

Midcom



COOKBOOK

FOR DO-IT-YOURSELF TRANSFORMER DESIGN

Content





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Introduction

The Speedy Design Kits are made for engineers to wind first transformer samples to test and optimize their Switch Mode Power Supply (SMPS). The material in the Design Kits is standard material. Thus there will be no material shortage in mass production. The material is suitable for the power ranges:

- **5-15 W (Low Power Kit)**
Order Code: 750 102
- **15-30 W (Medium Power Kit)**
Order Code: 750 101
- **5-30 W (All inclusive Design Rack)**
Only available on request

This "Cookbook" in hand shows you examples how to design and wind a transformer. For engineers which want to concentrate on there circuit and not design their own transformer we also offer our SPEEDY DESIGN SERVICE. For the SPEEDY DESIGN SERVICE please see page 20.

SPEEDY DESIGN SERVICE is the world's fastest sample service for customized transformers. The service offers the unique possibility to get samples designed to your requirements and delivered when you need them – guaranteed! Order our SPEEDY DESIGN SERVICE when requesting samples and samples will be shipped within the selected time.

PLEASE NOTE:




Although great care has been taken to provide accurate and current information, neither the authors nor the publisher, nor anyone else associated with this publication, shall be liable for any loss, damage, or liability directly or indirectly caused or alleged to be caused by this book.

All appropriate material is only valid for low power applications. For applications with $60 V_{DC}$ / $48 V_{AC}$ or more, please refer to relating safety regulations.





Content of the Speedy Design Kits

	Speedy Design Kit Low Power 5-15 W	Speedy Design Kit Medium Power 15-30 W	Speedy Design Rack (only available on request)
			
Bobbins	ER11, ER14.5, EFD15, EE13	EFD20, EE16, EE20, EE25	ER11, ER14.5, EFD15, EFD20, EE13, EE16, EE20, EE25
Wires (ø)	0.1 mm (AWG38) 0.15 mm (AWG34) 0.2 mm (AWG32) 0.28 mm (AWG29) 0.3 mm (AWG28)	0.1 mm (AWG38) 0.3 mm (AWG28) 0.35 mm (AWG27) 0.4 mm (AWG26) 0.5 mm (AWG24)	0.1 mm (AWG38) 0.15 mm (AWG34) 0.2 mm (AWG32) 0.28 mm (AWG29) 0.3 mm (AWG28) 0.35 mm (AWG27) 0.4 mm (AWG26) 0.5 mm (AWG24)
Wrapper tape	Suitable for all bobbins in Kit	Suitable for all bobbins in Kit	Suitable for all bobbins in Rack
Cores	ER11, ER14.5 (different airgaps) EFD15 (different airgaps) EE13 (no gap)	EFD20 (different airgaps) EE16, EE20, EE25 (no gap)	ER11, ER14.5 (different airgaps) EFD15, EFD20 (different airgaps) EE16, EE20, EE25 (no gap)
Gapping Material	Mylar 0.05 mm, 0.1 mm, 0.15 mm, 0.19 mm	Mylar 0.05 mm, 0.1 mm, 0.15 mm, 0.19 mm	Mylar 0.05 mm, 0.1 mm, 0.15 mm, 0.19 mm
Extras	-	-	Design Guide „Abc of transformers“ and Software for Flyback Design „WE-FLEX-DESIGNER“
Order Code	750 102	750 101	on request

Tab. 1: Contents of the Speedy Design Kits

Transformer Design

The following example gives you an idea how to design a transformer for a flyback converter.

Fig. 1 is an overview on how to proceed. As you see from this flow chart transformer design is a highly iterative process.

Further transformer designs for forward converters and push pull converters are integrated in Würth Elektronik's Application and Design Guide "Abc of Transformers".



