Design of Magnetic Cores Lm and Lr

Table of contents

Inputs and claculated parameters

```
V_In_min 360.0 V_In_max 400.0 Vo_nom 48.0 Power   1200.0
V_In_nom 380.0   Vo_min  42.0 Vo_max 54.0 f_nom 100000.0
```

```
  Lnc   3.000   Lm_uH     65.392     Ioe_rms  7.636 Re_110    22.637
  Qec   0.550 fsw_min  60170.000     Ios_rms 30.545     Cr       0.0
Cr_nF 116.209 fsw_max 156220.000      Ir_rms 10.354     Lr  0.000022
    n   4.000  Im_rms      6.992 L_second_uH  4.087     Lm  0.000065
Lr_uH  21.797       Io     25.000      Re_nom 24.901
```

Transformer design

	Transormer parameters
n	4.000
Lm_uH	65.392
fsw_min	60170.000
fsw_max	156220.000
Ir_rms	10.354
Im_rms	6.992
Ioe_rms	7.636
Ios_rms	30.545
L_second_uH	4.087
Al_uH	4.087

Bpeak formula

$$B_{peak} = \frac{L_m \cdot Im_{peak}}{N_p \cdot A_e} = \frac{L_m \cdot \sqrt{2} \cdot Im_{rms}}{N_p \cdot A_e}$$

Where

- `A_e` = effective core area (in m²)
- `N_p` = primary turns

The `Al` value:

$$\begin{aligned} \mathrm{Al}_{nH} &= 1 \times 10^3 \cdot \frac{\mathrm{Lm}_{uH}}{(n)^2} \\ &= 1 \times 10^3 \cdot \frac{65.392}{(4.000)^2} \\ &= 4087.000 \ \ (\mathrm{nH/turn\ squared}) \end{aligned}$$

We can reduce A_L by adding an air gap, below the formula of air gap length

$$A'_L = \frac{A_L}{1 + \mu_r \frac{L_g}{L_e}}$$

$$l_g = \frac{L_e}{\mu_r}\left(\frac{A_L}{A'_L} - 1\right)$$

Where

- A'_L : the corrected inductance factor (in nH or μH), after introducing the air gap
- A_L : the initial inductance factor provided by the core manufacturer (in nH or μH)
- l_g : the air gap length (in mm)
- L_e : the effective magnetic path length of the core (in mm)

Core ELP 64/10/50 with I 64/5/50

Inputs data

μ_r: relative permeability (material property) μ_e: effective permeability (assembly/shape property)

$$\text{core} = \quad (\text{ELP 64/10/50 with I 64/5/50})$$

$$\text{Al}_{nH} = 14000 \ \ (\text{nH})$$

$$A_e = 519 \ \ (\text{mm2})$$

$$A_{e_{min}} = 518 \ \ (\text{mm2})$$

$$l_e = 69.700 \ \ (\text{mm})$$

$$\mu_r = 1450 \ \ (\text{N87})$$

$$B_{sat} = 300 \ \ (\text{mT @ 250A/m 10kHz } 100^{\circ}\text{C})$$

$$\text{K1} = 835 \ \ (\text{@ } 25^{\circ}\text{C, 0.10 mm} < \text{s} < \text{2.00 mm})$$

$$\text{K2} = -0.790 \ \ (\text{@ } 25^{\circ}\text{C, 0.10 mm} < \text{s} < \text{2.00 mm})$$

$$\mu_0 = 4 \cdot \pi \cdot 1 \times 10^{-7} = 4 \cdot 3.142 \cdot 1 \times 10^{-7} \qquad = 0.000 \ \ (\text{H m}{-1})$$

The air gap

$$\mathrm{Lm}_{nH} = \mathrm{Lm}_{uH} \cdot 1 \times 10^{3} = 65.392 \cdot 1 \times 10^{3} \qquad = 65392.000 \ \ (\mathrm{nH})$$

$$\mathrm{Al}_{nH} = 14000 \ \ (\mathrm{nH})$$

$$\mathrm{Al}_{Target} = \frac{\mathrm{Lm}_{nH}}{(n)^{2}} = \frac{65392.000}{(4.000)^{2}} \qquad = 4087.000 \ \ (\mathrm{nH})$$

$$\mu_{eTarget} = \mu_{r} \cdot \frac{\mathrm{Al}_{Target}}{\mathrm{Al}_{nH}} = 1450 \cdot \frac{4087.000}{14000} \qquad = 423.296$$

Simified formula of air gap

See the formula above

$$\begin{aligned} l_{g} &= 1 \times 10^{3} \cdot \left(\frac{\mu_{0} \cdot (n)^{2} \cdot A_{e} \cdot 1 \times 10^{-6}}{\mathrm{Lm}} - l_{e} \cdot \frac{1 \times 10^{-3}}{\mu_{r}} \right) \\ &= 1 \times 10^{3} \cdot \left(\frac{0.000 \cdot (4.000)^{2} \cdot 519 \cdot 1 \times 10^{-6}}{0.000} - 69.700 \cdot \frac{1 \times 10^{-3}}{1450} \right) \\ &= 0.112 \ \ (\mathrm{mm}) \end{aligned}$$

TDK formula of air gap using K1 and K2

a) Air gap and A_L value

The typical A_L value tabulated in the individual data sheets refers to a core set comprising a gapped core with dimension „g“ and an ungapped core with „g“ approx. 0.

