LLC Resonance Power Transformers
Pin terminal type

SRX series

Type:       SRX45EM(Drop-in)
            SRX38EM(Drop-in)
            SRX43EM(Drop-in/Through hole)
            SRX30ER(Through hole)
            SRX35ER(Through hole)
            SRX38ER(Through hole)
            SRX48EM(Through hole)
            SRX40ER(Through hole)

Issue date: September 2010

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# LLC Resonance Power Transformers
## SRX Series

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<td>4</td>
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<td>5</td>
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<td>6</td>
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<td>10</td>
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<td>11</td>
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*All specifications are subject to change without notice.*
LLC Resonance Power Transformer
SRX Series

Development Concept

Compliant with worldwide safety standards, this is a small and thin transformer with the advantages of effective use of low-loss ferrite material.

**MATERIAL**
Optimized materials and core shapes have been developed. The necessary power can be transmitted with a small number of windings.

While optimizing materials, TDK has further improved its proprietary core shape to develop a new-type ECO core.

The transformer has been downsized considerably, and its temperature increase has also been curbed.

**MANUFACTURING METHOD**
Since the ECO Series supports automatic winding, the product is of a high quality and can be manufactured stably.

It is designed to support automatic winding, which enables a remarkable reduction in the loss generated to achieve a proficient in manual winding until stable production.

In addition, the characteristic variations of the winding wire and creepage tape have largely been removed, stabilizing the transformer's characteristics.

**OPTIMIZATION DESIGN**
Using design tools developed with TDK’s comprehensive know-how, high-precision design has been achieved in a short period of time.

1) For optimization design and high-quality stable production, customers can use a specification request form.

   If you provide the necessary information in the form, you will receive the optimization design in a short time.

2) TDK recommends design with a standard core gap (AL-value) for optimization and shorter trial and mass production lead time.

   Design is simple as each shape retains its GAP, AL-value, and K parameters beforehand.

**ENVIRONMENT**
The SRX series is RoHS directive-compliant product.

- Ferrite cores, bobbins, cases, etc. are not sold individually.

- Conformity to RoHS Directive: This means that, in conformity with EU Directive 2002/95/EC, lead, cadmium, mercury, hexavalent chromium, and specific bromine-based flame retardants, PBB and PBDE, have not been used, except for exempted applications.

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LLC Resonance Power Transformer
SRX Series

TDK now provides a characteristically thin resonance LLC resonance power transformer. In order to develop this transformer, TDK made effective use of low loss performance (which is a feature of the PC47 family), optimized the structure of the core and the bobbin, and utilized its proprietary automatic winding industrial method.

 FEATURES
- A low height (8 to 31.5mm in height) is achieved.
- Large power is achieved in a small shape.
- The automatic winding industrial method is adopted.
- It is a product conforming to RoHS directive.

 APPLICATIONS
AV equipment, digital consumer electronic

 PRODUCT IDENTIFICATION
(1) Series name
(2) Core size
(3) Input voltage code
(4) Output voltage code
(5) Internal control code

 ELECTRICAL CHARACTERISTICS

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Mount method¹</th>
<th>Height H (mm)</th>
<th>Frequency (kHz) min.</th>
<th>Maximum output power (W) max.</th>
<th>Number of outputs</th>
<th>D (mm)</th>
<th>W (mm)</th>
<th>Lead space F (mm)</th>
<th>Number of pins (pieces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRX45EM</td>
<td>Drop-in</td>
<td>7.7 ²</td>
<td>120</td>
<td>180</td>
<td>2</td>
<td>57</td>
<td>46.5</td>
<td>69.6</td>
<td>5 7</td>
</tr>
<tr>
<td>SRX38EM</td>
<td>Drop-in</td>
<td>10 120</td>
<td>125</td>
<td>2</td>
<td>50</td>
<td>40</td>
<td>65.5</td>
<td>6</td>
<td>6 6</td>
</tr>
<tr>
<td>SRX43EM</td>
<td>Drop-in</td>
<td>10 100</td>
<td>180</td>
<td>2</td>
<td>53</td>
<td>52</td>
<td>60</td>
<td>6</td>
<td>5 7</td>
</tr>
<tr>
<td></td>
<td>Through hole</td>
<td>15 100</td>
<td>180</td>
<td>2</td>
<td>53</td>
<td>46</td>
<td>65.2</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>SRX30ER</td>
<td>Through hole</td>
<td>27 100</td>
<td>180</td>
<td>2</td>
<td>57</td>
<td>41.5</td>
<td>40</td>
<td>8</td>
<td>8 8</td>
</tr>
<tr>
<td>SRX35ER</td>
<td>Through hole</td>
<td>25 80</td>
<td>250</td>
<td>3</td>
<td>55</td>
<td>45.5</td>
<td>35</td>
<td>6</td>
<td>6 6</td>
</tr>
<tr>
<td>SRX38ER</td>
<td>Through hole</td>
<td>27 60</td>
<td>250</td>
<td>3</td>
<td>58</td>
<td>53</td>
<td>40</td>
<td>6</td>
<td>6 9</td>
</tr>
<tr>
<td>SRX48EM</td>
<td>Through hole</td>
<td>25 60</td>
<td>300</td>
<td>3</td>
<td>58</td>
<td>51</td>
<td>35</td>
<td>6</td>
<td>8 8</td>
</tr>
<tr>
<td>SRX40ER</td>
<td>Through hole</td>
<td>31.5 60</td>
<td>300</td>
<td>3</td>
<td>54</td>
<td>43</td>
<td>35</td>
<td>8</td>
<td>8 8</td>
</tr>
</tbody>
</table>