Order Code: English version 749 002
German version 749 001
French version 744 044

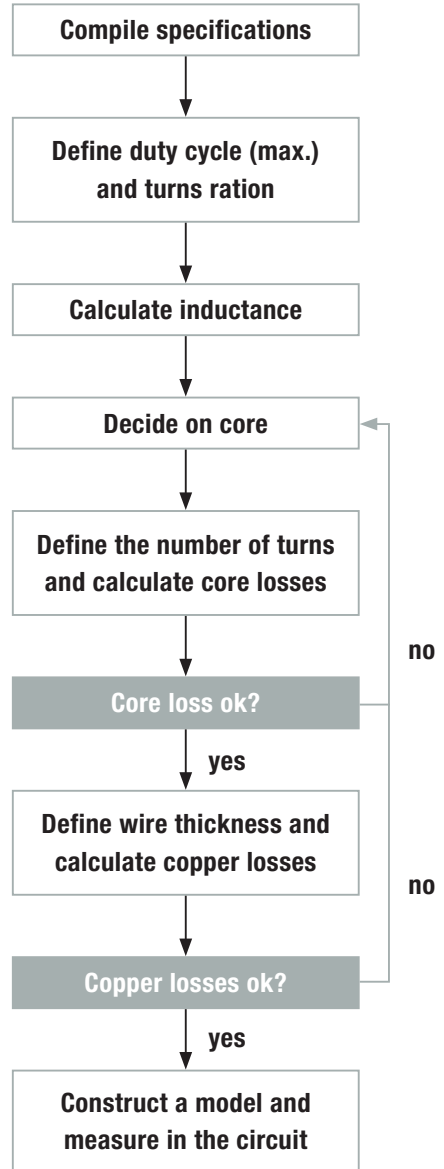


Fig. 1: Flow chart for the approach in designing a flyback transformer

Step-by-step to flyback converter design

Fig. 2 shows the basic schematics of a flyback converter. The switch S1 is a controlled switch, e.g. a MOSFET. To understand the basic function of the flyback converter the switching processes are described as follows:

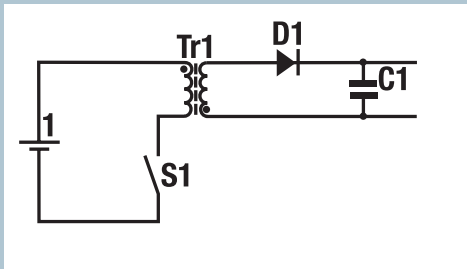


Fig. 2: Circuit diagram of a flyback converter

1. Switch closed:

The closed switch applies the input voltage on the transformer's primary. As a result of the inductance a current rises linearly on the primary side. The polarity of the transformer is that the diode blocks the current on the secondary side. The energy fed is stored in the gap.

2. Switch open:

With the switch open the current is interrupted on primary side. The inductance of the transformer tries to maintain the flow of energy, so that the polarity of the secondary side changes. The diode becomes conducting and a linear declining current flows on the secondary side.

Fig. 3 shows the current and voltage profile on the primary and secondary sides of the transformer.

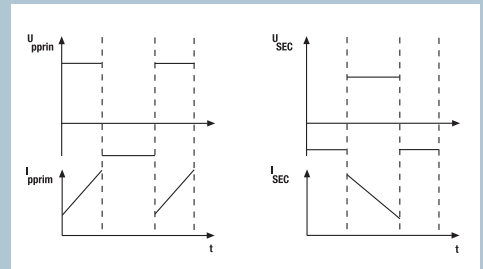


Fig. 3: Current and voltage profiles at the transformer of a flyback converter

Two flyback converter operating modes are distinguished depending on the current profile.

1. Continuous mode:

In continuous mode (trapezoid operation or continuous conduction mode CCM) energy is still stored at the end of the switching cycle. The linear decline in current does not return to zero.

2. Discontinuous mode:

In discontinuous mode (triangular operation or discontinuous conduction mode DCM) the current on secondary side will be zero at the end of the cycle. There are current gaps in which no current flows, neither on the primary nor on the secondary side.

Prior to design the following parameters must be known:

- Input voltage range
- Output voltage
- Output power or output current
- Switching frequency
- Operating mode
- Maximum duty cycle of the IC
- Safety requirements
- Ambient temperature

Especially the safety requirements such as dielectric withstand voltage, creepage and clearance distances should be considered in the design phase, as a transformer requires a larger package if these requirements are considered. Special care should be taken for Off-line applications.

An idea about the clearance and creepage distances and the dielectric withstand voltages are given in **Tab. 2 and 3**. The values therein are based on IEC60950.

Attention:

Supplied Copper Wire is not able to withstand high voltage applications. Please take care about common practice for safety in transformers.