By inserting the core-specific constants K1 and K2, a nominal A_L value can be calculated for the materials N27 and N87 within the relevant quoted air-gap validity range:

$$s = \left(\frac{A_L}{K1}\right)^{\frac{1}{K2}} \qquad \begin{aligned} s &= [\mathrm{mm}] \\ A_L &= [\mathrm{nH}] \end{aligned}$$

Figure 1: The empirical air-gap formula using the coefficients K1 and K2 from the TDK datasheet

See page 6 [1].

$$\begin{aligned} s_{mm} &= \left(\frac{\mathrm{Al}_{Target}}{\mathrm{K1}} \right)^{\left(\frac{1}{\mathrm{K2}}\right)} \\ &= \left(\frac{4087.000}{835} \right)^{\left(\frac{1}{-0.790}\right)} \\ &= 0.134 \ \ (\mathrm{mm\ airgap}) \end{aligned}$$

TDK air gap curve

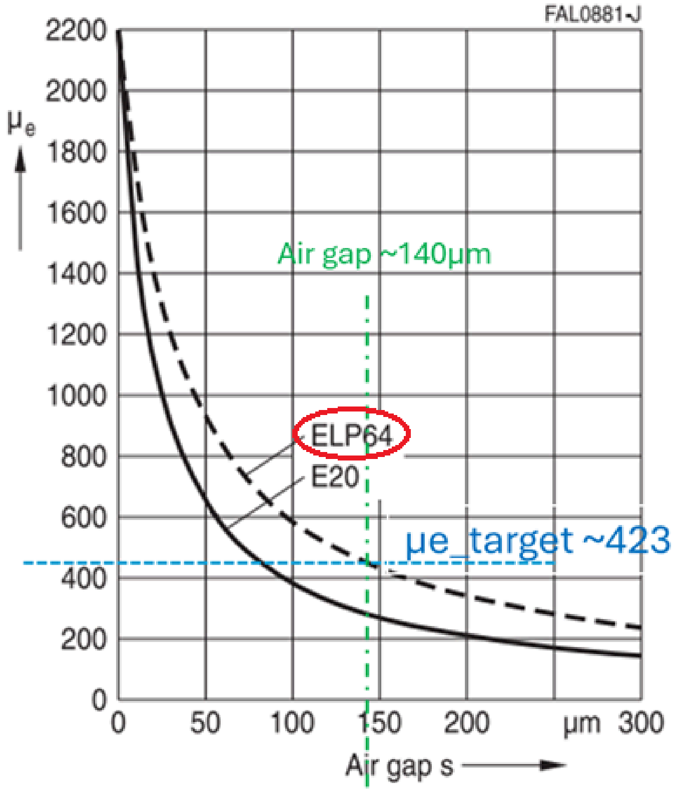


Figure 26
Relationship between permeability μ_e and air gap s for an E 20/10/11 N87 and ELP 64/10/50 N87 ferrite core

Figure 2: The empirical air-gap formula using the coefficients K1 and K2 from the TDK datasheet

See page 2 [2].

$$l_{g_{curve}} = 0.140 \quad (\text{mm})$$

Air gap using the tree methods

$$\begin{aligned} s_{mm} &= 0.134 \quad (\text{mm using TDK formula K1, K2}) \\ l_g &= 0.112 \quad (\text{mm using the simple formula}) \\ l_{g_{curve}} &= 0.140 \quad (\text{mm using TDK graph}) \end{aligned}$$

The three results are close to each other; we will prefer the TDK formula using K1 and K2 if these coefficients are provided in the datasheet.

The Bpeak and Bsat

Reluctance formulas

$$\mu_e = \frac{l_e + l_g}{l_g + \frac{l_e}{\mu_r}} = \frac{69.700 + 0.112}{0.112 + \frac{69.700}{1450}} \qquad = 437.476$$

$$\begin{aligned} R_{core} &= l_e \cdot \frac{1 \times 10^{-3}}{\mu_0 \cdot \mu_r \cdot A_e \cdot 1 \times 10^{-6}} \\ &= 69.700 \cdot \frac{1 \times 10^{-3}}{0.000 \cdot 1450 \cdot 519 \cdot 1 \times 10^{-6}} \\ &= 73703.405 \end{aligned}$$

$$\begin{aligned} R_{gap} &= 1 \times 10^{-3} \cdot \frac{l_g}{\mu_0 \cdot A_e \cdot 1 \times 10^{-6}} \\ &= 1 \times 10^{-3} \cdot \frac{0.112}{0.000 \cdot 519 \cdot 1 \times 10^{-6}} \\ &= 170974.843 \end{aligned}$$

$$\begin{aligned} R_{tot} &= R_{core} + R_{gap} \\ &= 73703.405 + 170974.843 \\ &= 244678.248 \;\; \text{(At/Wb, using Rcore, Rgap)} \end{aligned}$$

$$\begin{aligned} R_{tot_2} &= 1 \times 10^{-3} \cdot \frac{l_g + l_e}{\mu_0 \cdot \mu_e \cdot A_e \cdot 1 \times 10^{-6}} \\ &= 1 \times 10^{-3} \cdot \frac{0.112 + 69.700}{0.000 \cdot 437.476 \cdot 519 \cdot 1 \times 10^{-6}} \\ &= 244678.248 \;\; \text{(At/Wb, using μe)} \end{aligned}$$

$$\begin{aligned} \mathrm{Im}_{sat} &= B_{sat} \cdot 1 \times 10^{-3} \cdot A_e \cdot 1 \times 10^{-6} \cdot \frac{R_{core} + R_{gap}}{n} \\ &= 300 \cdot 1 \times 10^{-3} \cdot 519 \cdot 1 \times 10^{-6} \cdot \frac{73703.405 + 170974.843}{4.000} \\ &= 9.524 \;\; \text{(A)} \end{aligned}$$

$$\mathrm{Im}_{peak} = \sqrt{2} \cdot \mathrm{Im}_{rms} = \sqrt{2} \cdot 6.992 \qquad = 9.888 \;\; \text{(A)}$$

$I_{m_{peak}} > I_{m_{sat}}$, let's double-check our hypothesis and margins.

Verification of the Hypothesis

$$\mathrm{Vf} = 0.200 \;\; \text{(drop voltage in the mos)}$$

$$\text{efficiency} = 0.950 \;\; \text{(Hypothesis, efficiency} = 95\backslash\%)$$

$$\text{loss} = \frac{1 - \text{efficiency}}{3}$$
$$= \frac{1 - 0.950}{3}$$
$$= 0.017 \quad \text{(Hypothesis: Joule loss} = 1/3 \text{ of total losses)}$$

