cadence®

# Magnetic Parts Editor User Guide

**Product Version 23.1**
**September 2023**

# Contents

# Introduction

## What is Magnetic Parts Editor?

Magnetic Parts Editor is a tool used for designing magnetic components, such as, inductors and transformers, for a switch mode power supply. Designing a transformer or a DC Inductor involves selecting appropriate core, windings, and insulation material to obtain the desired output for a given set of input conditions. To achieve all this, designers solve various equations iteratively until desired results are obtained.

Traditionally, designers depend on manual calculations to finalize the design parameters. Magnetic Parts Editor helps you design a transformer or an inductor in an efficient and easy-to-use manner. Using Magnetic Parts Editor, you can:

- design magnetic components, such as power transformers, transformers for forward and flyback converters, and DC inductors.
- generate PSpice simulation models for the designed magnetic component. These models can then be used in PSpice simulatable circuits.
- maintain a database of commercially available components such as iron cores, bobbins, wires, and insulation material.
- generate data required for manufacturing the transformers for end-user. The Manufacturer Report that is generated by Magnetic Parts Editor after the completion of design process contains the complete data required by a vendor to manufacture the magnetic components for end use.

## Magnetic Parts Editor modules

Magnetic Parts Editor can be divided into two modules:

- Magnetic Parts Editor database that contains information about commercially available cores, wires, and insulation materials; and
- Magnetic Parts Editor interface that uses user inputs and database information for designing the selected magnetic component.

## Magnetic Parts Editor database

The Magnetic Parts Editor database stores information about the material required for creating a transformer or an inductor. Data such as, properties of core material, physical dimensions of core, type of bobbin, AWG or SWG details of winding wire, and properties of the insulation material, can be read from the database. The Magnetic Parts Editor database also contains detailed information about the core vendors.

You can use the Magnetic Parts Editor interface to navigate through the database, add new records to the database, and delete old records from the database.

**Note:** You cannot edit the records available by default in the database shipped with Magnetic Parts Editor.

To know more details about Magnetic Parts Editor database, see Chapter 7, "Magnetic Parts Editor Database."

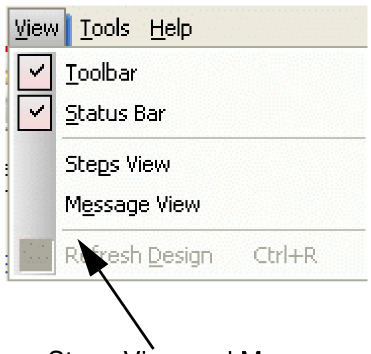
## Magnetic Parts Editor interface

This is the main interface used for designing magnetic components. This is divided into three parts, the Magnetic Parts Editor window, the steps view, and the message view.

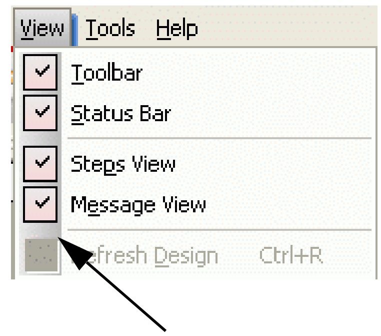
Magnetic Parts Editor window is used for designing purposes. The Steps view lists the steps in the transformer design process that you have either completed or are currently performing. By default, this view appears as the left pane in the Magnetic Parts Editor interface. The message view displays the errors, warnings, and the status of the processes being performed by Magnetic Parts Editor. By default, message view appears at the bottom of the Magnetic Parts Editor interface.

By default, all three views are visible, but if required, you can hide the Steps view and the Message view.

To hide the message view, from the View menu, choose Message View. Similarly, you can also hide the Steps view.

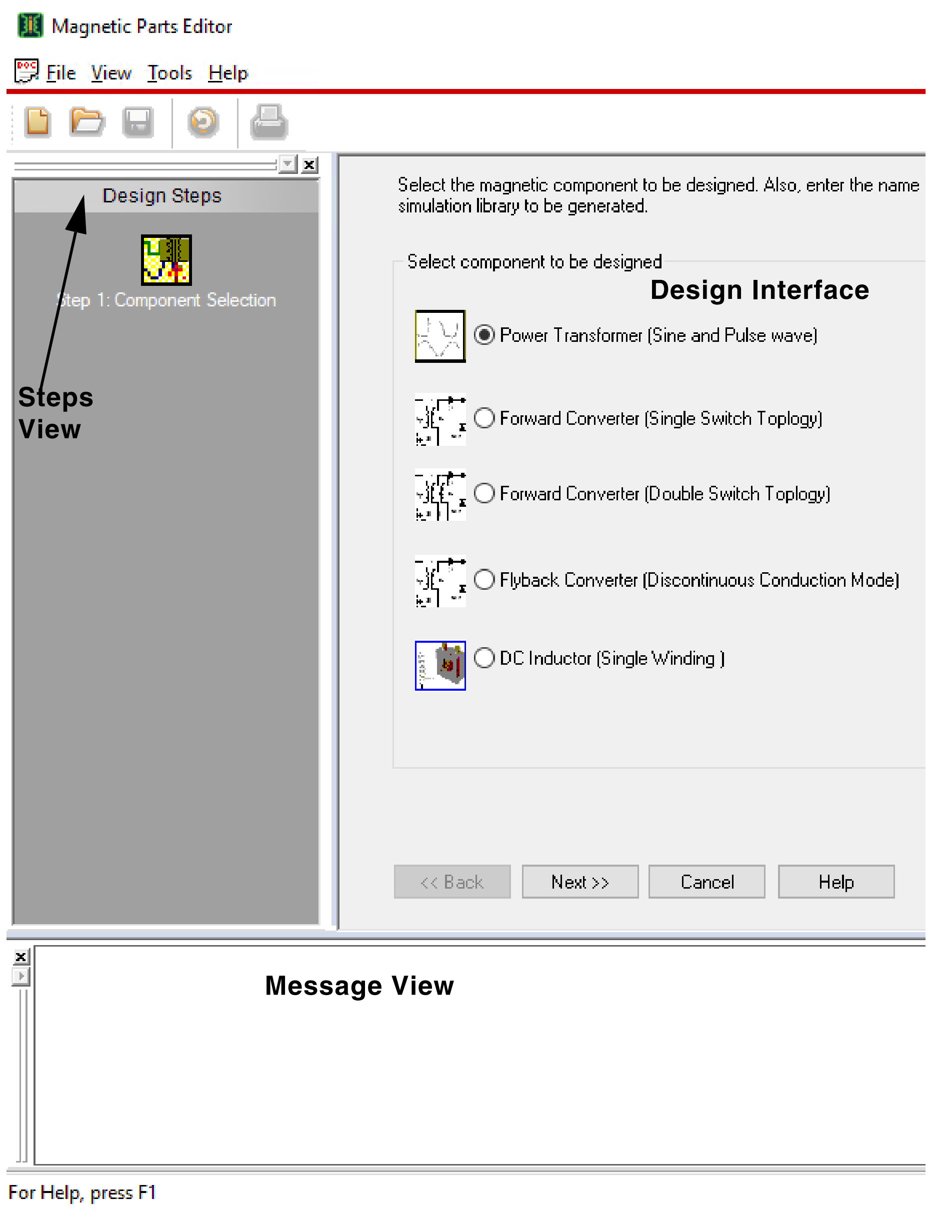



Steps View and Message View hidden




Steps View and Message View displayed

### Figure 1-1 Magnetic Parts Editor Interface




Magnetic Parts Editor uses a wizard-based approach for designing components. As a result, you can use the Back and the Next buttons to move to the previous or next steps, respectively. Besides this, you can also use the Steps view to jump to any of the already completed steps. For example, if you are in the Step 5 of the design process, you can directly go to the second step by selecting the icon above Step 2.

# Conventions used in Magnetic Parts Editor

Numbers may be typed in either decimal form or exponential notation. For example, 1000 may be entered as 1000 or 1K.

**Table 1-1 Conventions support in Magnetic Parts Editor**

| Letter | Indicates |
|---|---|
| `f` | $10^{-15}$ |
| `p` | $10^{-12}$ |
| `n` | $10^{-9}$ |
| `u` | $10^{-6}$ |
| `m` | $10^{-3}$ |
| `K` | $10^{3}$ |
| `M(MEG)` | $10^{6}$<br>**Note:** A lower case m represent milli and not mega. |
| `G` | $10^{9}$ |

**Table 1-2 Symbols used in this user guide**

| Symbol representation | Description |
|---|---|
| $A_e$ | Cross-section area of the core, $mm^2$ |
| AL | inductance factor, mH/1000 Turns |
| B | Operating flux density, Tesla |
| $B_{ac}$ | alternating current flux density, Tesla |
| $B_{pk}$ | peak current flux density, Tesla |
| $B_r$ | Ramminent flux density, Tesla |
| $B_{sat}$ | Saturation flux density, Tesla |
| BLDP | winding buildup, mm |
| d | skin depth, mm |

**Table 1-2 Symbols used in this user guide**

| Symbol representation | Description |
|---|---|
| D | maximum duty cycle |
| $E_{tp}$ | volts per turn for primary, Volts |
| $E_{ts}$ | volts per turn for secondary, Volts |
| f | operating frequency, Hz |
| FFC | fringing flux coefficient |
| $\eta$ | efficiency |
| $H_c$ | coercive force, |
| | magnetizing force require to return flux to zero, oersteds |
| $H_{wdg}$ | window height available for winding, mm |
| $I_{ac}$ | ac current, Amp |
| $I_{dc}$ | dc current, Amp |
| $I_{mag}$ | magnetizing current, Amp |
| $I_p$ | primary current, Amp |
| $I_{ppeak}$ | peak primary current, Amp |
| $I_{prms}$ | primary rms current, Amp |
| $I_s$ | secondary current, Amp |
| $I_{speak}$ | peak secondary current, Amp |
| $I_{srms}$ | secondary rms current, Amp |
| J | current density, Amp per $mm^2$ |
| K | window utilization factor |
| L | inductance, Henry |
| $L_g$ | gap length, cm |
| $L_p$ | primary inductance, Henry |
| $\mu$ | permeability |
| $\mu_0$ | permeability of air, $4*\pi*10^{-7}$ Henry/meter |
| MLT | mean length turn, mm |

**Table 1-2 Symbols used in this user guide**

| Symbol representation | Description |
|---|---|
| MPL | magnetic path length, mm |
| $\mu_r$ | relative permeability, equal to `1` for air |
| N | number of winding turns |
| $N_L$ | number of winding layers |
| $N_m$ | modified number of turns in primary winding |
| $N_p$ | turns in primary winding |
| $N_s$ | turns in secondary winding |
| $P_{in}$ | input power, Watts |
| $P_{out}$ | output power, Watts |
| R | resistance, Ohms |
| T | total time period, seconds |
| T | bobbin thickness, mm |
| $T_r$ | Temperature rise, centigrade |
| $V_p$ | primary voltage, Volts |
| $V_s$ | secondary voltage, Volts |
| $W_aA_e$ | window area product, $mm^4$ |
| $W_{wdg}$ | window width available for winding, mm |
| $X_L$ | inductive reactance, Ohms |
| $Z_0$ | impedance, Ohms |

# Finding information in this manual

The table below summarizes the topics covered in this manual.

| If you want to know.. | Read.. |
|---|---|
| About the steps involved in designing a magnetic component using Magnetic Parts Editor | Chapter 1, “Design Process,” |
| About the electrical parameters calculated by Magnetic Parts Editor that influence the design | Chapter 2, “Electrical Parameters.” |
| About the steps involved in designing the winding layout using Magnetic Parts Editor | Chapter 3, “Winding Layout.” |
| About the design parameters that effect transformer performance | Chapter 4, “Performance Parameters.” |
| How to use Magnetic Parts Editor to design a DC inductor | Chapter 5, “Designing DC Inductors” |
| How to interpret Manufacturer Report | Chapter 6, “Design Results” |
| How to use Magnetic Parts Editor database | Chapter 7, “Magnetic Parts Editor Database” |
| About template files used for default settings | Chapter 8, “Template Files” |
| How to use PSpice models generated by Magnetic Parts Editor in a schematic | Chapter 9, “Using PSpice Models” |

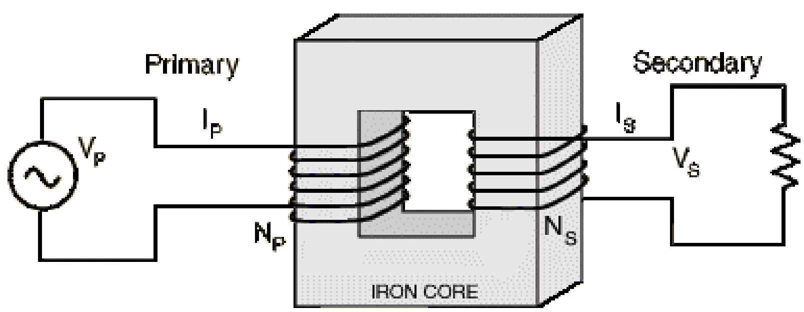
# 1

# Design Process

This chapter provides you an overview of the design steps involved in designing a magnetic component using Magnetic Parts Editor.

One of the most commonly used magnetic component is a transformer. A simple ideal transformer, shown in Figure 1-1 on page 17, consists of a core, primary and secondary windings, and an insulation material used between windings layers and also between core and winding.

**Figure 1-1 Basic Transformer**




The basic steps to be followed while designing a transformer or any other magnetic component are:

1. Decide component specifications.
2. Choose an appropriate core.
3. Select winding wires and design the winding layout.
4. Calculate performance parameters.
5. Verify if the calculated parameters match the required specifications. If not, change a few design parameters and redesign the component.

The steps to be completed when you use Magnetic Parts Editor to design a magnetic component, are:

1. Selecting a component
2. Providing general inputs
3. Providing electrical data
4. Selecting a core
5. Bobbin and Wire selection
6. Results View

**Note:** To learn how Magnetic Parts Editor completes winding layout and calculates performance parameters, see Chapter 3, “Winding Layout,” and Chapter 4, “Performance Parameters,” respectively.

## Starting Magnetic Parts Editor

➡ From the *Start* menu, choose *Cadence PCB Utilities 17.4-2019 – PSpice Magnetic Parts Editor 17.4*.

The Magnetic Parts Editor window opens.

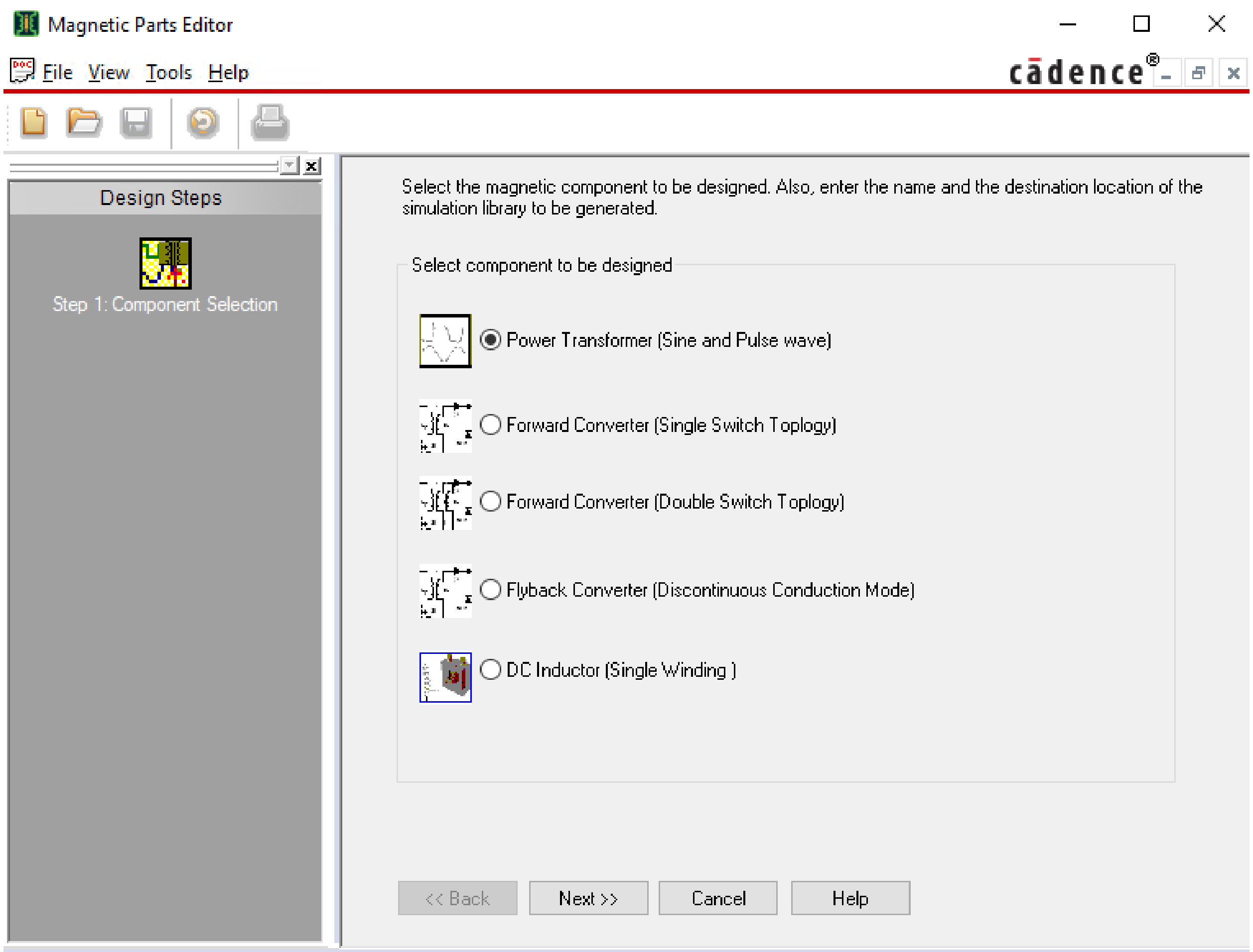
## Selecting a component

The first step while using Magnetic Parts Editor is to specify the type of magnetic component to be designed. Using Magnetic Parts Editor, you can design the components listed below.

- Power transformers
- Transformers for single switch and double switch forward converters
- Transformers for flyback converters operating in discontinuous conduction mode
- Single winding DC Inductor operating in the continuous conduction mode

To start the design process, using Magnetic Parts Editor, follow the steps listed below.

1. From the *File* menu, choose *New*.
2. Specify the component to be designed, by selecting an appropriate radio button.




