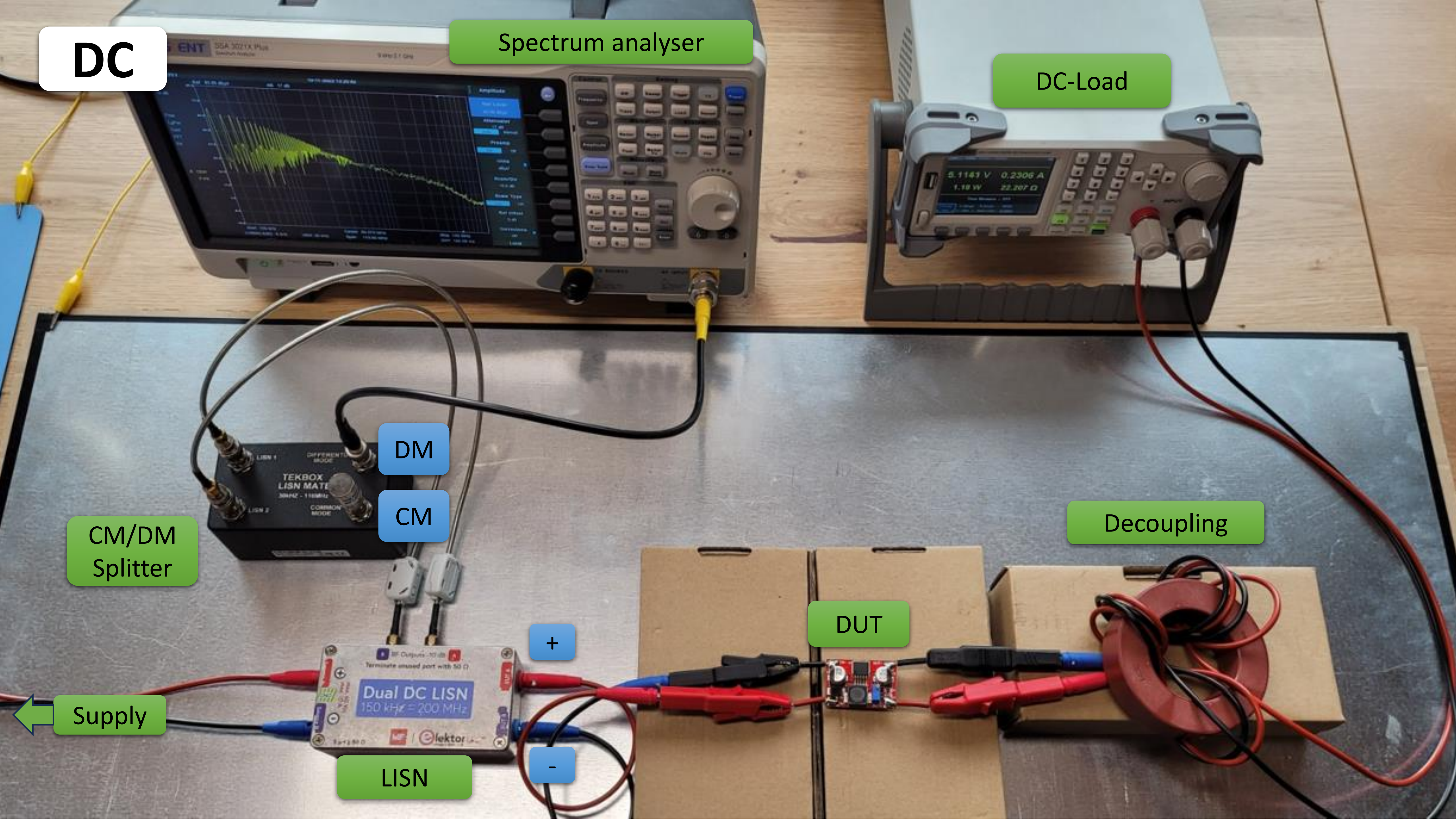
4 **Schirmung**

5 **Zum EMV-Seminar anmelden**

# 1. Gleich- und Gegentaktstörung

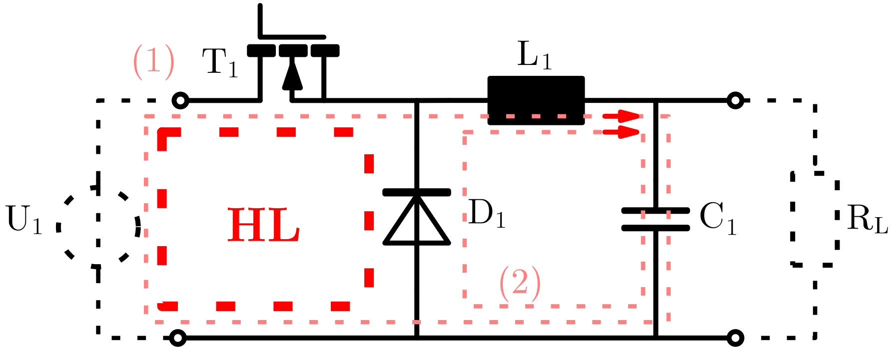


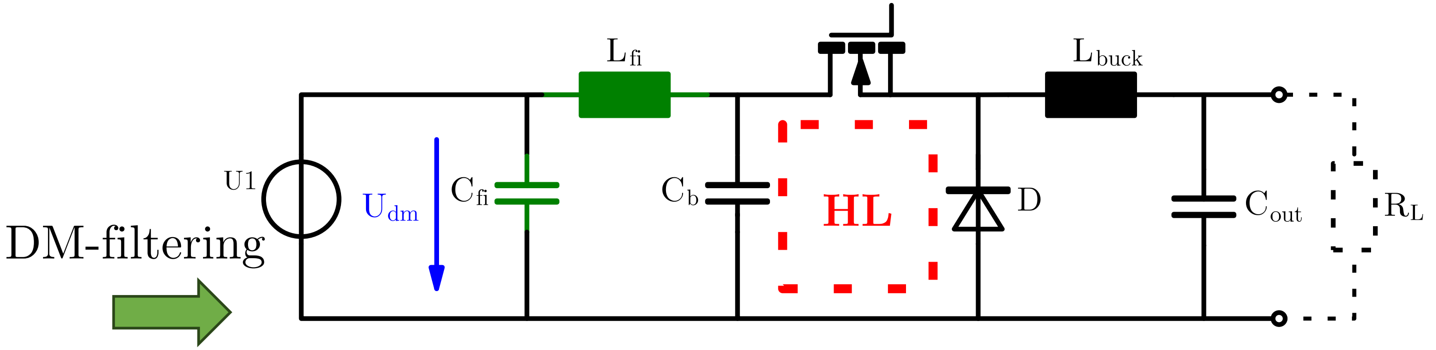

AC
Spektralanalysator
DC-Last
LISN
Entkopplung
Trenn-Transformator
DUT

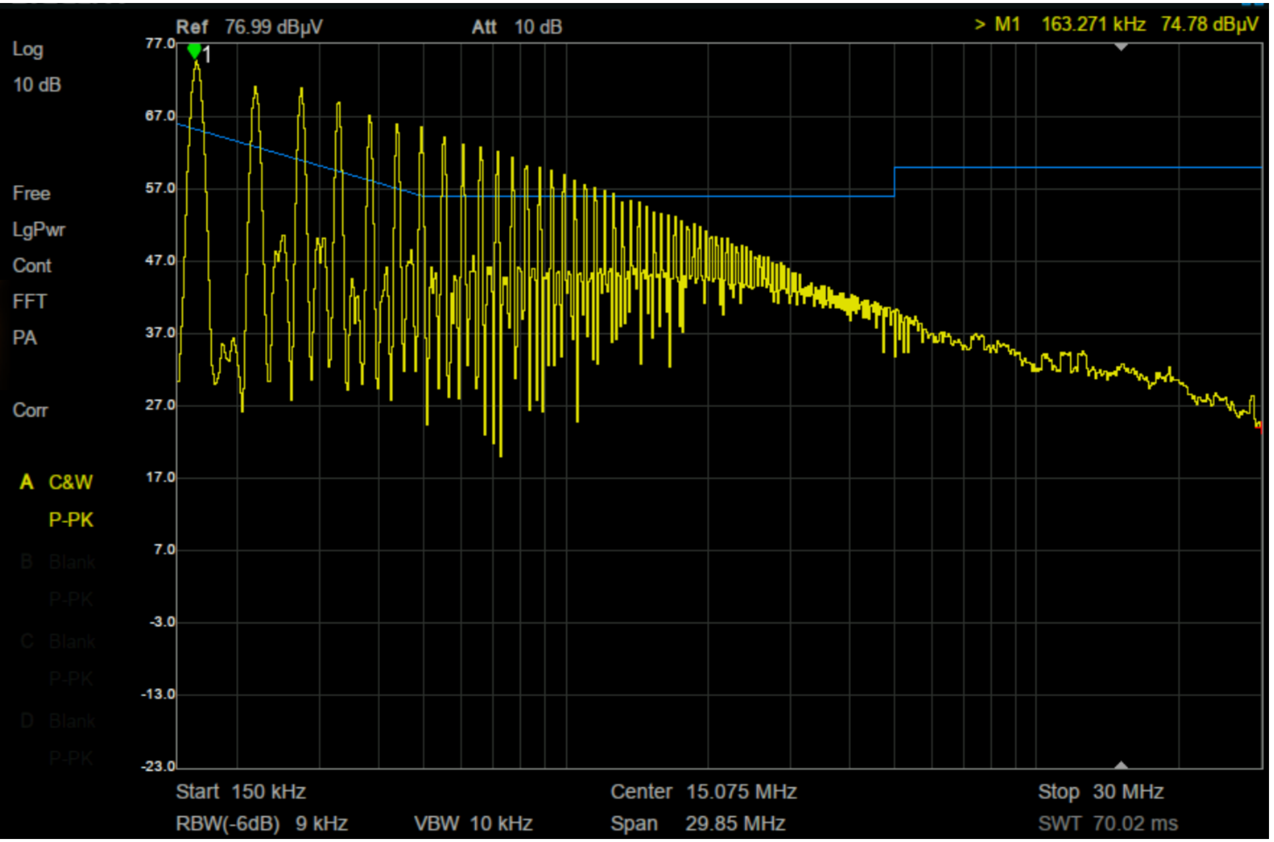


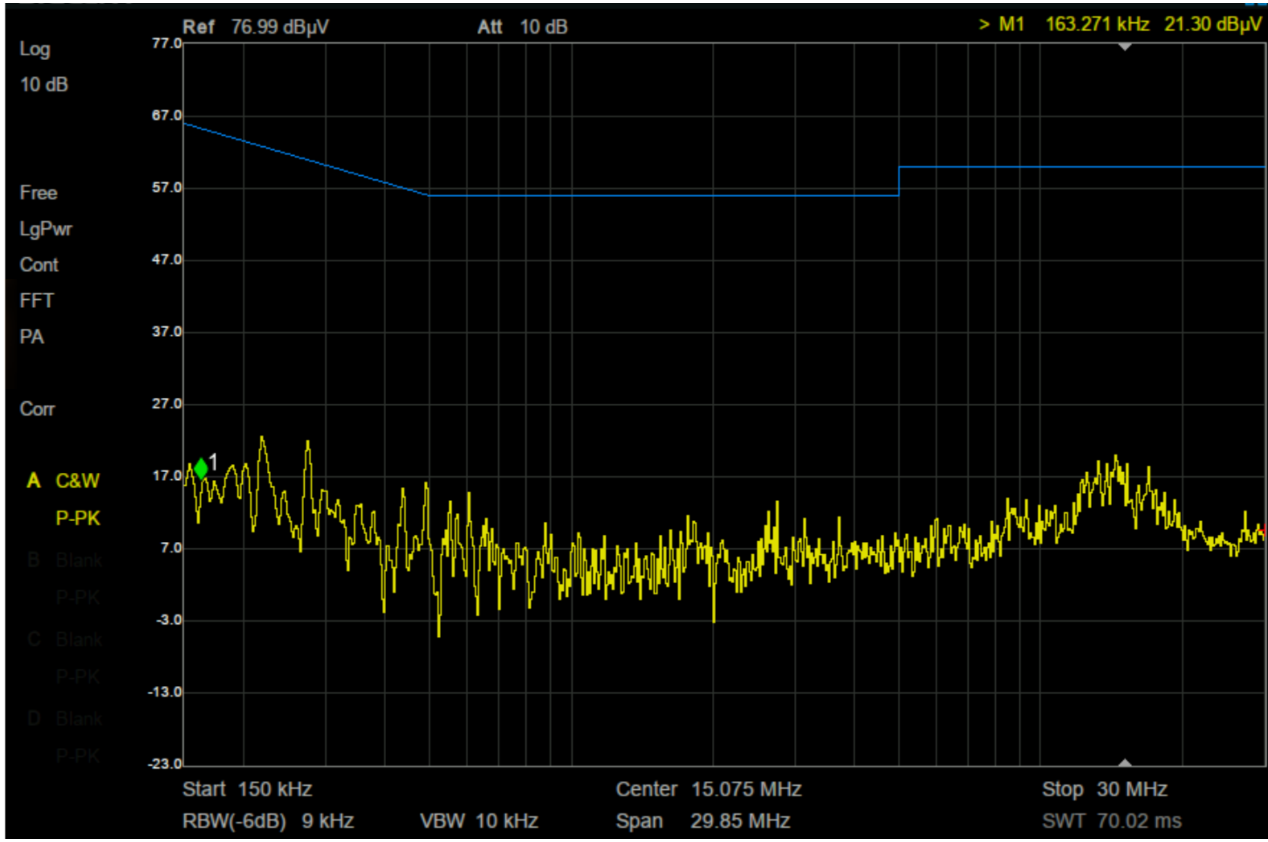
DC
Spectrum analyser
DC-Load
DM
CM
CM/DM Splitter
Decoupling
DUT
+
-
Supply
LISN
Dual DC LISN
150 kHz – 200 MHz
TEKBOX
LISN MATE