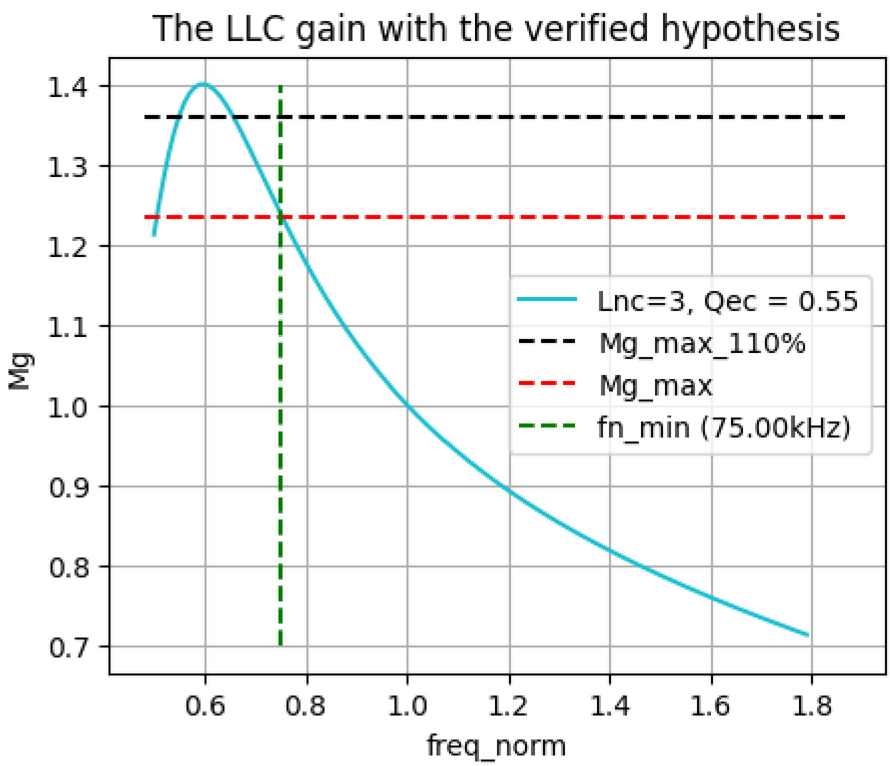
$$\text{Io}_{nom} = \frac{\text{Power}}{\text{Vo}_{nom}} = \frac{1200.000}{48.000} \qquad = 25.000 \ \ (\text{A})$$

$$V_{loss} = \frac{\frac{\text{Power}\cdot\text{loss}}{\text{efficiency}}}{\text{Io}_{nom}} = \frac{\frac{1200.000\cdot 0.017}{0.950}}{25.000} \qquad = 0.842 \ \ (\text{v})$$

$$\text{margin} = 0.010$$

$$\text{Mg}_{max} = n \cdot \frac{\text{Vo}_{max}\cdot(1+\text{margin}) + \text{Vf} + V_{loss}}{\frac{V_{In_{min}}}{2}}$$
$$= 4.000 \cdot \frac{54.000\cdot(1+0.010) + 0.200 + 0.842}{\frac{360.000}{2}}$$
$$= 1.235$$

$$\text{Mg}_{max110} = \text{Mg}_{max}\cdot\left(\frac{110}{100}\right) = 1.235\cdot\left(\frac{110}{100}\right) \qquad = 1.359$$



$$\mathrm{fmin}_2 = 75000.000$$

$$\omega_{min} = 471238.898$$

$$\begin{aligned}\mathrm{Im}_{rms2} &= 2 \cdot \sqrt{2} \cdot n \cdot \frac{\mathrm{Vo}_{nom}}{\pi \cdot \mathrm{Lm} \cdot \omega_{min}} \\ &= 2 \cdot \sqrt{2} \cdot 4.000 \cdot \frac{48.000}{3.142 \cdot 0.000 \cdot 471238.898} \\ &= 5.610 \ \ (\mathrm{Arms})\end{aligned}$$

$$\mathrm{Im}_{peak2} = \sqrt{2} \cdot \mathrm{Im}_{rms2} = \sqrt{2} \cdot 5.610 \qquad = 7.933 \ \ (\mathrm{A})$$

$$I_{satMargin} = 100 \cdot \frac{\mathrm{Im}_{sat} - \mathrm{Im}_{peak2}}{\mathrm{Im}_{sat}} = 100 \cdot \frac{9.524 - 7.933}{9.524} \qquad = 16.704 \ \ (\backslash\%)$$

We can calculate also B_{peak2} using Im_{rms2}

$$B_{sat} = 300 \ \ (\mathrm{mT})$$

$$\begin{aligned}B_{peak2} &= 1 \times 10^3 \cdot \mathrm{Lm} \cdot \sqrt{2} \cdot \frac{\mathrm{Im}_{rms2}}{n \cdot A_{e_{min}} \cdot 1 \times 10^{-6}} \\ &= 1 \times 10^3 \cdot 0.000 \cdot \sqrt{2} \cdot \frac{5.610}{4.000 \cdot 518 \cdot 1 \times 10^{-6}} \\ &= 250.369 \ \ (\mathrm{mT} < \mathrm{Bs}{=}\ 300\mathrm{mT\ OK})\end{aligned}$$

We calculate the margin for B_{peak2}

$$\begin{aligned}B_{satMargin} &= 100 \cdot \frac{B_{sat} - B_{peak2}}{B_{sat}} \\ &= 100 \cdot \frac{300 - 250.369}{300} \\ &= 16.544 \ \ (\backslash\%)\end{aligned}$$

The calculation $I_{m,\mathrm{sat}}/I_{m,\mathrm{peak}}$ and $B_{\mathrm{peak}}/B_{\mathrm{sat}}$ are equivalent, see the result below

$$I_{satMargin} = 16.704 \ \ (\backslash\%)$$

$$B_{satMargin} = 16.544 \ \ (\backslash\%)$$

Other cores

Let’s apply the same formula to other cores, using the datasheet information shown below.