Operating voltage RMS-voltage or DC	Creepage distance Pollution degree 2 [mm]					
	Basic insulation			Reinforced insulation		
	CTI>600	400<CTI<600	CTI<400	CTI>600	400<CTI<600	CTI<400
50	0.6	0.9	1.2	1.2	1.8	2.4
100	0.7	1.0	1.4	1.4	2.0	2.8
125	0.8	1.1	1.5	1.6	2.2	3.0
150	0.8	1.1	1.6	1.6	2.2	3.2
200	1.0	1.4	2.0	2.0	2.8	4.0
250	1.3	1.8	2.5	2.6	3.6	5.0
300	1.6	2.2	3.2	3.2	4.4	6.4
400	2.0	2.8	4.0	4.0	5.6	8.0
600	3.2	4.5	6.3	6.4	9.0	12.6
800	4.0	5.6	8.0	8.0	11.2	16.0
1000	5.0	7.1	10.0	10.0	14.2	20.0

Tab. 2: Creepage distances for different operating voltages according to EN60950 for Pollution degree 2*

* Pollution degree 2 (P2): Only non-conductible pollution can occur. Temporary conductivity can occur due to bedewing. Remark: Transformers with almost closed housing belong typically to pollution degree P2. It has not to be air tight.



Operating voltage peak value or DC	Dielectric withstand voltage [V]	
	Basic insulation	Reinforced insulation
50	1000	2000
100	1000	2000
125	1000	2000
150	1000	2000
200	1500	3000
250	1500	3000
300	1500	3000
400	1569	3000
600	1893	3000
800	2164	3000
1000	2399	3000

Tab. 3: Dielectric withstand voltages according to EN60950

We now want to show the step-by-step design process for a flyback converter.

The following example should help to understand the design steps:

Input voltage range U_i:	36-57 V
Output voltage U_o:	5V
Output current I_o:	1.5 A
Maximum duty cycle T_{max}:	50%
Switching frequency f:	300 kHz
Safety requirements:	Functional operation*

* Insulation which is needed for the faultless operation of the device.

1st step: Definition of the turns ratio and the duty cycle

Turns ratio and duty cycle determine each other i.e. if one of the parameters is defined, so is the other.

The maximum duty cycle and the highest currents do occur at the minimum input voltage. This is the worst case. In fast transient response the duty cycle can be higher for a short time.

DESIGN TIP 1:
Keep a little safety margin to the maximum allowed duty cycle of the IC.

We choose instead of 50% a lower DC of 40% (0.4). The relationship between maximum duty cycle and turns ratio is given by the following formula .

$$\frac{N_1}{N_2} = \frac{v_{Tmax}}{1-v_{Tmax}} \cdot \frac{U_{i,min}}{U_o^*} \Leftrightarrow$$

$$v_{Tmax} = \frac{\frac{N_1}{N_2}}{\frac{N_1}{N_2} + \frac{U_{i,min}}{U_o^*}}$$

v_{Tmax} maximum duty cycle: $v_{Tmax} = T_{on} / (T_{on} + T_{off})$

U_i = input voltage

$T_{on, off}$ = switch-on time, switch-off time of the MOSFET

N_1, N_2 = number of primary and secondary turns

U_o^* = output voltage taking the diode voltage into account ($U_o + U_D$)

For our example we get a turns ratio of:

$$\frac{N_1}{N_2} = \frac{0.4}{1-0.4} \cdot \frac{36 \text{ V}}{5 \text{ V} + 0.7 \text{ V}} = 4.2$$

For ease of design we choose a turns ratio of 4:1. Now we calculate the maximum duty cycle with this turns ratio:

$$v_{Tmax} = \frac{4}{4 + \frac{36 \text{ V}}{5 \text{ V} + 0.7 \text{ V}}} = 0.39$$

Care should be taken on the breakdown voltage of the MOSFET. The voltage between drain and source of this MOSFET during the off time is:

$$U_{DS} = U_i + \frac{N_1}{N_2} \cdot U_o^* + U_{L\sigma}$$

$U_{L\sigma}$ = input voltage

DESIGN TIP 2:
Use a MOSFET with a sufficient safety margin in breakdown voltage as the voltage spike from the discharge of the leakage inductance can destroy the MOSFET.



2nd step: Definition of inductance

As with storage chokes, first the currents have to be calculated. The RMS current, the average current and the peak current can be distinguished by examining the current curves.