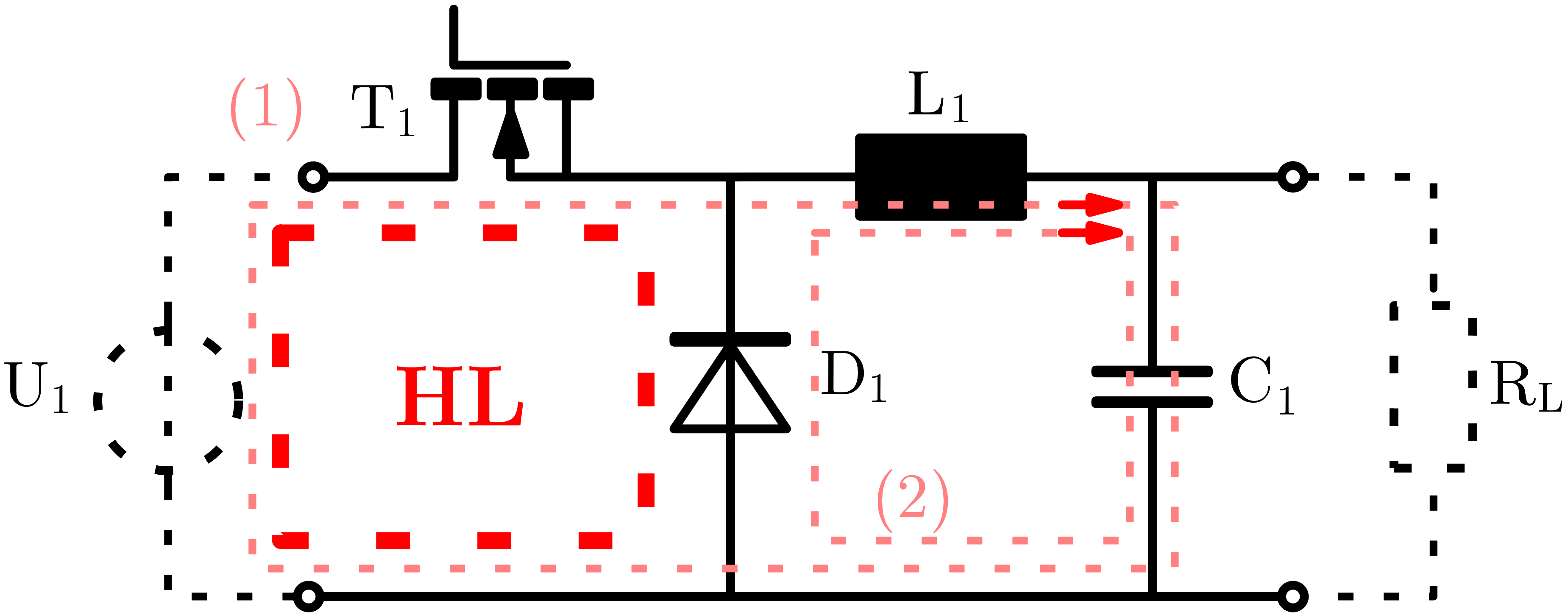
# 2 Filterentwurf mit der HF-Tapete

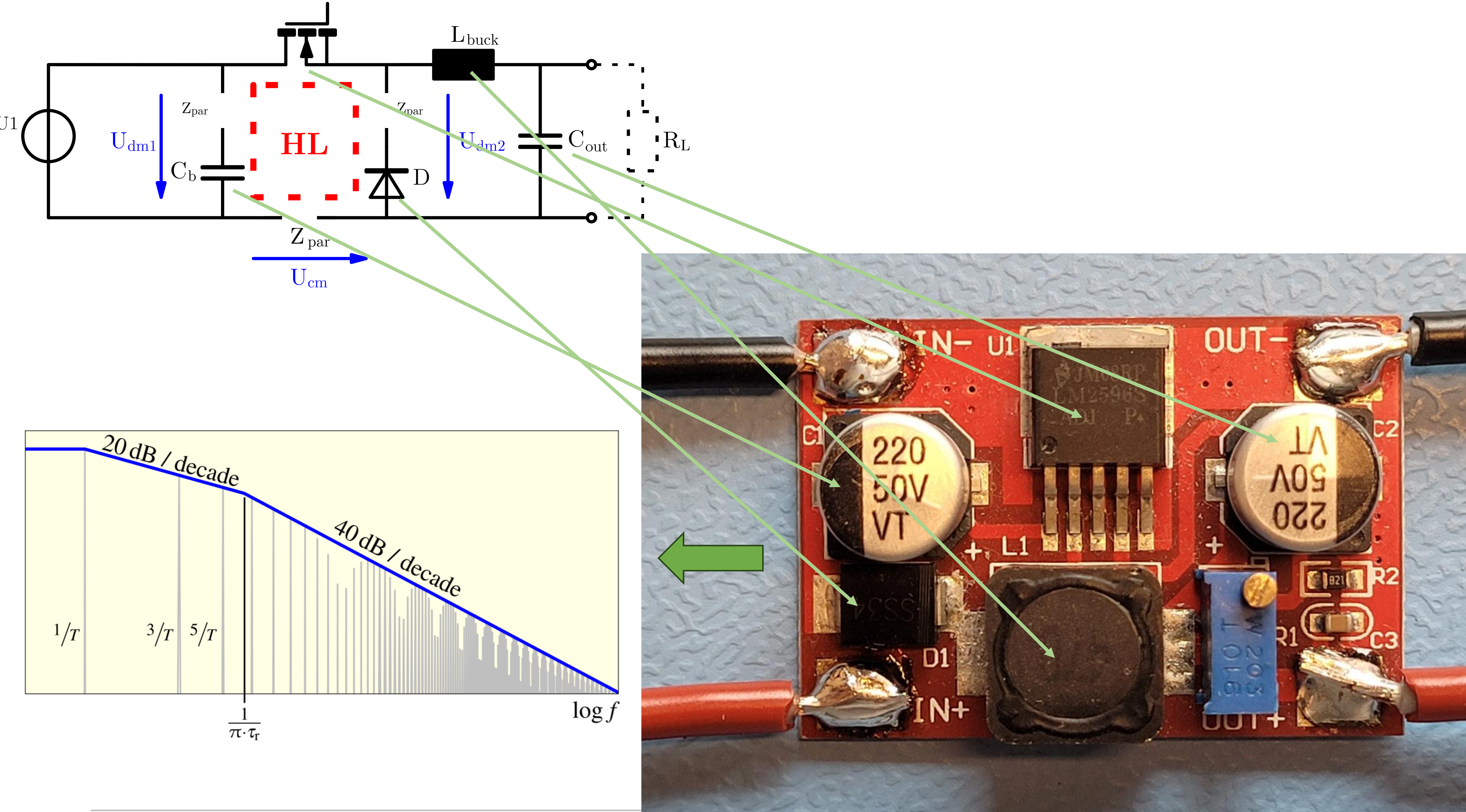


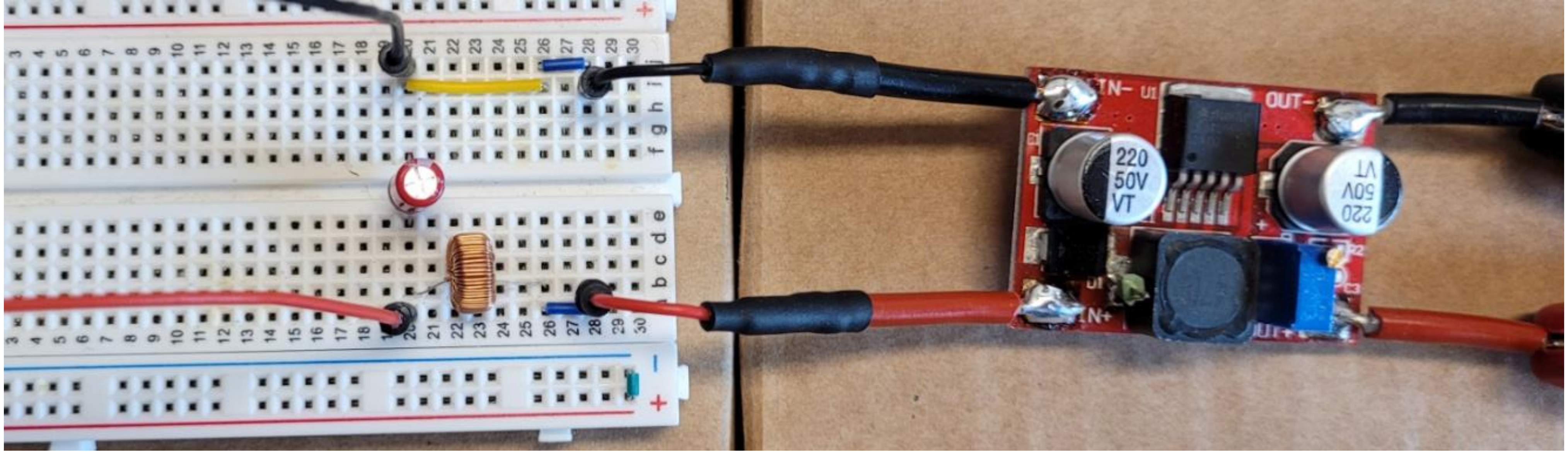



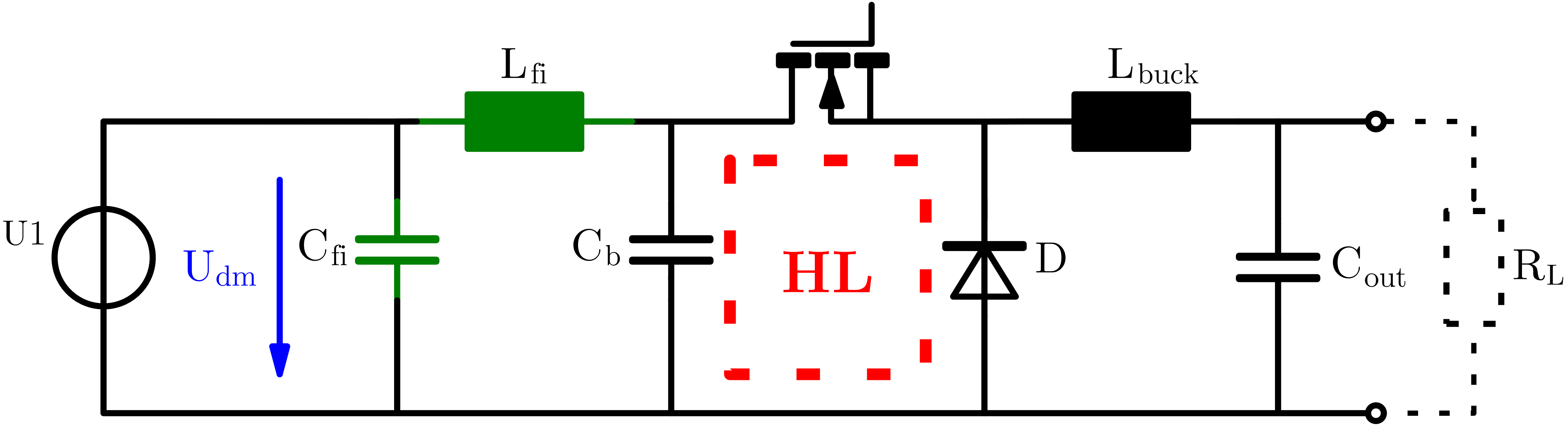



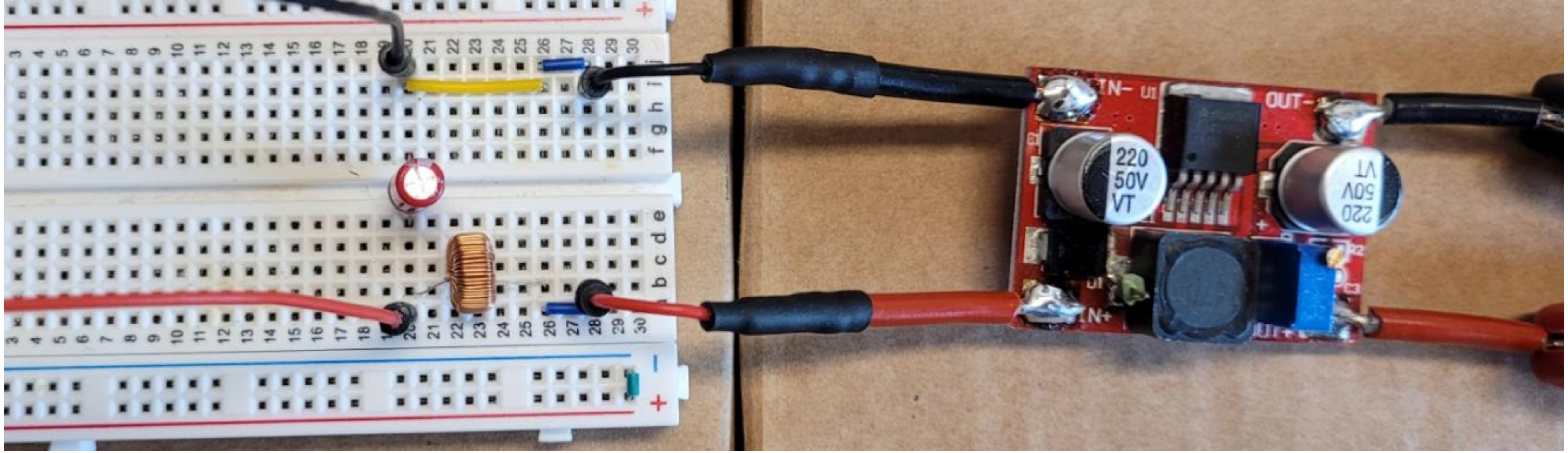

(1)
T1
L1
U1
HL
D1
C1
RL
(2)

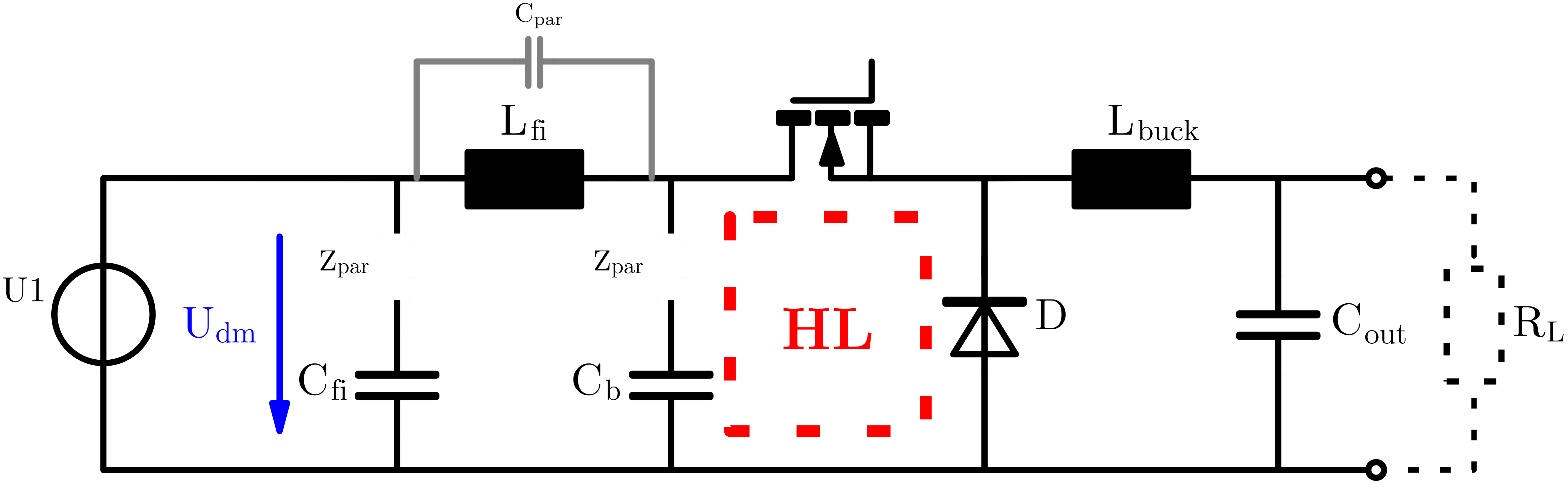


U1
$Z_{par}$
$U_{dm1}$
$C_b$
HL
$Z_{par}$
$U_{dm2}$
$C_{out}$
$R_L$
D
$L_{buck}$
$Z_{par}$
$U_{cm}$
20 dB / decade
40 dB / decade
$1/T$
$3/T$
$5/T$
$\frac{1}{\pi \cdot \tau_r}$
$\log f$
IN-
U1
LM2596S
OUT-
C1
220
50V
VT
C2
L1
SS34
D1
IN+
R2
R1
C3
OUT+