	core	Aemin(mm2)	Le(mm)	Ve(mm3)	Bsat mT	Loss (W/set)	K1	K2	µe	Al(nH)	price by set
0	E64/10/50-3C95	519.0	79.9	40700	330.0	20.0	NaN	NaN	NaN	17000	11.05
1	ELP 43/10/28 with I 43/4/28 N87	217.0	50.8	11430	350.0	7.8	390.0	-0.784	1480.0	850	2.61
2	ELP 64/10/50 with I 64/5/50 N87	512.0	69.7	36200	300.0	4.8	835.0	-0.790	1450.0	14000	NaN
3	ELP 64/10/50 with ELP 64/10/50 N95	518.0	79.9	41500	320.0	5.1	NaN	NaN	1880.0	15500	14.52
4	ELP 64/10/50 with ELP 64/10/50 N87	518.0	79.9	41500	300.0	5.5	820.0	-0.767	1490.0	12500	11.27
5	E64/10/50 + PLT64/50/5 3C95	519.0	69.7	35500	330.0	17.0	NaN	NaN	NaN	18500	NaN
6	ER64/13/51-3C92 3C95	507.0	93.0	52600	330.0	25.0	NaN	NaN	NaN	17100	19.62
7	E100/60/28 N87	690.0	274.0	201390	300.0	4.7	NaN	NaN	1930.0	6500	17.40
8	ELP 102/20/38 with ELP 102/20/38 N87	524.5	147.6	79410	300.0	11.0	NaN	NaN	1790.0	8200	12.88
9	ELP 102/20/38 with ELP 102/20/38 N97	524.5	147.6	79410	300.0	9.7	NaN	NaN	1855.0	8500	14.07
10	ELP 102/20/38 with I 102/7/38 N97	534.2	121.2	67745	300.0	8.0	NaN	NaN	1740.0	9600	NaN
11	E 80/38/20 N95	388.0	184.0	71800	330.0	8.0	NaN	NaN	1680.0	4500	4.33

The table below shows the calculated saturation current and air gap of each core.

	core	Im_sat	l_g
0	E64/10/50-3C95	NaN	NaN
1	ELP 43/10/28 with I 43/4/28 N87	4.645828	0.032397
2	ELP 64/10/50 with I 64/5/50 N87	9.395645	0.109357
3	ELP 64/10/50 with ELP 64/10/50 N95	10.139467	0.116770
4	ELP 64/10/50 with ELP 64/10/50 N87	9.505750	0.105646
5	E64/10/50 + PLT64/50/5 3C95	NaN	NaN
6	ER64/13/51-3C92 3C95	NaN	NaN
7	E100/60/28 N87	12.662099	0.070187
8	ELP 102/20/38 with ELP 102/20/38 N87	9.625031	0.078811
9	ELP 102/20/38 with ELP 102/20/38 N97	9.625031	0.081700
10	ELP 102/20/38 with I 102/7/38 N97	9.803034	0.094596
11	E 80/38/20 N95	7.832151	0.009775

And the peak current is:

$$\mathrm{Im}_{peak2} = 7.933 \ \ (\mathrm{A})$$

Below are the cores where the peak current is lower than the saturation current.

	core	Im_sat	l_g	I_sat_Margin %
2	ELP 64/10/50 with I 64/5/50 N87	9.395645	0.109357	15.565680
4	ELP 64/10/50 with ELP 64/10/50 N87	9.505750	0.105646	16.543684
9	ELP 102/20/38 with ELP 102/20/38 N97	9.625031	0.081700	17.577938
8	ELP 102/20/38 with ELP 102/20/38 N87	9.625031	0.078811	17.577938
10	ELP 102/20/38 with I 102/7/38 N97	9.803034	0.094596	19.074557
3	ELP 64/10/50 with ELP 64/10/50 N95	10.139467	0.116770	21.759704
7	E100/60/28 N87	12.662099	0.070187	37.347287

`E100/60/28 N87` is not a planar core for pcb transformer.
so the choice will be between : `ELP 64/10/50 with ELP 64/10/50 N95` and `ELP 102/20/38 with I 102/7/38 N97`

Choice of the transformer core ELP 64 vs ELP 102

Below the 2D of cores ELP 64 and ELP 102

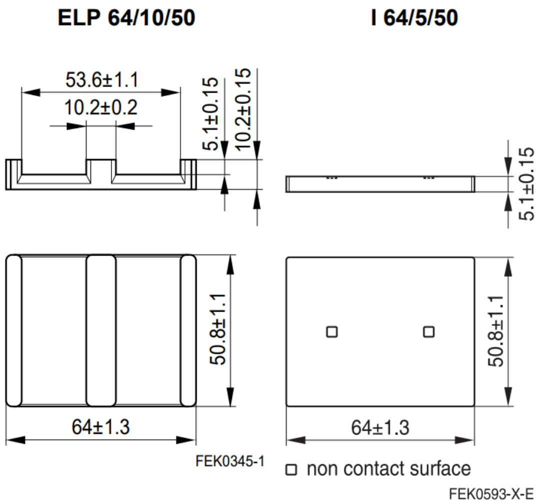


Figure 3: ELP 64/10/50 TDK core

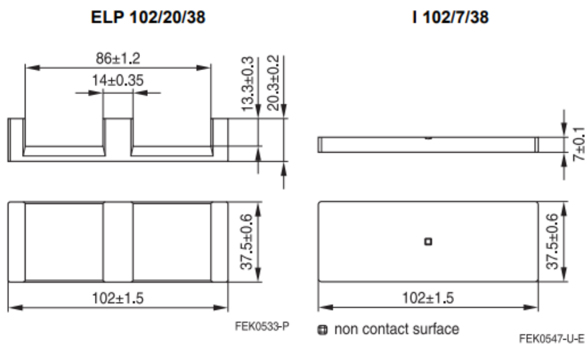


Figure 4: ELP 102/20/38 TDK core

Below some dimensions of ELP 102 and ELP 64 and a figure show the PCB trace and the margin of a PCB layer