3. To move to the next step of the design process, click *Next*.

# Providing design specifications

In the second and the third step of the design process, you enter the specifications for the magnetic component to be designed. To design any kind of component, you need to know basic design parameters, such as input and output voltages, operating frequency, voltage isolation, current density, insulation material, and so on.

In the second step, Providing general inputs, you provide design-related information and in the third step, Providing electrical data, you specify electrical data required as input for the design process.

## Providing general inputs

In this step, you enter design-related information by specifying parameters, such as insulation material to be used, current density in the winding wire(s), and efficiency of the transformer to be designed. The actual parameter to be specified depends on the type of component to be designed. For example, while designing Power Transformers, you specify the desired regulation, which is not required for other topologies.

Table 1-1 on page 20 lists the general design parameters to be specified as inputs to Magnetic Parts Editor for different topologies.

**Table 1-1 General Design Parameters**

| Parameter Name | Required for... | | | |
|---|---|---|---|---|
| | **Power Transformers** | **Forward Converters** | **Flyback Converter** | **DC Inductors** |
| Number of secondary | ✓ | Not required | ✓ | Not required |
| Insulation Material | ✓ | ✓ | ✓ | ✓ |
| Current density (J) | ✓ | ✓ | ✓ | ✓ |
| Efficiency (η) | ✓ | ✓ | ✓ | Not required |
| Regulation | ✓ | Not required | Not required | Not required |
| Inductance (L) | Not required | Not required | Not required | ✓ |

### *Number of secondary*

➡ In the *No. of secondary* text box, enter the required number of secondary windings.

For example, if you want to design a transformer with two secondary windings, enter 2 in the *No. of secondary* text box.

*Important*

Using Magnetic Parts Editor, you can design a transformer with a maximum of nine secondary windings. Therefore, the valid values for this field are integer values from 1 to 9.

**Note:** For Forward Converters, Magnetic Parts Editor supports only one secondary winding.

### *Insulation Material*

➡ Specify the insulation material to be used by selecting an entry from the *Insulation Material* drop-down list.

**Note:** If the material that you want to use is not available in the *Insulation Material* drop-down list, you can add the information for the same in the Magnetic Parts Editor database. For more information, see Add Insulation information on page 152.

The breakdown of the insulation material influences window utilization.

### *Current density (J)*

➡ In the *Current Density* text box, enter the value of the current density in the transformer winding.

Current density is the amount of current flowing per unit area. The value of the current density influences copper loss and wire selection for core winding.

### *Efficiency (η)*

➡ In the *Efficiency* text box, specify the desired output efficiency for the transformer.

Transformer efficiency is used to compute required input power.

#### *Regulation*

➡ In the *Regulation* text box, specify the required voltage regulation.

**Note:** Voltage regulation is required only in case of Power transformers. For other topologies, voltage regulation is not required.

#### *Inductance (L)*

➡ In the *Inductance* text box, enter the inductance value required for the DC Inductor to be designed.

**Note:** Inductance is required only in case of DC Inductors.

After you have entered appropriate values in all the fields, click *Next* to move to the next step of the design process.

### Providing electrical data

In the third step, you specify the value of the electrical parameters required for designing the selected magnetic component. The electrical parameters may differ depending on the type of magnetic component being designed. Table 1-2 on page 22 lists the electrical parameter to be specified as input while designing different types of magnetic components using Magnetic Parts Editor.

**Table 1-2 Electrical Parameters**

| **Parameter Name** | **Required for...** | | | |
|---|---|---|---|---|
| | **Power Transformers** | **Forward Converters** | **Flyback Converter** | **DC Inductors** |
| Primary voltage ($V_p/V_{in}$) | ✓ | ✓ | ✓ | ✗ |
| Secondary winding | | | | |
| Voltage | ✓ | Not Required | ✓ | Not Required |

**Table 1-2 Electrical Parameters,** *continued*

| Parameter Name | Required for... Power Transformers | Forward Converters | Flyback Converter | DC Inductors |
|---|---|---|---|---|
| Current | ✓ | Not Required | ✓ | Not Required |
| Operating frequency (f) | ✓ | ✓ | ✓ | ✓ |
| Voltage isolation | ✓ | ✓ | ✓ | Not Required |
| Waveform | ✓ | Not Required | Not Required | Not Required |
| Maximum Duty Cycle (D) | Not Required | ✓ | ✓ | Not Required |

### *Primary voltage ($V_p$/$V_{in}$)*

Primary voltage is the voltage across the primary winding of a transformer or an inductor.

➡ In the Primary Voltage text box, specify the input voltage applied to the primary winding.

### *Secondary winding*

This field is available only if you are using Magnetic Parts Editor to design a power transformer or a transformer for flyback converter.

In the secondary winding group box, you specify the electrical parameters for each of the secondary winding in the component. For transformers with multiple secondary winding, the Winding Name column lists the name of each of the secondary winding. This field is not editable.

**Note:** The number of windings that appear in the Winding Name column is equal to the number of secondary windings specified by you in the second step of Magnetic Parts Editor. To change the number of secondary windings, you need to change the value in the Number of secondary text box.

Depending on the type of transformer being designed, for each secondary winding, you might need to specify one or more electrical parameters.

**Voltage ($V_S$)**

➡ In the *Voltage* column, enter the rms voltage across the secondary winding.

**Current ($I_S$)**

➡ In the *Current* column, enter the rms current through the secondary winding.

**Note:** The voltage and current across secondary windings is used to calculate the output power.

***Operating frequency (f)***

➡ In the *Operating Frequency* text box, enter the frequency of operation for the transformer in Hertz (Hz).

***Voltage isolation***

➡ In the *Voltage Isolation* text box, specify the gap or the distance between primary and secondary windings in millimeters (mm).

***Output power ($P_{out}$)***

➡ For forward converters, you need to specify the output power in the *Output Power* text box.

**Note:** For other transformer topologies, output power is calculated as the sum of the power across each secondary winding.

***Waveform***

➡ In the *Waveform* list box, select the type of waveform that is to be provided as input to the transformer.

**Note:** This field is editable only for power transformers where you can either have a sine wave or a square wave as input waveform.

#### *Maximum Duty Cycle (D)*

Duty cycle is required for forward and flyback converters.

**Note:** For double switch forward converter, maximum duty cycle cannot be more than 50%.

*Important*

Maximum duty cycle is a design parameter that should not be changed during the iterations required to design a transformer. Changing this causes a change in the winding turns as well as winding currents, which in turn might effect the winding layout and transformer performance.

After you have entered appropriate values for all required parameters, move to the next step in the design process by clicking the *Next* button.

## Selecting a core

While designing a component using Magnetic Parts Editor, the fourth step is to select a core. Core selection is a step that is common for all types of components designed using Magnetic Parts Editor.

Core selection involves:

**a.** Selecting a core vendor

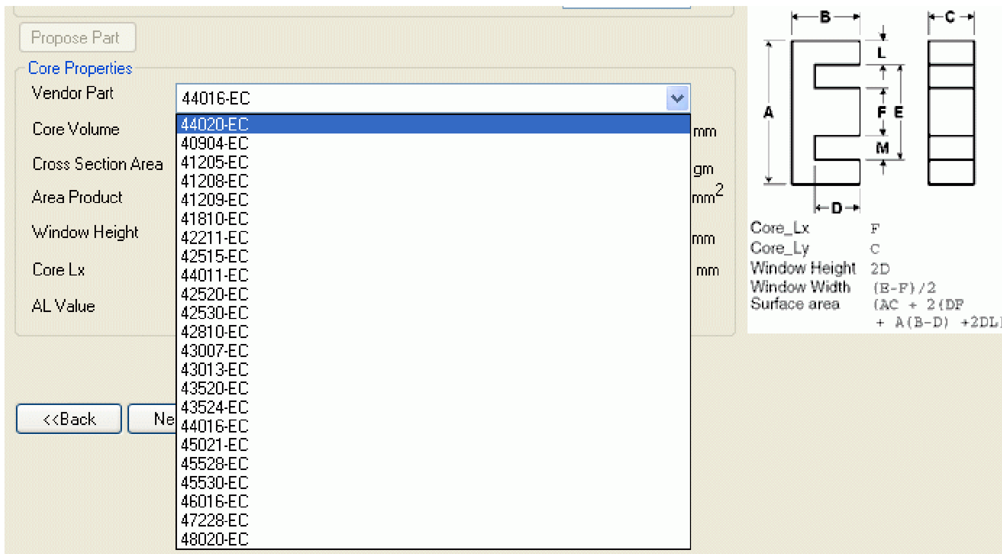
**b.** Selecting the shape of the core

**c.** Selecting the material used for core construction

**d.** Selecting a core with appropriate physical dimensions, such that all the design requirements are satisfied.

The information required for first three steps in the core design process, namely selecting a core vendor, selecting the shape of the core, and the material used for core construction, is provided by you as an input to Magnetic Parts Editor.

Based on the your inputs, and the required input/output specifications, Magnetic Parts Editor calculates the required window area product ($W_aA_e$) for the core. It then reads the Magnetic Parts Editor database to find a list of available parts that have window area product equal to or greater than the calculated value. All parts that fulfill this requirement are listed in the *Vendor Part* drop-down list box, as shown in the figure given below.




Magnetic Parts Editor displays the complete physical data for the selected core part. If required, you can refer to this data before you finalize a part from the *Vendor Part* list box.

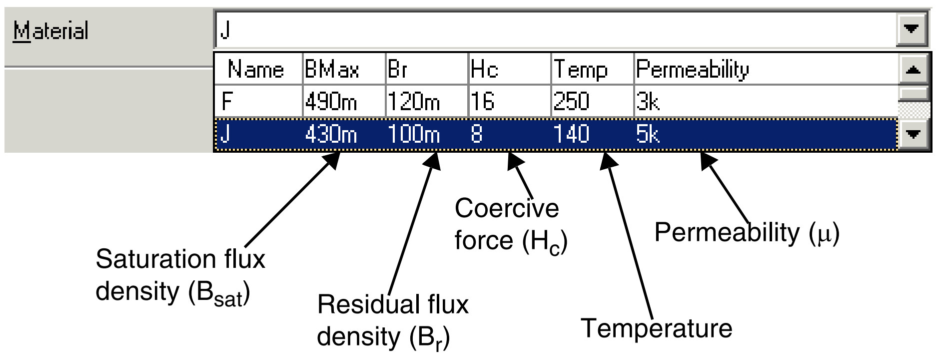
### To select a core using Magnetic Parts Editor:

1. From the *Vendor Name* drop-down list, select the desired manufacturer name.
2. From the *Family Name* drop-down list, select the required core geometry.

   The *Family Name* list provides a list of all core geometries provided by the selected manufacturer and are supported by Magnetic Parts Editor. Core geometries currently supported are, EE, UU, and toroid.

   **Note:** For more information on Family Name, see Adding core properties on page 146.

3. From the *Material* drop-down list, choose the material that should be used for core construction.




**Note:** This list is also populated using entries from the database.

*Tip*

Material properties such as $B_{sat}$, $B_r$, and $\mu$ affect the transformer design to a great extent.

4. In the *Operating B* text box, specify the operating flux density for the transformer. The default value is derived from the saturation flux density for the material used and is different for different transformer topologies.

   For example, for power transformers, operating flux is `0.75` times the saturation flux density ($B_{sat}$). In case of forward converters, this value is `.75(`$B_{sat}$`-`$B_r$`)`.

   The value of the operating flux density is used to calculate window product area, which influences core selection.

5. The *Utilization Factor* text box is also populated by default. The default value depends on the type of component being designed. The default values are read from the template files. If required, you can change the default value to any value greater than 0 and less than 1.

   Utilization factor is an indication of the window area used for winding. For example, utilization factor of `0.6` indicates that 60% of available window area will be used for winding purposes.

*Tip*

For the same power, Magnetic Parts Editor proposes a larger size core for a transformer with low utilization factor.

6. Finally, to select an actual core part, click the *Propose Part* button.

   When you select the *Propose Part* button, Magnetic Parts Editor generates a list of core parts that meet your requirements.

   The part number visible in the *Vendor Part* list box is actually the part that is a best match for your requirements. For the selected part, Core Properties get populated. You can either use this part or select any other part from the *Vendor Part* list.

   Notice that as the part number changes, the core properties also change.

   **Note:** To learn how Magnetic Parts Editor filters the core parts, see Selecting a Core on page 38.

7. After you have selected a core for the magnetic component to be designed, click Next.

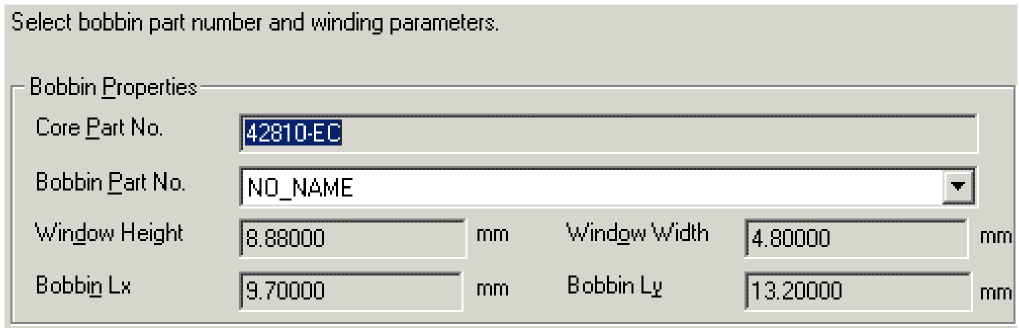
# Bobbin and Wire selection

The last step in the design process using Magnetic Parts Editor, is to select a bobbin to be used between the core and the winding, and to select winding wires of appropriate size.

## Specifying bobbin properties

Magnetic Parts Editor uses core dimensions to calculate the bobbin dimensions. The dimensions for the required bobbin are displayed as window width, window height, bobbin length and bobbin width. If there are any bobbins in the Magnetic Parts Editor database with dimensions matching the calculated dimensions, they appear in the

*Bobbin Part Number* list box. If not, the *Bobbin Part Number* list box displays NO_NAME.




If there are no bobbins available in the database for the selected core, Magnetic Parts Editor uses the bobbin thickness defined in the template files, to calculate bobbin dimensions.

**Note:** To know more about template files, see Chapter 8, “Template Files.”

Selecting an appropriate bobbin is important as bobbin configuration influences the area available for windings.

Depending on the core geometry, bobbin dimensions also vary. To know more about equations used to calculate bobbin dimensions, use the links in the table given below.

| Core shape.. | See.. |
|---|---|
| EE | Bobbins on page 40 |
| UU | Bobbins on page 40 |
| Toroid | Bobbins on page 40 |

## Selecting winding wire

This is the last step in the transformer design process using Magnetic Parts Editor. Choice of winding wire influences design parameters such as, the winding layout and copper loss.

While selecting a winding, you need to select the following.

a. the wire type
   For example, single or Litz

b. wire standards
   AWG or SWG

c. wire gauge

When you use Magnetic Parts Editor to design a transformer winding, the first two values are provided by you as inputs. Depending on these inputs, Magnetic Parts Editor selects the appropriate wire gauge, which is a measurement of the diameter of the winding wire.

To select a wire, Magnetic Parts Editor first computes the required cross-section area, based on the rms current through the wire and the acceptable current density. It then scans the database to search wires that have cross-section area equal to or greater than the computed cross-section area.

## Type of windings

Magnetic Parts Editor supports three types of windings.

- Single
- Litz
- Foil


### *Single*

Indicates a circular shaped single strand of wire used as a winding. For single wire type, you need to specify whether AWG or SWG wire standard is to be used. Based on the inputs, Magnetic Parts Editor selects a suitable wire gauge from the database.

To know more about the factors that influence wire gauge selection, see Wire gauge on page 64.

### *Litz*

Indicates multiple circular wires in parallel. A number of insulated single wire strands are used together to achieve required cross-section area while ensuring that the skin depth requirement is not violated.

For a transformer with Litz winding, along with the wire gauge information, Magnetic Parts Editor also calculates the suitable number of strands to be used in the Litz wire.

To know more about how these selections are made, see Wire gauge on page 64 and Number of strands (Litz only) on page 67.

### *Foil*

When you select Foil, instead of wires, a thin foil is used as transformer winding. For foil windings, Magnetic Parts Editor calculates the thickness and width of the foil to be used as primary and secondary windings.

## Steps

To specify the details of the winding wire in Magnetic Parts Editor, complete the steps listed below.

1. Specify the wire type by selecting either Single, Litz, or Foil radio button.

   **Note:** Foil type winding is not supported for toroid cores.

2. Specify the wire standard by selecting the AWG or SWG radio buttons.
3. You can either use the wire gauge proposed by Magnetic Parts Editor, or select a suitable wire gauge from the Gauge drop-down list for each of the windings listed below the *Winding Name* column.
4. To complete the design process and to view the results generated by Magnetic Parts Editor, click Next.

# Results View

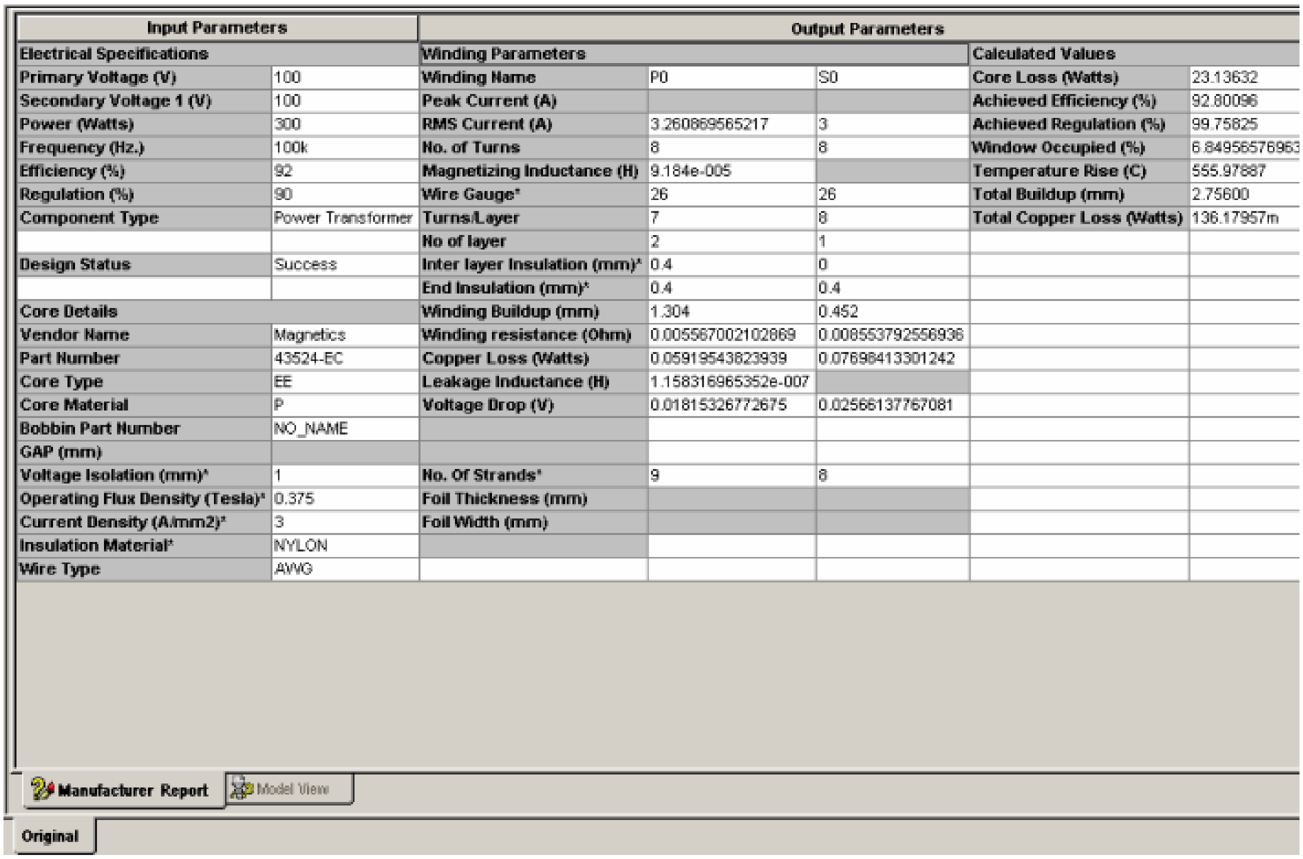
The final step in the design process using Magnetic Parts Editor is to view the results generated by Magnetic Parts Editor. After you complete the bobbin and winding selection, Magnetic Parts Editor calculates the winding layout and performance parameters for the magnetic component.