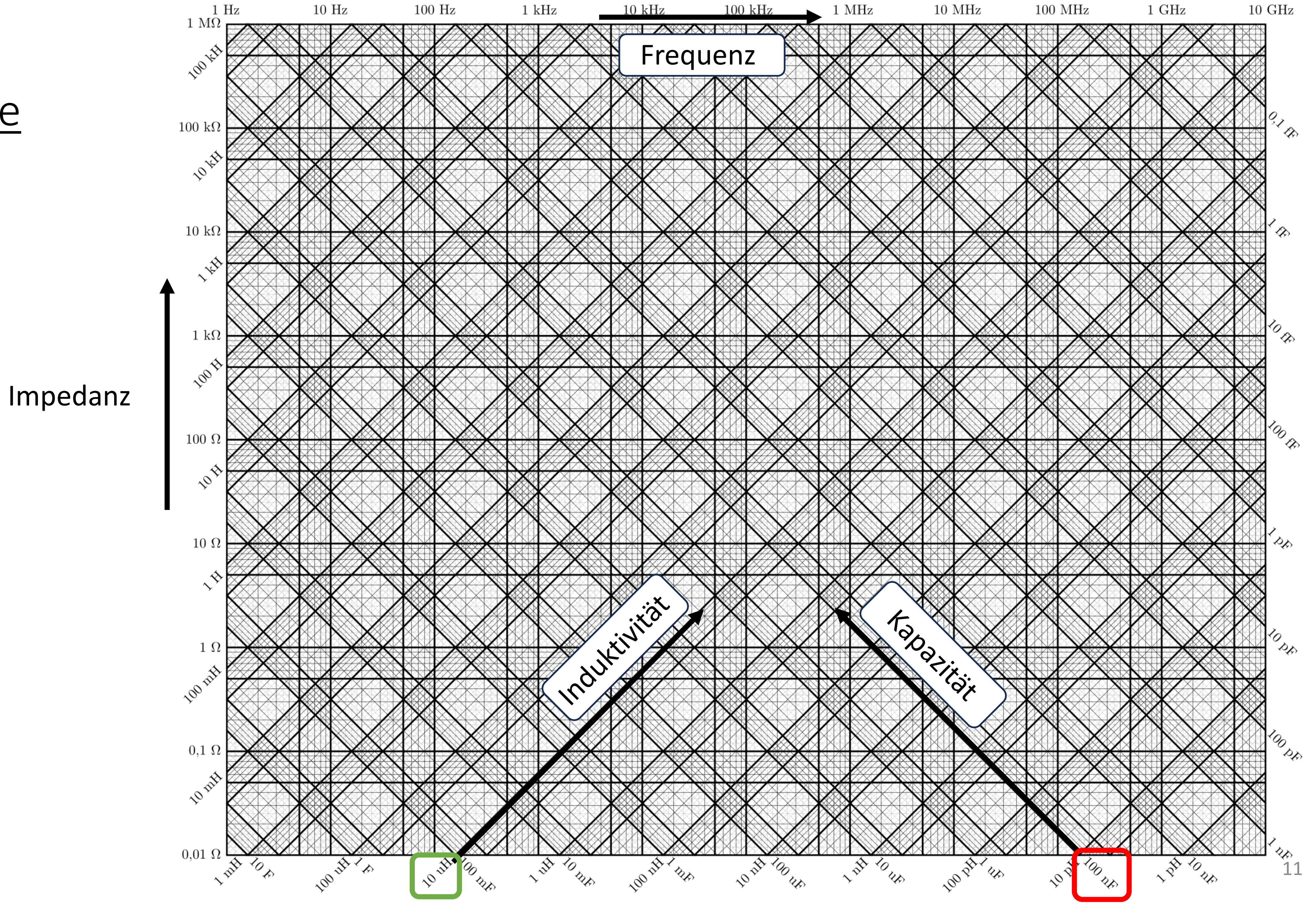

IN-
OUT-
220
50V
VT
IN+


$L_{fi}$
$L_{buck}$
U1
$U_{dm}$
$C_{fi}$
$C_b$
HL
D
$C_{out}$
$R_L$


IN-
OUT-
220
50V
VT
IN+

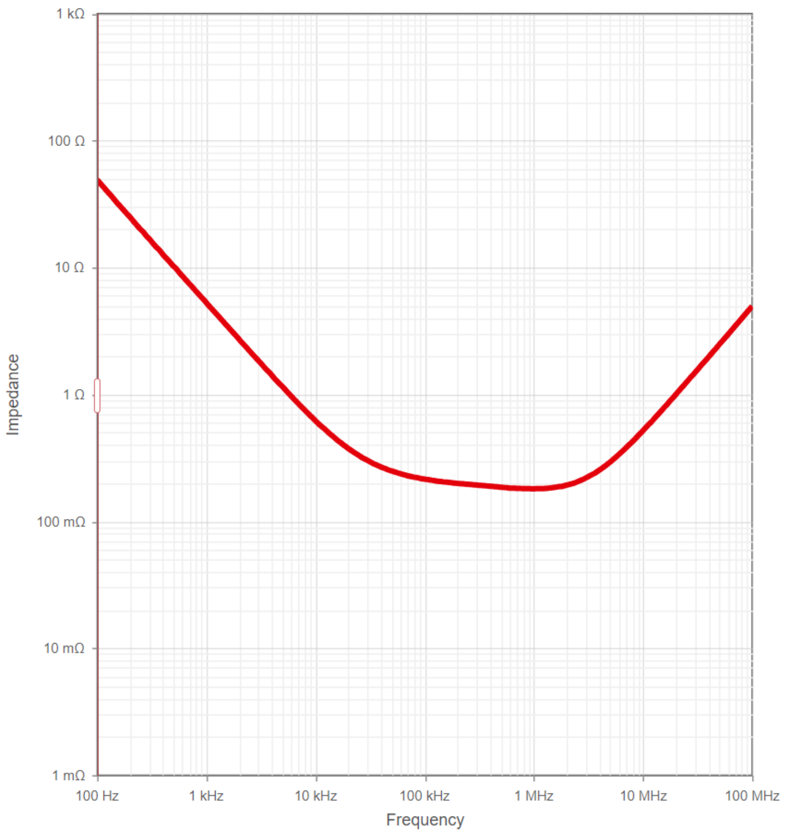

$C_{par}$
$L_{fi}$
$L_{buck}$
U1
$U_{dm}$
$Z_{par}$
$Z_{par}$
$C_{fi}$
$C_b$
HL
D
$C_{out}$
$R_L$

# HF-Tapete



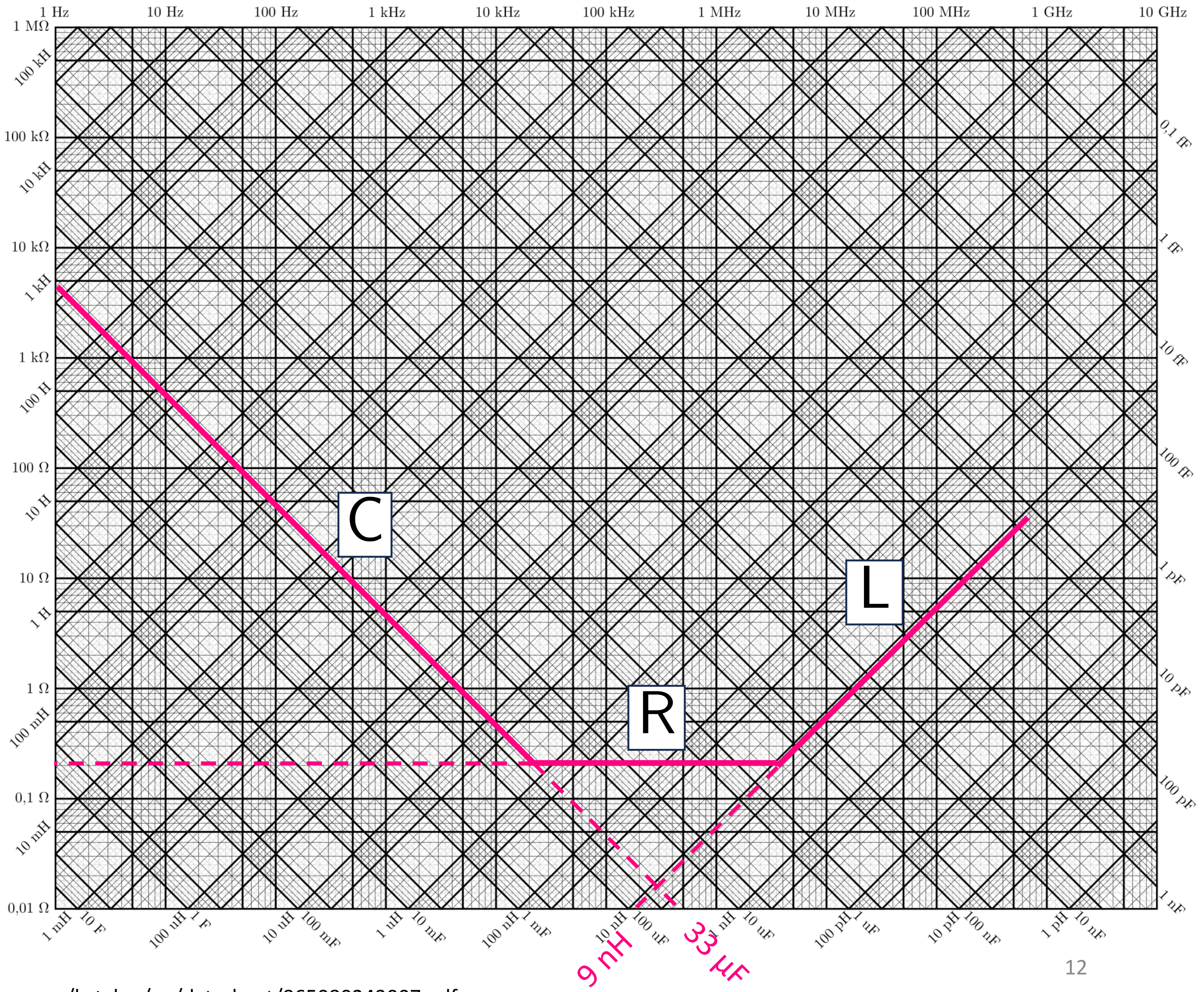
Frequenz
Impedanz
Induktivität
Kapazität
1 Hz
10 Hz
100 Hz
1 kHz
10 kHz
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
1 MΩ
100 kΩ
10 kΩ
1 kΩ
100 Ω
10 Ω
1 Ω
0,1 Ω
0,01 Ω
100 kH
10 kH
1 kH
100 H
10 H
1 H
100 mH
10 mH
1 mH
10 F
100 uH
1 F
10 uH
100 mF
1 uH
10 mF
100 nH
1 mF
10 nH
100 uF
1 nH
10 uF
100 pH
1 uF
100 nF
1 pH
10 nF
1 nF
100 pF
10 pF
1 pF
100 fF
10 fF
1 fF
0,1 fF

# Elektrolyth Kondensator





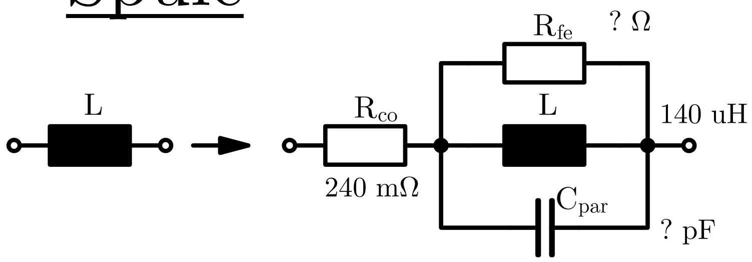
[WELCA1]

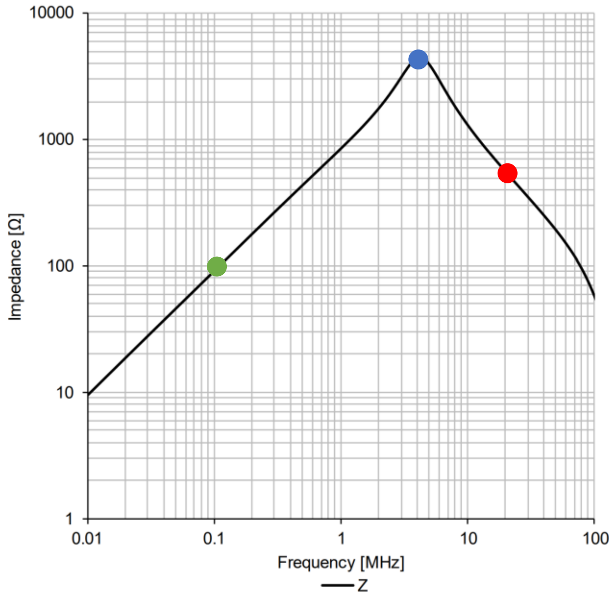





[WELCA1] Würth-Electronic -> https://www.we-online.com/katalog/en/datasheet/865080243007.pdf

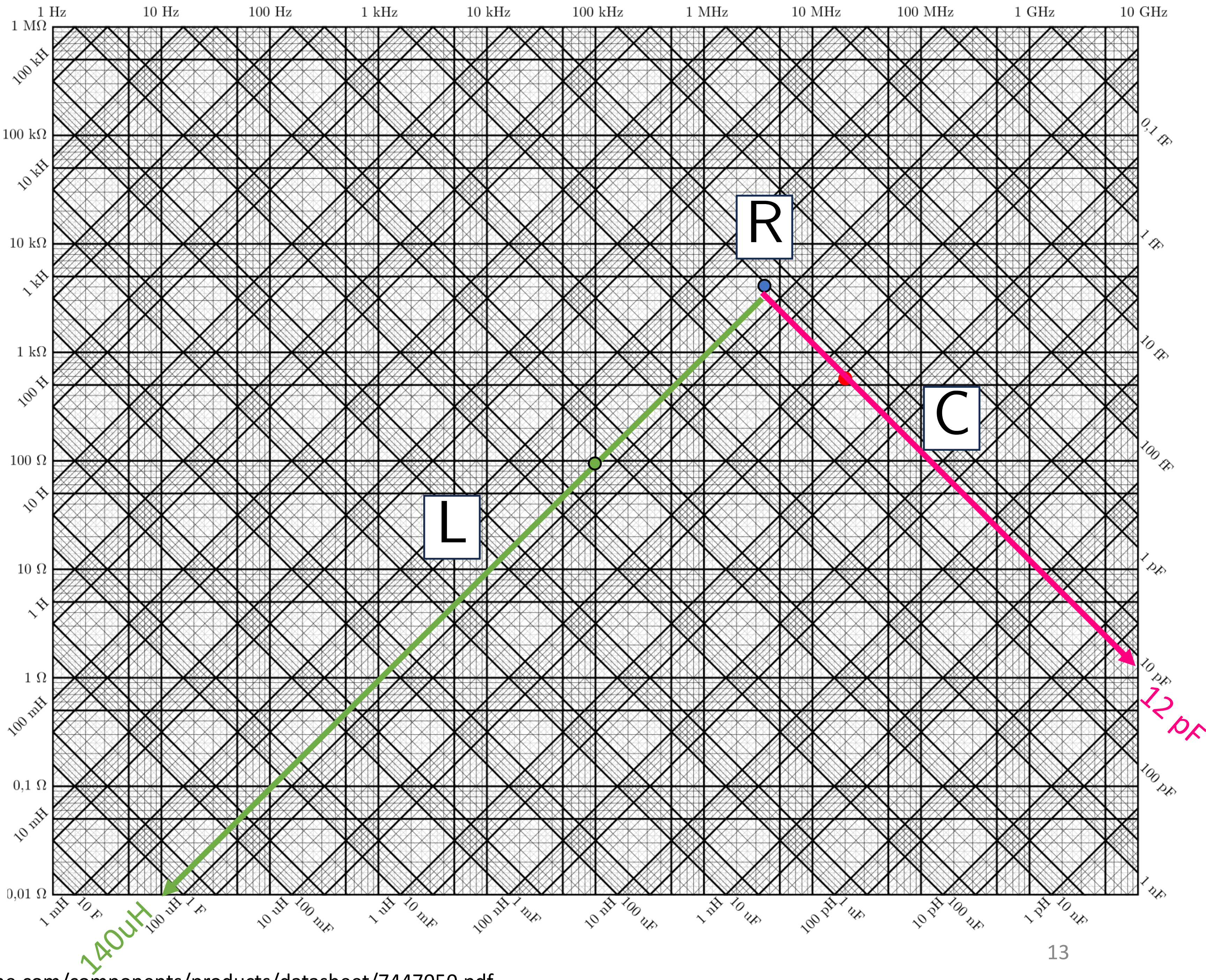
# Spule




[WELIND]