	core	E	F	Margin
0	ELP 102	86.0	14.0	4
1	ELP 64	53.6	10.2	4

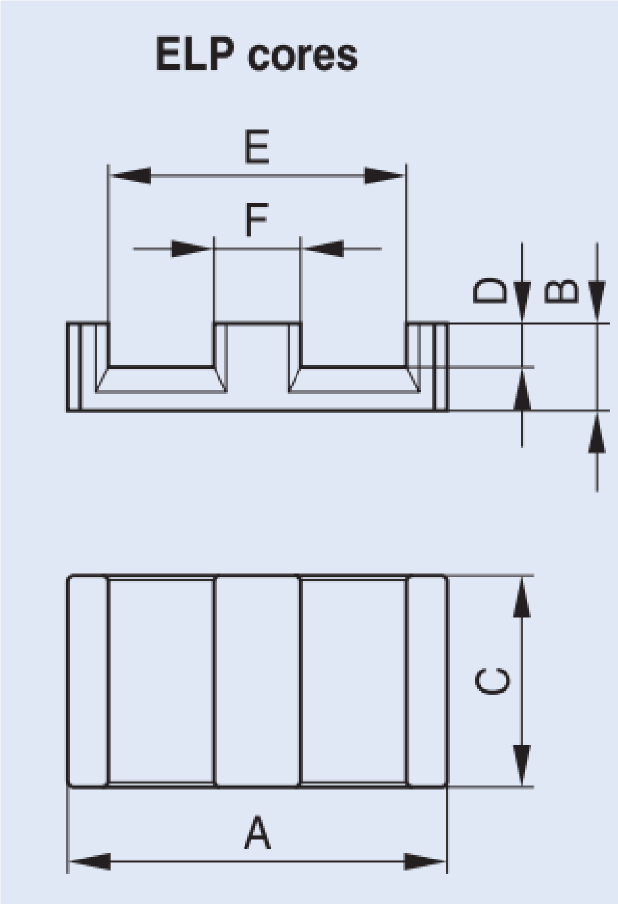


Figure 5: ELP set, TDK, some mechanical dimensions

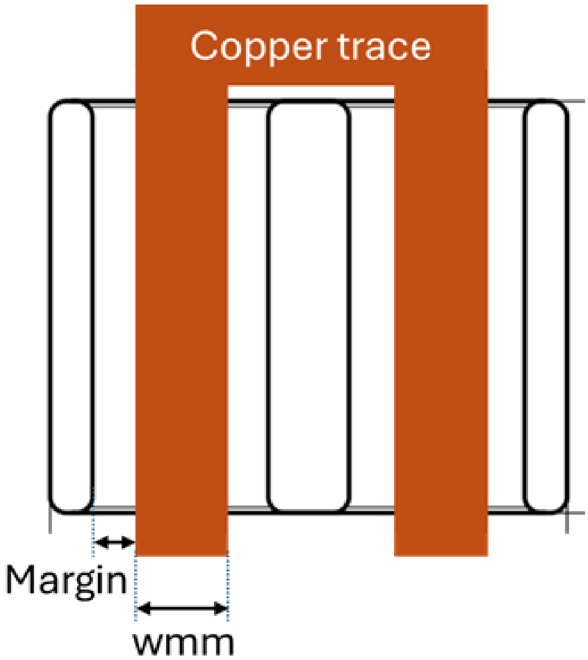


Figure 6: ELP PCB trace (one PCB layer)

See page 2 [4].

We will use the below formula to calculate the maximum alowed current for pcb trace

$$I = k\Delta T^{0.44} A^{0.725}$$

Where I = current in amperes, A = cross section in sq. mils, and ΔT = temperature rise in °C and k is a constant such that:

k = 0.048 for outer layers
k = 0.024 for inner layers

Figure 7: ELP set, TDK, some mechanical dimensions

See page 50 [5].

In general, PCB copper is specified in ounces (oz). This can be converted to thickness using a simple formulas as below:

$$M_{density} = 2 \quad (\text{oz/ft2, PCB layer surface mass density})$$

$$M_{density2} = M_{density} \cdot 28.3495 = 2 \cdot 28.3495 \qquad = 56.699 \quad (\text{g/ft2 (1 oz} = 28.3$$

$$M_{density3} = \frac{M_{density2}}{(30.48)^2} = \frac{56.699}{(30.48)^2} \qquad = 0.061 \quad (\text{g/cm2 (1ft} = 30,4$$

$$\text{Thickness}_{cm} = \frac{M_{density3}}{8.96} = \frac{0.061}{8.96} \qquad = 0.007 \quad (\text{cm, copper density 8,96 g}$$

$$\text{Thickness}_{um} = \text{Thickness}_{cm} \cdot 1 \times 10^4 = 0.007 \cdot 1 \times 10^4 \qquad = 68.114$$

The following table summarizes all results for ELP 102 compared to ELP 64, for both outer and inner layers (Copper layer of 2 oz/ft^2), and delta Temp = 30°C

	core	E	F	Margin	kind	wmm	Current
0	ELP 102	86.0	14.0	4	outer	28.0	71.787917
1	ELP 102	86.0	14.0	4	inner	28.0	35.893959
2	ELP 64	53.6	10.2	4	outer	13.7	42.754732
3	ELP 64	53.6	10.2	4	inner	13.7	21.377366

The ELP 102 allows higher current due to its larger width, so we will choose this core. To minimize core losses, we will adopt N97 or N95 material.

Below is an example of an ELP/I 102 pair; the transformer cost will be around 24€.