The results of the design process are displayed in the Results View. The results view has data displayed in two tabs.

1. The Manufacturer Report tab
2. The Model View tab

## The Manufacturer Report tab

The Manufacturer Report tab displays a summary of the entire design process. It provides a list of design parameters, and their corresponding values, that are required by a manufacturer to generate the designed part. This tab also allows design engineers to make changes to the design and iterate the design.



| Input Parameters | | Output Parameters | | | | |
|---|---|---|---|---|---|---|
| Electrical Specifications | | Winding Parameters | | | Calculated Values | |
| Primary Voltage (V) | 100 | Winding Name | P0 | S0 | Core Loss (Watts) | 23.13632 |
| Secondary Voltage 1 (V) | 100 | Peak Current (A) | | | Achieved Efficiency (%) | 92.80096 |
| Power (Watts) | 300 | RMS Current (A) | 3.260869565217 | 3 | Achieved Regulation (%) | 99.75825 |
| Frequency (Hz.) | 100k | No. of Turns | 8 | 8 | Window Occupied (%) | 6.84956576963 |
| Efficiency (%) | 92 | Magnetizing Inductance (H) | 9.184e-005 | | Temperature Rise (C) | 555.97887 |
| Regulation (%) | 90 | Wire Gauge* | 26 | 26 | Total Buildup (mm) | 2.75600 |
| Component Type | Power Transformer | Turns/Layer | 7 | 8 | Total Copper Loss (Watts) | 136.17957m |
| | | No of layer | 2 | 1 | | |
| Design Status | Success | Inter layer Insulation (mm)* | 0.4 | 0 | | |
| | | End Insulation (mm)* | 0.4 | 0.4 | | |
| Core Details | | Winding Buildup (mm) | 1.304 | 0.452 | | |
| Vendor Name | Magnetics | Winding resistance (Ohm) | 0.005567002102869 | 0.008553792556936 | | |
| Part Number | 43524-EC | Copper Loss (Watts) | 0.05919543823939 | 0.07698413301242 | | |
| Core Type | EE | Leakage Inductance (H) | 1.158316965352e-007 | | | |
| Core Material | P | Voltage Drop (V) | 0.01815326772675 | 0.02566137767081 | | |
| Bobbin Part Number | NO_NAME | | | | | |
| GAP (mm) | | | | | | |
| Voltage Isolation (mm)* | 1 | No. Of Strands* | 9 | 8 | | |
| Operating Flux Density (Tesla)* | 0.375 | Foil Thickness (mm) | | | | |
| Current Density (A/mm2)* | 3 | Foil Width (mm) | | | | |
| Insulation Material* | NYLON | | | | | |
| Wire Type | AWG | | | | | |

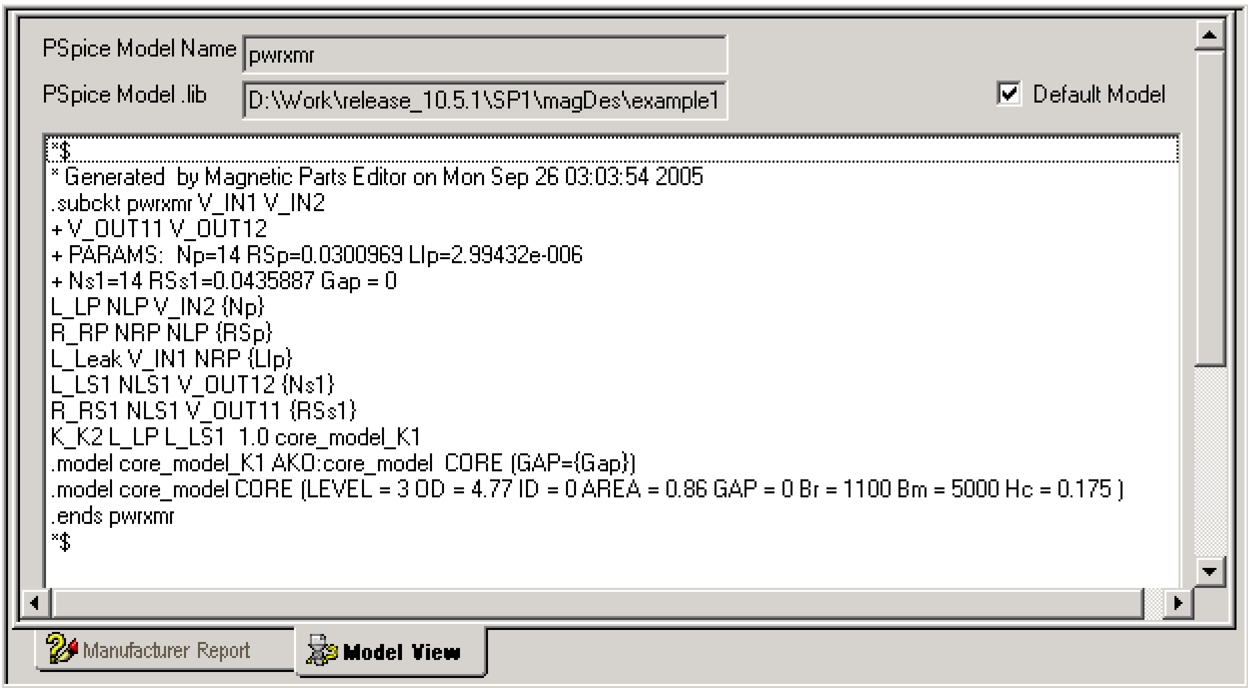


The design parameter values, irrespective of whether they were specified as inputs by you or were calculated by the Magnetic Parts Editor, are displayed in one of the three columns of the report. The columns in the report are Electrical Specifications, Winding Parameters, and Calculated Values. The values listed in the Winding Parameters and Calculated Values columns are the winding layout and performance parameters values, calculated by Magnetic Parts Editor after you have selected a winding wire.

The success or the failure of the design process is indicated in the Design Status field. In case of error, you can change certain values and recalculate the results. To know more about various fields in the Manufacturer Report, see Chapter 6, “Design Results.”

### The Model View tab

The Model View tab displays the model text for the PSpice model generated by Magnetic Parts Editor. The PSpice model is saved in a `.lib` file. The name of the `.lib` file is same as the name specified by you while saving the file.




## Saving the design

➡ To save the design, choose *Save* from the *File* drop-down menu.

When you save the design, two files, `<design_name>.mgd` and `<design_name>.lib` are generated. The *`design_name`* is same as the library name specified by you in the <u>Selecting a component</u> section of this chapter.

**Note:** In case you use the *Save As* command, the name of the `.lib` file and the PSpice model in the `.lib` file, will be same as the name of the `.mgd` file specified by you in the *Save As* dialog box.

## Summary

In this chapter, you learned about the steps involved in designing a magnetic component using Magnetic Parts Editor. Table 1-3 on page 35 lists the synopsis of the design process using Magnetic Parts Editor.

**Table 1-3 Designing transformers and DC Inductors using Magnetic Parts Editor**

| | **Steps** | **Tasks performed** |
|---|---|---|
| Step 1 | Component Selection | ■ Select the component to be designed<br>■ Specify the name of the PSpice model to be generated |
| Step 2 | General Information | Specify the values for the Input and Output design parameters listed in Table 1-1 on page 20. |
| Step 3 | Electrical Parameters | Specify the values of electrical parameters listed in Table 1-2 on page 22. |
| Step 4 | Core Selection | Select a core for the magnetic component being designed<br>**a.** Select core shape - select appropriate entry from the *Family Name* drop-down list<br>**b.** Select core material - select an entry from the *Material* drop-down list<br>**c.** Select core size - select a part from the *Vendor Part* drop-down list, which is populated by Magnetic Parts Editor |
| Step 5 | Bobbin-Winding Selection | For the selected core, select a bobbin from the *Bobbin Part Number* drop-down list.<br>**Note:** If no bobbins are available, bobbin dimensions calculated by Magnetic Parts Editor are used. |

**Table 1-3 Designing transformers and DC Inductors using Magnetic Parts Editor,**

| | Steps | Tasks performed |
|---|---|---|
| Step 6 | Results View | View and, if required, modify the results generated by the Magnetic Parts Editor<br><br>*Important*<br><br>You may have to go through various iterations before you finalize the transformer design but under normal circumstances, it is recommended that the design parameters defined in the initial steps of the design process must not be changed. |

# 2

# Electrical Parameters

There are various physical and electrical parameters that influence the transformer design. Some of these parameters are provided as inputs and rest are calculated by the Magnetic Parts Editor. The inputs are either provided by you or in some cases are read from the Magnetic Parts Editor database. This chapter covers the electrical parameters to be considered while designing a transformer.

When you design a transformer using Magnetic Parts Editor, Magnetic Parts Editor follows the sequence of steps listed below.

1. Selects a core.
   This can be considered as the starting point of the transformer design process. For selecting a core, Magnetic Parts Editor uses window area product calculated using Equation 2-1 on page 38.
2. Calculates bobbin dimensions.
   See the section, Bobbins on page 40.
3. Calculates the number of turns in primary and secondary windings.
4. Calculates winding currents.
   See Turns per winding on page 47.
5. Calculates winding layout parameters. See Chapter 3, “Winding Layout.”
6. Calculates parameters that influence transformer performance.
   See Chapter 4, “Performance Parameters.”

The electrical properties required in the first four steps of the design process are covered in this chapter. Winding layout and transformer performance parameters are covered in subsequent chapters of the book.

# Selecting a Core

Core selection can be considered as a starting point for designing a transformer. After you have defined your design requirements, one of the most common approaches for designing a transformer is to select a core with appropriate shape and size. Designing a transformer using Magnetic Parts Editor also follows this approach. Based on the inputs provided by you, Magnetic Parts Editor generates a list of core parts that can be used in the transformer. To generate this list, Magnetic Parts Editor uses the value of an electrical property, Window Area Product $(W_aA_e)$. Irrespective of the type of magnetics being designed using Magnetic Parts Editor, the core selection is always based on window area product. Besides the window area product, the core geometry also influences the core selection. Core geometries currently supported by Magnetic Parts Editor are, EE cores, UU cores, and toroid cores.

**Note:** Currently Coupling is supported only for non-linear core.

## Window Area Product

For a given value of the output power, the required window area product, $W_aA_e$, is calculated using the following equation.

**(2-1)** $$W_aA_e = (P \cdot 10^4)/(K \cdot J \cdot B \cdot f)$$

where

| | |
|---|---|
| $W_aA_e$ | Window area product in $cm^4$ |

| | |
|---|---|
| `K` | Utilization factor, default values:<br>0.6 for power transformer<br>0.112 for forward converters<br>0.3 for flyback converters<br>0.5 for DC inductors |
| `P(P`$_{in}$`)` | Input power of transformer in Volt-Ampere or Watt |
| `J` | current density in `A/cm`$^2$<br>**Note:** Value of `J` entered by you in the Magnetic Parts Editor interface is in `A/mm`$^2$. Therefore, to obtain `J` in `A/cm`$^2$, multiply the value by 100. |
| B | Flux density in Tesla<br>Default value for power transformer, flyback, and DC Inductor<br>$= 0.75\ B_{sat}$<br>Default value for forward converters<br>$= 0.75\ (B_{sat} - B_r)$ |
| `F` | Operating frequency in Hertz |

For the commercially available core parts, $W_aA_e$ is specified by the manufacturer. For the core geometry selected by you, Magnetic Parts Editor compares the required window area product, calculated using Equation 2-1 on page 38, with the window area product provided by the manufacturer. All the parts in the Magnetic Parts Editor database that belong to the Family selected by you and have the area product greater than or equal to the calculated area product are made available for selection. Of these, the core that has window area product nearest to the calculated value, is the part proposed by the Magnetic Parts Editor. The part number of this core appears selected. You can either use the part proposed by Magnetic Parts Editor or select any other part from the list.

**Note:** For information on database shipped with Magnetic Parts Editor, see Magnetic Parts Editor Database on page 137.

Selecting a core is an important steps in the design process as it influences other transformer properties such as winding layout and transformer performance. Table 2-4 on page 68 lists some of the core properties along with the transformer design parameters that are influenced by these properties.

**Table 2-1 Useful core properties**

| Property | Property |
|---|---|
| Area Product ($W_aA_e$) | Magnetic Path Length (MPL) |
| Cross-section Area ($A_e$) | Surface Area |
| Core dimensions | Core Volume |

# Bobbins

After selecting a core, the next step is to select a bobbin for the core. A bobbin can be considered as a frame placed between core and winding. Depending on whether bobbin data is available for the selected core, Magnetic Parts Editor either lists the bobbin name and dimensions, or it calculates the bobbin dimensions using 1 mm as the default value of bobbin thickness. Bobbin dimensions are influenced both by the core size (see Figure 2-1 on page 64) and the core geometry.

The core family specified by you decides the core geometry. Bobbin selection is important as it defines the window area available for winding.

### *EE and UU cores*

For EE and UU cores, bobbin dimensions are calculated using the equations given below.

**(2-2)** bobbin window height = core window height - 2T;

**(2-3)** bobbin window width = core window width - T;

**(2-4)** Bobbin_Lx = Core_Lx + 2T;

**(2-5)** Bobbin_Ly = Core_Ly + 2T;

where T = Bobbin Thickness read from the template file.

**Note:** To know more about the template files, see Chapter 8, "Template Files."

### *Toroid cores*

Bobbin values are not required for toroid cores.

*Important*

Bobbin window height calculated using Equation 2-2 on page 40 is equal to the Window Height ($H_{wdg}$ or $G$) available for winding. Similarly, bobbin window width, calculated using Equation 2-3 on page 40, is equal to the Window Width ($W_{wdg}$) available for winding.

# Power Transformers

This section covers the electrical parameters required for designing a power transformer. Some of the electrical parameters, such as voltages across primary and secondary windings, are provided as inputs by you. Magnetic Parts Editor uses these values to calculate other parameters such as currents through primary and secondary windings, and volts per turn. These values are then used to calculate other design parameters such as the number of turns per winding, required cross section area of the winding wire, and so on. This section covers the mathematical equations used by Magnetic Parts Editor for calculating currents through each of the transformer winding and the required number of turns per winding.

## Winding current

The current through the secondary winding is provided as input by you. Therefore, this section covers the steps and the equations used by Magnetic Parts Editor to calculate current through the primary winding for a power transformer.

Current through the primary winding is calculated using Equation 2-6 on page 42.

**(2-6)** $I_p = \frac{P_{in}}{V_{in}}$

where

$P_{in}$ Input Power

(Calculated using Equation 2-7 on page 42.)

$V_{in}$ Input Voltage

(User Input. See Providing electrical data on page 22.)

**(2-7)** $P_{in} = P_{out}/\eta$

where

$P_{out}$ Output Power

$\eta$ Efficiency

$P_{out}$ is calculated as the sum of the output power across all secondary windings.

**(2-8)** $P_{out} = \sum V_s \cdot I_s$

where

$P_{out}$ Output Power

$V_s$ Voltage across a secondary winding

$I_s$ Current through a secondary winding

**Note:** The Values `Vs` and `Is` are specified by you as inputs. See Providing electrical data on page 22.

## Turns per winding

While deciding on a layout for the transformer winding, the number of turns for the primary and secondary winding should be known. For computing the number of turns required for each of the transformer winding, Magnetic Parts Editor follows the steps listed below.

1. Calculate the volts per turn ($E_{tp}$), using Equation 2-9 on page 43.
2. Divide the voltage across the primary winding ($V_{in}$ or $V_p$) by volts per turn to get the required number of turns in the primary winding.
3. If the value obtained in step 2 is not an integer, the ceiling value is taken as number of turns in the primary ($N_p$).

   For example, if the required number of turns is calculated to be 39.2, the number of turns for the primary winding would be 40.
4. For the changed value of $N_p$, recalculate volts per turn for primary ($E_{tp}'$) using Equation 2-11 on page 44.
5. Calculate number of turns in the secondary winding ($N_s$)
   a. Divide $V_s$ by $E_{ts}$ calculated using Equation 2-11 on page 44.
   b. $N_s$ is the nearest integer greater than $V_s/E_{ts}$

### Calculating volts per turn for primary winding

The formula used for computing volts per turn for primary is given below.

**(2-9)** $$E_{tp} = 4 \cdot F \cdot B \cdot f \cdot A$$

where

F Form factor

= 1.11 for Sine wave

= 1 for Square wave

B Flux Density in Tesla ($0.75 * B_{max}$)

$A_e$ Core cross-section area in meter square

*Caution*

***In the Magnetic Parts Editor database, this value is in*** $mm^2$***.***

f Frequency in hertz

### Number of turns

#### *For primary winding*

The number of turns required for the primary winding is calculated using the equation given below.