[WELIND]

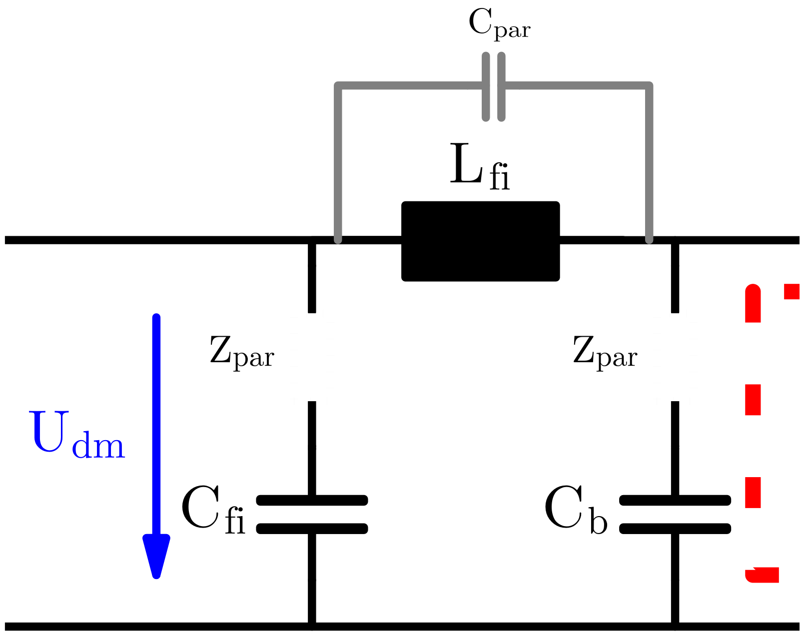


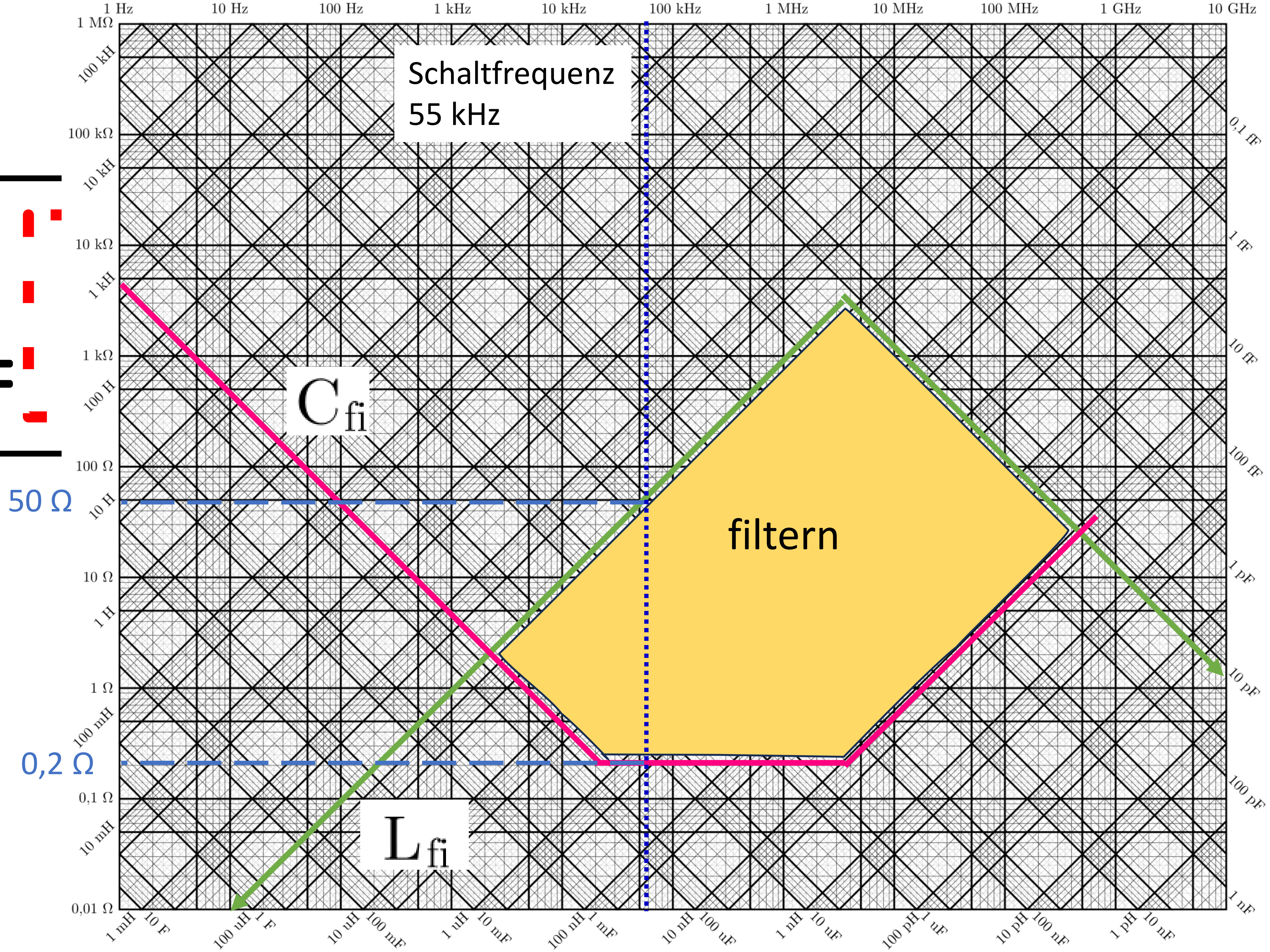

## Electrical Properties:

| Properties | | Test conditions | Value | Unit | Tol. |
|---|---|---|---|---|---|
| **Inductance** | L | 10 kHz/ 5 mA | 140 | µH | ±20% |
| **Rated Current** | $I_R$ | ΔT = 40 K | 1.1 | A | max. |
| **DC Resistance** | $R_{DC}$ | @ 20 °C | 0.26 | Ω | max. |

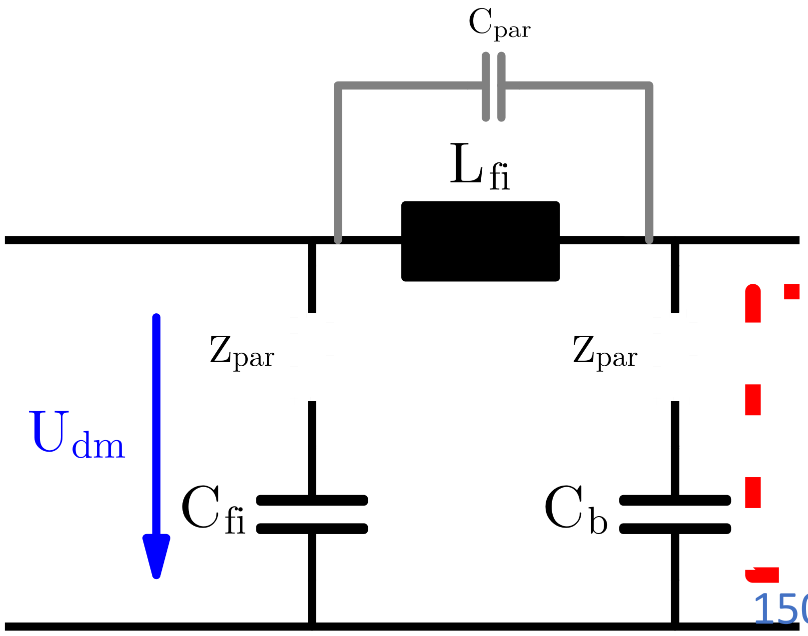


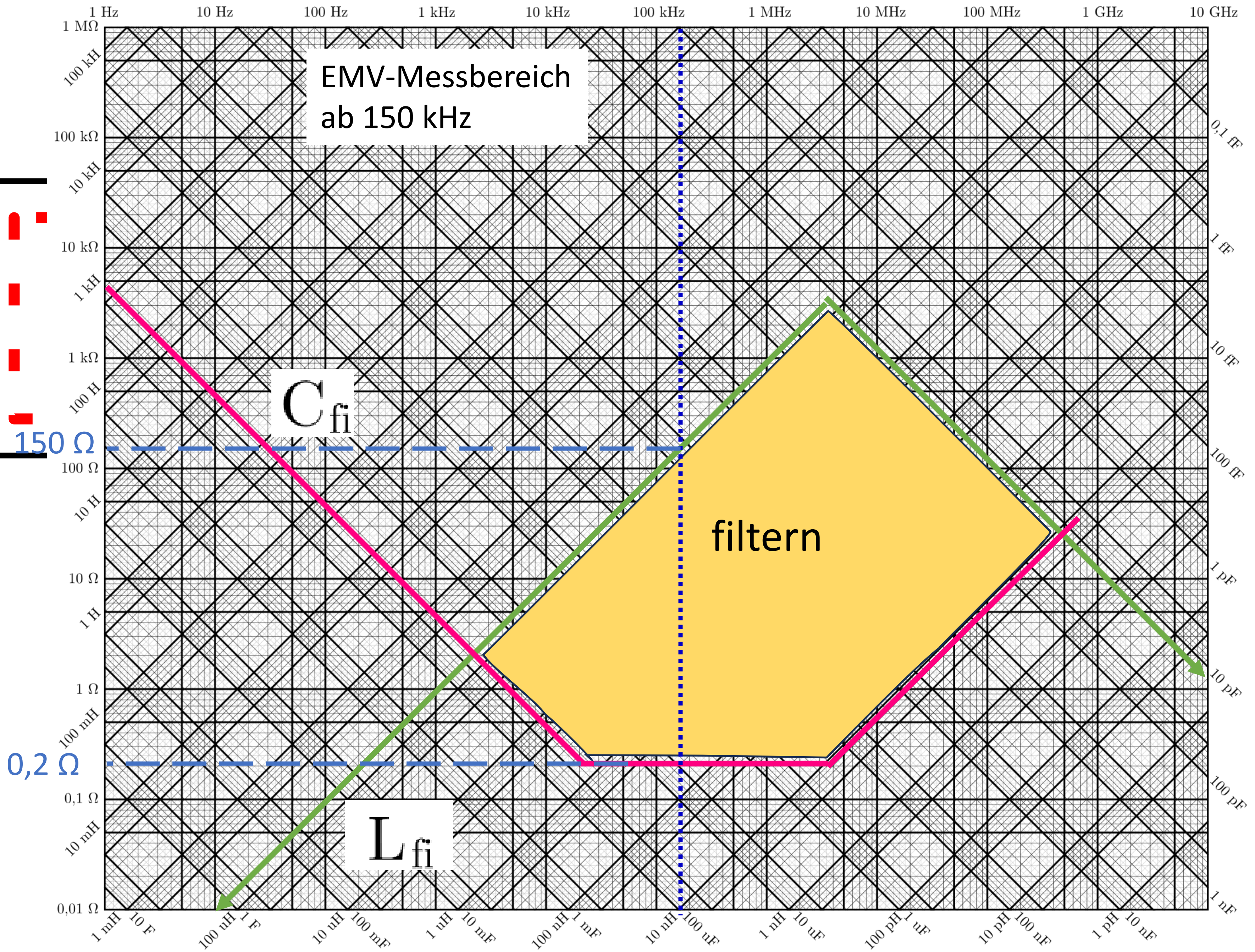
[WELIND] Würth-Electronic -> https://www.we-online.com/components/products/datasheet/7447050.pdf