¹ When applying flow solder to a drop-in transformer, be careful to ensure that only the terminals come into contact with the solder.
² Typical dimensions (maximum dimensions may vary depending on the specifications.)

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Lineup of Resonance Switching Power Transformers

![Diagram of power transformers with specifications]

**EXTERNAL SHAPES OF THROUGH HOLE AND DROP-IN TRANSFORMERS**

**THROUGH HOLE TYPE**

When multiple transformers are used.

<table>
<thead>
<tr>
<th>Power (W)</th>
<th>Height from substrate (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>150</td>
<td>15</td>
</tr>
<tr>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>250</td>
<td>25</td>
</tr>
<tr>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>350</td>
<td>35</td>
</tr>
<tr>
<td>400</td>
<td>40</td>
</tr>
</tbody>
</table>

**DROP-IN TYPE**

When the board height (H) is decreased further, holes are made in the board (PCB) in order for the transformer to be mounted.

---

- All specifications are subject to change without notice.
SRX45EM Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

* Maximum dimensions may vary depending on the specifications.

All specifications are subject to change without notice.
SRX38EM Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

PIN DETAILS

• All specifications are subject to change without notice.
SRX43EM Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

Dimensions in mm

- All specifications are subject to change without notice.
SRX43EM Series

**SHAPES AND DIMENSIONS**

[Diagram showing shapes and dimensions]

**RECOMMENDED BASE MATERIAL OPENING SIZE**

[Diagram showing recommended base material opening size]

- All specifications are subject to change without notice.
SRX43EM Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

Dimensions in mm

All specifications are subject to change without notice.
SRX43EM Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

• All specifications are subject to change without notice.
SRX30ER Series

SHAPES AND DIMENSIONS

TYPE A

Dimensions in mm

TYPE B

Dimensions in mm

TYPE C

Dimensions in mm

• All specifications are subject to change without notice.
SRX35ER Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

Dimensions in mm
SRX38ER Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

Dimensions in mm

• All specifications are subject to change without notice.
SRX48EM Series

SHAPES AND DIMENSIONS

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>51 max.</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>58 max.</td>
<td></td>
</tr>
<tr>
<td>14-ø1.0</td>
<td>35.0</td>
<td></td>
</tr>
<tr>
<td>25 max.</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

RECOMMENDED BASE MATERIAL OPENING SIZE

Dimensions in mm

- 14-ø1.6
- 35.0
- 6
- 6
- 6
- 6
- 6
- 6
- 6
- 6
- 6
- 6
- 3
- 3

All specifications are subject to change without notice.
SRX40ER Series

SHAPES AND DIMENSIONS

RECOMMENDED BASE MATERIAL OPENING SIZE

Dimensions in mm

All specifications are subject to change without notice.
Design Reference for LLC Resonant Power Transformers

LLC RESONANT CONVERTER
The LLC resonant converter features low noise and high efficiency and is a circuit system suitable for relatively large power requirements. The LLC resonant converter is of SRC (Series Resonant Converter) type.

SFM (Frequency modulation control) is generally used for control of the converter.

The converter is driven by a half bridge and, because the usage rate of the core is high, low-loss core materials are recommended for the downsizing of the converter.

In addition, because its input voltage range is narrower than that of a PWM-system power supply, it is recommended that PFC be used at the front stage to stabilize input voltage. Even when PFC is not used, increasing the ratio of resonance inductance to excitation inductance can stabilize input voltage to some extent. Under such circumstances, however, optimized design and efficiency will be difficult to achieve.

It therefore follows that there are difficulties facing global design of this system.