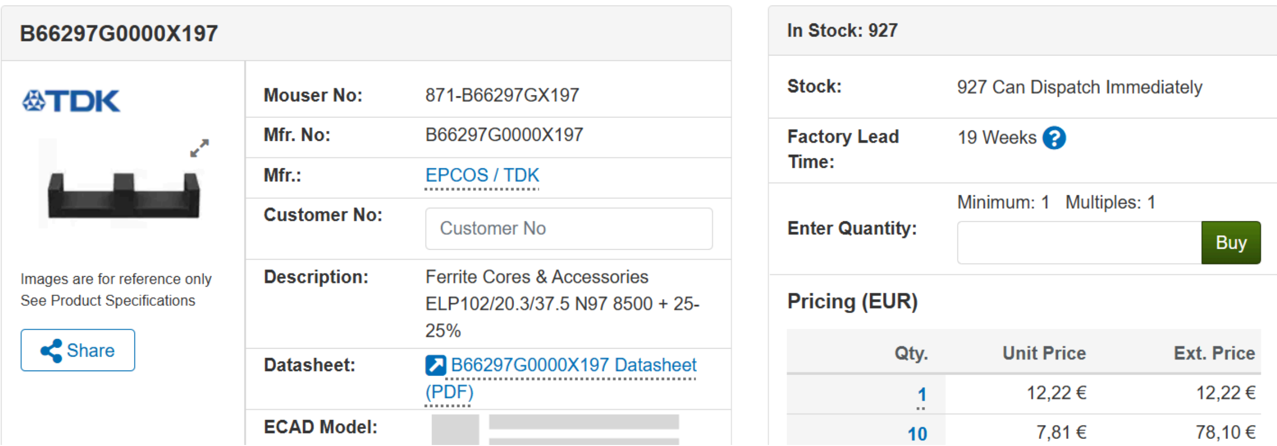


Figure 8: Mouser, TDK, I 102/7/38 N97, B66297G0000X197

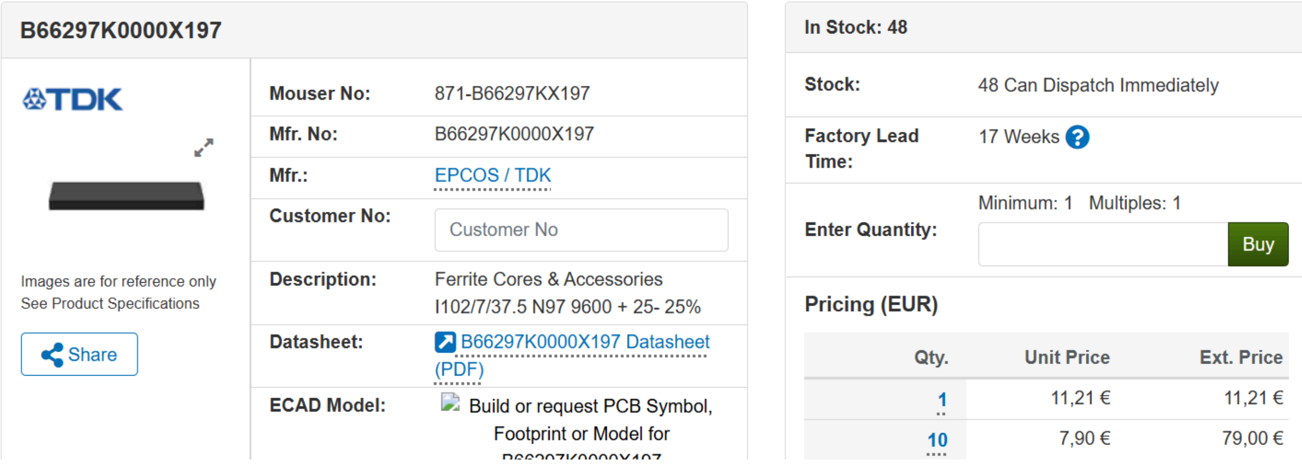


Figure 9: Mouser, TDK, I 102/7/38 N97, B66297K0000X197

Below the datasheet of each studied core#dfcores = pd.read_csv("FerriteCores.csv",sep=";") dfcores = pd.read_csv("03_data/FerriteCores.csv",sep=";") names = dfcores["core"].values i = 0 for x in dfcores['link to the datasheet '].dropna().drop_duplicates().values: print(names[i]) i=i+1 print(x)

Lr design

The input data

$$\mathrm{Lr}_{uH} = 21.797 \quad (\mu\mathrm{H})$$

$$\mathrm{Ir}_{rms} = 10.354 \quad (\mathrm{Arms})$$

Relationship Between Inductance Ratio and Number of Turns

	Nb	Al_nH
0	1.0	21797.000000
1	2.0	5449.250000
2	3.0	2421.888889
3	4.0	1362.312500
4	5.0	871.880000
5	6.0	605.472222
6	7.0	444.836735
7	8.0	340.578125
8	9.0	269.098765

4 turns, one turns by layer

alculation Using the ELP 58/11/38 Core

Datasgeet information

$$\mathrm{core} = \mathrm{ELP58/11/38}\ \mathit{with}\ I58/4/38N87$$

$$\mathrm{Aemin} = 308 \ \ (\mathrm{mm2{:}\ datasheet})$$

$$\mathrm{Al}_{nH0} = 8400 \ \ (\mathrm{nH{:}\ datasheet})$$

$$\mathrm{Le} = 67.700 \ \ (\mathrm{mm{:}\ datasheet})$$

$$\mathrm{K1} = 591 \ \ (\mathrm{datasheet})$$

$$\mathrm{K2} = -0.685 \ \ (\mathrm{datasheet})$$

$$B_{sat} = 300 \ \ (\mathrm{mT{:}\ datasheet})$$

$$\mu_e = 1540$$

$$n = 4 \ \ (\mathrm{turns{:}\ 4\ layers\ pcb})$$

B_{peak} and the margin

$$\begin{aligned} B_{peak} &= 1\times 10^{-3}\cdot \mathrm{Lr}_{uH}\cdot\sqrt{2}\cdot\frac{\mathrm{Ir}_{rms}}{n\cdot\mathrm{Aemin}\cdot 1\times 10^{-6}} \\ &= 1\times 10^{-3}\cdot 21.797\cdot\sqrt{2}\cdot\frac{10.354}{4\cdot 308\cdot 1\times 10^{-6}} \\ &= 259.065 \ \ (\mathrm{mT}) \end{aligned}$$

$$\begin{aligned} B_{margin} &= 100\cdot\frac{B_{sat}-B_{peak}}{B_{sat}} \\ &= 100\cdot\frac{300-259.065}{300} \\ &= 13.645 \ \ (\backslash\%) \end{aligned}$$

The Air Gap Calculated Using the TDK Factors K_1, K_2, and the Simple Formula

TDK empirical formula using K1, K2

$$\mathrm{Al}_{nH} = 1\times 10^{3}\cdot\frac{\mathrm{Lr}_{uH}}{(n)^2} = 1\times 10^{3}\cdot\frac{21.797}{(4)^2} \qquad = 1362.312 \ \ (\mathrm{nH/turn\ squared})$$

$$s_{mm} = \left(\frac{\mathrm{Al}_{nH}}{\mathrm{K1}}\right)^{\left(\frac{1}{\mathrm{K2}}\right)} = \left(\frac{1362.312}{591}\right)^{\left(\frac{1}{-0.685}\right)} \qquad = 0.295 \ \ (\mathrm{mm\ airgap})$$

Simple formula

$$\mathrm{lg}_{mm} = \mathrm{Le}\cdot\frac{\frac{\mathrm{Al}_{nH0}}{\mathrm{Al}_{nH}}-1}{\mu_e} = 67.700\cdot\frac{\frac{8400}{1362.312}-1}{1540} \qquad = 0.227 \ \ (\mathrm{mm})$$

