COOKBOOK
FOR DO-IT-YOURSELF TRANSFORMER DESIGN
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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.

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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 alloyed to be caused by this book. All appropriate material is only valid for low power applications. For applications with $60 \text{ V}_{\text{dc}} / 48 \text{ V}_{\text{ac}}$ or more, please refer to relating safety regulations.
## Content of the Speedy Design Kits

<table>
<thead>
<tr>
<th></th>
<th>Speedy Design Kit Low Power 5-15 W</th>
<th>Speedy Design Kit Medium Power 15-30 W</th>
<th>Speedy Design Rack (only available on request)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bobbins</td>
<td>ER11, ER14.5, EFD15, EE13</td>
<td>EFD20, EE16, EE20, EE25</td>
<td>ER11, ER14.5, EFD15, EFD20, EE13, EE16, EE20, EE25</td>
</tr>
<tr>
<td>Wires (⌀)</td>
<td>0.1 mm (AWG38)</td>
<td>0.1 mm (AWG38)</td>
<td>0.1 mm (AWG38)</td>
</tr>
<tr>
<td></td>
<td>0.15 mm (AWG34)</td>
<td>0.15 mm (AWG34)</td>
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</tr>
<tr>
<td></td>
<td>0.2 mm (AWG32)</td>
<td>0.2 mm (AWG32)</td>
<td>0.2 mm (AWG32)</td>
</tr>
<tr>
<td></td>
<td>0.28 mm (AWG29)</td>
<td>0.28 mm (AWG29)</td>
<td>0.28 mm (AWG29)</td>
</tr>
<tr>
<td></td>
<td>0.3 mm (AWG28)</td>
<td>0.3 mm (AWG28)</td>
<td>0.3 mm (AWG28)</td>
</tr>
<tr>
<td>Wrapper tape</td>
<td>Suitable for all bobbins in Kit</td>
<td>Suitable for all bobbins in Kit</td>
<td>Suitable for all bobbins in Rack</td>
</tr>
<tr>
<td>Cores</td>
<td>ER11, ER14.5 (different airgaps) EFD15 (different airgaps) EE13 (no gap)</td>
<td>EFD20 (different airgaps) EE16, EE20, EE25 (no gap)</td>
<td>ER11, ER14.5 (different airgaps) EFD15, EFD20 (different airgaps) EE16, EE20, EE25 (no gap)</td>
</tr>
<tr>
<td>Gapping Material</td>
<td>Mylar 0.05 mm, 0.1 mm, 0.15 mm, 0.19 mm</td>
<td>Mylar 0.05 mm, 0.1 mm, 0.15 mm, 0.19 mm</td>
<td>Mylar 0.05 mm, 0.1 mm, 0.15 mm, 0.19 mm</td>
</tr>
<tr>
<td>Order Code</td>
<td>750 102</td>
<td>750 101</td>
<td>on request</td>
</tr>
</tbody>
</table>

Tab. 1: Contents of the Speedy Design Kits
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:

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.

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.

<table>
<thead>
<tr>
<th>Operating voltage RMS-voltage or DC</th>
<th>Creepage distance Polution degree 2 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic insulation</td>
</tr>
<tr>
<td></td>
<td>CTI&gt;600</td>
</tr>
<tr>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>100</td>
<td>0.7</td>
</tr>
<tr>
<td>125</td>
<td>0.8</td>
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<tr>
<td>150</td>
<td>0.8</td>
</tr>
<tr>
<td>200</td>
<td>1.0</td>
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<tr>
<td>250</td>
<td>1.3</td>
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<td>300</td>
<td>1.6</td>
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<td>400</td>
<td>2.0</td>
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<td>600</td>
<td>3.2</td>
</tr>
<tr>
<td>800</td>
<td>4.0</td>
</tr>
<tr>
<td>1000</td>
<td>5.0</td>
</tr>
</tbody>
</table>

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

* Pollution degree 2 (P2): Only non-conductive 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.
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** $T_{\text{max}}$: 50%  
**Switching frequency** $f$: 300 kHz  
**Safety requirements:** Functional operation*

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

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**Operating voltage peak value or DC**

<table>
<thead>
<tr>
<th>Operating voltage peak value or DC</th>
<th>Dielectric withstand voltage [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic insulation</td>
</tr>
<tr>
<td>50</td>
<td>1000</td>
</tr>
<tr>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>125</td>
<td>1000</td>
</tr>
<tr>
<td>150</td>
<td>1000</td>
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<tr>
<td>200</td>
<td>1500</td>
</tr>
<tr>
<td>250</td>
<td>1500</td>
</tr>
<tr>
<td>300</td>
<td>1500</td>
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<tr>
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<td>1569</td>
</tr>
<tr>
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<td>1893</td>
</tr>
<tr>
<td>800</td>
<td>2164</td>
</tr>
<tr>
<td>1000</td>
<td>2399</td>
</tr>
</tbody>
</table>

**Tab. 3: Dielectric withstand voltages according to EN60950**
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:

\[
\frac{N_1}{N_2} = \frac{V_{T_{\text{max}}}}{1 - V_{T_{\text{max}}}} \cdot \frac{U_{i,\text{min}}}{U_{o}^{*}}
\]

\[
V_{T_{\text{max}}} = \frac{N_1}{N_2} \cdot \frac{U_{i,\text{min}}}{U_{o}^{*}}
\]