The effective or RMS current is that with which the copper losses are calculated. It is the current averaged over the period. For the secondary side we get:

$$I_{\text{RMS, sek}} = \frac{1}{\sqrt{1-v_T}} = \frac{1.5 \text{ A}}{\sqrt{1-0.39}} = 1.92 \text{ A}$$

$I_{\text{RMS, sek}}$ = effective current on secondary winding

For the effective current on the primary winding we calculate:

$$I_{\text{RMS, prim}} = \frac{P_o}{U_i \cdot \eta \cdot \sqrt{v_T}} = \frac{7.5 \text{ W}}{36 \text{ V} \cdot 0.8 \cdot \sqrt{0.39}} = 0.42 \text{ A}$$

η = efficiency (generally around 80%)

The average current is the arithmetic mean of the current during on-state (primary) resp. off-state (secondary). This is:

$$I_{\text{avg, sek}} = \frac{I_o}{1-v_T} = \frac{1.5}{1-0.39} = 2.45 \text{ A}$$

$$I_{\text{avg, prim}} = \frac{P_o}{U_i \cdot \eta \cdot v_T} = \frac{7.5 \text{ W}}{36 \text{ V} \cdot 0.8 \cdot 0.39} = 0.67 \text{ A}$$

Various criteria can now be applied to determine the inductance.

DESIGN TIP 3:

Usually inductance is defined by the ripple current on secondary side which is a certain percentage of the average current. For continuous mode designs choose a ripple of 20% to 50% of the average current.

We calculate the following secondary inductance with a ripple of 25%:

$$L_{\text{sek}} = \frac{U_o^* \cdot (1-v_T)}{0.25 \cdot I_{\text{avg, sek}} \cdot f} = \frac{5.7 \text{ V} \cdot 0.39}{0.25 \cdot 2.45 \text{ A} \cdot 300 \text{ kHz}} = 12.1 \mu\text{H}$$

Together with turns ratio we get the following inductance on primary side:

$$L_{\text{prim}} = L_{\text{sek}} \cdot \left(\frac{N_1}{N_2}\right)^2 = 12.1 \mu\text{H} \cdot 16 = 193.6 \mu\text{H}$$

3

3rd step: Selection of the core

For frequencies between 100 and 500 kHz, the best choice for core material are so called power ferrites, MnZn ferrite with a permeability of 2000-2500 e.g. 1P2400. The saturation flux density B_s of 1P24000 is 360 mT at 100°C.

Fig. 4 shows the specific losses for given frequencies and flux densities. The package type depends on the power to be transformed. A starting point is provided in **Tab. 4**.

In our example we choose EFD15 as core size.

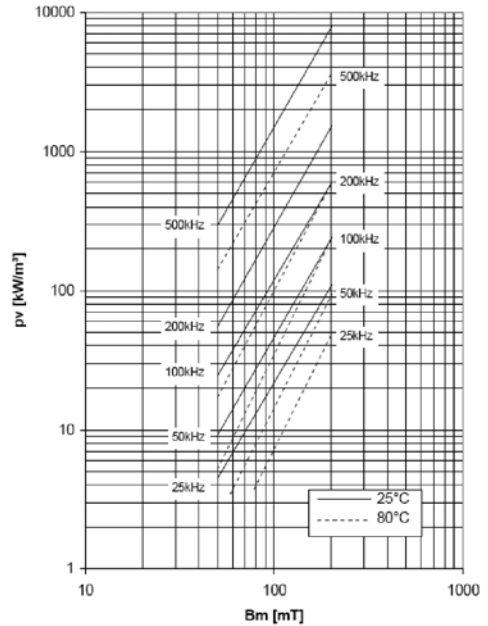


Fig. 4: Specific losses of Ferrite 1P2400 against the change in flux density

Core geometry	Transformable power (W)		
	Flyback converter	Forward converter	Push-Pull Converter
ER 11/5	8.5	10	14
ER14.5/6	20	23	32
EFD15	26	30	42
EFD20	50	57	80
EE12.6	17	20	28
EE16	41	48	67
EE20	73	85	118
EE25	135	155	218

Tab. 4: Core geometries and typical transformable power at 100kHz

4th step: Calculating primary turns

The minimum number of turns is defined by the saturation flux density for a given core. The ferrite material 1P2400 has a saturation flux density of 360 mT. Thus the minimum number of turns is:

We can also take **Fig. 5** to determine the number of turns. To have a little safety margin and a number which is divisible by 4 we chose to wind 32 turns on primary side.

$$N_{\text{prim}} > \frac{L_{\text{prim}} \cdot I_{\text{prim}}}{B_{\text{sat}} \cdot A_e} = \frac{193.6 \mu\text{H} \cdot 0.75 \text{ A}}{0.36 \text{ T} \cdot 15 \text{ mm}^2} = 27$$

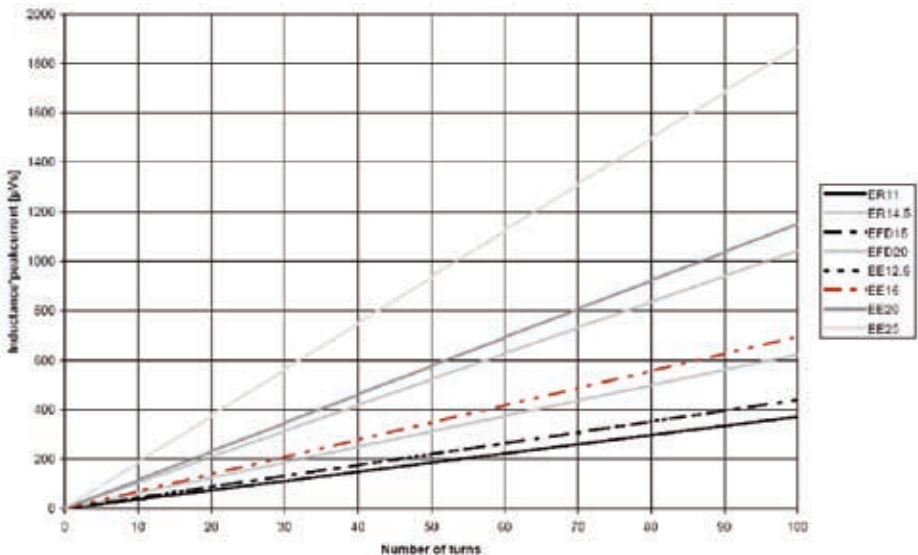


Fig. 5: Maximum magnetic flux against the number of turns for different package styles. Note: For flyback converters magnetic flux is calculated by inductance*peak current.

A second criterium for the number of turns is core loss due to change of the flux density.

Out of **Fig. 4** we can determine the specific loss and together with effective volume of **Tab. 5** we can calculate the core losses. Please use only half of ΔB to get the specific core loss.

$$\Delta B = \frac{L_{\text{prim}} \cdot I_{\text{ripple, prim}}}{n_{\text{primt}} \cdot A_e} = \frac{193.6 \mu\text{H} \cdot 0.17 \text{ A}}{32 \cdot 15 \text{ mm}^2} = 68 \text{ mT}$$

For our example we get a core loss of 30 mW.

Core geometry	A_e (mm ²)	L_e (mm)	V_e (mm ³)	R_{th} (K/W)	winding window height (mm)
ER 11/5	11.9	14.7	174	134	1.6
ER14.5/6	17.6	19	333	99	2.75
EFD15	15	34	510	75	1.8
EFD20	31	47	1460	45	1.8
EE 12.6	12.4	29.7	369	94	2.1
EE 16	20.1	37.6	750	76	2.5
EE 20	32	46	1490	46	3.15
EE 25	52.5	57.5	3020	40	3.95

Tab. 5: Core geometries and parameters

5

5th step: Defining the wire cross section

Select the wire cross section that the total power loss and the resulting temperature rise remain within reasonable bounds.

DESIGN TIP 4:
For small parts the temperature rise should be less than 40 K.

DESIGN TIP 5:
A good starting point is to select a current density of 4 A/mm².

The copper losses are calculated by Ohm's law. As we have only thin wires in the kits it is reasonable to disregard eddy current losses in the first step.

Check if the selected wire fits into the winding window of the bobbin. By using **Fig. 6** you can determine the number of layers you need. Note that this figure is only valid if you don't need creepage and clearance distances.