**(2-10)** $$N_p = CEIL\left(\frac{V_p}{E_{tp}}\right)$$

where

| | |
|---|---|
| $V_p$ | voltage across primary |
| $E_{tp}$ | voltage per turn, calculated using Equation 2-9 on page 43 |
| CEIL( ) | This function returns an integer greater than the value of argument passed to the function. For example, `CEIL(4.5)=5`. |

The equation used for recalculating voltage per turn for the primary is given below.

**(2-11)** $$E_{tp}' = (V_p/N_p) = E_{ts}$$

***For secondary winding***

To calculate the number of turns required for the secondary, divide voltage across secondary by the volts per turn for the secondary winding. The volts per turn for secondary and primary are same as calculated using Equation 2-11 on page 44.

The equation used for calculating number of turns for the secondary winding is given below.

**(2-12)** $$N_s = \frac{V_s}{E_{ts}}$$

# Forward converters

Magnetic Parts Editor supports two types of forward converters.

- Single switch
  - with reset winding
  - without reset winding
- Double switch

When you use a single switch with reset winding, a reset winding is used for handling the current due to the decaying flux.

In case of double switch forward converter transformer, the current decay is through the free-wheel diode used in the circuit.

The electrical parameters that are specified as inputs, while designing a Forward converter using Magnetic Parts Editor, are listed in the table given below. Magnetic Parts Editor uses some of these parameters to calculate the turns per winding and the current through the windings.

| Input Parameters | Comments | Input Parameter | Comments |
|---|---|---|---|
| Primary voltage | $V_p$ ($V_{in}$) | Operating frequency | f |

| Input Parameters | Comments | Input Parameter | Comments |
|---|---|---|---|
| Secondary Average Voltage | $V_{sin}$ | Secondary Average Current | $I_{sin}$ |
| Voltage Isolation | Isolation between primary and secondary winding | Efficiency | $\eta$ |
| Maximum Duty Cycle | D | Utilization factor | By default this is set to 0.25 |

When you design a forward converter, the electrical parameters and the sequence in which these parameters are calculated by Magnetic Parts Editor is listed in Table 2-2 on page 46.

**Table 2-2 Electrical parameters calculated for forward converter**

| S.No | Electrical parameter to be calculated... |
|---|---|
| **1.** | Output Power ($P_{out}$) |
| **2.** | Input Power ($P_{in}$) |
| **3.** | Window Area Product ($W_aA_e$) |
| **4.** | Turns in the primary winding ($N_p$) |
| **5.** | Number of turns in the secondary winding ($N_s$) |
| **6.** | Required inductance through the primary winding ($L_p$) |
| **7.** | Magnetizing current ($I_{mag}$) |
| **8.** | Primary load current ($I_p$) |
| **9.** | Secondary current and secondary load current |
| **10.** | Number of turns in the reset winding (if required) |
| **11.** | Reset winding currents |
| **12.** | Wire gauge or Foil Width |
| **13.** | Number of strands in the winding wire or Foil thickness |

## Output Power ($P_{out}$)

Output power for a forward converter transformer is the sum of the output power for each secondary winding.

**(2-13)** $$P_{out} = \sum_{i=1}^{n} V_{sin} I_{sin}$$

## Input Power ($P_{in}$)

Input power is calculated as a function of $P_{out}$ and efficiency ($\eta$).

**(2-14)** $$P_{in} = \frac{P_{out}}{\eta}$$

## Turns per winding

To calculate the required number of turns in the primary and secondary windings for a forward converter, core properties from Table 2-1 on page 40 are used. The values for these properties are read from the Magnetic Parts Editor database.

### Turns in primary

The number of turns required for the primary winding is calculated using Equation 2-15 on page 47.

**(2-15)** $$N_p = CEIL\left(\frac{V_{in} \cdot D \cdot 10^4}{f \cdot A_e \cdot B}\right)$$

where

| | |
|---|---|
| $V_{in}$ | Primary Voltage |

| | |
|---|---|
| D | maximum duty cycle (User input)<br>For single switch topology<br>> 0.5<br><br>For double switch topology<br><= 0.5 |
| $A_e$ | core cross-section area (read from the database), $cm^2$ |
| f | Operating frequency (user input) |
| B | operating flux density<br>default value = 0.75 ($B_{sat}$-$B_r$) |

For all practical applications, number of turns in a primary winding has to be an integer value. Therefore, if the value of $N_p$ calculated using Equation 2-15 on page 47 is a non-integer value, Magnetic Parts Editor rounds off the result such that the modified value of $N_p$ is the nearest integer value greater than the calculated value of $N_p$.

### Turns in secondary

After you have computed the required number of turns for primary, you can find the required number of turns for secondary using the equation given below.

**(2-16)** $$N_s = \frac{N_p}{V_p} \times \frac{V_s}{D}$$

where $N_p$ is calculated using Equation 2-15 on page 47

### Turns in the reset winding

**Note:** Reset winding is required only in case of single switch topology.

Number of turns required for the reset winding is calculated using the equations given below.

***For D >= 0.5***

**(2-17)** $N_{reset} = N_p \cdot \frac{D}{1-D}$

where

$N_p$ Turns in the primary winding, calculated using Equation 2-15 on page 47.

D Maximum duty cycle specified by you as input

*Tip*

If the maximum duty cycle is 0.5, the number of turns in the reset winding will be same as the number of turns in the primary winding.

**(2-18)** $V_{reset} = V_p \times \frac{D}{1-D}$

*Caution*

***While designing transformers for forward converters using double switch topology, maximum duty cycle cannot be more that*** `0.5`***.***

***For D<0.5***

**(2-19)** $N_{reset} = N_p$

**(2-20)** $V_{reset} = V_p$

## Winding currents

In forward converters, besides the primary, secondary, and reset current, you also need to calculate the magnetizing current. Magnetizing current can be defined as current necessary for building up a magnetic field in an electrical machine.

### Primary inductance

To calculate magnetizing current, you need to know the primary inductance. The primary inductance, $L_p$, is affected by the transformer core and can be calculated using one of the methods listed below.

- Using Inductance Factor
- Using Magnetic Path Length

#### *Using Inductance Factor*

**(2-21)** $L_p = AL \times N_p^{\,2}$

where

AL core inductance factor

(read from Magnetic Parts Editor database)

$N_p$ Turns in the primary winding

(calculated using Equation 2-15 on page 47)

#### *Using Magnetic Path Length*

**(2-22)** $L_p = \mu_0 \cdot \mu_r \cdot N_p^{\,2} \cdot \dfrac{A_e}{MPL}$

where

$\mu_0$ $4\pi * 10^{-7}$ (Henry/meter)

$\mu_r$ relative permeability of the material
(read from Magnetic Parts Editor database)

$N_p$ Turns in the primary winding

(calculated using Equation 2-15 on page 47)

| | |
|---|---|
| $A_e$ | core cross-section area in $cm^2$ (Read from Magnetic Parts Editor database) |
| MPL | Magnetic Path Length in $cm$ (read from Magnetic Parts Editor database) |

**Current through primary**

Primary current is calculated using Equation 2-23 on page 51.

**(2-23)** $$I_p = \frac{P_{in}}{V_{in}}$$

**Magnetizing current**

**(2-24)** $$I_{mag} = \frac{V_{in} \cdot D}{L_p \cdot f}$$

where

| | |
|---|---|
| $V_{in}$ | Input voltage ($V_p$) (user input) |
| D | Maximum duty cycle (user input) |
| $L_p$ | Primary Inductance, calculated using Equation 2-21 on page 50 or Equation 2-22 on page 50 |
| f | Operating frequency (user input) |

The magnetizing current, $I_{mag}$, should be less than 10% of peak primary load current, $I_p$, calculated using Equation 2-23 on page 51.

The rms value for $I_p$ is calculated using the equation given below.

**(2-25)** $$I_{prms} = \frac{I_p + I_{mag}}{\sqrt{D}}$$

where

| | |
|---|---|
| $I_p$ | Peak primary load current, calculated using Equation 2-23 on page 51. |
| $I_{mag}$ | Magnetizing current, calculated using Equation 2-24 on page 51. |
| D | Maximum duty cycle (user input) |

### Secondary Winding

The rms current through each secondary winding in calculated using the equation given below.

**(2-26)** $$I_{srms} = I_s \cdot \sqrt{D}$$

where

| | |
|---|---|
| D | Maximum duty cycle (user input) |
| $I_s$ | Average current through the secondary winding (user input) |

### Reset Winding

The current through the reset winding can be calculated using the equation below.

**(2-27)** $$I_{rrms} = \frac{V_{in} \cdot D \cdot \sqrt{D}}{\sqrt{3} \cdot L_p \cdot f}$$

where

| | |
|---|---|
| $V_{in}$ | Input Voltage |
| D | Maximum Duty Cycle |

$L_p$ Primary Inductance

(calculated using Equation 2-21 on page 50 or Equation 2-22 on page 50)

f Operating frequency

The values of $I_p$, $I_{prms}$, $I_s$, $I_{srms}$, $I_{rrms,}$ and $I_{mag}$ are used to select a respective winding wires and to calculate copper loss in the transformer.

# Flyback converters

A flyback converter is a kind of transformer that is used for buck-boost power supplies. A flyback converter first stores energy received from the input power supply, which is charging phase of the cycle, and then transfers energy to the output during the discharge phase of a cycle. The primary winding acts as inductor that stores the energy. This energy is later transferred to the secondary winding during the discharge phase. As the reset of magnetization current is done through decay of current in secondary winding, tertiary or reset windings are not required for flyback converters.

Using Magnetic Parts Editor, you can design a flyback converter that operates in a discontinuous conduction mode.

When you design a flyback converter using Magnetic Parts Editor, Magnetic Parts Editor calculates the value of electrical parameters listed in Table 2-3 on page 54.

**Table 2-3 Sequence for calculating electrical parameters**

| S.No | Electrical parameter to be calculated... |
|---|---|
| **1.** | Output Power (P) |
| **2.** | Peak currents<br>■ through the primary winding ($I_{ppeak}$)<br>■ through the secondary winding ($I_{speak}$) |
| **3.** | RMS currents<br>■ through the primary winding ($I_{prms}$)<br>■ through the secondary winding ($I_{srms}$) |
| **4.** | Required inductance through the primary winding ($L_p$) |
| **5.** | Window Area Product ($W_a$) |
| **6.** | Turns in the primary winding ($N_p$) |
| **7.** | Gap length ($L_g$) |
| **8.** | Fringing Flux Coefficient (FFC) |
| **9.** | Modified number of turns for primary winding ($N_m$) |

**Table 2-3 Sequence for calculating electrical parameters,** *continued*

| S.No | Electrical parameter to be calculated... |
|---|---|
| **10.** | Maximum flux density ($B_{peak}$)<br>Ensure that $B_{peak} < B_{sat}$<br>If not, change number of turns for primary, $N_m$ and recalculate $B_{peak}$. Repeat step 9 and step 10, till $B_{peak} < B_{sat}$.<br>**Note:** For $B_{peak}$ greater that $B_{sat}$, Magnetic Parts Editor increases the number of turns in the primary winding by factor proportional to and greater than $B_{peak}/B_{sat}$. |
| **11.** | Number of turns in the secondary winding ($N_s$) |
| **12.** | Wire gauge or Foil Width |
| **13.** | Number of strands in the winding wire or Foil thickness |

## Output power

The output power for a flyback converter is calculated as the product of current through the secondary winding and the voltage across secondary winding.

**(2-28)** $P = V_s \times I_s$

## Winding currents

This section covers the equations for calculating winding current through the primary and secondary windings of a flyback converter.

### Calculating average current

Average current through the windings is calculated using Equation 2-29 on page 55.

**(2-29)** $I_s = P/V_s$

**(2-30)** $I_p = P/(\eta \times V_p)$

where

| | |
|---|---|
| P | Output power, calculated using Equation 2-28 on page 55 |
| $I_s$ | Secondary current |
| $I_p$ | Primary current |
| $\eta$ | Efficiency |
| $V_s$ | Secondary voltage |
| $V_p$ | Primary voltage |

### Calculating peak current

#### *For primary winding*

Peak current for the primary winding is calculated using the equation given below.

**(2-31)** $$I_{ppeak} = \frac{2 \cdot P}{\eta \cdot V_p \cdot D}$$

where

| | |
|---|---|
| P | Output power |
| D | Maximum duty cycle |
| $\eta$ | Efficiency |
| $V_p$ | Primary voltage |

#### *For secondary winding*

**(2-32)** $$I_{spk} = \frac{2P}{(1-D) \cdot V_s}$$

where

| | |
|---|---|
| P | Output power |
| $V_s$ | Secondary voltage |
| D | Duty cycle for the input waveform |

### Calculating rms current

#### *For primary winding*

The rms current in the primary winding is given by the equation:

**(2-33)** $I_{prms} = I_{ppeak} \cdot \sqrt{D/3}$

where

| | |
|---|---|
| $I_{ppeak}$ | Peak current through the primary winding, calculated using Equation 2-31 on page 56 |
| D | Maximum duty cycle for the input waveform |

#### *For secondary winding*

Similarly, rms current in the secondary winding is calculated using the equation given below.

**(2-34)** $I_{srms} = I_{spk} \cdot \sqrt{(1-D)/3}$

where

| | |
|---|---|
| $I_{spk}$ | Peak current through secondary winding, calculated using Equation 2-32 on page 56 |
| D | Maximum duty cycle for the input waveform |

## Required primary inductance

The primary inductance required by a flyback transformer is calculated using the equation given below.

**(2-35)** $$L_p = \frac{{V_p}^2 \cdot D^2 \cdot T \cdot \eta}{2 \cdot P}$$

where

| | |
|---|---|
| $V_p$ | Voltage across primary winding |
| D | Maximum duty cycle for the input waveform |
| T | Time period (`1/f`) |
| $\eta$ | Efficiency |
| P | Output power |

## Turns in primary winding

If you have the inductance factor (`AL`) available, you can calculate number of turns in the primary winding using Equation 2-36 on page 58. If the `AL` value is not known, use Equation 2-37 on page 58 to calculate the number of turns in the primary winding.

**(2-36)** $$N = 10^3 \cdot \sqrt{\frac{L_p}{AL}}$$

**(2-37)** $$N = \frac{L_p \cdot I_{ppeak}}{B_{max} \cdot A_e}$$

where

| | |
|---|---|
| $L_p$ | Required Primary Inductance, calculated using Equation 2-35 on page 58 |

| | |
|---|---|
| AL | Inductance factor in mH/1000 turns |
| | (read from the database) |
| $I_{ppeak}$ | Peak current through the primary winding, calculated using Equation 2-31 on page 56 |
| $B_{max}$ | Maximum flux density for core |
| | (read from the database) |
| $A_e$ | Core cross-section area in $cm^2$ |
| | (read from the database) |

The flyback converter has an air gap in series with the core. This gives rise to fringing flux at the intersection of core and air gap. Because of the fringing flux, the effective cross-section area increases, thereby reducing the inductance through the primary winding. As a result, the actual number of turns required to achieve the required inductance, is more than the calculated value. Magnetic Parts Editor starts this iterative process by increasing the calculated value by 20%. Therefore, the number of turns in the primary winding used for successive calculations is given by Equation 2-38 on page 59.

Therefore, number of turns for the primary winding will be given by Equation 2-38 on page 59.

**(2-38)** $N_p = 1.2 \cdot N$

## Gap length

Flyback converters (and DC inductors) designed using Magnetic Parts Editor are gapped. This implies that the flyback converters have an air gap in series with the core. Gapped core structures increase the magnetizing force needed to reach saturation and lower the inductance of the flyback transformer (or inductor). As a result, a gapped flyback transformer (or inductor) can handle higher peak current values, and thus store more energy, most of which is stored in the magnetic field of the gap.

**Note:** You can specify the gap length as 0 cm, which will be treated as an infinitesimal number for all calculations.

For a flyback converter, Magnetic Parts Editor calculates the gap length using the equation given below.

**(2-39)** $$L_g = \frac{0.4 \cdot \pi \cdot N_p^{\ 2} \cdot A_e \cdot 10^{-8}}{L_p} - \frac{MPL}{\mu}$$

where

$N_p$ Number of turns in the primary winding
(calculated using Equation 2-38 on page 59)

$A_e$ Core cross-section area in $cm^2$
(read from the database)

$L_p$ Inductance of the primary winding
(calculated using Equation 2-35 on page 58.)

MPL Magnetic path length in cm
(read from the database)

$\mu$ Maximum permeability of the core material
(read from the database)

$L_g$ Gap length in cm

## Fringing flux coefficient (FFC)

### What is FFC?

The fringing flux decreases the total reluctance of the magnetic path, thus resulting in an increase in the inductance by a factor, FFC, called the fringing flux coefficient. To account for this increase in the inductance value, you need to calculate the modified number of turns in the primary winding, $N_m$.The FFC is calculated using the equation given below.

**(2-40)** $$\mathrm{FFC} = 1 + \frac{L_g}{\sqrt{A_e}} \ln\left(\frac{2G}{L_g}\right)$$

where

| | |
|---|---|
| $L_g$ | Gap length<br>(calculated using Equation 2-39 on page 60) |
| $A_e$ | Core cross-section area in $cm^2$<br>(read from the database) |
| G | Available winding height<br>(This is same as bobbin window height and is read from the database) |

### ***Calculating modified number of turns in the primary winding***

**(2-41)** $$N_m = \sqrt{\frac{L_g \cdot L_p}{0.4 \cdot \Pi \cdot 10^{-8} \cdot A_e \cdot \mathrm{FFC}}}$$

where

| | |
|---|---|
| $L_g$ | Gap length in $cm$<br>(calculated using Equation 2-39 on page 60) |
| $A_e$ | Core cross-section area in $cm^2$<br>(read from the core database) |
| FFC | Fringing flux coefficient<br>(calculated using Equation 2-40 on page 61) |
| $L_p$ | Primary inductance<br>(calculated using Equation 2-35 on page 58) |

## Peak flux density

For the calculated value of $N_m$, Magnetic Parts Editor calculates $B_{peak}$, using Equation 2-42 on page 62.

**(2-42)**

$$B_{peak} = \frac{0.4 \cdot \pi \cdot 10^{-4} \cdot N_m \cdot FFC \cdot (I_{ppeak})}{L_g + \frac{MPL}{\mu}}$$

where

| | |
|---|---|
| $N_m$ | Number of turns in the primary winding |
| | (calculated using Equation 2-41 on page 61) |
| $I_{ppeak}$ | Primary peak current |
| $L_g$ | Gap length |
| | (calculated using Equation 2-39 on page 60.) |
| FFC | Fringing flux coefficient |
| | (calculated using Equation 2-40 on page 61.) |
| MPL | Magnetic path length in cm |
| | (read from the database) |
| $\mu$ | Maximum permeability of the core material |
| | (read from the database) |

After calculating $B_{peak}$, Magnetic Parts Editor checks this value against $B_{sat}$. For $B_{peak}$ greater that $B_{sat}$, Magnetic Parts Editor increases the number of turns in the primary winding by a factor proportional to and greater than $B_{peak}/B_{sat}$. For this changed value for the number of turns in the primary winding, Magnetic Parts Editor recalculates $L_g$, FFC, and $B_{peak}$. This iterative process continues till for a particular $N_p$, $B_{peak}$ is less than $B_{sat}$.