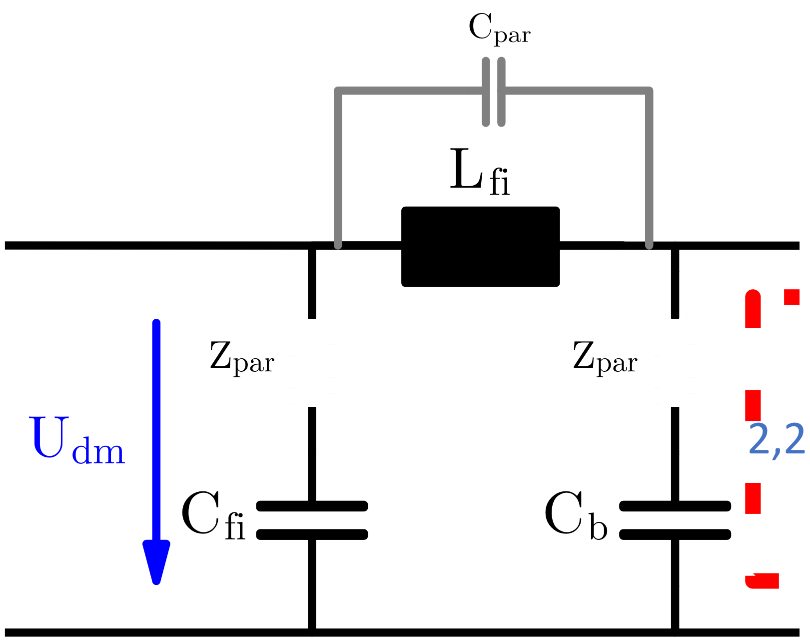



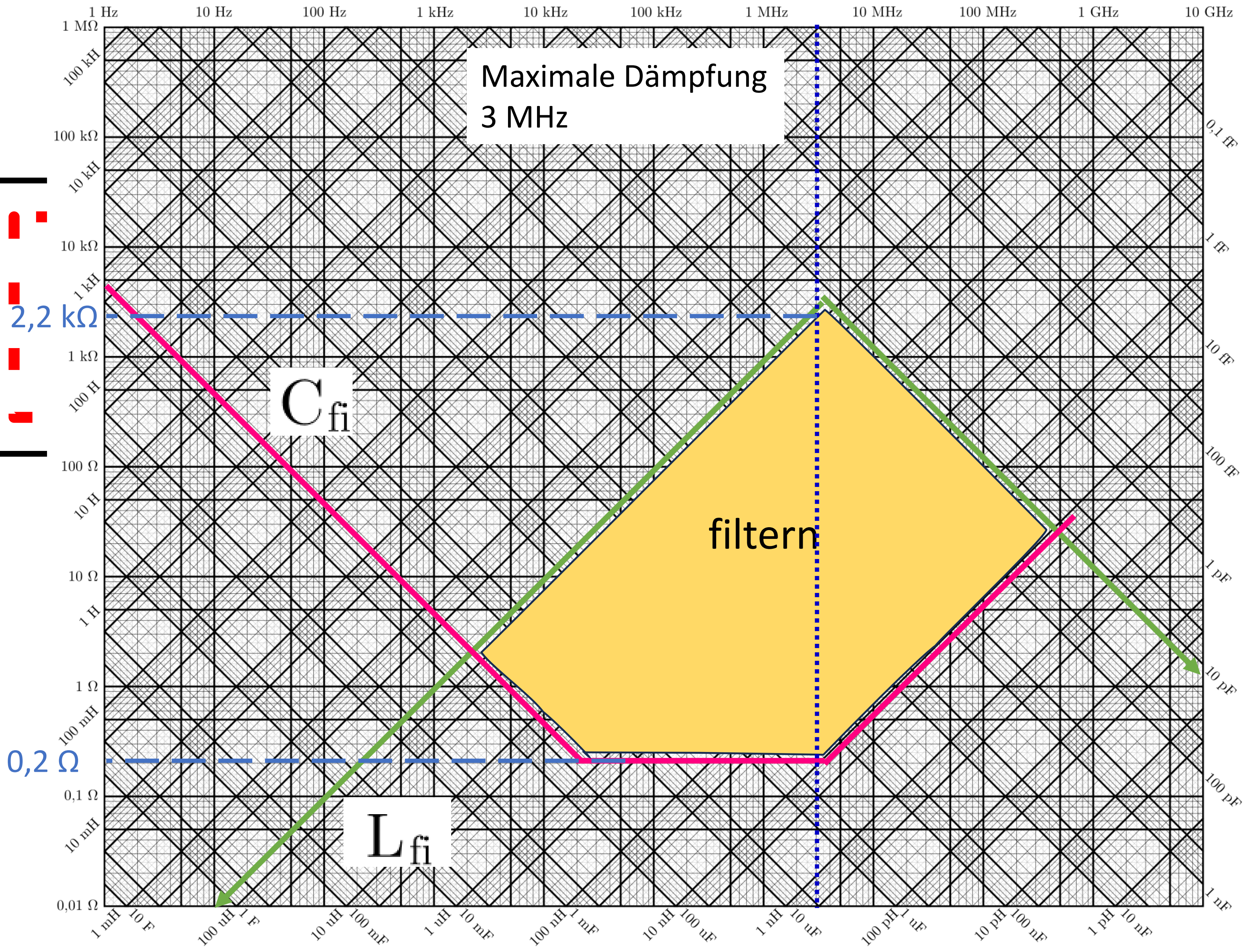

$$20 \cdot \log_{10} \frac{50}{0{,}2} \approx 48\ dB$$



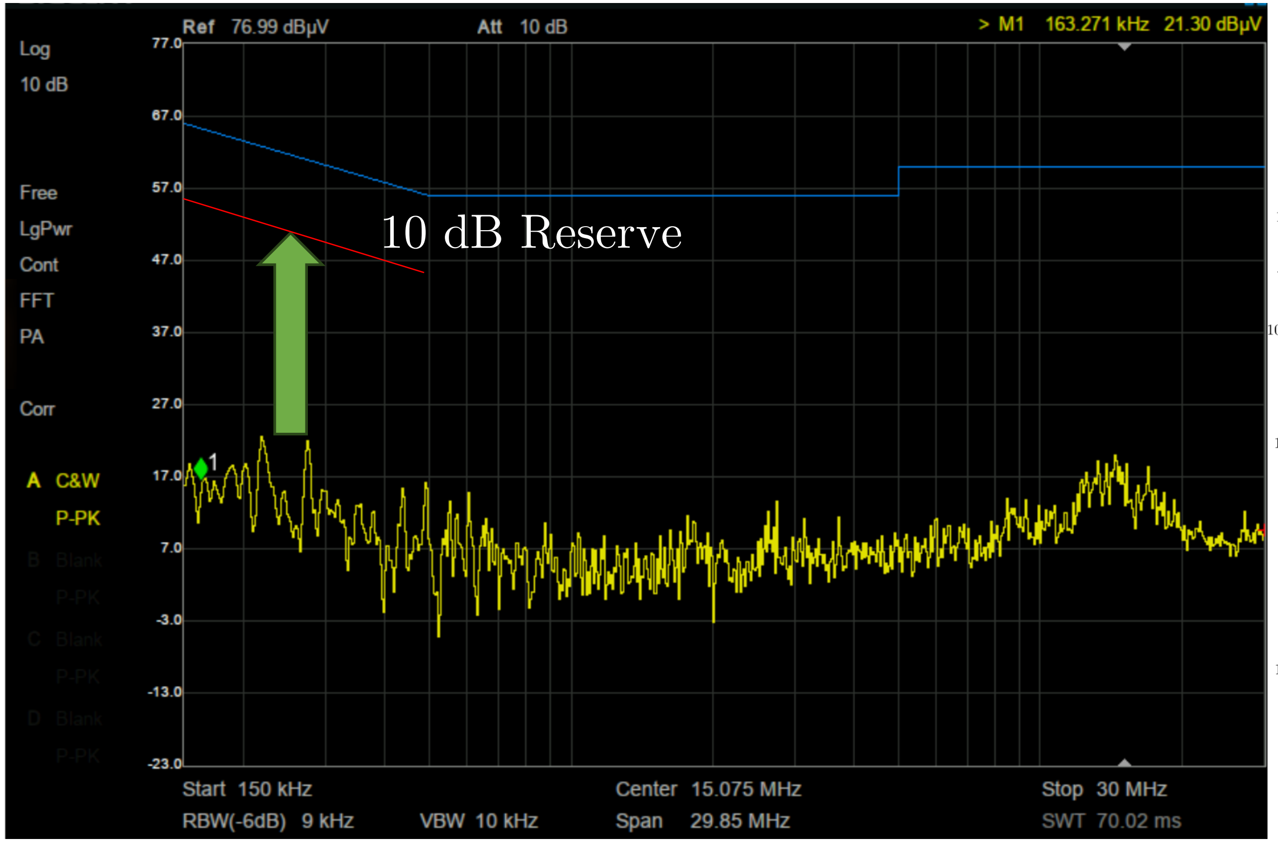




$$20 \cdot \log_{10} \frac{150}{0{,}2} \approx 58\ dB$$

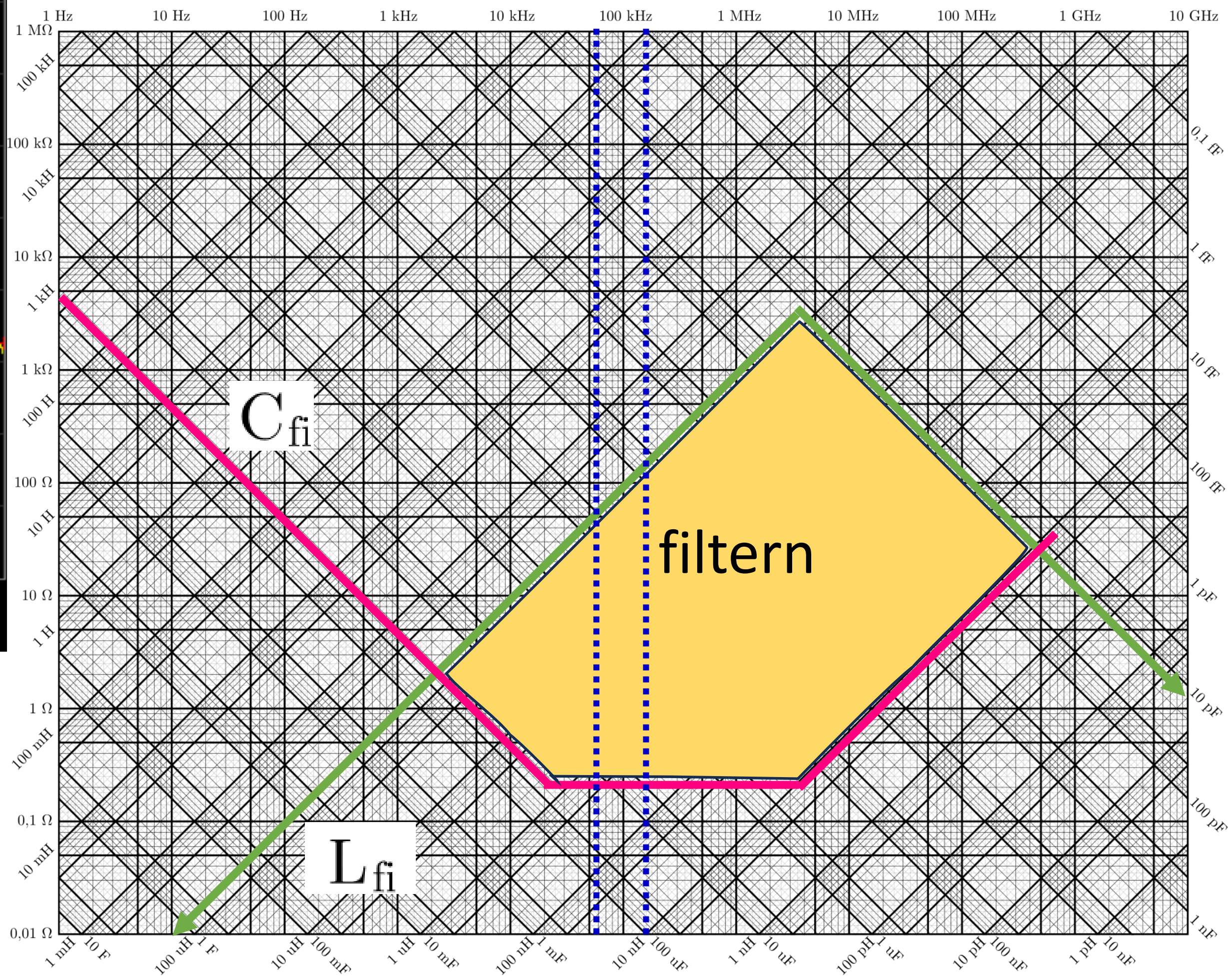


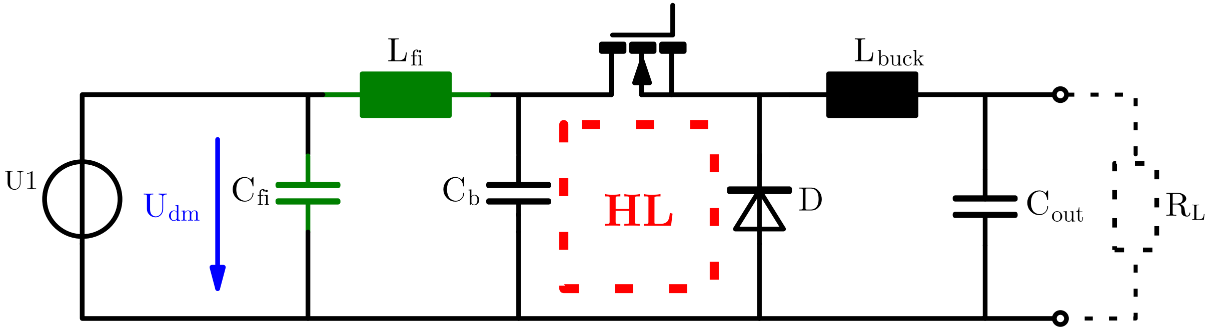




$$20 \cdot \log_{10} \frac{2200}{0{,}2} \approx 81\ dB$$

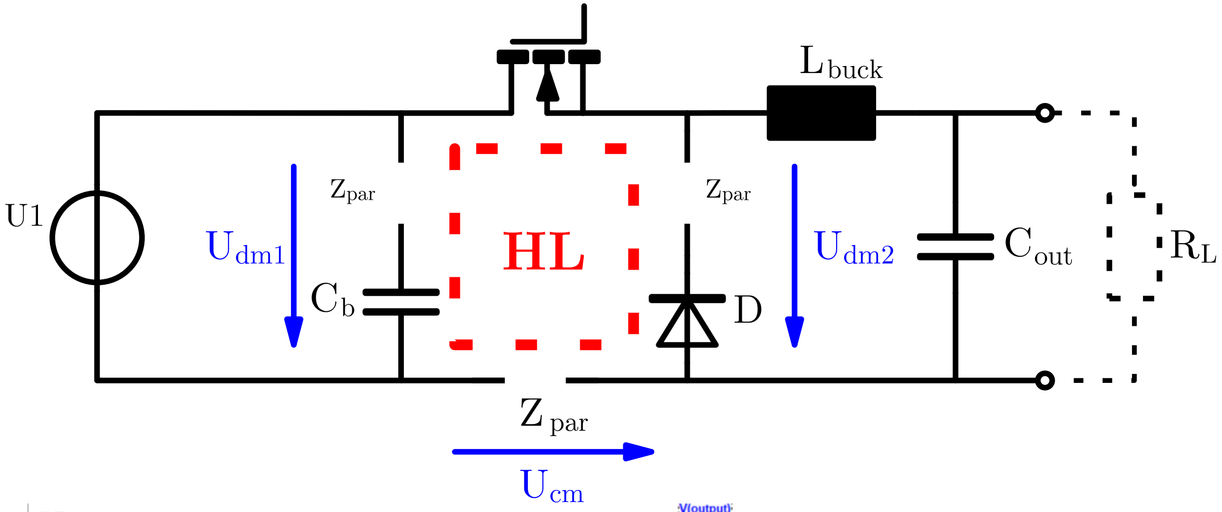


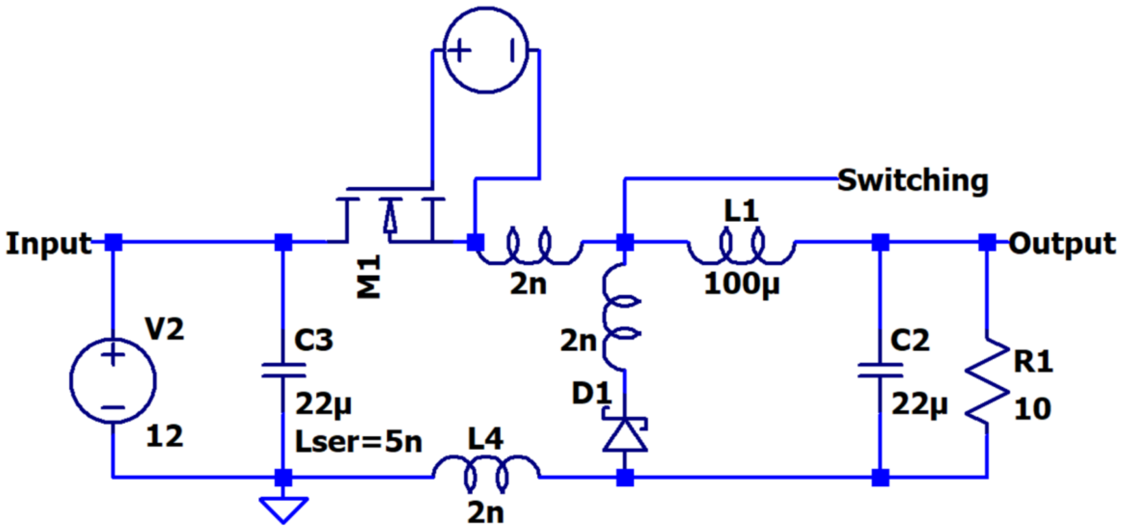

Kosten senken durch Bauteilauswahl?