We use the TDK empirical formula

Gap error effect

One case calculation

$$s_{nom} = 0.295 \quad \text{(mm)}$$

$$\text{error} = 10 \quad (\backslash\%)$$

$$s_{min} = s_{nom} \cdot \left(1 - \frac{\text{error}}{100}\right) = 0.295 \cdot \left(1 - \frac{10}{100}\right) = 0.266$$

$$s_{max} = s_{nom} \cdot \left(1 + \frac{\text{error}}{100}\right) = 0.295 \cdot \left(1 + \frac{10}{100}\right) = 0.325$$

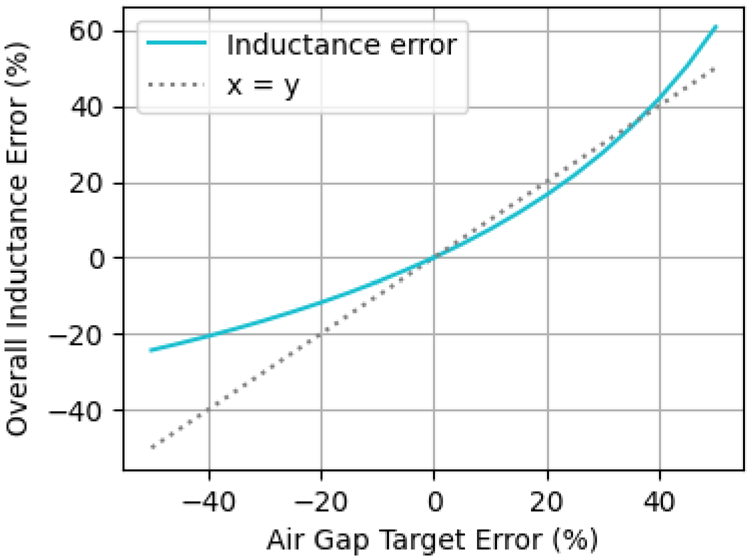
$$\text{Al}_{max} = (s_{min})^{\text{K2}} \cdot \text{K1} = (0.266)^{-0.685} \cdot 591 = 1464.268$$

$$\text{Al}_{min} = (s_{max})^{\text{K2}} \cdot \text{K1} = (0.325)^{-0.685} \cdot 591 = 1276.212$$

$$\text{Al}_{errorP} = 100 \cdot \frac{\text{Al}_{max} - \text{Al}_{nH}}{\text{Al}_{nH}} = 100 \cdot \frac{1464.268 - 1362.312}{1362.312} = 7.484 \quad (\backslash\% \text{ of error of nH})$$

$$\text{Al}_{errorN} = 100 \cdot \frac{\text{Al}_{min} - \text{Al}_{nH}}{\text{Al}_{nH}} = 100 \cdot \frac{1276.212 - 1362.312}{1362.312} = -6.320 \quad (\backslash\% \text{ of error of nH})$$

Curve of air gap error impact for range [-50%, 50%]



The cores listed below are verified, but only the ‘ELP 58/11/38’ yields a B_peak below 300 mT.

	core	Ae_min(mm2)	B_peak(mT)
0	ELP 22/6/16 with ELP 22/6/16	78.3	1019.056152
1	ELP 32/6/20 with ELP 32/6/20	128	623.375732
2	ELP 38/8/25 with ELP 38/8/25	192	415.583832
3	ELP 43/10/28 with ELP 43/10/28	217	367.705536
4	ELP 58/11/38 with ELP 58/11/38	308	259.065247

More than 4 turns

Below the B_peak of rach core, with number of turns : (same formulas as above)

core	ELP 22/6/16 with ELP 22/6/16	ELP 32/6/20 with ELP 32/6/20	ELP 38/8/25 with ELP 38/8/25	ELP 43/10/28 with ELP 43/10/28	ELP 58/11/38 with ELP 58/11/38
Ae_min(mm2)	78.3	128	192	217	308
B_peak n=1	4076.224609	2493.50293	1662.335327	1470.822144	1036.260986
B_peak n=2	2038.112305	1246.751465	831.167664	735.411072	518.130493
B_peak n=3	1358.741455	831.167664	554.111755	490.274017	345.420349
B_peak n=4	1019.056152	623.375732	415.583832	367.705536	259.065247
B_peak n=5	815.244873	498.700623	332.467072	294.164429	207.252197
B_peak n=6	679.370728	415.583832	277.055878	245.137009	172.710175
B_peak n=7	582.317749	356.214722	237.476486	210.117432	148.037292
B_peak n=8	509.528076	311.687866	207.791916	183.852768	129.532623

The cases with B_peak < B_sat

core	ELP 38/8/25 with ELP 38/8/25	ELP 43/10/28 with ELP 43/10/28	ELP 58/11/38 with ELP 58/11/38
n			
4	NaN	NaN	259.065247
5	NaN	294.164429	207.252197
6	277.055878	245.137009	172.710175
7	237.476486	210.117432	148.037292
8	207.791916	183.852768	129.532623

Remind the relationship Between Inductance Ratio and Number of Turns

	0	1	2	3	4	5	6	7	8
Nb	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Al_nH	21797.0	5449.0	2422.0	1362.0	872.0	605.0	445.0	341.0	269.0

Case of turns number = 7

$$N = 7$$

$$\mathrm{Al}_{nH} = 340$$

$$\mathrm{Al}_{nom} = 355 \;\; (\mathrm{ELP43/10/28, Gapped, see\ below})$$

ELP 43/10/28

Core (with clamp recess) **B66291**

Core set EELP 43

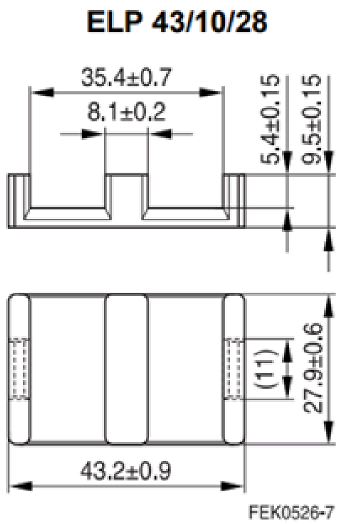
Combination: ELP 43/10/28 with ELP 43/10/28

- To IEC 63093-9
- Delivery mode: single units

Magnetic characteristics (per set)

$\Sigma l/A$ = 0.274 mm^{-1}
l_e = 61.6 mm
A_e = 225 mm^2
A_{min} = 217 mm^2
V_e = 13748 mm^3