### Turns in secondary winding

**(2-43)** $$N_s = \frac{N_m \cdot V_s \cdot (1-D)}{V_p \cdot D}$$

where

- $N_m$ Number of turns in primary

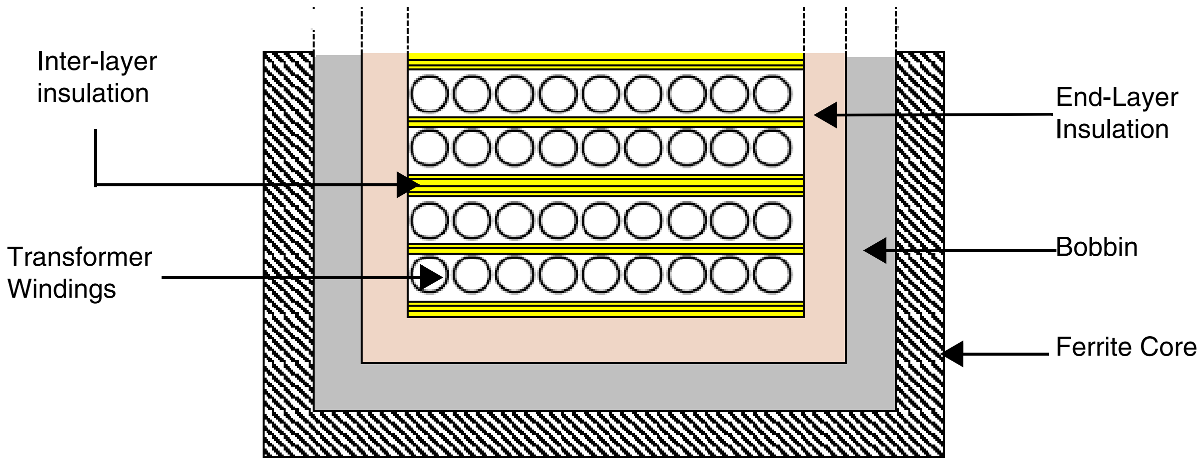
  (calculated using Equation 2-41 on page 61)
- $V_s$ Voltage across secondary winding
- D Duty cycle for the input waveform
- $V_p$ Primary voltage

## Selecting winding wire

While designing a transformer, you need to take care of the physical design of the transformer as well as the electrical parameters. These two factors are interlinked and one factor influences the other.

Irrespective of the type of magnetic component being designed, Magnetic Parts Editor follows a common procedure to select a winding wire for the magnetic component. Selecting a winding wire can be considered as a prerequisite for winding layout. This is so because as seen in Figure 2-1 on page 64, the size or the cross-section of the winding wire influences the winding layout.

**Figure 2-1 Transformer Design**




Before you start the winding layout, you must decide the size and the type of wire to be used for winding. Depending on the wire type selected, Magnetic Parts Editor performs some calculations to select a winding wire. The table below lists the values that are calculated by the Magnetic Parts Editor for each wire type.

| Wire Type | Magnetic Parts Editor calculates.. |
| --- | --- |
| Single | Wire gauge |
| Litz | ■ Wire gauge<br>■ Number of strands in the wire |
| Foil | ■ Foil thickness<br>■ Foil width |

## Wire gauge

For Single and Litz type of windings, Magnetic Parts Editor selects an appropriate wire gauge from the Magnetic Parts Editor database. This selection is based on the cross-sectional area of the wire.

The desired cross-section area is calculated by dividing the current flowing through the winding by the current density. Therefore, to select a wire gauge, you need to know the Winding current and the Wire cross-section area. These two values are calculated by

Magnetic Parts Editor using the inputs provided by you. After calculating the required cross-section area, Magnetic Parts Editor reads the database to select wires with cross-section area equal to or greater than the calculated area. If required, you can select different winding wire as opposed to the one selected by Magnetic Parts Editor.

### Wire cross-section area

To obtain the required cross-section area for the wire, divide the current flowing through the winding by the current density.

Therefore, required cross-section area for primary winding is equal to $I_p/J$.

**(2-44)** $$A_{crosssection} = \frac{I_1}{J}$$

where J is the current density specified by you.

Similarly, for each of the secondary winding, cross-section area is calculated as $I_s/J$.

### Selecting wire gauge

Using the cross-section area and the wire measurement standard specified by you, Magnetic Parts Editor reads the database to select an appropriate wire. The gauge number of the selected wire is displayed against each winding in the *Gauge* drop-down list box.

#### *Verifying the selection*

After you have selected the wire gauge, Magnetic Parts Editor validates your selection for the skin effect. Skin effect is a phenomenon observed in conductors. As a result of skin-effect, as you go below the surface of the conductor, the current density, $J$, decreases exponentially. The depth below the surface of the conductor at which the current is 1/e (about 0.37) times the current at the surface is called skin depth.

As per the design guideline, diameter of the selected wire should be less than twice the skin-depth of the wire at the operating frequency.

### *Calculating Skin Depth*

Skin-depth, $d$, is calculated using Equation 2-45 on page 66.

**(2-45)** $$d = \sqrt{\frac{2\rho}{\omega\mu}}$$

where

| | |
|---|---|
| $\rho$ | resistivity of conductor<br>= $1.67 \times 10^{-5}$ Ohm-mm, for copper |
| $\omega$ | angular frequency of current<br>= $2\pi \times$ frequency in MegaHertz |

The skin depth for copper wire is calculated using the equation given below.

**(2-46)** $$d = \left(\frac{66.2}{\sqrt{f}}\right)$$

where

| | |
|---|---|
| `d` | skin depth in meters (mm) |
| `f` | operating frequency in Hertz (Hz) |

If the condition `diameter(without_insulation)<2d` is not satisfied, Magnetic Parts Editor displays a warning message in the Message pane. In such cases, it is recommended that instead of single wire, Litz type of wire should be used as the winding wire, where multiple wires are used parallel to get required cross-section area.

## Number of strands (Litz only)

For Litz type windings, besides the wire gauge, Magnetic Parts Editor also calculates the number of strands to be used in parallel in the winding wire.

The steps for calculating the number of strands are:

1. Calculate the winding current, using equations described in section, Winding current on page 41.
2. Calculate the required cross-sectional area using equations described in section, Wire cross-section area on page 65.
3. Select a wire from the database that has diameter nearest to, but less than twice the skin depth for the wire:
4. Calculates the number of strand using the formula:

**(2-47)** `Number_of_strands`
`= Required Area/Area_of_single strand`

The number of strands calculated is displayed in the Strands column against each of the windings.

*Important*

The number of wires in parallel impacts the window utilization. Higher the number of wires, lesser is the utilization. To take care of this, a separate multiplier, $K_{adj}$, is used while calculating turns per layer using Equation 3-2 on page 75.

## Foil winding calculations

For foil type of winding, you need to calculate the thickness and width of the foil to be used as the winding.

### Foil thickness

To calculate the foil thickness, Magnetic Parts Editor first calculates the required cross-section area of the foil using Equation 2-44 on page 65. The required cross section area is then used to calculate foil thickness, using Equation 2-48 on page 68.

**(2-48)** $oilThickness = \frac{FoilCrossSectionArea}{AvailableWindowHeight}$

### Foil width

For EE and UU cores, foil width is calculated using Equation 2-49 on page 68.

**Note:** Magnetic Parts Editor does not support Foil winding for Toroid cores.

**(2-49)**
$oilWidth = AvailableWindowWidth - 2EndInsulatio$

## Summary

This chapter covered the equations used by Magnetic Parts Editor to calculate winding currents and number of turns required for primary and secondary windings. For these calculations the data is either read from the database or is provided by you as inputs. Depending on the transformer topology, different equations and formulas were used to derived these values. Based on the winding current, transformer winding wire is selected, such that the selected wire has:

a. cross-section area equal to or greater than the required area, and

b. diameter less than two times the skin depth of the wire.

Table 2-4 on page 68 lists the design parameters that are calculated by the Magnetic Parts Editor for each type of transformer, using same or different equations. Some of the values computed by Magnetic Parts Editor are displayed at appropriated columns in the Manufacturer Report.

**Table 2-4 Winding Layout Properties**

| Parameters | Comments... |
|---|---|
| Window Area Product ($W_aA_e$) | See Equation 2-1 on page 38 |
| Wire gauge | See Wire gauge on page 64 |

**Table 2-4 Winding Layout Properties,** *continued*

| Parameters | Comments... |
|---|---|
| Number of turns in the primary ($N_p$) and secondary ($N_s$) winding | Depends on the transformer topology |
| Current through primary ($I_p$) and secondary ($I_s$) winding | Depends on the transformer topology |
| Number of strands | Number of strands (Litz only) on page 67 |
| Foil height and width | Foil winding calculations on page 67 |

# 3

# Winding Layout

This chapter provides you an overview of the winding layout process. It also provides you an insight to the winding layout design steps that are completed by Magnetic Parts Editor. Topics included in this chapter are:



## Process Overview

You now have the physical dimension of the winding wire and the number of turns for both primary and secondary windings. For winding layout, you need to compute the transformer properties listed below.

- End insulation
- Number of winding layer
- Inter layer insulation

**Note:** Magnetic Parts Editor does not support split-windings.

To successfully perform the tasks listed above, Magnetic Parts Editor needs appropriate information in form of inputs. Some of the these inputs are provided by you, for rest of the parameters, Magnetic Parts Editor reads the values from the database.

| **Inputs required** | **Provided by...** | **Inputs required** | **Provided by...** |
|---|---|---|---|
| Operating flux density $(B)$ | User or calculated by Magnetic Parts Editor | Operating Frequency $(f)$ | User |
| Primary Voltage $(V_p)$ | User | Secondary Voltage $(V_s)$ | User |
| Core cross-section area $(A_e)$ | Magnetic Parts Editor database | Insulation Breakdown voltage (per unit length) | Magnetic Parts Editor database |

# End insulation

End insulation is the insulation used between the core and the winding. The thickness for the end insulation depends on two factors, the peak voltage in the winding and the breakdown voltage of the insulation material.

For end insulation, you need to know the following.

1. Insulation thickness required

   To compute the required insulation thickness, divide the peak winding voltage by the breakdown voltage of the insulation material used.

**(3-1)** $$\text{nsulationThickness} = \frac{V_{peak}}{V_{InsulatorBreakdo}}$$

   **Note:** For a sine wave power transformer, the peak voltage can be calculated from the rms voltage using the equation, $V_{peak} = \sqrt{2} \cdot V_{rms}$ .

   The breakdown voltage of an insulator is the maximum voltage per unit length that the insulator can withstand. For the selected insulation material, this value is available in the Magnetic Parts Editor database

2. Number of insulation layers required to attain required thickness

Commercially, each insulation material is available in form of sheets of fixed thickness. You can use multiple insulation sheets in parallel, To achieve the required insulation thickness.

### *Example*

What should be the end insulation for the primary winding of a sine wave power transformer, that uses Nylon as the insulation material and Input Voltage as 1KV.

**Note:** To get a solution for the above scenario, we will refer the entries in the Magnetic Parts Editor database to obtain the properties of the insulation material used.

### *Solution:*

For the given input, the maximum voltage across the primary winding is $V_{ppeak}$.

$$V_{ppeak} = \sqrt{2} \times 1000$$

From the Magnetic Parts Editor database, the breakdown voltage of nylon is 700 V/mm and it is commercially available as sheets of 0.2 mm, 0.5 mm and 1mm.

Therefore, required insulation thickness is:

$$nsulationThickness = \frac{\sqrt{2} \cdot 100}{700}$$

= 2.02 mm

This can be realized by using 11 sheets of 0.2mm in parallel, or by using 5 sheets of 0.5mm in parallel, or by using 3 sheets of 1mm in parallel. Of these, the nearest combination is using 11 sheets of .2mm in parallel. Therefore, the effective insulation thickness between core and winding is (`11*0.2`) `2.2mm`.

# Winding layers

Having calculated the number of turns in the primary winding and in the secondary winding, the next step is to find out the number of layers required to accommodate these windings.

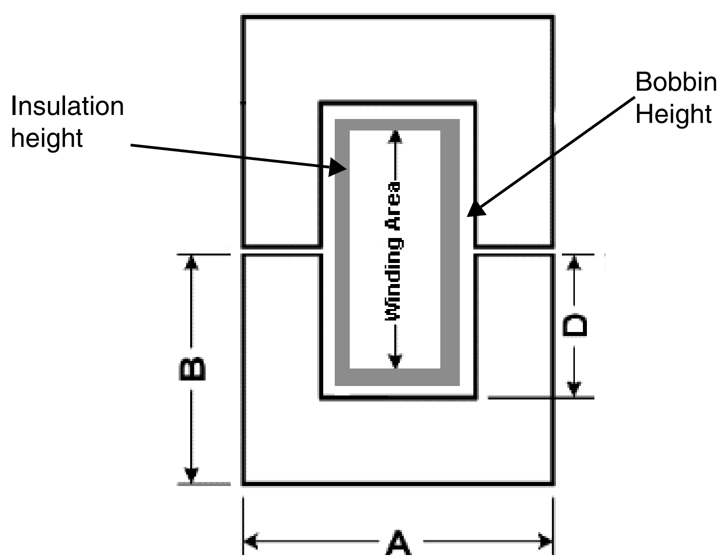
To arrive at the number of layers required for the primary and secondary windings, Magnetic Parts Editor follows the steps listed below.

1. Compute the window height available for winding.
2. Compute turns per layer
3. Calculate number of layers

## Window height

The winding height, $H_{wdg}$, is the space available for the transformer windings. See Figure 3-1 on page 74.

**Figure 3-1 $H_{wdg}$ in a transformer with UU core**



*Caution*

***Winding area in influenced by the shape of the core and bobbin.***

***For EE and UU cores***

For Figure 3-1 on page 74, winding area is calculate using the equation given below.

$$H_{wdg} = CoreWindowHeight - 2EndIndsulationThickness - 2BobbinThickness$$

***For Toroid cores***

$$H_{wdg} = CoreWindowHeight - EndIndsulationThickness$$

## Turns per layer

Number of winding turns that can be accommodated in a single layer is calculated using the formula given below.

**(3-2)** Turns/layer

$$INT(\frac{WindingHeight}{DiameterOverInsulation} \cdot K_{adj} \cdot K_{litz}$$

where

$K_{adj}$ = 0.95 if turns/layer >= 50

= 0.9 if 10< turns/layer < 50

= 0.85 if turns/layer = < 10

$K_{litz}$ = 1 for single wire

= (1/number of strands) for multiple wires in parallel

*Important*

For Litz type wires, DiameterOverInsulation is the product of diameter of the wire including insulation and the number of strands in the litz wire.

*Caution*

***The INT function used in** Equation 3-2 **on page 75 returns an integer value that is nearest to and smaller than the parameter value. For example, if the calculated number of turns per layer is 9.7, the value returned by the INT() would be 9. This is so because in real world we cannot have fractional turns in a layer. Therefore, the maximum turns per layer will be an integer value less than the calculated value.***

## Number of Layers

To obtain total number of winding layers, divide the number of turns in the winding, calculated in section, Turns per winding, by the number of turns per layer, calculated in the Turns per layer section.

Therefore, for the primary winding,

**(3-3)** Number of layers = $N_p$/turns per layer for primary

Similarly, for secondary winding,

**(3-4)** Number of layers = $N_s$/turns per layer for secondary

# Inter Layer insulation

Having decided the number of winding layers for the primary and the secondary winding, you also need to finalize on the thickness of insulation material to be used between two consecutive winding layers. The insulation thickness between two consecutive layers is effected by the voltage buildup between two layers. Voltage buildup can be defined as the maximum possible voltage difference between two winding layers.

For example, for a sine wave power transformer, voltage build up is calculated as:

$$\mathrm{oltageBuildup} = 2\sqrt{2} \times \mathrm{TurnsPerLayer} \times \mathrm{VoltsPerTur}$$

As in case of end insulation, here also the required insulation thickness is obtained by dividing the voltage buildup by the breakdown voltage of the insulator.

**(3-5)**

$$\mathrm{erLayerInsulation} = \frac{\mathrm{VoltageBuildup}}{\mathrm{InsulationBreakdownVolta}}$$

# Winding Buildup

The final step in designing the winding layout is to calculated the winding buildup. Winding buildup is the total height of the winding layers, obtained after the winding layout is complete. For the success for the design process, winding buildup must be less than the available window height, $H_{wdg}$, calculated in the section Window height on page 74.

For example, for an EE core, winding buildup is calculated as,

$$\mathrm{BLDP} = N_L \times \mathrm{Insulated}, D_w + (N_L - 1) \times \mathrm{InterLayerInsulatio}$$

where

| | |
|---|---|
| $N_L$ | Number of winding layers |
| Insulated, $D_w$ | Diameter of the insulated winding wire |

InterLayerInsulation Calculated using Equation 3-5 on page 77

## Summary

This chapter introduced you to the factors that influence the winding layout in a transformer. Table 3-1 on page 78 lists the winding layout parameters, along with the links to the equations used by the Magnetic Parts Editor to calculate these parameter values. The values computed by Magnetic Parts Editor are displayed at appropriated columns in the Manufacturer Report.

**Table 3-1 Winding Layout Properties**

| Property | Calculated using.. | Property | Calculated using.. |
|---|---|---|---|
| End insulation | Equation 3-1 on page 72 | Turns per layer | Equation 3-2 on page 75 |
| Number of layers for primary | Equation 3-3 on page 76 | Number of layers for secondary | Equation 3-4 on page 76 |
| Inter layer insulation | Equation 3-5 on page 77 | | |

# 4

# Performance Parameters

In this chapter, you will learn about the factors that influence the performance of a transformer and are therefore, also considered as a measure of the transformer performance. The topics covered in this chapter are:



## Transformer Losses

Power losses in a transformer are mainly due to Core Loss and Copper Loss. These losses are common in all types of transformers.

*Important*

In this version of Magnetic Parts Editor, Proximity losses have not been accounted for.

### Copper Loss

Copper loss is defined as the power lost due to the ohmic resistance of the windings. Copper loss of a transformer is the sum of copper losses for each windings. Total copper loss in a transformer, can be found using Equation 4-1 on page 79.