Figure 1 Basic circuit (1) (with a resonance inductor separated)

Figure 2 Basic circuit (2) (with a resonance inductor one type)

Here, the following equation applies:

\[ L_p = L_r + L_m \]
\[ L_r = (1 - k) \times L_p \]
\[ L_m = k \times L_p \]

Lp: Primary inductance
Lm: Excitation inductance
Lr: Leakage inductance
k: Coupling coefficient

LEAKAGE-FLUX TRANSFORMER FOR LLC POWER SUPPLY
This is a transformer in which leakage inductance has been intentionally increased and the value of the inductance has been standardized. Here, when the secondary side has completely short-circuited, the primary-side inductance is handled as resonance inductance \( L_{LK} \).

As a structure, the primary and secondary sides are separated from each other by a wall installed in the reel, which decreases the coupling. When the resonance inductance, primary inductance, and coupling coefficient are \( L_{LK} \), \( L_p \), and \( k \), respectively, the equation shown below applies. \( L_{LK} \) operates as a resonance inductor.

\[ L_{LK} = L_p \times (1 - k^2) \]

\( L_p \) is \( A_L \)-value \( \times N_p^2 \). \( A_L \)-value is determined according to the core gap, and \( k \) is a parameter determined according to the core gap and a bobbin structure.

ABOUT TRANSFORMER DESIGN
The stationary operation condition is set so that it is near to CRM (Critical Mode). However, it may be changed to some extent in relation to the input voltage range and output voltage.

Figure 3 shows the voltage conversion rate of a leakage-flux transformer-type LLC circuit, calculated with \( k \) being 0.85 according to a theoretical formula. Initially, FR (normalized frequency) is set so that it is near 1.

Figure 3 LLC resonant circuit normalized frequency characteristics

Here, \( Q \) shows the ratio of load resistance to characteristic impedance; in many cases, it is set in the range of about 0.5 to 1.5 at stationary loading.

When \( k \) is higher, the exciting current can be decreased further. Normally, \( k \) is set at about 0.8 to 0.95. However, when the input voltage range is wide, it is set lower, and when the range is narrow, it is set higher.

The figure below is an example of a transformer designed with the following conditions: \( V_{in}=390V \), \( V_o=24V \), \( I_o=8A \), and stationary frequency=100kHz.

Shown below is a design example with the operation point near \( F_s \).

Conditions: \( A_L=410hH/n^2 \) \( k=0.906 \)
\( V_{in}=390V \), \( V_o=24V \), \( V_F=0.65V \), \( I_o=8A \), \( F_s=100kHz \), \( Q=0.80 \)
1. The ratio of turns $n$ is determined from input voltage $V_{in}$ and output voltage $V_o$.

\[
n = \frac{V_{in}}{2 \times k \times (V_o + V_F)} = \frac{390}{2 \times 0.906 \times 24.65} = 8.732
\]

2. Calculation of characteristic impedance $Z_o$

\[
R_L = \frac{V_o}{I_o} = \frac{24}{8} = 3.0
\]

\[
Z_o = \frac{n^2 \times R_L}{Q} = \frac{8.732^2 \times 3.0}{0.80} = 285.9 \Omega [Ω]
\]

3. Calculation of $C_r$ (resonance capacity) and $LL_K$ (resonance inductance)

\[
Z_o = \frac{k}{1 - k^2} \sqrt{\frac{L_K}{C_r}}
\]

\[
C_r = \frac{1}{2 \times \pi \times \frac{1 - k^2}{k} \times F_s \times Z_o} = \frac{2 \times \pi \times 0.1978 \times 100000 \times 285.9}{28.14[nF]}
\]

\[
LL_K = \left( \frac{1 - k^2}{k} \right)^2 \times Z_o^2 \times C_r = 0.1978^2 \times 285.9^2 \times 28.14 \times 10^{-9} = 90.0[µH]
\]

4. Calculation of transformer parameters

\[
L_P = \frac{L_K}{(1 - k^2)} = \frac{90.0}{(1 - 0.906^2)} = 502.3[µH]
\]

\[
N_p = \frac{L_P}{\sqrt{A_c}} = \frac{502.3}{0.410} = 35.0[Ts]
\]

\[
N_s = \frac{N_p}{n} = \frac{35.0}{8.732} = 4.0[Ts]
\]

Repeating the above calculation several times will optimize each parameter. It is better for $N_s$ with a smaller number of turns to be near an integer.

Design is complete when the flux, current, etc., calculated with this number of turns are within acceptable values. When they exceed the values, the frequency, Q, and transformer parameters ($AL$-value and $k$) need to be revised.

Figure 4 shows frequency characteristics illustrated graphically, based on the results of conditions set after the aforementioned calculation results have been further optimized.