By multiplying the number of layers with the outer wire diameter (**Tab. 6**) we get the winding height. Calculate the total winding height by adding the winding heights of all windings. Check if the total winding height is less than the height of the winding window (**Tab. 5**)

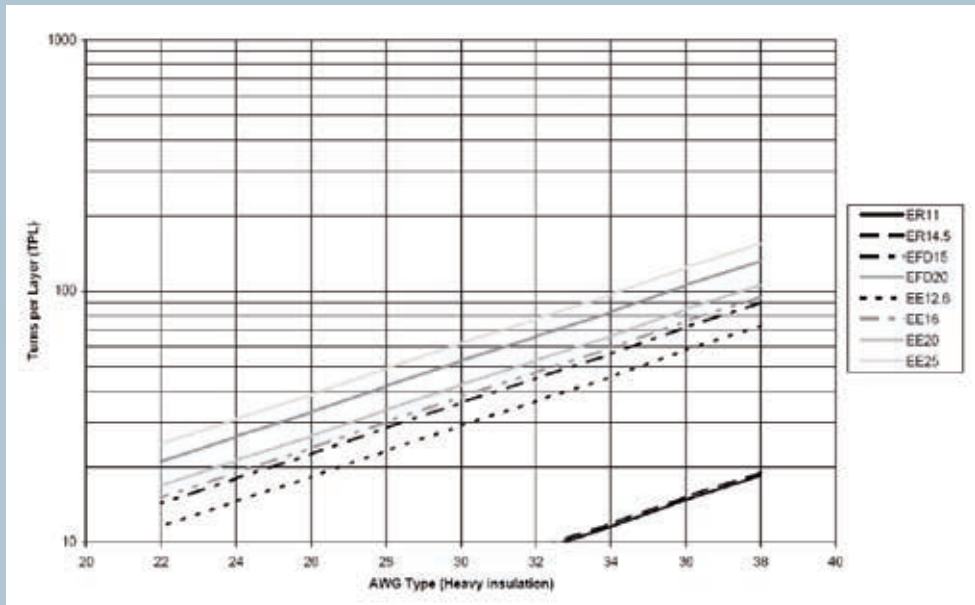


Fig. 6: Number of turns per layer for different packages and wires

Wire diameter (mm)	AWG	Outer diameter (mm)	DCR/Turn (mΩ/Turn)							
			ER11	ER14.5	EFD15	EFD20	EE12.6	EE16	EE20	EE25
0.1	38	0.125	57.18	71.47	69.62	90.26	63.53	92.65	103.23	139.76
0.15	34	0.177	24.00	30.00	29.22	37.89	26.66	38.89	43.33	58.66
0.2	32	0.239	13.10	16.38	15.96	20.69	14.56	21.23	23.66	32.03
0.28	29	0.329	6.55	8.19	7.98	10.34	7.28	10.62	11.83	16.01
0.3	28	0.337	5.68	7.10	6.91	8.96	6.31	9.20	10.25	13.88
0.35	27	0.387	4.13	5.16	5.03	6.52	4.59	6.69	7.46	10.10
0.4	26	0.459	3.14	3.92	3.82	4.95	3.49	5.09	5.67	7.67
0.5	24	0.566	1.97	2.47	2.40	3.12	2.19	3.20	3.57	4.83

Tab. 6: Winding wires and parameters

In our example we have a RMS current of 0.42 A on primary and 1.92 A on secondary side. At 4 A/mm² we need cross sections of 0.1 mm² resp. 0.48 mm². The diameters have to be 0.35 mm resp. 0.78 mm. We choose a wire diameter of 0.3 mm on primary side and 2 strands of 0.5 mm wire on secondary side. This results in a resistance of 221 mΩ for primary winding and about 10 mΩ for the secondary side (see Tab 6). According to Ohm's law we get winding losses of 39 mW resp. 37 mW.

This sums up to a total loss of 106 mW and a temperature rise (RTH in Table 5) of 8 K.

Now we have fixed the design and can start with the winding of the transformer:

- 1) Core and bobbin: EFD15
- 2) Primary 32 ts ø 0.3 mm wire
- 3) Insulation tape between primary and secondary
- 4) Secondary: 2*8 ts ø 0.5 mm wire.



Transformer Construction

Now that the steps in figure 3-5 are completed you can begin the construction of the transformer. Review the following questions 1-9 to see if anything was missed in the steps leading up to the construction process.

Q1: Is the transformer required to meet safety agency standards that are intended to reduce risks of fire, electric shock or injury to personnel?

What Material Group/CTI rating is required for the materials?