Approx. weight 70 g/set



Gapped (A_L values/air gaps examples)

Material	g mm	A_L value approx. nH	μ_e	Ordering code
N87	0.1 ±0.02 1.0 ±0.05	2225 355	470 75	B66291G0100X187 B66291G1000X187

Figure 10: TDK, ELP43/10/28 datasheet screenshot

Below a core set thant meet aour calculation in mouser:

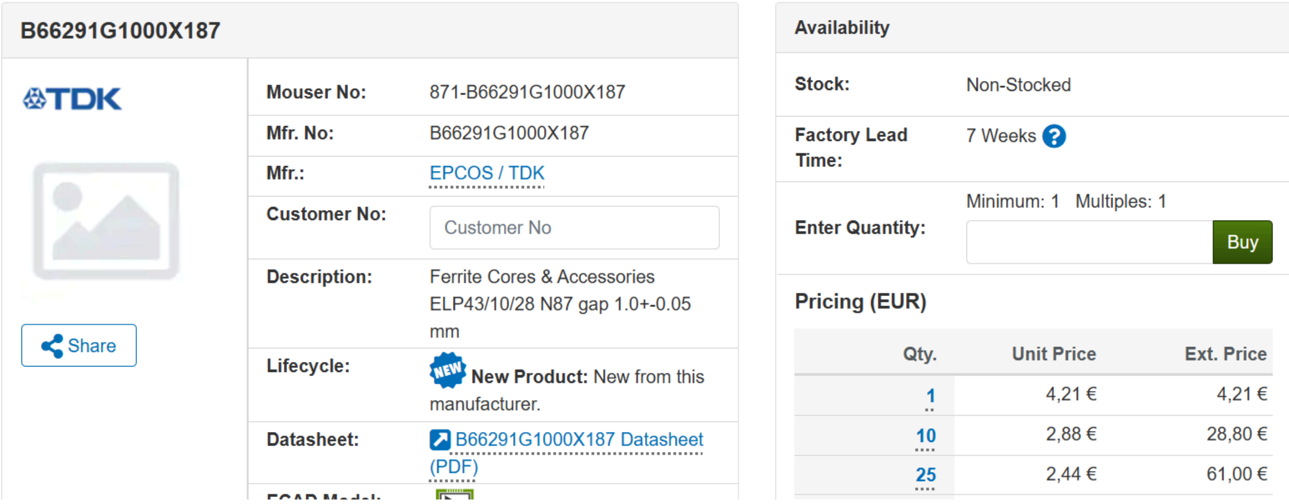


Figure 11: Mouser, TDK, ELP43/10/28 N87 gap 1.0+-0.05 mm, B66291G1000X187

Max current of each layer

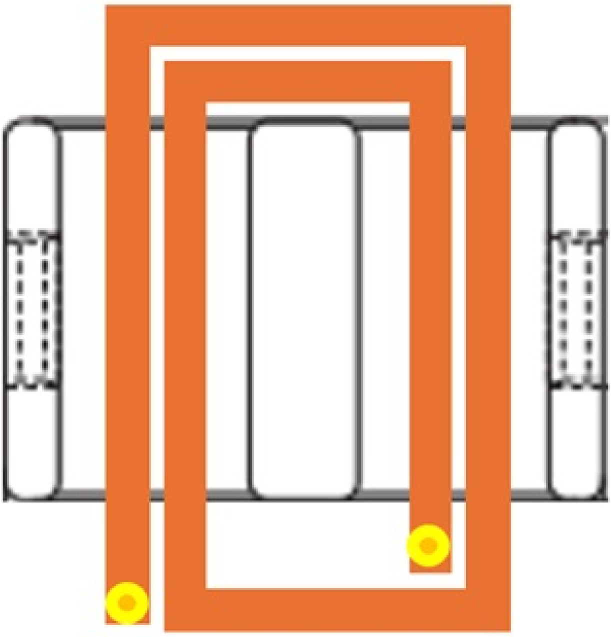


Figure 12: PCB copper trace proposition: 2 turns by layer

We will use the same formula as in the section `Choice of the transformer core ELP 64 vs ELP 102`. Using this, we can determine the current for the inner and outer layers.

From the datasheet:

	core	E	F	Margin
0	ELP 43	35.4	8.1	3

The following table summarizes all results for ELP 43, for both outer and inner layers (Copper layer of 2 oz/ft^2), and delta Temp = 30°C

	core	E	F	Margin	kind	wmm	Current
0	ELP 43	35.4	8.1	3	outer	7.65	28.023109
1	ELP 43	35.4	8.1	3	inner	7.65	14.011555

Reminde the RMS max current of the `Lr`

$$\mathrm{Ir}_{rms} = 10.354 \ \ (\mathrm{Arms} < \mathrm{Imax\ inner\ layer})$$

Bill of Materials (BOM) of this transformer and Lr (Cores)

	Mouser No	Mfr. No	Number	componenent	remark
0	871-B66291G1000X187	B66291G1000X187	2	LLC resonant inductor	ELP43/10/28 N87 gap 1.0+-0.05 mm
1	871-B66297GX197	B66297G0000X197	1	LLC Transformer	ELP102/20.3/37.5 N97 8500 + 25-25%
2	871-B66297KX197	B66297K0000X197	1	LLC Transformer	I102/7/37.5 N97 9600 + 25- 25%

References

[1] TDK, Ferrites and accessories, E cores General information

[2] TDK, Ferrites and accessories, Processing notes

[3] TDK, EPCOS Data Book 2013

[4] TDK, Planar Cores for Power Applications

[5] IPC-2221A, Generic Standard on Printed Board Design

Datasheets of the transformer core candidates

https://www.ferroxcube.com/upload/media/product/file/Pr_ds/E64_10_50.pdf
https://www.tdk-electronics.tdk.com/inf/80/db/fer/elp_43_10_28.pdf
https://product.tdk.com/system/files/dam/doc/product/ferrite/ferrite/ferrite-core/data_sheet/80/db/fer/elp_64_10_50.pdf
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Datasheets of the resonant inductor core candidates

https://www.tdk-electronics.tdk.com/inf/80/db/fer/elp_22_6_16.pdf
https://www.tdk-electronics.tdk.com/inf/80/db/fer/elp_32_6_20.pdf

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