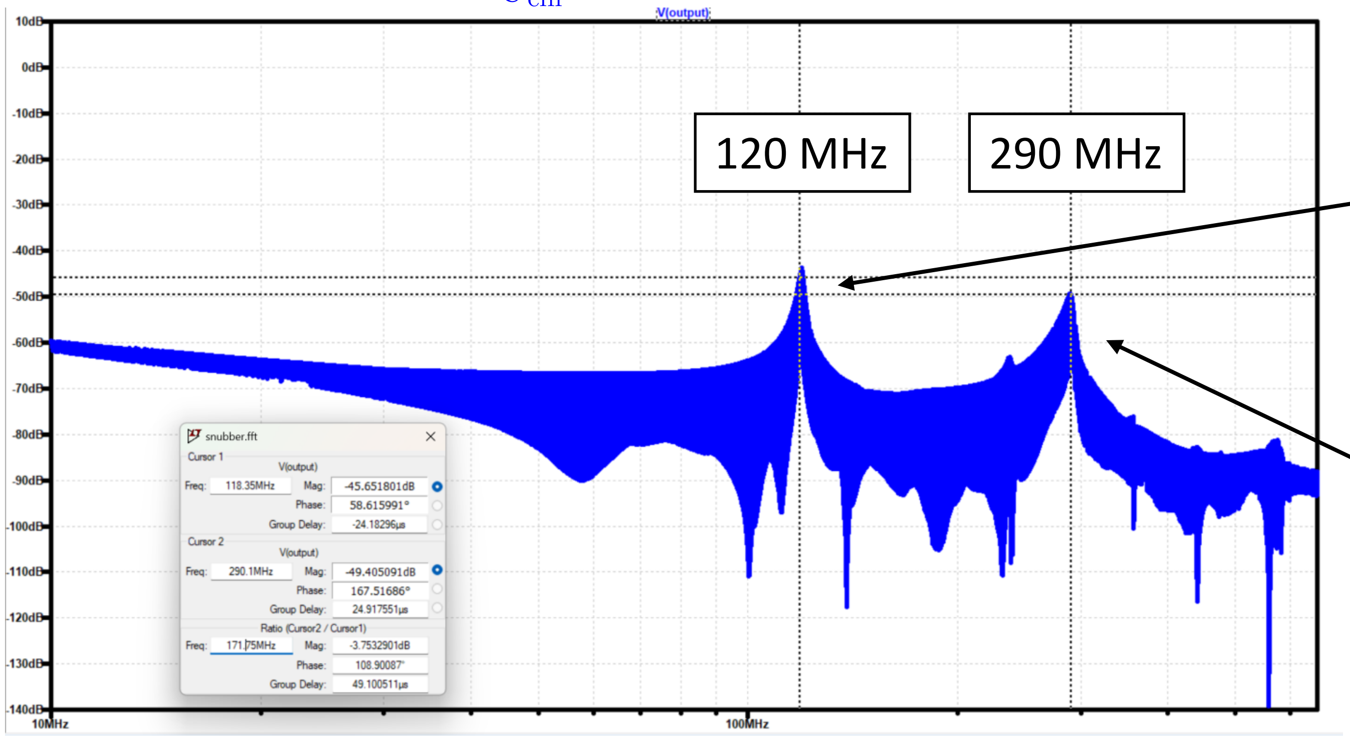


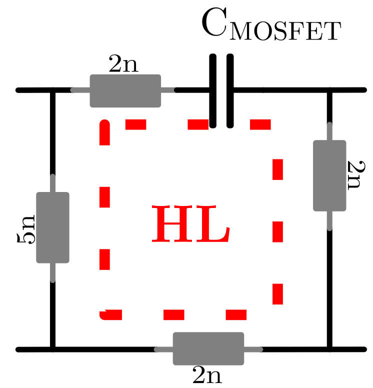



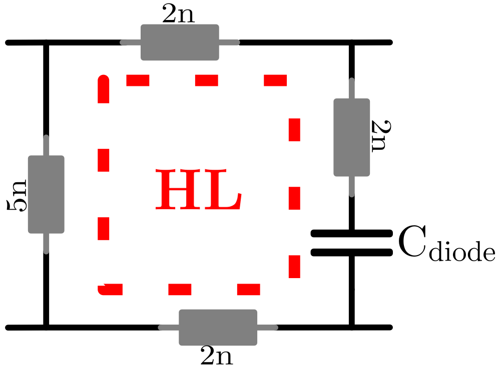
# 3. Snubber-Design

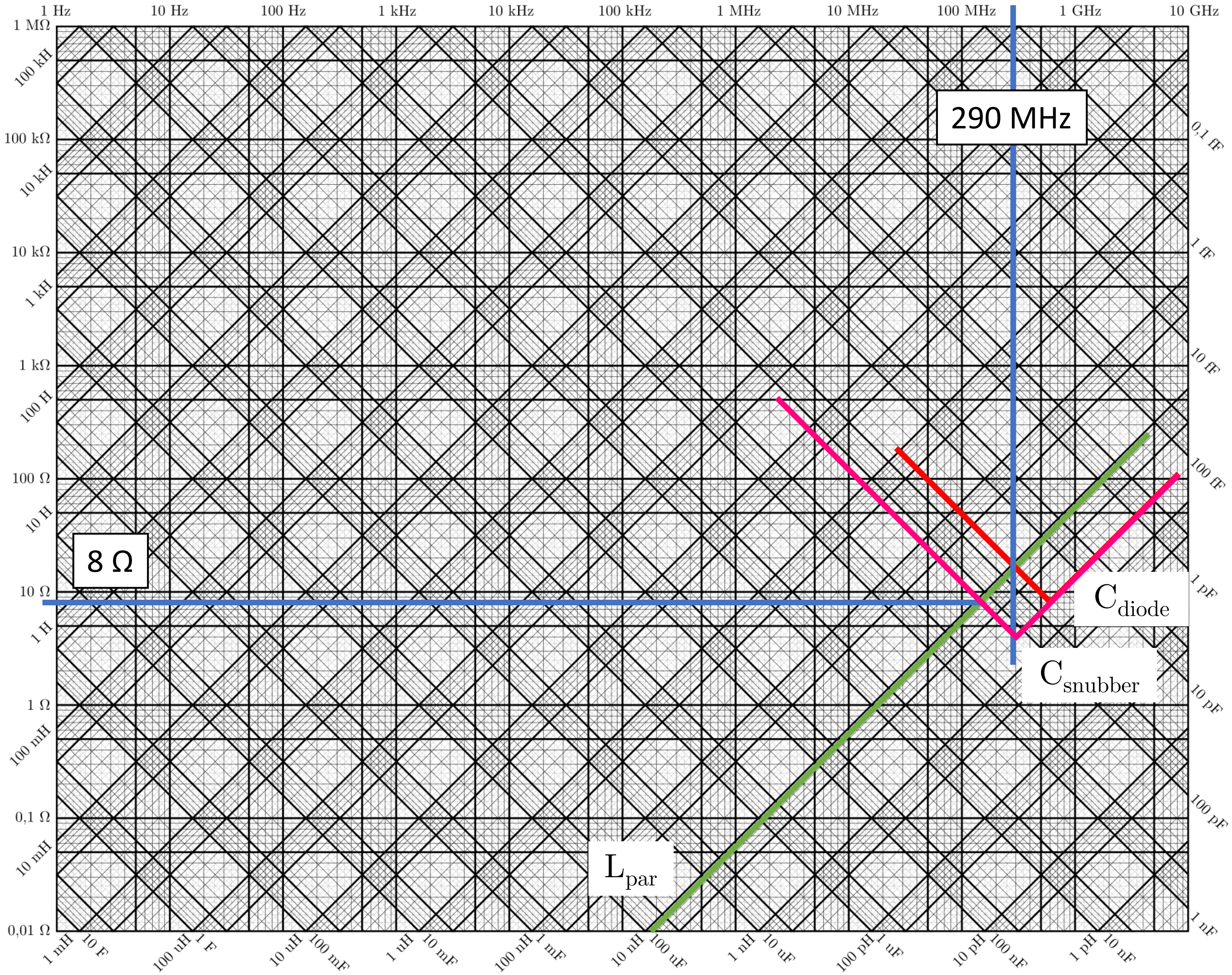


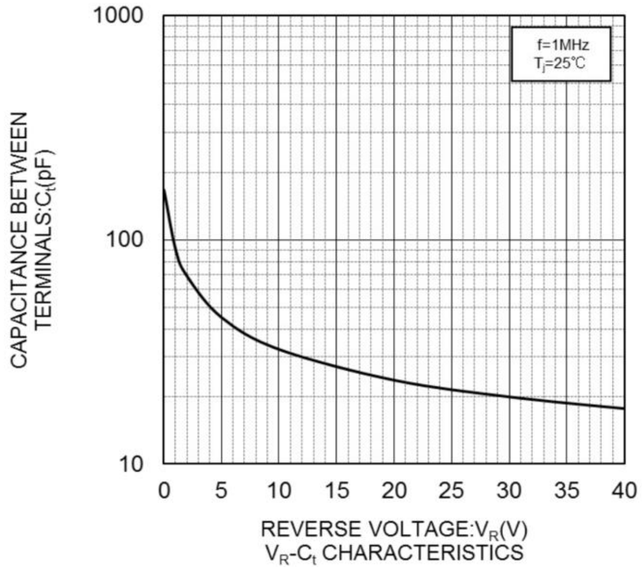



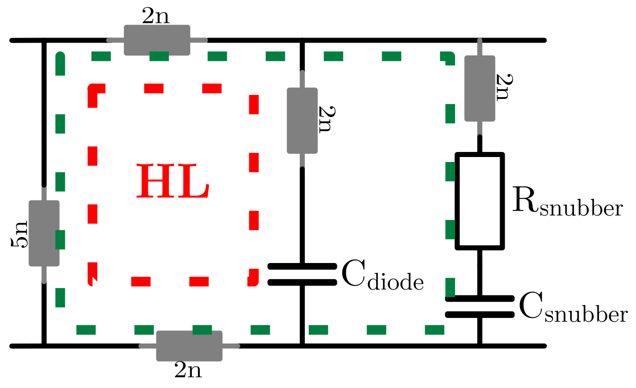



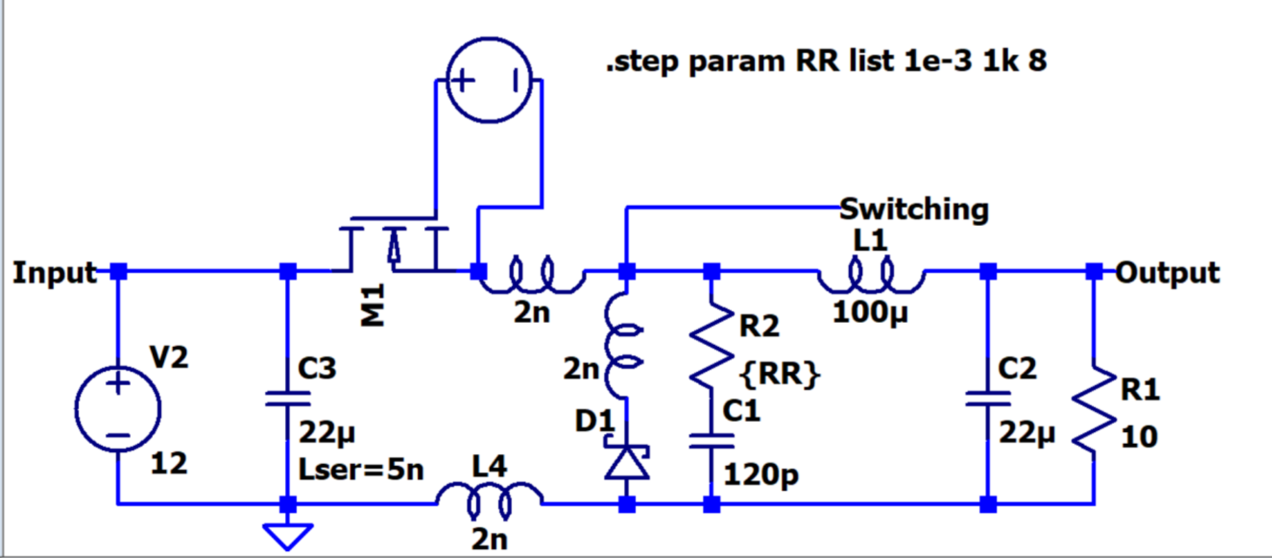



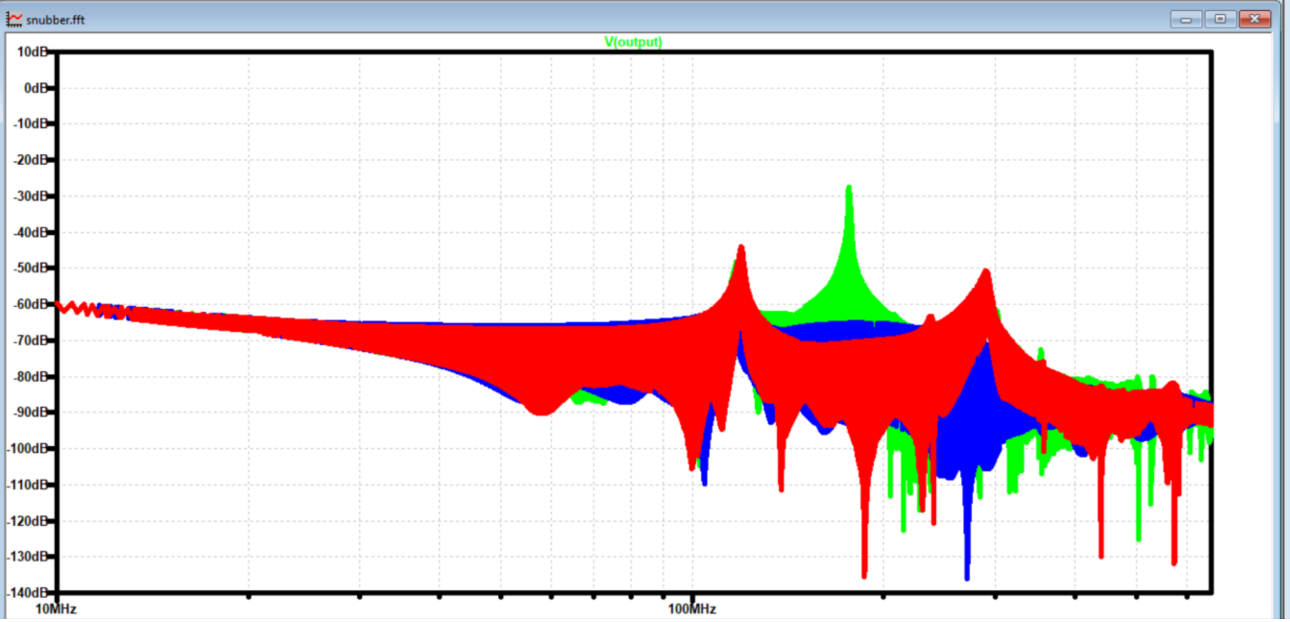



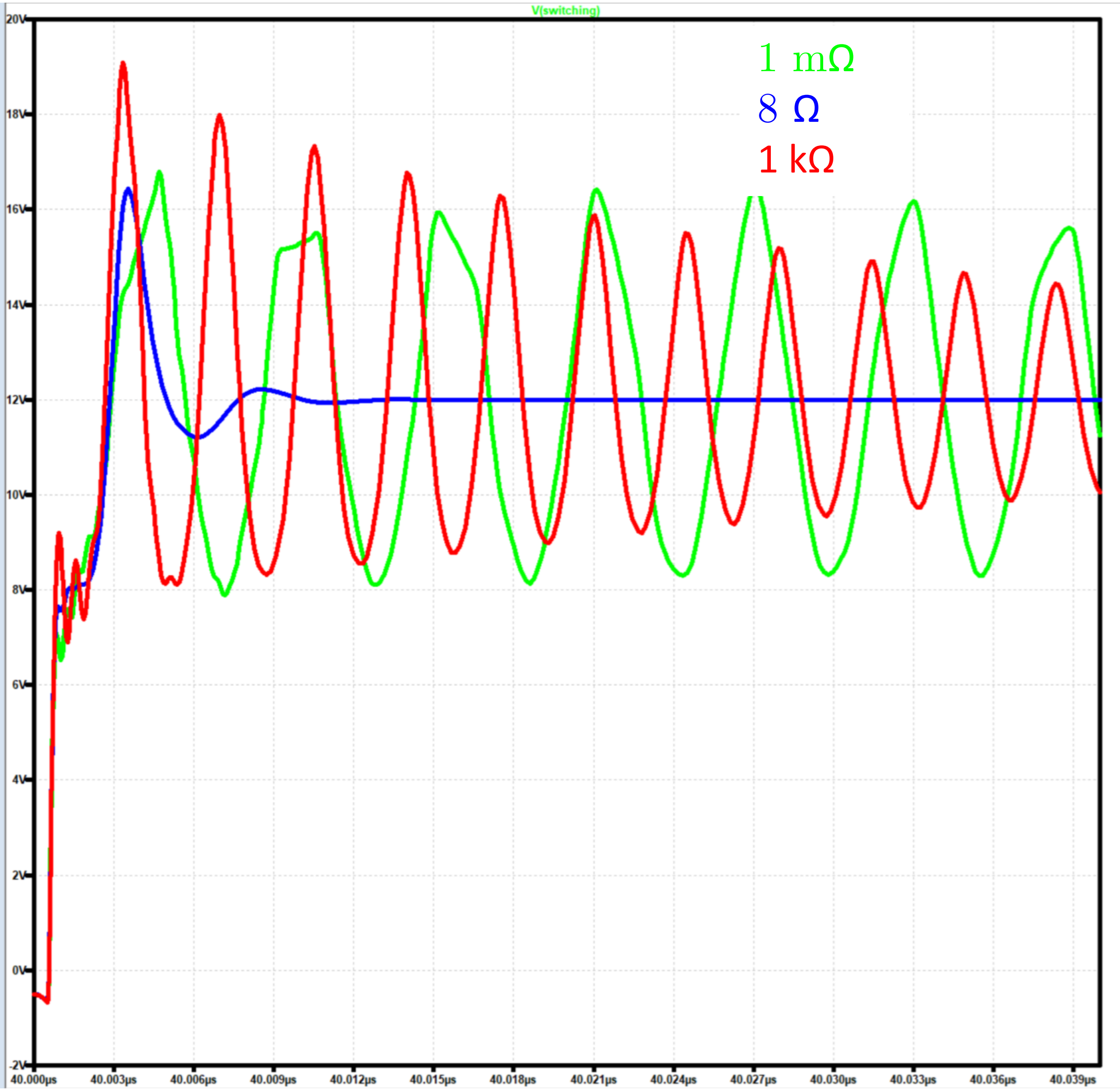

1 Hz
10 Hz
100 Hz
1 kHz
10 kHz
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
10 GHz
1 MΩ
100 kΩ
10 kΩ
1 kΩ
100 Ω
10 Ω
1 Ω
0,1 Ω
0,01 Ω
100 kH
10 kH
1 kH
100 H
10 H
1 H
100 mH
10 mH
1 mH
10 F
100 uH
1 F
10 uH
100 mF
1 uH
10 mF
100 nH
1 mF
10 nH
100 uF
1 nH
10 uF
100 pH
1 uF
10 pH
100 nF
1 pH
10 nF
0,1 fF
1 fF
10 fF
100 fF
1 pF
10 pF
100 pF
1 nF
290 MHz
8 Ω
$C_{diode}$
$C_{snubber}$
$L_{par}$


f=1MHz
$T_j$=25℃
1000
100
10
0
5
10
15
20
25
30
35
40
CAPACITANCE BETWEEN TERMINALS:$C_t$(pF)
REVERSE VOLTAGE:$V_R$(V)
$V_R$-$C_t$ CHARACTERISTICS

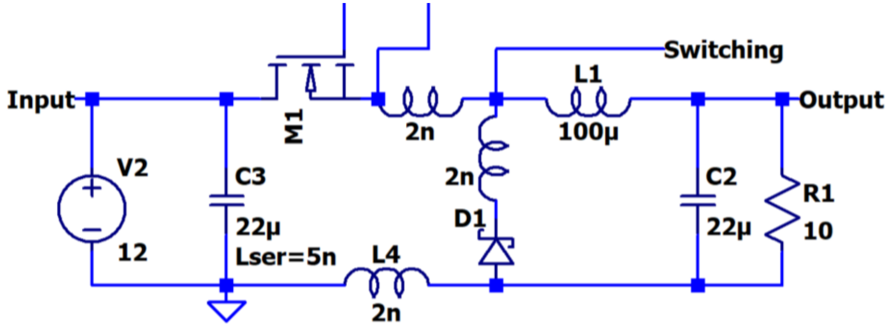

2n
2n
2n
5n
2n
HL
$R_{snubber}$
$C_{diode}$
$C_{snubber}$