**(4-1)** $$P_{cu} = I_p^2 \cdot R_p + I_s^2 \cdot R_s$$

where

| | |
|---|---|
| $I_p$ | Current through primary winding |
| $R_p$ | Resistance of the primary winding |
| $I_s$ | Current through secondary winding |
| $R_s$ | Resistance of the secondary winding |

For calculation of copper loss we need $I_{rms}$ and resistance for each winding.

### *Calculating winding resistance*

Resistance of each winding can be calculated by using cross-section area of wires, length of wire, and resistively of copper. The resistivity of copper is read from the template file.

**Note:** If the diameter of the selected wire is more than twice the skin depth at operating frequency, AC resistance will deviate from DC resistance.

**(4-2)** $$R = \frac{\zeta L}{A}$$

where

| | |
|---|---|
| $\zeta$ | Resistivity of the conductor |
| L | Length of the wire |
| A | Cross-section area for the wire (without insulation) |

### *Calculating L, length of the wire*

The length of the wire is calculated using the equation given below.

**(4-3)**

$$= \sum_{n=1}^{n=n-1} MeanTurnLengthforLayer(n) \times (turns)/(layer$$

The MeanTurnLength for each layer depends on the bobbin shape.

***For rectangular bobbin***

**(4-4)** `Mean Turn length`
`= 2*(bobbin_len+bobbin_wid+2*n*OD)`

where OD is the outer diameter of the winding wire with insulation

***For toroid cores***

**(4-5)** `Mean Turn length`
`= ((OD-ID)+core_height + 2*n*OD)*2`

## Core Loss

Core losses in a transformer is the sum of hysteresis loss and eddy current losses. Hysteresis loss is the energy loss because of the reversing magnetic fields in the core. Eddy current loss is the power lost as a result of induced currents circulating in the core.

Core loss is a function of the material used for core construction. Depending on the material type and the core vendor, different equations are used for calculating core loss.

For calculating core loss, most of the vendors use the empirical formula listed below.

$$(mW)/cm^3 = a \cdot f^c \cdot B_{ac}{}^d$$

Values of empirical coefficients a, c, and d depending on the core vendor, magnetic material used for core construction, and the units used by the vendor to specify the core loss values.

For ferrite cores, Magnetic Parts Editor calculates core loss using the set of equations given below.

**(4-6)** $$CoreLoss = CoreWeight \times (Watt)/(KG)$$

**(4-7)** $$(Watts)/(KG) = 8.64 \times 10^{-7} \cdot f^{1.834} \cdot B_{ac}^{2.112}$$

where

| | |
|---|---|
| f | operating frequency is in Hertz (Hz) |
| $B_{ac}$ | AC component of Magnetic flux density (Tesla)<br>This value is calculated differently for different transformer topologies, see the section on Calculating AC flux density ($B_{ac}$). |

Core loss can also be calculated using the set of equations given below.

**(4-8)** $$CoreLoss = CoreVolume \times (mW)/cm^3$$

**(4-9)** $$(mW)/cm^3 = a \cdot f^c \cdot B_{ac}^d$$

where

| | |
|---|---|
| a, c, d | empirical coefficients obtained from datasheets provided by vendors |
| f | operating frequency, specified in KiloHertz (KHz) |
| $B_{ac}$ | AC component of Magnetic flux density, specified in KiloGauss |

*Tip*

1 tesla = 10 KiloGauss

**Note:** For cores provided by Magnetics, the coefficient values are known to the Magnetic Parts Editor. For cores provided by other vendors, Magnetic Parts Editor extracts the values of the empirical coefficients based on the core loss values entered by you in the material database.

### Calculating AC flux density ($B_{ac}$)

#### *Power Transformer*

Same as operating flux, which is equal to `0.75*B`$_{sat}$.

#### *Forward converters*

For Forward converters, $B_{ac}$ is calculated using the equation given below.

**(4-10)** $$B_{ac} = \frac{4 \cdot \pi \times 10^{-5} \cdot N_p \cdot \frac{I_{mag}}{2} \cdot \mu_i}{MPL}$$

where

| | |
|---|---|
| $N_p$ | Number of turns in the primary winding<br>(Calculated using Equation 2-15 on page 47) |
| $I_{mag}$ | Magnetizing current<br>(Calculated using Equation 2-24 on page 51) |
| MPL | Magnetic path length in `cm`<br>(read from the material database) |
| $\mu_i$ | Initial permeability of the core material<br>(read from the material database) |

### *Flyback converter*

**(4-11)**

$$B_{peak} = \frac{4 \cdot \pi \times 10^{-5} \cdot N_m \cdot (I_{ppeak}) \cdot FFC}{\frac{MPL}{\mu_i} + l_g}$$

where

| | |
|---|---|
| $I_{ppeak}$ | Primary peak current |
| MPL | Magnetic path length in cm (read from the database) |
| $N_m$ | Number of turns in the winding (calculated using Equation 2-41 on page 61) |
| $L_g$ | gap length in cm |
| $\mu_i$ | Initial permeability |
| FFC | fringing flux coefficient |

### *DC Inductor*

**(4-12)**
$$B_{ac} = \frac{4 \cdot \pi \times 10^{-5} \cdot N_m \cdot \frac{I_{ac}}{2} \cdot FFC}{\frac{MPL}{\mu_i} + l_g}$$

where

| | |
|---|---|
| $I_{ac}$ | AC current (user input) |
| MPL | Magnetic path length in cm (read from the database) |
| $N_m$ | Number of turns in the winding (calculated using Equation 5-7 on page 94) |
| $L_g$ | gap length in cm |
| FFC | fringing flux coefficient |

For all non-ferrite cores, an empirical formula derived from the core-loss values entered in the Magnetic Parts Editor database is used. See Add material information on page 142.

# Transformer Efficiency

Transformer efficiency can be calculated using Equation 4-13 on page 85.

**(4-13)** $$\eta = \frac{P_{out}}{CopperLoss + CoreLoss + P_{out}}$$

# Temperature Rise

### *Calculating Temperature rise*

**(4-14)** $T_{rise} = 450*(\text{Watt Density})^{0.826}$

where Watt Density is calculated using the equation given below.

**(4-15)** Watt Density = Total Loss/core surface area

Unit of measurement for these values are:

| | |
|---|---|
| $T_{rise}$ | °C |
| Total Loss | W (Watts) |
| Core Surface Area | $cm^2$ |

# Leakage Inductance

Leakage inductance ($L_{leak}$) represents energy stored in the non-magnetic regions between windings, caused by imperfect flux coupling. In the equivalent electrical circuit, leakage inductance is in series with the windings, and the stored energy is proportional to square of the load current. Leakage inductance is influenced by the physical layout of the winding. Magnetic Parts Editor support simple winding layout, where complete winding height is available for windings and winding are done on top of each other. For such a layout, $L_{leak}$ is calculated using Equation 4-16 on page 86.

**(4-16)** $$L_{leak} = \left(\mu_0 \cdot 10^{-2} \cdot {N_p}^2 \cdot \frac{MLT}{H_{wdg}}\right) \times \frac{BLDP}{3}$$

where

| | |
|---|---|
| $N_p$ | Number of turns in the primary winding |
| MLT | Average mean turn length (cm) |
| $H_{wdg}$ | Winding window height (cm) |
| BLDP | Copper buildup including insulation (cm) |
| $\mu_o$ | $4\pi 10^{-7}$ henry/m |

## Voltage Regulation

**Note:** Magnetic Parts Editor calculates voltage regulation only for power transformers.

Voltage regulation is the measure of how well a power transformer maintains constant secondary voltage over a range of load currents. It is defined as per unit drop in voltage at transformer output terminal at full load in comparison to the no load voltage.

Magnetic Parts Editor uses Equation 4-17 on page 86 to calculate the voltage regulation.

**(4-17)** $$'oltageRegulation = \left(1 - \frac{V_{drop}}{V_{noload}}\right) \times 10(\%$$

where

| | |
|---|---|
| $V_{noload}$ | $V_p$ ($V_{in}$) |
| $V_{drop}$ | voltage drop from no load to full load |
| | calculated using Equation 4-21 on page 88 |

The full load voltage is influenced by the winding resistance and the series reactance, which is due to the leakage flux.

### *Winding resistance referred to primary*

In the section Calculating winding resistance on page 80, you calculated the resistance of individual windings. To calculated the net effective resistance of all transformer windings, calculate the effect of the secondary winding resistance on the primary winding. The combined effective resistance of the two windings is calculated using Equation 4-18 on page 87.

**(4-18)** $$R_{wdg} = R_p + R_s \cdot \left(\frac{V_p}{V_s}\right)^2$$

where

| | |
|---|---|
| $R_p$ | Primary winding resistance |
| $R_s$ | Secondary winding resistance |
| $V_p$ | Voltage across primary winding |
| $V_s$ | Voltage across secondary winding |

### *Calculating leakage reactance*

To calculate the leakage reactance, you need the leakage inductance ($L_{leak}$). Leakage inductance is calculated using Equation 4-16 on page 86.

Leakage reactance ($X_{leak}$) is calculated using the equation given below.

**(4-19)** $$X_{leak} = \omega L_{leak} = 2\pi f L_{leak}$$

where

| | |
|---|---|
| f | operating frequency |

| | |
|---|---|
| $L_{leak}$ | Leakage inductance |

Using the effective winding resistance and leakage reactance, you can calculate final impedance.

**(4-20)** $$Z_{final} = \sqrt{R_{wdg}^2 + X_{leak}^2}$$

The voltage drop, as current changes from no load to full load voltage can now be calculated as the product of final impedance and current through the primary.

**(4-21)** $$V_{drop} = I_p \cdot Z_{final}$$

You can now use the value of $V_{fullload}$ in Equation 4-17 on page 86, to calculate voltage regulation for a power transformer.

# Percentage window occupied

The percentage window occupied is measure of the window area utilized for conducting electricity. Window occupied percentage is calculated using Equation 4-22 on page 88.

**(4-22)** $$WindowOccupied = \frac{AreaOccupiedbyCopper}{TotalWindowArea} \times 100$$

The area occupied by copper is calculated as the area occupied by the conductor. For each winding, the area occupied by copper is calculated using the equation given below. The total area occupied by copper is the sum of area occupied by copper for individual windings.

**(4-23)**

$$AreaOccupiedbyCopper = \frac{I_{rms}}{J} \times NumberOfTurns$$

**Note:** For foil type winding, number of turns is equal to the number of winding layers.

## Summary

In this chapter, you were introduced to the equations used by Magnetic Parts Editor to calculate the parameters that influence the performance of the components designed using Magnetic Parts Editor. Table 4-1 on page 89 lists the performance parameters along with the links to the equations used to calculate these parameters.

**Table 4-1 Performance parameters for magnetic components**

| Parameter.. | Calculated using.. | Parameter... | Calculated using... |
|---|---|---|---|
| Copper loss | Equation 4-1 on page 79 | Efficiency | Equation 4-13 on page 85 |
| Core loss | Equation 4-6 on page 82 | Temperature rise | Equation 4-14 on page 85 |
| Leakage Inductance | Equation 4-16 on page 86 | Voltage Regulation | Equation 4-17 on page 86<br>**Note:** Only for power transformers |

# 5

# Designing DC Inductors

This chapter describes the process for designing DC inductors. DC inductors are different from transformers in the sense that they have only one winding.

You can use Magnetic Parts Editor to design a DC inductor that operates in the continuous conduction mode. The steps for designing a DC inductor using Magnetic Parts Editor are:

1. Provide input specifications
2. Select a core.
3. Calculate number of turns required to achieve the required inductance.
4. Calculate air gap.
5. Calculate fringing flux coefficient.
6. Ensure that the peak flux density is less than the saturation flux density.
7. Design winding layout.
8. Calculate performance parameters, such as copper loss, core loss, and efficiency.

## Selecting a core

To select a core for the DC inductor, Magnetic Parts Editor uses the value of window area product ($W_aA_e$). For a DC inductor, $W_aA_e$ is calculated using the equation given below.

**(5-1)** $$W_a A_e = \frac{L \cdot I_{pk} \cdot I_{rms}}{J \cdot K \cdot B} \times 10^4 \text{ cm}^4$$

where

| | |
|---|---|
| L | Required Inductance in H (user input) |
| $I_{pk}$ | Peak current |
| | Calculated using Equation 5-2 on page 92. |
| $I_{rms}$ | RMS current |
| | Calculated using Equation 5-3 on page 92. |
| J | Current density in Amp per $cm^2$ |
| B | 0.75 $B_{sat}$ |
| K | 0.5 |

**(5-2)** $$I_{pk} = I_{dc} + \frac{I_{ac}}{2} \text{ amp}$$

**(5-3)** $$I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2} \text{ amp}$$

where

| | |
|---|---|
| $I_{dc}$ | DC current through the inductor (user input) |
| $I_{ac}$ | AC current through the inductor (user input) |

## Winding turns

In a DC inductor, the number of turns in the winding is directly proportional to the required inductance. The minimum number of turns required to achieve the desired inductance is calculated using the equation given below.

**(5-4)** $$N = \frac{L \cdot I_{pk}}{B \cdot A_e} \times 10^4$$

where

L Required inductance (user input)

$I_{pk}$ Peak current

calculated using Equation 5-2 on page 92.

B Operating flux density

By default, it is set to `0.75 *B`$_{sat}$.

$A_e$ Core cross-section area in $cm^2$

(read from the Magnetic Parts Editor database)

# Gap Length

Using Magnetic Parts Editor you design DC Inductor operating in the continuous induction mode. In continuous induction mode, the length of the air gap is calculated using the equation given below.

**(5-5)** $$L_g = \frac{0.4 \cdot \pi \cdot N \cdot N \cdot A_e \cdot 10^{-8}}{L} \text{ cm}$$

where

N Number of turns in the primary winding

(calculated using Equation 5-4 on page 93)

$A_e$ Core cross-section area in $cm^2$

L Required Inductance (user input)

## Fringing flux

While designing a magnetic part with an air gap, you need to account for the stray flux associated with the air gap. Stray flux is due to the energy stored in a fringing field outside the air gap. Because of this fringing field, the effective gap area is larger than the core center-pole area. To avoid design errors, you need to analyze the effect of the increased area on various design parameters. The effect of fringing flux on the inductor design is accommodated using an electrical parameter called fringing flux coefficient (FFC). In Magnetic Parts Editor, FFC for a DC inductor is calculated using the equation given below.

**(5-6)** $$FFC = 1 + \frac{L_g}{\sqrt{A_e}} \ln\left(\frac{2G}{L_g}\right)$$

where

$L_g$ Gap length

(calculated using Equation 5-5 on page 93)

$A_e$ Core cross-section area in $cm^2$ (read from the database)

G bobbin window height (read from the database)

To accommodate the change in inductance due to an increase in the effective air gap area, the number of turns in the inductor winding is changed. The modified number of turns is calculated using the equation given below.

**(5-7)** $$N_m = \sqrt{\frac{L_g \cdot L}{\mu_0 \cdot A_e \cdot FFC}}$$

where

$L_g$ Length of the air gap, calculated using Equation 5-5 on page 93.

| | |
|---|---|
| L | Required Inductance<br>(Input value) |
| $\mu_0$ | Permeability constant, $4\pi*10^{-7}$ (Henry/meter) |
| $A_e$ | Core cross-section area in $cm^2$ |
| FFC | Fringing Flux Coefficient, calculated using<br>Equation 5-6 on page 94. |

## Selecting Winding wire

The procedure for selecting a wire gauge for the inductor winding is same as the procedure for selecting transformer winding wire.

1. Calculate required cross-section area $(I_{rms} / J)$
2. Select a wire from the database.
3. Check for skin effect.
   a. Calculate skin depth (d) using Equation 2-45 on page 66.
   b. Verify that the diameter of the selected wire is less than twice the skin depth (2d).
   c. If diameter of the selected wire (without insulation) is greater than 2d, select a different wire that satisfies the 2d criteria.
4. Calculate the number of strands required to achieve the required cross-section area. See Equation 2-47 on page 67.

# Winding Layout

To design the winding layout for a DC inductor, following steps are performed.

1. Calculate end insulation.
2. Calculate available winding height, $H_{wdg.}$
3. Calculate number of turns per layers.
4. Calculate number of layers required.
5. Calculate inter layer insulation.

## End insulation

To calculate end insulation, first calculate maximum voltage and then decide the thickness of the insulation material required to withstand the maximum voltage.

### Calculating peak voltage

For DC inductors, maximum voltage is calculated using the equation given below.

**(5-8)** $V_{peak} = L \cdot I_{pk} \cdot f / 0.5$ volts

where

| | | |
|---|---|---|
| $I_{pk}$ | Peak current through the winding, calculated using Equation 5-2 on page 92. | |
| L | Required Inductance | (user input) |
| f | Operating frequency | |

### Calculating insulation thickness

The insulation thickness is calculated using Equation 3-5 on page 77.

$$\mathrm{sulationThickness} = \frac{V_{peak}}{V_{InsulatorBreakdo}}$$

## Interlayer insulation

Interlayer insulation is the insulation required between two consecutive winding layers. To calculate the required insulation thickness, you first calculate maximum voltage different between two winding layers.

### Calculating layer voltage

**(5-9)** $$V_{layer} = \frac{V_{peak}}{\mathrm{NumberOfLayers}}$$

where

| | |
|---|---|
| $V_{peak}$ | Maximum voltage, calculated using Equation 5-8 on page 96 |
| Number of layers | Number of winding layers |

### Calculating insulation thickness

**(5-10)**

$$\mathrm{sulationThickness} = \frac{2 \cdot V_{layer}}{V_{InsulationBreakdo}}$$

# Performance parameters

This section covers the procedure involves for calculating the copper loss and the core loss in a DC inductor.

## Copper Loss

Copper loss is calculated using the equation given below.

**(5-11)** $P_{cu} = I_{rms}^{2} \cdot R$

where

| | |
|---|---|
| I | current through the inductor |
| R | wInding Resistance |

Winding resistance R, is calculated as

**(5-12)** $R = \frac{\zeta L}{A}$

where

| | |
|---|---|
| $\zeta$ | Resistivity of the winding material |
| L | Length of the winding wire |
| A | cross-section area of the wire (without insulation) |

## Core Loss

The core loss in a DC Inductor depends on the AC flux density.

