Starting from the specifications in *Table 2*, a step-by-step design procedure and some design hints to obtain a symmetrical layout are given below.

Table 2. Push-pull converter specifications

Specification	Symbol	Value
Nominal input voltage	V_{in}	24 V
Maximum input voltage	V_{inmax}	28 V
Minimum input voltage	V_{inmin}	20 V
Nominal output power	P_{out}	1000 W
Nominal output voltage	V_{out}	350 V
Target efficiency	η	> 90%
Switching frequency	f	100 kHz

A switching frequency of f = 100 kHz was chosen to minimize passive components size and weight, then the following step-by-step calculation was done:

- Switching period:

Equation 2

$$T = \frac{1}{f} = \frac{1}{10^5} = 10\ \mu s$$

- Maximum duty cycle

The theoretical maximum on time for each phase of the push-pull converter is:

Equation 3

$$t^*_{on} = 0.5T = 5\ \mu s$$

Since deadtime has to be provided in order to avoid simultaneous device conduction, it is better to choose the maximum duty cycle of each phase as:

Equation 4

$$D_{max} = 0.9\frac{t^*_{on}}{T} = 0.45$$

This means a total deadtime of 1µs at maximum duty cycle, occurring for minimum input voltage operation.

- Input power

Assuming 90% efficiency the input power is:

Equation 5

$$P_{in} = \frac{P_{out}}{0.9} = 1111W$$

- Maximum average input current:

Equation 6

$$I_{in} = \frac{P_{in}}{V_{inmin}} = \frac{1111}{20} = 55.55\,A$$

- Maximum equivalent flat topped input current:

Equation 7

$$I_{pft} = \frac{I_{in}}{2D_{max}} = \frac{55.55}{0.9} = 61.72\,A$$

- Maximum input RMS current:

Equation 8

$$I_{in_{RMS}} = I_{pft}\sqrt{2D_{max}} = 58.55A$$

- Maximum MOSFET RMS current:

Equation 9

$$I_{MosRMS} = I_{pft}\sqrt{D_{max}} = 41.4A$$

- Minimum MOSFET breakdown voltage:

Equation 10

$$V_{Brk_{Mos}} = 1.3 \bullet 2 \bullet V_{inMax} = 72.8\,V$$

- Transformer turns ratio:

Equation 11

$$N = \frac{N_2}{N_1} = \frac{V_{out}}{2V_{in_{min}}D_{max}} = 19$$

- Minimum duty cycle value:

Equation 12

$$D_{min} = \frac{V_{out}}{2NV_{inmax}} = 0.32$$

- Duty cycle at nominal input voltage:

Equation 13

$$D_{min} = \frac{V_{out}}{2NV_{in}} = 0.38$$

- Maximum average output current:

Equation 14

$$I_{out} = \frac{P_{out}}{V_{out}} = 2.86\,A$$

- Secondary maximum RMS current

Assuming that the secondary top flat current value is equal to the average output value the rms secondary current is:

Equation 15

$$I_{sec_{RMS}} = I_{out}\sqrt{D_{max}} = 1.91\,A$$

- Rectifier diode voltage:

Equation 16

$$V_{diode} = NV_{inMax} = 532\,V$$

- Output filter inductor value:

Equation 17

$$L_{min} \geq \left(\frac{N_2}{N_1}V_{in} - V_{out}\right)\frac{t_{on_{Max}}}{\Delta I}$$

Assuming a ripple current value $\Delta I = 15\%\ I_{out} = 0.43A$, the minimum value for the output filter inductance is:

Equation 18

$$L_{min} = 1.109\ mH$$

With this value of inductance continuous current mode (CCM) operation is guaranteed for a minimum output current of:

Equation 19

$$I_{out_{Min}} = \frac{\Delta I}{2} = 0.215\,A$$

which means a minimum load of 75 W is required for CCM operation. The chosen value for this design is L=1.5 mH.

- Output filter capacitor value:

Equation 20

$$C = \frac{1}{8}\frac{\Delta I_L}{\Delta V_0}T_s$$

Considering a maximum output ripple value equal to:

Equation 21

$$\Delta V_0 = 0.1\%V_{out} = 0.35\,V$$

the minimum value of capacitance is:

Equation 22

$$C_{min} = 1.53\ \mu F$$

and the equivalent series resistance (ESR) has to be lower than:

Equation 23

$$ESR_{max} = \frac{\Delta V_0}{\Delta I_L} = 0.81\,\Omega$$

- Input capacitor:

Equation 24

$$C_{in} = I_{Crms} \frac{\Delta T_{onMax}}{\Delta V_{in}}$$

where I_{crms} is the RMS capacitor current value given by:

Equation 25

$$I_{C_{rms}} = \sqrt{I^2_{In_{Rms}} - I^2_{in}} = 19A$$

and

Equation 26

$$\Delta V_{in} = 0.1\% V_{in_{Max}} = 0.028V$$

then

Equation 27

$$C_{in} = I_{Crms} \frac{\Delta T_{onMax}}{\Delta V_{in}} = 3053\ \mu F$$