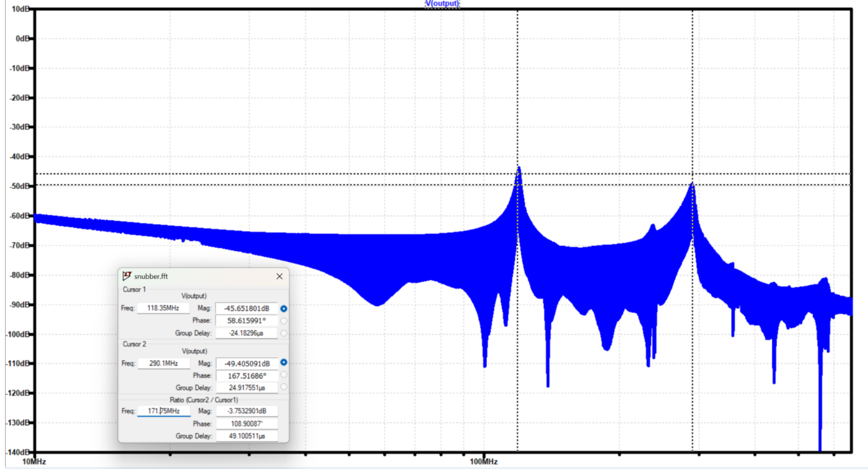

.step param RR list 1e-3 1k 8
Input
V2
12
C3
22µ
Lser=5n
M1
2n
L4
2n
Switching
L1
100µ
2n
D1
R2
{RR}
C1
120p
C2
22µ
R1
10
Output


snubber.fft
V(output)
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
-80dB
-90dB
-100dB
-110dB
-120dB
-130dB
-140dB
10MHz
100MHz

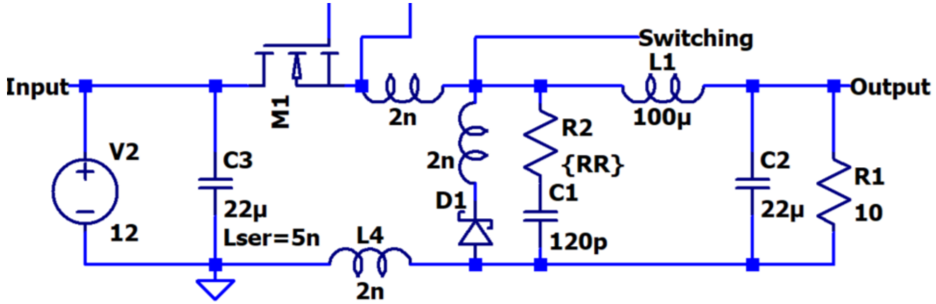

V(switching)
1 mΩ
8 Ω
1 kΩ
20V
18V
16V
14V
12V
10V
8V
6V
4V
2V
0V
-2V
40.000µs
40.003µs
40.006µs
40.009µs
40.012µs
40.015µs
40.018µs
40.021µs
40.024µs
40.027µs
40.030µs
40.033µs
40.036µs
40.039µs

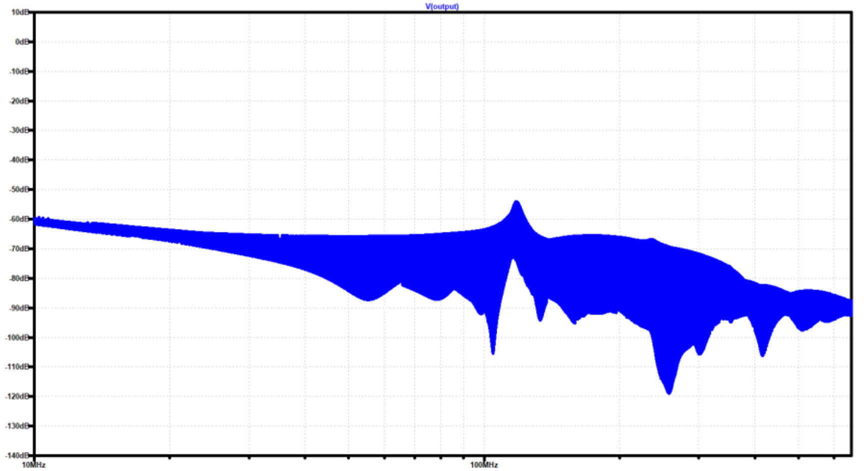
Kein Snubber



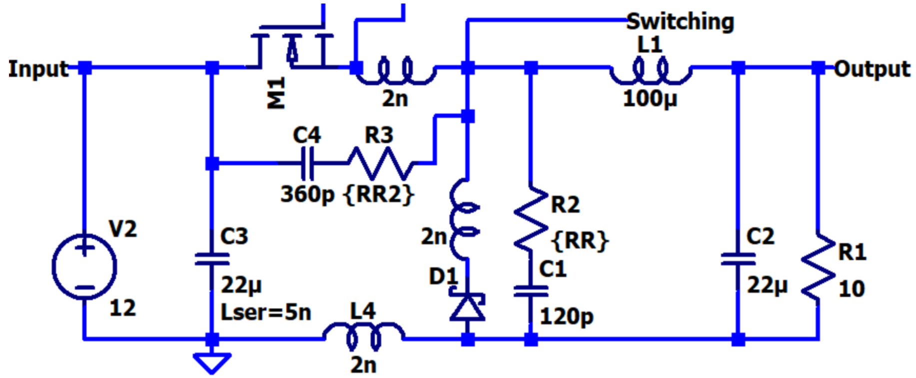



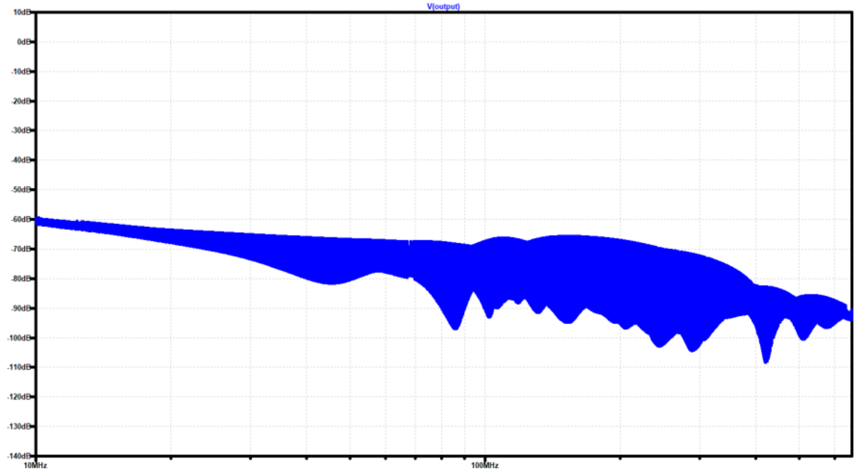

Ein Snubber



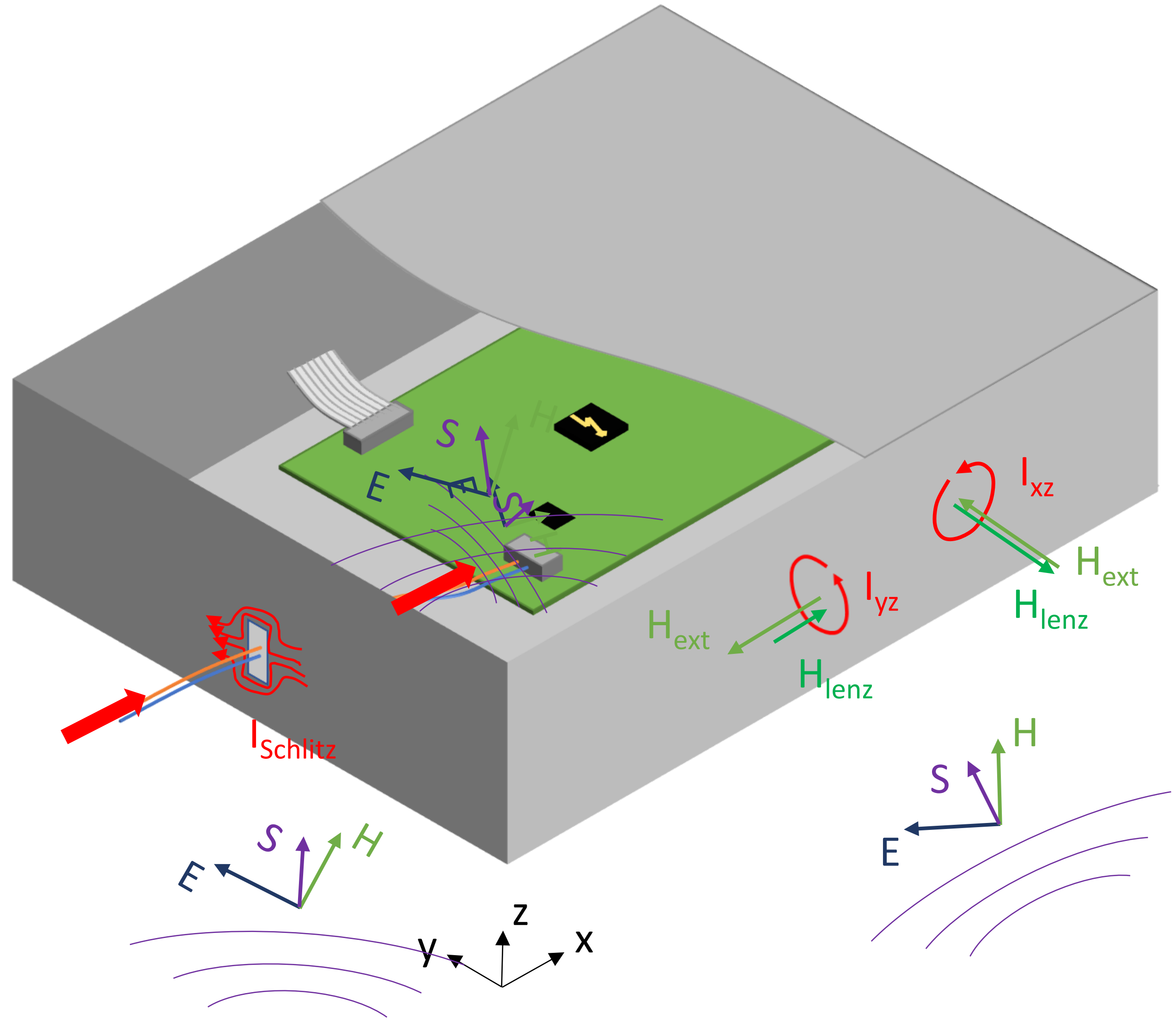




Zwei Snubber



# 4. Gehäuseschirmung




**Niederfrequent elektrisch**
→ Faraday'scher Käfig

**Hochfrequent elektrisch**
→ Geschlossene leitfähige Schirmung

Stromdichte:

$$J(x) = -\frac{\mathrm{d}H(x)}{\mathrm{d}x}$$

$$|J(x)| = |J(0)| \cdot \mathrm{e}^{-\frac{x}{\delta}}$$

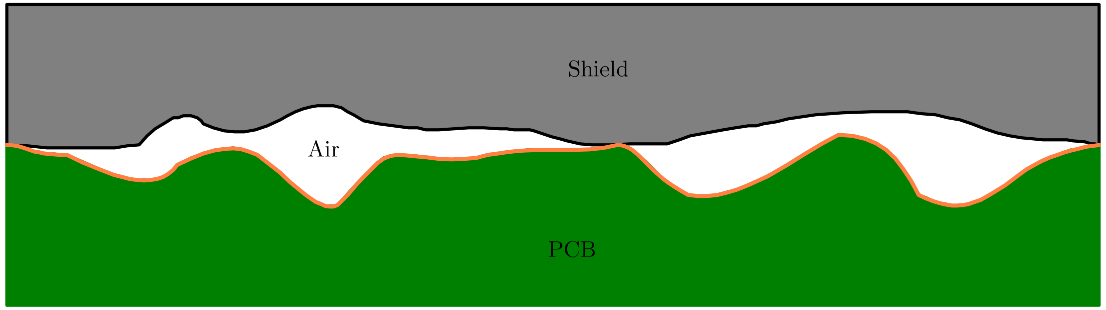
Skin-Tiefe:

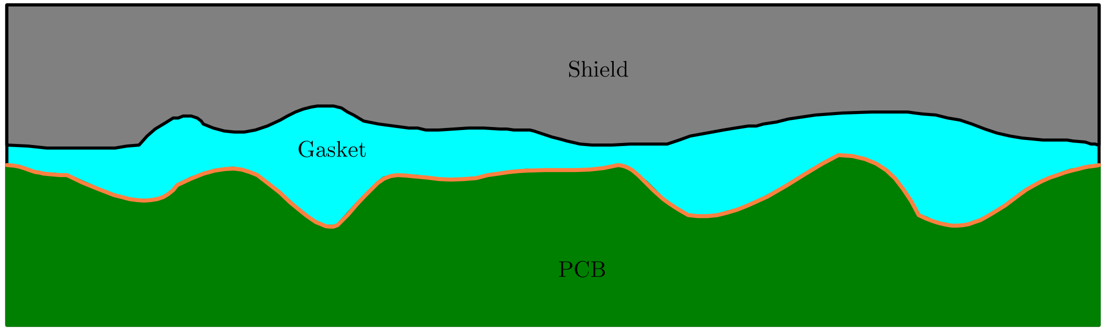
$$\delta = \sqrt{\frac{1}{\pi f \kappa \mu}}$$

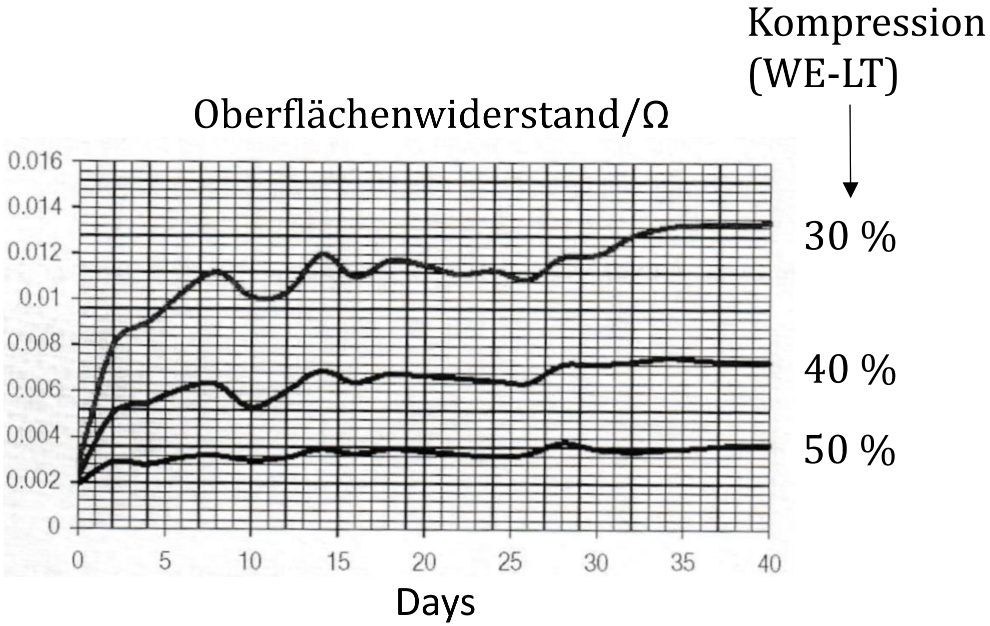
Kupfer:
$\delta \approx 1$mm @ 5 kHz
$\delta \approx 0{,}1$mm @ 0,5 MHz
$\delta \approx 0{,}01$mm @ 50 MHz

**Niederfrequent magnetisch**
→ mit Mumetal umschießen, um Feldlinien umzuleiten

**Hochfrequent magnetisch**
→ Geschlossene leitfähige Schirmung



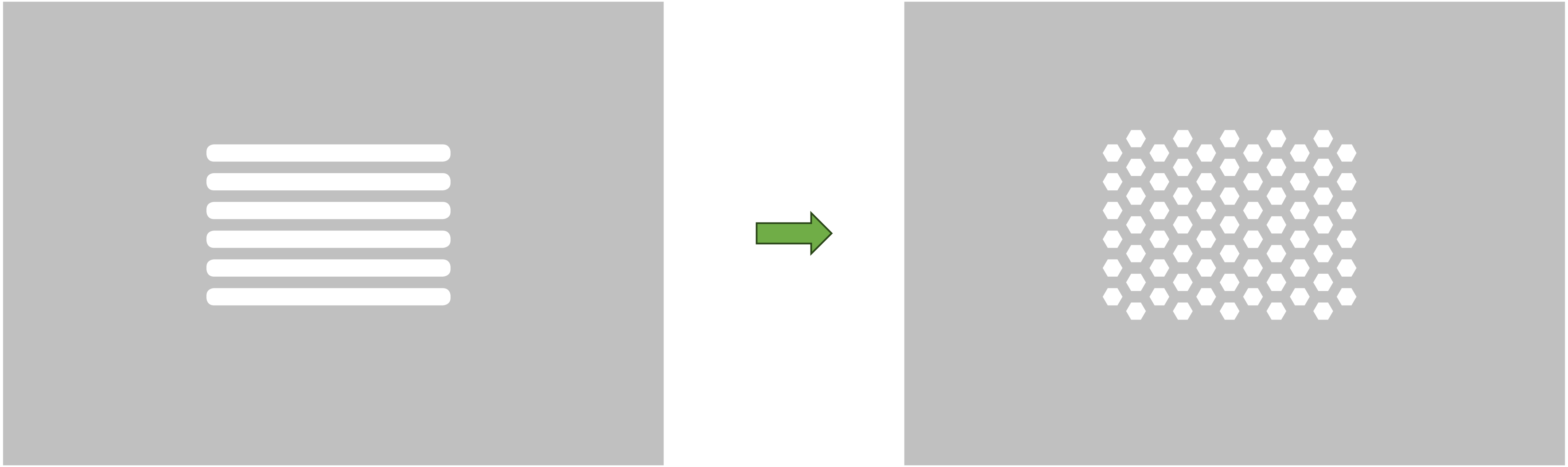

[WELTRIL]

| Kombinationen von Materialien (WE-LT) | |
|---|---|
| + | Aluminium |
| + | Eisen, Gold |
| ++ | Silber |
| - | Stahl galvanisiert |
| ++ | Zinn |
| -- | Magnesiumlegierung |
| ++ | Kupfer |

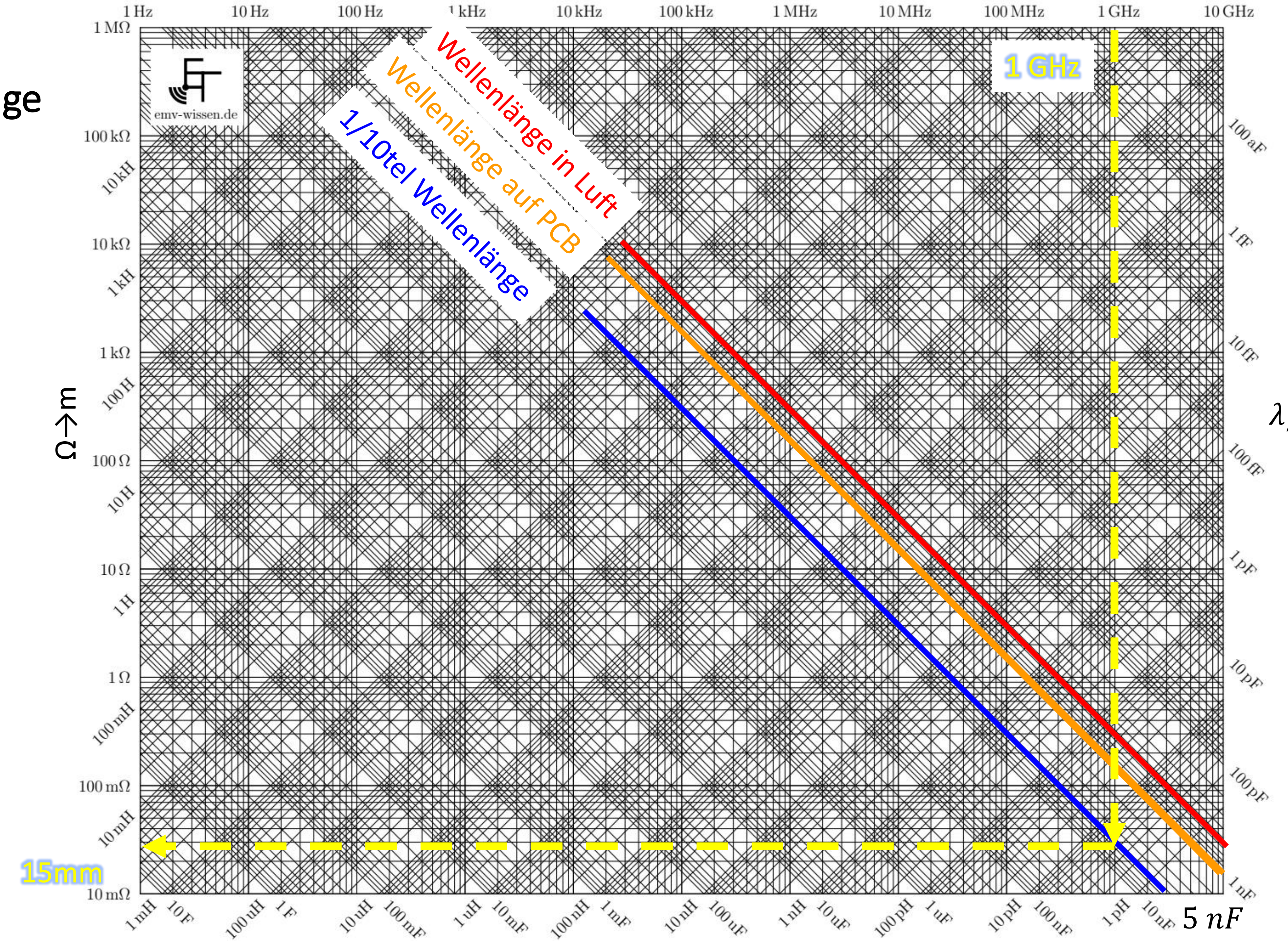


[WELTRIL] Trilogie der Induktiven Bauelemente; Dr. Brander, Gerfer, Rall, Zenkner; Wprth Elektronik; 4. Auflage

# Lüftung



# Schlitzlänge

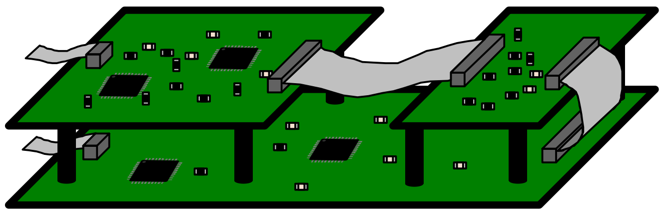



$$\lambda = \frac{c}{f}$$

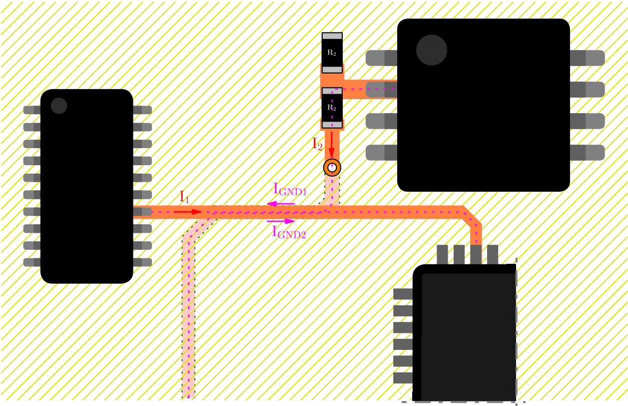
$$\lambda/m \approx \frac{300}{f/MHz}$$

# EMV/HF Workshop in Regensburg 5.-8.11.2024 (Anmeldung beendet)
# Für nächstes Jahr bereits anfragen und Frühbucherrabatt sichern.

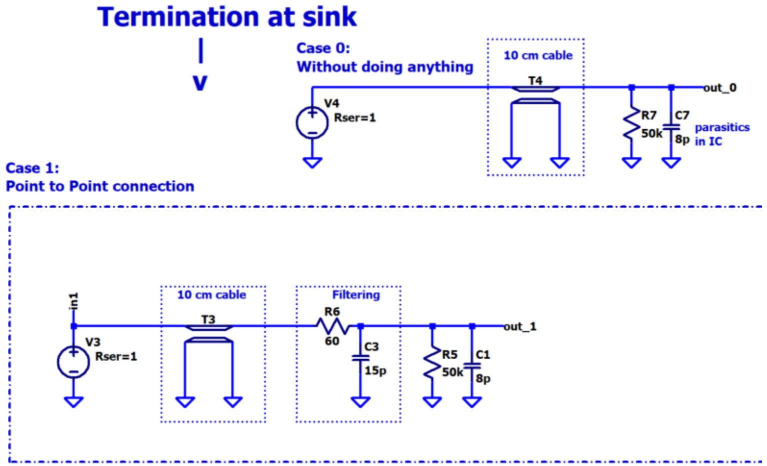
## Tag 1:
## EMV auf Geräteebene



## Tag 2:
## EMV auf Leiterplattenebene



## Tag 3:
## EMV-Entwicklung




## Tag 4:
## Hochfrequenztechnik