### *Calculating $B_{ac}$*

**(5-13)** $$B_{ac} = \frac{4 \cdot \pi \cdot 10^{-5} \cdot N_m \cdot FFC \cdot (I_{ac}/2)}{L_g + \frac{MPL}{\mu_i}}$$

where

| | |
|---|---|
| $N_m$ | Number of turns in the primary winding<br>(calculated using Equation 5-7 on page 94) |
| $L_g$ | gap length in cm<br>(calculated using Equation 5-5 on page 93.) |
| FFC | Fringing flux coefficient<br>(calculated using Equation 5-6 on page 94.) |
| MPL | Magnetic path length in cm<br>(read from the database) |
| $\mu_i$ | initial permeability of the core material<br>(read from the database) |

### *Calculating Core loss*

Core loss in a DC Inductor is calculated using the equations given below.

**(5-14)** $$CoreLoss = CoreWeight \times (Watt)/(KG)$$

**(5-15)** $$(Watts)/(KG) = 8.64 \times 10^{-7} \cdot f^{1.834} \cdot B_{ac}^{2.112}$$

where

f operating frequency (in Hertz)

$B_{ac}$ AC component of Magnetic flux density (Tesla)

# Design Example

This section covers the steps for designing a DC Inductor with given specifications.

| | |
|---|---|
| Inductance, $L$ | 0.0024 henrys |
| DC current, $I_{dc}$ | 2 amp |
| AC current, $I_{ac}$ | 0.1 amp |
| Current Density, $J$ | 300 amp-per-cm$^2$ |
| Operating Frequency, $f$ | 100 kHz |
| Core Material | P (from Magnetics) |
| Core shape | EE core |
| Window utilization, k | 0.5 |

### Step 1: Calculate the peak current, $I_{pk}$

Using Equation 5-2 on page 92,

$$I_{pk} = I_{dc} + \frac{I_{ac}}{2} \text{ amp}$$

$$I_{pk} = 2 + \frac{0.1}{2} \text{ amp}$$

$$I_{pk} = 2.05 \text{ amp}$$

### Step 2: Calculate rms current $I_{rms}$

Using Equation 5-3 on page 92,

$$I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2}$$

$$I_{rms} = \sqrt{0.1^2 + 2^2}\ \text{amp}$$

$$I_{rms} = \sqrt{4.01}\ \text{amp}$$

$$I_{rms} = 2.0025\ \text{amp}$$

**Step 3: Calculate Window Area Product, $W_aA_e$**

Using Equation 5-1 on page 92,

$$W_aA_e = \frac{L \cdot I_{pk} \cdot I_{rms}}{J \cdot K \cdot B} \times 10^4$$

$$W_aA_e = \frac{(0.0024) \cdot (2.05) \cdot (2.0025)}{(300) \cdot (0.5) \cdot (0.375)} \times 10^4$$

$$W_aA_e = 1.7515\ \text{cm}^4$$

Converting the area product to $mm^4$, we get,

$$W_aA_e = 1.7515 \times 10^4\ \text{mm}^4$$

$$W_aA_e = 17.515 \times 10^3\ \text{mm}^4$$

**Step 4: Select core from the Magnetic Parts Editor database**

The properties of the EE- core with the nearest area product are listed below.

| | |
|---|---|
| Part Number | 44016-EC |
| Core Volume | 10.5k $mm^3$ |

| | |
|---|---|
| Magnetic Path Length, MPL | 98.4 mm |
| Core Cross-Section Area, $A_e$ | 106 $mm^2$ |
| Core Weight | 52 grams |
| Area Product, $W_a A_e$ | 20.8k $mm^4$ |
| Surface Area | 3.99752k $mm^2$ |
| Window Height | 30 mm |
| Window Width | 9.54 mm |
| Inductance Factor, AL | 2.18k mH/1000 $turns^2$ |
| Core $L_x$ | 11.9 mm |
| Core $L_y$ | 9 mm |

### Step 5: Calculations using bobbin dimensions

The core selected in the previous step in an EE core. Bobbin dimensions calculated using the default value of bobbin thickness, T, are listed in Table 5-1 on page 103.

**Table 5-1 Bobbin Properties**

| Property | Value |
|---|---|
| Bobbin Thickness, T | 1 mm |
| Bobbin $L_x$ | Core $L_x$ + 2T |
| | = 11.9 + 2*1 |
| | = 13.9 mm |
| Bobbin $L_y$ | Core $L_y$ + 2T |
| | = 9 + 2*1 |
| | = 11 mm |
| Window Width ($W_w$) available for winding | $W_w$-T |
| (this is same as bobbin window width) | = 9.54-1 |
| | = 8.54 mm |

**Table 5-1 Bobbin Properties**

| Property | Value |
|---|---|
| Window Height ($H_w$ or G) available for winding | $H_w$-2T |
| (this is same as bobbin window height) | = 30-2*1 |
| | = 28 mm |

**Step 6: Calculate winding turns, N**

Using Equation 5-4 on page 93,

$$N = \frac{L \cdot I_{pk}}{B \cdot A_e} \times 10^4$$

$$N = \frac{(0.0024) \cdot (2.05)}{(0.375) \cdot 106 \times 10^{-2}} \times 10^4$$

$$N = 1.2377 \times 10^2$$

$$N = 123.77$$

$$N = 124$$

**Step 7: Calculate gap length, $L_g$**

Using Equation 5-5 on page 93,

$$L_g = \frac{0.4 \cdot \pi \cdot N \cdot N \cdot A_e \cdot 10^{-8}}{L}$$

$$L_g = \frac{0.4 \cdot \pi \cdot 124 \cdot 124 \cdot 1.06 \cdot 10^{-8}}{0.0024}$$

$$L_g = 0.0853390 \text{ cm}$$

$$L_g = 0.0853390 \times 10^{-2} \text{ m}$$

$$L_g = 853.39 \times 10^{-6} \text{ m}$$

**Step 8: Calculate fringing flux coefficient, FFC**

Using Equation 5-6 on page 94,

$$FFC = 1 + \frac{L_g}{\sqrt{A_e}} \ln\left(\frac{2G}{L_g}\right)$$

Substituting the values in mm,

$$FFC = 1 + \frac{0.85339}{\sqrt{106}} \ln\left(\frac{2 \cdot 28}{0.85339}\right)$$

$$FFC = 1 + 0.082889 \ln(65.62064)$$

$$FFC = 1.3468$$

**Step 9: Calculate modified number of turns, $N_m$**

$$N_m = \sqrt{\frac{L_g \cdot L}{\mu_0 \cdot A_e \cdot FFC}}$$

$$N_m = \sqrt{\frac{0.85339 \cdot 0.0024}{\mu_0 \cdot 106 \cdot 1.3468}}$$

$$N_m = \sqrt{\frac{1.43466\times10^{-5}}{\mu_0}}$$

Substituting the value of $\mu_o$ in the above equation, we get

$$N_m = \sqrt{\frac{1.43466\times10^{-5}}{4\pi\times10^{-10}}}$$

$$N_m = \sqrt{0.1141665\times10^{5}}$$

$$N_m = 106.85$$

Rounding off to the nearest integer, we get

$$N_m = 107$$

**Step 10: Calculate peak flux density, $B_{peak}$**

$$B_{peak} = \frac{4\cdot\pi\cdot10^{-7}\cdot N_m\cdot FFC\cdot I_{peak}}{L_g + \frac{MPL}{\mu_i}}$$

$$B_{peak} = \frac{4\cdot\pi\cdot10^{-7}\cdot107\cdot1.3468\cdot2.05}{853.39\times10^{-6} + \frac{9.84\times10^{-2}}{2500}}\text{ tesla}$$

$$B_{peak} = \frac{4\cdot\pi\cdot144.1076\cdot2.05\cdot10^{-7}}{853.39\times10^{-6} + 0.003936\times10^{-2}}\text{ tesla}$$

$$B_{peak} = \frac{1181.68232 \cdot \pi \cdot 10^{-7}}{853.39 \times 10^{-6} + 39.36 \times 10^{-6}} \text{ tesla}$$

$$B_{peak} = \frac{3712.364495 \cdot 10^{-7}}{892.75 \times 10^{-6}} \text{ tesla}$$

$$B_{peak} = 0.415834 \text{ tesla}$$

As per the design requirements $B_{peak}$ (`0.415 tesla`) is less than $B_{sat}$ (`0.5 tesla`).

**Step 11: Calculate skin depth, d**

$$d = \left(\frac{6.62}{\sqrt{f}}\right) 10^{-2} \text{ m}$$

$$d = \left(\frac{6.62}{\sqrt{10^5}}\right) 10^{-2} \text{ m}$$

$$d = 0.02093 \times 10^{-2} \text{ m}$$

Converting d into mm, we get

$$d = 0.2093 \text{ mm}$$

Therefore, maximum possible diameter of the winding wire can be 2d = 0.4186 mm

**Step 12: Select wire**

Select the wire gauge that has wire diameter nearest to 0.4186 mm is wire gauge number 26.

AWG = #26
Diameter of bare copper wire = **0.40386** mm
Diameter of insulated copper wire = **0.452** mm
Copper cross-section area = **0.12815228** mm$^2$

### Step 13: Calculate required wire area

Using <u>Equation 2-44</u> on page 65,

$$A_{crosssection} = \frac{I_{rms}}{J}$$

$$A_{crosssection} = \frac{2.002}{300}$$

$$A_{crosssection} = 0.6675\times10^{-2}\ \text{cm}^2$$

$$A_{crosssection} = 0.667\ \text{mm}^2$$

As required area is greater than the cross-section area of the single strand, Litz type of winding should be used.

### Step 14: Calculate number of strands

Using <u>Equation 2-47</u> on page 67,

$$Strands = \frac{0.6675}{0.12815}$$

$$Strands = 5.2$$

Rounding to an intriguer value, we get number of strands as **6**.

### Step 15: Calculate end layer voltage

Using <u>Equation 5-8</u> on page 96,

$$V = L \cdot I_{pk} \cdot f / 0.5 \text{ volts}$$

$$V = 0.0024 \cdot 2.05 \cdot 100 \times 10^{3} / 0.5$$

$$V = 0.00984 \times 10^{5}$$

$$V = 984 \text{ volts}$$

**Step 16: Calculate end insulation**

Using Equation 3-5 on page 77,

$$InsulationThickness = \frac{V_{peak}}{V_{InsulatorBreakdown}}$$

For TEFLON, the breakdown voltage is 5000 V/mm.

$$InsulationThickness = \frac{984}{500}$$

$$InsulationThickness = 0.1968 \text{ mm}$$

To achieve the minimum thickness of 0.1968 mm, you will use two TEFLON sheets of 0.1mm thickness in parallel.

Therefore, thickness for end insulation is **0.2 mm**.

**Step 17: Calculate window height available for winding**

**(5-16)**

$$H_{wdg} = H_{w} - 2T - (2 \cdot insulationthickness)$$

$$H_{wdg} = 30 - (2 \cdot 1) - (2 \times 0.2)$$

$$H_{wdg} = 28 - 0.4$$

$$H_{wdg} = 27.6 \text{ mm}$$

### Step 18: Calculate number of turns per layer

Using Equation 3-2 on page 75,

$$\frac{urns}{ayer} = INT(\frac{WindingHeight}{DiameterOverInsulation} \times K_{lit}$$

Using the value of $H_{wdg}$, calculated in the previous step:

$$\frac{Turns}{Layer} = INT(\frac{27.6}{0.452} \times \frac{1}{6})$$

$$\frac{Turns}{Layer} = INT(\frac{27.6}{0.452} \times \frac{1}{6})$$

$$\frac{Turns}{Layer} = INT(10.17)$$

$$\frac{Turns}{Layer} = 10$$

If turns per layer is 10, $K_{adj}$ is 0.85. Taking $K_{adj}$ into account, turns per layer changes to

$$\frac{Turns}{Layer} = INT(10 \times 0.85)$$

Turns/layer= $INT(8.5)$

$$TurnsperLayer = 8$$

### Step 19: Calculate number of winding layers

$$NumberofLayers = \frac{NumberofTurns}{TurnsperLayer}$$

$$NumberofLayers = \frac{107}{8}$$

$$NumberofLayers = 13.375$$

Rounding off the value,

$$NumberofLayers = 14$$

**Step 20: Calculate inter layer insulation**

Using Equation 5-9 on page 97,

layer voltage = V/total number of layers

$$VoltageperLayer = 984/14$$

Voltage buildup between two layer is 2 times Voltage per layer.

$$VoltageBuildup = 984/14 \times 2$$

$$VoltageBuildup = 140.5714286$$

Using Equation 3-5 on page 77,

$$erLayerInsulation = \frac{VoltageBuildup}{InsulationBreakdownVolta}$$

$$nterLayerInsulation = \frac{2 \cdot (984/14}{5000}$$

$$terLayerInsulation = 0.0$$

Minimum width of the TEFLON available is **0.1 mm**.

**Step 21: Calculate winding buildup**

For an EE core, winding buildup is calculated as,

$$LDP = N_L \times Insulated{,}D_w + (N_L - 1) \times InterLayerInsulatio$$

$$BLDP = 14 \times 0.452 + (14 - 1) \times 0.1$$

$$BLDP = 6.328 + 1.3$$

$$BLDP = 7.628 \text{ mm}$$

**Step 22: Calculate $B_{ac}$**

Using Equation 5-13 on page 99,

$$B_{ac} = \frac{4 \cdot \pi \cdot 10^{-7} \cdot N_m \cdot FFC \cdot (I_{ac}/2)}{L_g + \frac{MPL}{\mu_i}}$$

$$B_{ac} = \frac{4 \cdot \pi \cdot 10^{-7} \cdot 107 \cdot 1.3468 \cdot (0.1/2)}{853.39 \times 10^{-6} + \frac{9.84 \times 10^{-2}}{2500}} \text{ tesla}$$

$$B_{ac} = \frac{4 \cdot \pi \cdot 144.1076 \cdot 0.05 \cdot 10^{-7}}{853.39 \times 10^{-6} + 0.003936 \times 10^{-2}} \text{ tesla}$$

$$B_{ac} = \frac{28.82152 \cdot \pi \cdot 10^{-7}}{853.39 \times 10^{-6} + 39.36 \times 10^{-6}} \text{ tesla}$$

$$B_{ac} = \frac{90.545475 \cdot 10^{-7}}{892.75 \times 10^{-6}} \text{ tesla}$$

$$B_{ac} = 0.101423 \times 10^{-1} \text{ tesla}$$

$$B_{ac} = 10.1423 \times 10^{-3} \text{ tesla}$$

### Step 23: Calculate winding length

Using Equation 4-3 on page 81, calculate the total length of the winding wire.

$$= \sum_{n=0}^{n=n-1} MeanTurnLengthforLayer(n) \times (turns)/(layer$$

**Note:** While calculating the length of the winding wire, you need to remember that it is not necessary that the number of turns in the last layer is same as the number of turns in other layers.

For this design example, the number of turns in the 14th layer is calculated as

$$107 - 13 \times 8 = 3$$

#### *Mean turn length of first layer*

The mean turn length for the first layer is calculated as:

2 [Bobbin_$L_x$ + Bobbin_$L_y$ + 2WireDiaInsu]

$= 2 \times (13.9 + 11 + 2 \times 452 \times 10^{-3})$ mm

$= 2 \times (24.9 + 904 \times 10^{-3})$ mm

$= 51.608$ mm

Similarly, mean turn length of the second layer is:

2 [Bobbin_$L_x$ +Bobbin_$L_y$+2WireDiaInsu+4 (InterlayerInsulation+WireDiaInsu)]

$= 2 \times (13.9 + 11 + 2 \times 452 \times 10^{-3}) + 8 \times (0.1 + 452 \times 10^{-3})$ mm

$= 51.608 + 8 \times 0.552$ mm

$= 56.024$ mm

Similarly, you can calculate the mean turn length of all 14 layers. The formula used is:

$2\ [\text{Bobbin\_L}_x + \text{Bobbin\_L}_y + 2\text{WireDiaInsu} + 4 * i(\text{WireDiaInsu} + \text{InterlayerInsulation})]$

where `i = n-1` for the $n^{th}$ layer

To calculate the total length of the winding wire, you multiple the mean turn length of a layer by the number of turns in that layer.

Therefore, the total length of the wire is calculated as:

$8*[51.608 + 56.024 + ........+ \text{mean\_turn\_length\_of\_13}^{th}\text{\_layer}] + 3*\text{mean\_turn\_length\_of\_14}^{th}\text{\_layer}$

Using this calculation, the total length of the wire is calculated as **8449.864 mm**.

### Step 24: Calculate winding resistance

To calculate the winding resistance, use Equation 4-2 on page 80,

$$R = \frac{\zeta L}{A}$$

The effective cross-section area of the wire is calculated as the product of cross-section area of one wire and the number of strands in parallel.

$$R = \frac{1.67\times10^{-5}\times8449.864}{128.15228\times10^{-3}\times6}\Omega$$

$$R = \frac{14111.27288\times10^{-5}}{768.91368\times10^{-3}}\Omega$$

$$R = 18.3522198\times10^{-2}\Omega$$

$$R = 0.1835\Omega$$

**Step 25: Calculate copper loss**

Substituting the value of R in Equation 5-11 on page 98, copper loss is calculated as:

$$P_{cu} = I_{rms}^{2} \cdot R$$

$$P_{cu} = 2.0025^{2} \cdot 0.1835$$

$P_{cu} = 0.73584$ Watt

**Step 26: Calculate core loss**

For calculating core loss, the empirical formula derived from the Magnetics data sheets is used.