Figure 4 Example of LLC resonant circuit frequency characteristics

**OPERATION POINT AND OPERATION WAVEFORM**

The operation point and operation waveform are briefly explained here. Figure 5 shows frequency characteristics according to the conditions in Figure 4, above. $Q=0.80$ and $Q=20$ are characteristics at stationary loading and at light loading, respectively.

In addition, $F_s$ and $F_m$ are calculated as 102.1kHz and 43.2kHz, respectively.

Figure 4 shows frequency characteristics illustrated graphically, based on the results of conditions set after the aforementioned calculation results have been further optimized.

Figure 5 Example of LLC resonant circuit frequency characteristics

When the operation point frequency is $F_m$, there are four modes available. Normally, the transformer is operated in modes other than the the off-resonance mode. Unless any special request is made, the transformer is designed so that its stationary operation condition is near to Critical Mode. In addition, when $F_m$ is larger than $F_s$, the control-limit voltage is reached, which causes the voltage not to decrease.

Figures 6a and 6b show examples of operation waveforms in each mode when a circuit simulator is used. When CRM is selected, the transformer

**Figure 6a** Operation waveforms in each mode

$F_m = F_s$: Continuous Mode (CCM) $F_m = F_s$: Critical Mode (CRM) $F_m < F_s$: Continual Mode (DCM) $F_m < F_m$: Off-resonance mode

**Figure 6b** Operation waveforms in each mode

$F_m > F_s$: Continuous Mode (CCM) $F_m = F_s$: Critical Mode (CRM) $F_m < F_m$: Continual Mode (DCM) $F_m < F_m$: Off-resonance mode

All specifications are subject to change without notice.
Figure 6b Operation waveforms in each mode

DCM

CCM

FLUX DENSITY AND CORE LOSS

Because the transformer is a bridge-system circuit, the core is excited in two quadrants. Therefore, low-loss materials that decrease core loss are suitable for transformer downsizing.

Shown below is a rough calculation formula of Bm of the LLC resonant converter. In addition, the variation width of B is twice this. Core loss needs to be evaluated with this ∆B.

\[ IP_{MAX} = \frac{V_o \times n}{4 \times k \times L_p \times F_s} \]

\[ B_m = \frac{L_p \times IP_{MAX}}{N_p \times A_e} \]

\[ \Delta B = 2 \times B_m \]

Vo: Output voltage  n: Ratio of turns
k: Coupling coefficient  Lp: Primary inductance
Np: Primary number of turns  Ae: Effective cross-sectional area
Fσ: Resonance frequency

Figure 7 shows core loss temperature characteristics in common power ferrite materials and TDK’s low-loss materials represented by PC47.

In an environment where the temperature of a core is 80°C or greater, low-loss materials have achieved a low loss of 20% compared with common materials, which contributes to the set’s temperature decrease and downsizing.

Figure 7 Example of core loss temperature characteristics

PRECAUTIONS

About Multi-output Transformers

In design, the number of turns on the secondary side may be small. Even in such cases, multi-output is possible, but it is difficult when voltage does not correspond with the ratio of turns on the secondary side.

For example, when this winding has been optimally designed with 4Ts at Vo=24V, note that the second output can have only 24/4=6V-step voltage.

Narrower Input Voltage Range Compared with the PWM System

As described earlier, the operation-enabling input voltage range is narrow in principle; therefore, it is recommended that a circuit that improves the input range of PFC, etc., be installed at the front stage of the LLC resonant converter.

About Multi-transformer Configuration

When one transformer cannot attain the necessary power because of shape restriction, etc., combining multiple same-shape transformers enables the required power to be obtained.

Contact us for more details on transformer design methods that correspond with each wire connection.

About the Influence of Leakage Flux

There are often problems with thin resonant transformers. When the transformer has a structure in which metal plates, etc., are arranged close to each other on the upper and lower sides during operation, leakage flux generated from the transformer crosses through the metal and overcurrent loss occurs as a result.

This in turn may cause the metal plate or the transformer to generate heat.
LLC Resonance Power Transformer Specification Request Form

1. Company name

2. Department, applicant’s name

3. Input specifications

4. Design condition

5. Inductance value for reference

6. Desired core size and external size

7. IC expected to be used

8. Production quantity information

9. Sample information

10. Note company regulations, such as safe distance and dielectric voltage strength, if there are any.

11. If there are any other requests (priorities in the company, size or price, etc.) or alterable items, please provide a description.

TDK Corporation Magnetics Business Group, Business Promotions Dept.
13-1, Nihonbashi 1-chome, Chuo-ku Tokyo 103-8272, Japan TEL: 81-3-5201-7229, FAX: 81-3-5201-7230

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