What are the creepage/clearance distances?

Q2: Is the transformer required to meet an insulation system?

Q3: What environment will the transformer operate in?

Q4: What power supply and transformer topology will be used?

Q5: How much space is allowed for the transformer on the printed circuit board?

Q6: What is the lowest and highest frequency of operation?

Q7: What is the wattage rating of the transformer?

Q8: What are the input and output voltages and currents of the transformer and how many windings are needed?

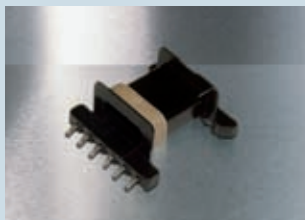
Q9: Are the materials suitable for a lead-free solder reflow process?

Here are some basic guidelines to follow when building the transformer. By following these guidelines you will minimize the manufacturing costs while optimizing the electrical performance. Note that these guidelines are not intended to show all possible methods of construction. The accompanying photographs show a surface mount EFD25 through the stages of construction.

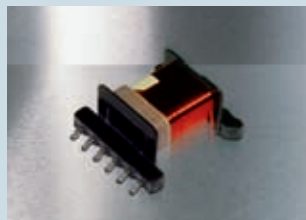
Step-by-step-construction



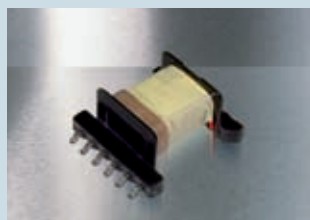
Step 1 – Bare Bobbin



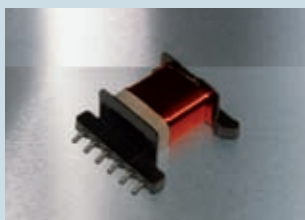
Step 2 – Shelf Tape



Step 3 – Wind 1



Step 4 Wrapper – Tape 1



Step 5 – Wind 2



Step 6 – Wrapper Tape 2



Step 7 – Wind 3



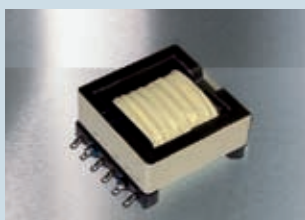
Step 8 – Finish Tape



Step 9 – Solder



Step 10 – Core



Step 11 – Core Tape



Glossary

Margin (shelf) Tape – Determine if a safety isolation barrier is required and where that barrier will be located. In the example, margin (shelf) tape is applied to one side of the bobbin (coil former). The number and placement of margin tapes will affect magnetic coupling and leakage inductance. An alternative to margin tape is double or triple insulated wire. This wire may be cost prohibitive on high turn windings.

Wire Strands/Wire Gauge – Choose the type of wire, number of strands, and wire gauge based on the frequency of operation and current carrying ability. Be aware that heavy gauge or multi-stranded wire may solder bridge together on adjacent terminals.

Turns Per Layer (TPL) – Pick a turns per layer of wire that fills the winding area of the bobbin. On low turns per layer windings it may be necessary to space the turns of wire evenly across the bobbin. This also applies to high turn, multilayered windings where the last layer does not entirely fill the bobbin. Minimize the number of layers of wire to reduce leakage inductance and eddy current losses.

Pinout – A number of factors will affect the bobbin pinout, including safety agency requirements and circuit board layout. Typically the primary windings are terminated on one side of the bobbin and the secondary windings are terminated on the other. Ideally the pinout for a particular winding will be dictated by the number of layers of wire, whether odd or even, although other factors will also affect it. If the winding ends on the side of the bobbin that is opposite from the intended finish terminal, bring the wire across the coil at a 90 degree angle. Place the wire in an area where it will be the least disruptive to subsequent windings and the ferrite core set.

Tape can be used to hold the wire down at the bend. It may be necessary to place a piece of tape under this wire to insulate it from its own winding to prevent cut-through and subsequent shorted turns. Pulling this wire across the coil at an angle other than 90 degrees will cause the subsequent windings to not lay uniformly and evenly.

Interlayer Insulation – Interlayer tape may be required if there is a high voltage potential between each layer of wire within the same winding.