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:

\[
V_{T_{\text{max}}} = \frac{4}{4 + \frac{36 \text{ V}}{5 \text{ V} + 0.7 \text{ V}}} = 0.39
\]

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:

\[
U_{DS} = U_i + \frac{N_1}{N_2} \cdot U_o^{*} + U_{L_o}
\]

\[U_{L_o} = \text{input voltage}\]

**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.
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:

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

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

For the effective current on the primary winding we calculate:

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

\[\eta = \text{efficiency (generally around 80\%)}\]

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\%:

\[
L_{\text{sek}} = \frac{U_o \cdot (1-v_T)}{0.25 \cdot I_{\text{avg, sek}} \cdot f} = \frac{5.7 \text{ V} \cdot 0.39}{0.25 \cdot 2.45 \text{ A} \cdot 300 \text{ kHz}} = 12.1 \text{ µH}
\]

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

\[
L_{\text{prim}} = L_{\text{sek}} \cdot \left(\frac{N_1}{N_2}\right)^2 = 12.1 \text{ µH} \cdot 16 = 193.6 \text{ µH}
\]

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

\[
I_{\text{avg, sek}} = \frac{I_0}{1-v_T} = \frac{1.5}{1-0.39} = 2.45 \text{ A}
\]

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

---

<table>
<thead>
<tr>
<th>Core geometry</th>
<th>Transformable power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flyback converter</td>
</tr>
<tr>
<td>ER 11/5</td>
<td>8.5</td>
</tr>
<tr>
<td>ER14.5/6</td>
<td>20</td>
</tr>
<tr>
<td>EFD15</td>
<td>26</td>
</tr>
<tr>
<td>EFD20</td>
<td>50</td>
</tr>
<tr>
<td>EE12.6</td>
<td>17</td>
</tr>
<tr>
<td>EE16</td>
<td>41</td>
</tr>
<tr>
<td>EE20</td>
<td>73</td>
</tr>
<tr>
<td>EE25</td>
<td>135</td>
</tr>
</tbody>
</table>

**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:

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

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.

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 $\Delta B$ to get the specific core loss.

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

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

<table>
<thead>
<tr>
<th>Core geometry</th>
<th>$A_e$ (mm$^2$)</th>
<th>$L_e$ (mm)</th>
<th>$V_e$ (mm$^3$)</th>
<th>$R_{th}$ (K/W)</th>
<th>winding window height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER 11/5</td>
<td>11.9</td>
<td>14.7</td>
<td>174</td>
<td>134</td>
<td>1.6</td>
</tr>
<tr>
<td>ER14.5/6</td>
<td>17.6</td>
<td>19</td>
<td>333</td>
<td>99</td>
<td>2.75</td>
</tr>
<tr>
<td>EFD15</td>
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<td>510</td>
<td>75</td>
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<td>94</td>
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<td>3020</td>
<td>40</td>
<td>3.95</td>
</tr>
</tbody>
</table>

Tab. 5: Core geometries and parameters
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
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.

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.

<table>
<thead>
<tr>
<th>Wire diameter (mm)</th>
<th>AWG</th>
<th>Outer diameter (mm)</th>
<th>DCR/Turn (mΩ/Turn)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>ER11</td>
</tr>
<tr>
<td>0.1</td>
<td>38</td>
<td>0.125</td>
<td>57.18</td>
</tr>
<tr>
<td>0.15</td>
<td>34</td>
<td>0.177</td>
<td>24.00</td>
</tr>
<tr>
<td>0.2</td>
<td>32</td>
<td>0.239</td>
<td>13.10</td>
</tr>
<tr>
<td>0.28</td>
<td>29</td>
<td>0.329</td>
<td>6.55</td>
</tr>
<tr>
<td>0.3</td>
<td>28</td>
<td>0.337</td>
<td>5.68</td>
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<td>0.35</td>
<td>27</td>
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<tr>
<td>0.4</td>
<td>26</td>
<td>0.459</td>
<td>3.14</td>
</tr>
<tr>
<td>0.5</td>
<td>24</td>
<td>0.566</td>
<td>1.97</td>
</tr>
</tbody>
</table>

Tab. 6: Winding wires and parameters
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

1. Bare Bobbin
2. Shelf Tape
3. Wind 1
4. Wrapper – Tape 1
5. Wind 2
6. Wrapper Tape 2
7. Wind 3
8. Finish Tape
9. Solder
10. Core
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.
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<table>
<thead>
<tr>
<th>Selected Service Time</th>
<th>Price in €</th>
<th>Price in US$</th>
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<tbody>
<tr>
<td>Ship next day*</td>
<td>300</td>
<td>400</td>
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<tr>
<td>Ship in 3 days*</td>
<td>200</td>
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<tr>
<td>Ship in 7 days*</td>
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<td>150</td>
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<tr>
<td>Ship in 8 days or longer</td>
<td>FREE</td>
<td>FREE</td>
</tr>
</tbody>
</table>

* Shipped with FedEx Priority
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Specification Sheet, Test Data & Deviation Report

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10 customized pieces
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**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**
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- Cable Assembly
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- Board-to-Board
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