Wrapper Tape/Finish (final) Tape – Select a wrapper tape that is slightly wider than the distance between the bobbin flanges. This extra width allows the tape to lap up the sides of the flanges without folding over. This ensures isolation between the windings, minimizing the risk of wire-to-wire contact and potential dielectric breakdown. The higher temperatures associated with a lead-free solder reflow process may cause the standard polyester tapes to shrink. Also smaller transformer packages will absorb more heat, causing more tape shrinkage. This tape shrinkage will have a direct affect on dielectric breakdown strength and the integrity of the safety isolation barrier. High temperature polyamide tapes are available but their comparative tracking index (CTI) is lower with a resulting change in the material group. This results in a greater creepage/clearance distance requirement.

Core Set/Core Tape/Insulation Tape – Choose the appropriate core set and AL inductance factor. Secure the core set to the coil with 2 layers of tape. Do not stretch the tape during the application process. It may be necessary to apply insulation tape to one or both sides of the core set to insulate the core from the terminals. Additionally the core set may be bonded to the coil (bobbin) with an adhesive or varnish coating.

Speedy Design Service for customized Power & Telecom Transformers

World's fastest sample service for customized Transformers

The world's fastest sample service for customized transformers offers the unique possibility to get samples designed to your requirements and delivered when you need them - guaranteed! Order our Speedy Design Service when requesting samples and samples will be shipped within the selected time or you will get the samples free of charge!



SPEEDY DESIGN SERVICE

Service Options for 10 customized Transformers

Selected Service Time	Price in €	Price in US\$
Ship next day*	300	400
Ship in 3 days*	200	300
Ship in 7 days*	100	150
Ship in 8 days or longer	FREE	FREE

* Shipped with FedEx Priority



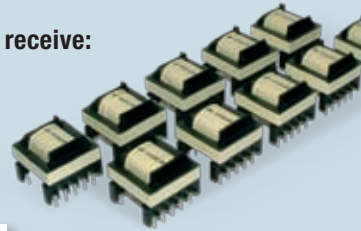
This is how it works:

- Complete Speedy Design Form on www.we-online.com/speedy
- Fax or email to Würth Electronics Midcom:

**+1 (0) 605-886-4486 or
email: speedy@we-online.com or
www.we-online.com/speedy**

or contact your local Würth Elektronik salesmen

This is what you receive:



- 1** 10 customized pieces
- 2** Specification Sheet, Test Data & Deviation Report

- 3** Shipped within selected service time

This is your added value:

- 10 customized samples shipped next day
- Designed to your specification
- Design-In support
- Worldwide availability
- Rapid prototyping
- Cost-effective through standard package styles

What application are supported?

- Any application that fits package style
- Switch Mode Power:
 - Flyback
 - Forward
 - Push-Pull
 - Coupled Inductors
- Telecom Applications:
 - xDSL
 - POTS Splitter Inductors

Product Overview



EMC Ferrites

EMC Ferrites for cable assembly
SMD Ferrites



Inductors

Filter & RF Chokes
Power Inductors
Common Mode Chokes



Transformers

LAN Transformers
Telecom Transformers
Power Transformers



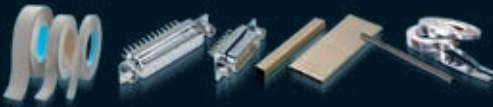
RF Components

RF Inductors
LTCC Components



Varistors

Disk Varistors
SMD Varistors
ESD Suppressors



D-SUB Filter Connectors & EMC Shielding Material

D-SUB Filter Connectors
EMC Shielding Materials



Assembly

Spacer
Cable Assembly
Shrink Tube



Connectors

Wire-to-Board
Board-to-Board
Wire-to-Wire



more than you expect

Würth Elektronik differs in several aspects from all other component manufacturers:
We deliver all catalogue products ex stock and our technical sales force can support your designs with market experience.

Samples free of charge – worldwide

Within 24 to 48 hours

Directly from the manufacturer!

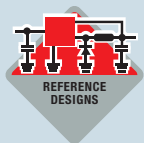
Below MOQ service



We deliver all products ex stock – right away



Worldwide Technical Sales Force



Reference Designs of the IC-manufacturers

Würth Elektronik is the only European manufacturer of power inductors who has reference designs with National Semiconductor, Linear Technology, Texas Instruments, Fairchild Semiconductor, ON Semiconductor, STMicroelectronics, MPS, Maxim, Semtech, Diodes and Sipex.



Customer Specific Solutions



Design Kits

With lifelong free refill



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