**(5-17)** $$CoreLoss = CoreVolume \times (mW)/cm^{3}$$

**(5-18)** $$(mW)/cm^{3} = a \cdot f^{c} \cdot B_{ac}^{\ d}$$

For P-type material at 100K frequency, the values of a, c, and d are listed in the table given below.

| | |
|---|---|
| a = | 0.0434 |
| d = | 2.62 |
| c = | 1.63 |

| | |
|---|---|
| f | operating frequency, specified in KiloHertz (KHz) |
| $B_{ac}$ | AC component of Magnetic flux density, specified in Kilogauss |

*Important*

To convert from tesla to kilo gauss, multiply by 10.
*1 tesla = 10 kilogauss*.

$$(mW)/cm^3 = 0.0434 \cdot 100^{1.63} \cdot 0.101423^{2.62}$$

$$(mW)/cm^3 = 0.1966$$

$$CoreLoss = 10.5 \times 0.1966$$

$$CoreLoss = 2.0646 \text{ mW}$$

**Step 27: Calculate temperature rise**

$$T_{rise} = 450 \times \left(\frac{TotalLoss}{CoreSurfaceArea}\right)^{0.826}$$

Total loss = Copper loss + Core loss

Total loss = 0.73584 + 0.0020646

Total loss = 0.7379 Watts

CoreSurfaceArea = $3.99752 \times 10^3$ mm²

Converting this in cm², CoreSurfaceArea = $39.975$ cm²

$$T_{rise} = 450 \times \left(\frac{0.7379}{39.975}\right)^{0.826}$$

$$T_{rise} = 450 \times 0.0369733$$

$$T_{rise} = 16.638 \, ^\circ C$$

### Step 28: Calculate percentage window occupied

The percentage of window occupied is calculated using the equation given below.

$$WindowOccupied = \frac{AreaoccupiedbyCopper}{WindowAreaofCore} \times 100$$

$$AreaOccupiedbyCopper = \frac{I_{rms}}{J} \times NumberOfTurns$$

$$AreaOccupiedbyCopper = \frac{2.0025}{3} \times 107$$

$$AreaOccupiedbyCopper = 71.4225\ mm^2$$

$$WindowAreaOfCore = H_w \times W_w$$

Substitution the values of $H_w$ and $W_w$ from Table 5-1 on page 103, window are is calculated as:

$$WindowAreaOfCore = 28 \times 8.54\ mm^2$$

$$WindowAreaOfCore = 239.12\ mm^2$$

$$WindowOccupied = \frac{71.4225}{239.12} \times 100$$

**WindowOccupied = 29.86889%**

These results are displayed in the Manufacturer Report tab of the Results View.

| Input Parameters | | Output Parameters | | | |
|---|---|---|---|---|---|
| **Electrical Specifications** | | **Winding Parameters** | | **Calculated Values** | |
| **Inductance (H)** | 0.0024 | **Winding Name** | Winding0 | **Core Loss (Watts)** | 2.11514m |
| **AC Current (A)** | 100m | **Peak Current (A)** | 2.05 | **Window Occupied (%)** | 0.30148019329 |
| **DC Current (A)** | 2 | **RMS Current (A)** | 2.00249843945 | **Temperature Rise (C)** | 16.81715 |
| **Component Type** | DC Inductor | **No. of Turns** | 108 | **Total Buildup (mm)** | 7.62800 |
| **Frequency (Hz.)** | 100k | **Inductance (H)** | 0.0024 | **Total Copper Loss (Watts)** | 745.41856m |
| | | **Wire Gauge*** | 26 | **Fringing Coefficient** | 1.34680 |
| | | **Turns/Layer** | 8 | **Operating Flux Density (Tesla)*** | 0.41583370176 |
| **Design Status** | Success | **No of layer** | 14 | **AC Flux Density (Tesla)** | 10.23707m |
| | | **Inter layer Insulation (mm)*** | 0.1 | | |
| **Core Details** | | **End Insulation (mm)*** | 0.2 | | |
| **Vendor Name** | Magnetics | **Winding Buildup (mm)** | 7.628 | | |
| **Part Number** | 44016-EC | **Winding resistance (Ohm)** | 0.185889914787 | | |
| **Core Type** | EE | **Copper Loss (Watts)** | 0.7454185582958 | | |
| **Core Material** | P | | | | |
| **Bobbin Part Number** | NO_NAME | **Voltage Drop (V)** | 0.3722442642704 | | |
| **GAP* (mm)** | 853.39260m | | | | |
| **Voltage Isolation (mm)** | | | | | |
| **Maximum Flux Density (Tesla)** | 375m | **No. Of Strands*** | 6 | | |
| **Current Density (A/mm2)*** | 3 | **Foil Thickness (mm)** | | | |
| **Insulation Material*** | TEFLON | **Foil Width (mm)** | | | |
| **Wire Type** | AWG | | | | |
| | | | | | |
| | | | | | |

# 6

# Design Results

This chapter details the output generated by the Magnetic Parts Editor at the completion of the design process. When you design a magnetic component using Magnetic Parts Editor, two types of outputs are generated, the PSpice model for the newly designed transformer and a manufacturer report with details required to design the transformer. Both these outputs are displayed in separate tabs in the Results view. The information required for manufacturing the transformer is displayed in the Manufacturer Report tab. The PSpice model for simulating the transformer can be viewed in the Model View tab. The model library specified by you at the beginning of the design process is also updated with the model information.

The topics detailed in this chapter are:

- Manufacturer Report
- PSpice Simulation Model

## Manufacturer Report

The manufacturer report generated by Magnetic Parts Editor lists all the design parameters along with the value assigned to them. The parameter names appear in gray fields where as the value assigned to these parameters appears in white colored grid boxes. The parameters in the manufacturer report are either Input parameters or Output parameters.

### Input parameters

All the design parameters that are used by Magnetic Parts Editor to calculate the values of intermediate or output design parameters are listed in the Input Parameters column. Mainly, these parameters are either specified as inputs by you or are read by Magnetic Parts Editor from the database. For example, operating frequency, insulation material, core part number, and voltage across the primary winding are listed in this column. The parameters listed in the Input parameter column are classified as:

- Electrical specifications
- Design Status
- Core Details

**Figure 6-1 Input parameters in the manufacturer report**

| Input Parameters | |
|---|---|
| **Electrical Specifications** | |
| **Primary Voltage (V)** | 28 |
| **Secondary Voltage 1 (V)** | 5 |
| **Power (Watts)** | 50 |
| **Frequency (Hz.)** | 100k |
| **Efficiency (%)** | 92 |
| **Regulation (%)** | |
| **Component Type** | Flyback Transformer |
| | |
| **Design Status** | Success |
| | |
| **Core Details** | |
| **Vendor Name** | Magnetics |
| **Part Number** | 42515-UC |
| **Core Type** | UU |
| **Core Material** | P |
| **Bobbin Part Number** | NO_NAME |
| **GAP*** | 248.22119m |
| **Voltage Isolation (mm)** | 1 |
| **Operating B (Tesla)*** | 375m |
| **Current Density (A/mm2)*** | 3 |
| **Insulation Material*** | NYLON |
| **Wire Type** | |
| | |

### Electrical specifications

The parameters that you enter in the first three steps of design process using Magnetic Parts Editor, namely selecting a component, providing general information, and providing electrical parameters, are listed as electrical specifications.

The parameters are:

- Primary Voltage
- Secondary Voltage
- Power - Indicates output power ($P_{out}$)
- Frequency - Indicates operating frequency
- Efficiency - Indicates desired efficiency
- Regulation - Indicates desired voltage regulation
- Type - Indicates the type of magnetics designed

### Design Status

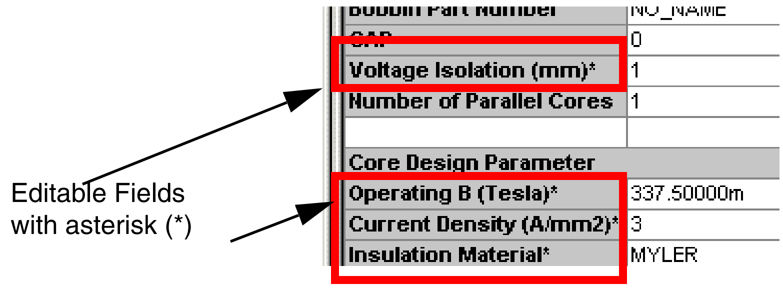
The next field in the Input Parameters column is Design Status. This is the most important field as it indicates whether the process of designing the selected magnetics was successful or not. This field has two possible values, Success or Error. Success indicates that Magnetic Parts Editor could come up with transformer design that matches all the input requirements.

An Error in the design status indicates that a fitment error has occurred while designing the winding layout. This implies that the total area available for the winding is less than the required buildup area, which is the sum of the insulation layers and the winding area. In this case, it is recommended that you change the insulation material and redesign the transformer.

### Core Details

The core details section of the manufacturer report lists the physical properties of the core used in the magnetics. The properties listed in the report are read from the Magnetic Parts Editor database and are used to calculate design parameters, such as interlayer and endlayer insulation.

Some of the fields in the manufacturer report have an asterisk (*) after the property name. These fields are editable. For example, an * after the Voltage Isolation property indicates that if required, you can change the value of this property. To know more about the editable properties, see Editable design parameters on page 131.




## Output parameters

The output parameters are the design parameters for which, values are calculated by Magnetic Parts Editor. The output parameters are listed in two columns under the headings Winding Details and Calculated values.

### Winding Details

The Winding Details column lists all the parameters used for the winding design. Number of columns below the Winding Parameters is dictated by the number of transformer windings. For example, for a transformer with one secondary winding, you will have two columns. The first column lists the parameter values for the primary winding and the second column lists the values for the secondary winding.

**Figure 6-2 Winding parameters in the manufacturer report**

| Winding Parameters | | |
|---|---|---|
| Winding Name | P0 | S0 |
| Peak Current (A) | 7.76397515528 | 40 |
| RMS Current (A) | 3.169629584347 | 16.32993161855 |
| No. of Turns | 9 | 2 |
| Min. Inductance (H) | 1.8032e-005 | |
| Wire Gauge | | |
| Turns/Layer | 1 | 1 |
| No of layer | 9 | 2 |
| Inter layer Insulation (mm)* | 0.2 | 0.2 |
| End Insulation (mm)* | 0.2 | 0.2 |
| Winding Buildup (mm) | 2.18915044 | 0.87451184 |
| Winding resistance (Ohm) | 0.005995483896724 | 0.000376919673336 |
| Copper Loss (Watts) | 0.06023393894675 | 0.1005119128896 |
| Leakage Inductance (H) | 6.279159965572e-007 | |
| Voltage Drop (V) | 0.01900346313153 | 0.006155072491264 |
| | | |
| | | |
| No. Of Strands | | |
| Foil Thickness (mm) | 0.06546116 | 0.33725592 |
| Foil Width (mm) | 16.14 | 16.14 |
| | | |

Winding properties that appear in the manufacturer report are listed in the table given below.

| Winding Property | Comments.... |
|---|---|
| Winding Name | Lists the names of the windings used in the magnetic component. |
| Peak Current (A) | Peak current through the windings. |
| RMS Current | Root mean square (rms) value of the current through the windings. |
| No of Turns | Number of turns in the transformer winding.<br><br>To know more about how number of turns is calculated in Magnetic Parts Editor for different types of magnetics, see Chapter 1, “Design Process.” |

| Winding Property | Comments.... |
|---|---|
| Magnetizing Inductance (H) | Inductance across the primary winding. The value of the magnetizing inductance affects the magnetizing current through the primary winding.<br><br>**Note:** Valid only for forward and flyback converters. |
| Wire Gauge | Wire gauge for each of the winding wire.<br><br>Wire gauge is the measure of the cross-section area of the winding wire. The values that appear in this field are the same values that appear in the Bobbin and winding selection step of the design process.<br><br>To know more about selecting a wire gauge, see Selecting wire gauge on page 65. |
| Turns/layer | Number of winding turns that can be accommodated in a single winding layer. |
| No of layer | Number of winding layers required to accommodate the required number of turns in the transformer winding. |
| Inter layer Insulation (mm) | Thickness of the insulation material between two consecutive winding layers.<br><br>This is an editable field. If required, you can adjust the insulation thickness. |
| End Insulation (mm) | Insulation thickness between the core (bobbin) and the first layer of the winding wire. |
| Winding Buildup (mm) | Total height of the winding layers including the inter layer and end insulation.<br><br>If winding buildup is greater than the window area available for the winding, a fitment error is generated. This error is reflected through the value of the design status parameter. An ERROR in the design status indicates that the fitment error has occurred. |
| Winding resistance (ohm) | Resistance of the winding wire calculated using Equation 4-2 on page 80. |
| Copper Loss (Watts) | Power loss due to the winding currents. |
| Leakage Inductance (H) | Represents energy stored in the non-magnetic regions between windings, caused by imperfect flux coupling.<br><br>Calculated using Equation 4-16 on page 86. |

| Winding Property | Comments.... |
|---|---|
| Voltage Drop (V) | Voltage drop across each transformer winding |
| No of Strands | Number of wires used in parallel in the winding wire.<br>This field is valid only if you have Lets type of windings. For Single winding, the value of this field is set to 1.<br>To know how Magnetic Parts Editor calculates the required number of strands for a winding wire, see Number of strands (Litz only) on page 67. |
| Foil Thickness (mm) | Thickness of foil used for the winding. This field is populated only if the Wire Type is selected as Foil.<br>**Note:** If Foil Thickness is specified, Wire Type, Wire Gauge, and Number of Strands fields will not be populated. |
| Foil Width (mm) | Width of foil used for the winding. |

### Calculated values

The parameters listed under this section are mainly the design parameters used to analyze the transformer performance.

| Design parameter | Comments.... |
|---|---|
| Core loss | Core loss is calculated using Equation 4-6 on page 82. To know more about core loss in a transformer, see Core Loss on page 81. |
| Achieved Efficiency | Efficiency of the transformer calculated using Equation 4-13 on page 85.<br>If the value of this parameter is less than the efficiency value entered by you as input, you might want to tweak your design till you achieve the desired results. To know more about adjusting parameter values in your design, see Tweaking designs on page 130. |
| Achieved Regulation | Measure of fluctuations in secondary voltage with a change in load currents.<br>**Note:** This field value is calculated only for power transformers, using Equation 4-17 on page 86. |

| Design parameter | Comments.... |
|---|---|
| Window Occupied | Percentage of the available window area used by the copper.<br>If the value of this property is greater than 100, fitment error occurs and the design status is set to ERROR. |
| Temperature Rise | Increase in temperature of magnetic component due to power loss. |
| Total copper loss | Sum of copper loss through all the transformer windings. |

# PSpice Simulation Model

After you have completed the design process, Magnetic Parts Editor generates a PSpice model for the transformer. This model can then be attached to a symbol and used in your circuit design to simulate a real-time transformer.

Besides the PSpice model, the Model View tab also list the name and the location of the `.lib` file that will contain the generated PSpice models.

If selected, the *Default Model* check box will make the displayed model as the default model in the generated `.lib` file. This option is useful in cases where you have more than one Results view. For example, if the design has an original view and a modified view, the `.lib` file generated when you save the design will have three models; *<project_name>*, *<project_name>*`_modified1`, and *<project_name>*`_Default`. Of these three, *<project_name>*`_Default` is the copy of one of the model for which *Default Model* check box was selected.

## Model for a Power Transformer

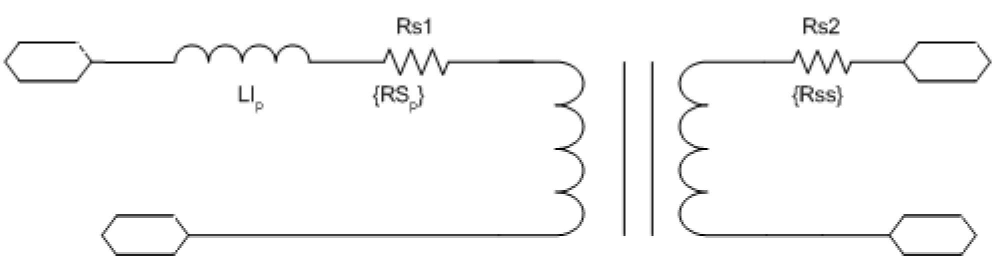
The sample PSpice model for the power transformer, generated using Magnetic Parts Editor is given below.

```
*$
* Generated  by Magnetic Parts Editor on Tue Jun 28 08:27:22 2005
.subckt powerxmer V_IN1 V_IN2
+ V_OUT11 V_OUT12
+ PARAMS:  Np=8 RSp=0.005567 LIp=1.15832e-007
+ Ns1=8 RSs1=0.00855379 Gap = 0
L_LP NLP V_IN2 {Np}
R_RP NRP NLP {RSp}
L_Leak V_IN1 NRP {LIp}
L_LS1 NLS1 V_OUT12 {Ns1}
R_RS1 NLS1 V_OUT11 {RSs1}
K_K2 L_LP L_LS1  1.0 core_model_K1
.model core_model_K1 AKO:core_model  CORE (GAP={Gap})
.model core_model CORE (LEVEL = 3 OD = 10.7 ID = 0 AREA = 0.831 GAP = 0 Br = 1100 Bm = 5000 Hc = 0.175 )
.ends powerxmer
*$
```

**Table 6-1 Model parameters for power transformers**

| Term.. | indicates... |
|---|---|
| Rsp | Primary Winding Resistance |
| Rss | Secondary Winding Resistance |
| Np | Number of turns in primary winding |
| Ns | Number of turns in secondary winding |
| LIp | Leakage inductance referred to primary |
| GAP | air gap in the core (Not valid for power transformer) |

**Figure 6-3 Schematic representation of power transformer**

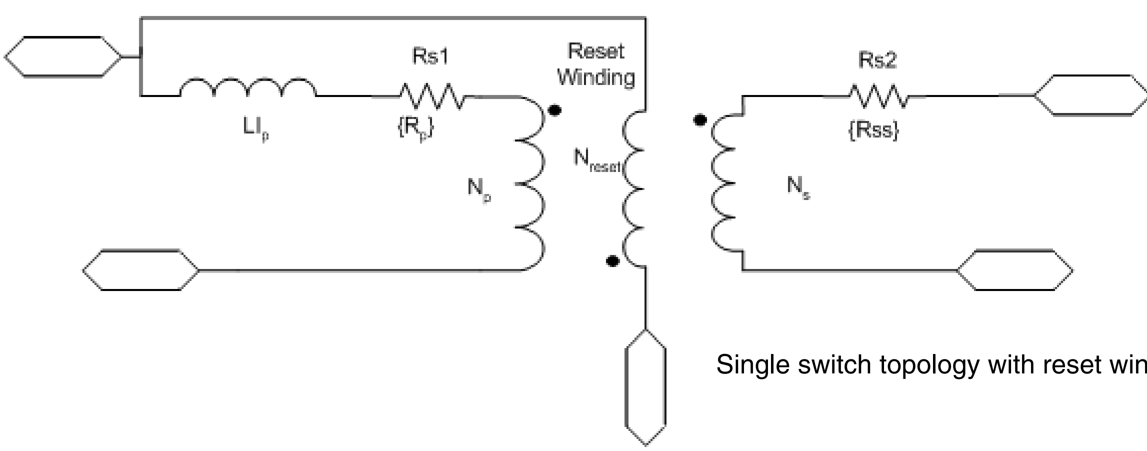


## Model for a Forward Converter transformer

```
*$
*|Generated by Magnetic Parts Editor on Tue Jun 28 08:32:54 2005
.subckt forconver V_IN1 V_IN2 V_IN3 V_IN4
+ V_OUT11 V_OUT12
+ PARAMS:  Np = 85 RSp = 0.210325 LIp=0.000139081
+ Nr = 85 RSr = 7.66697
+ Ns1 = 170 RSs1 = 2.08906 Gap = 0
L_LP NLP V_IN2 {Np}
R_RP NRP NLP {RSp}
L_Leak V_IN1 NRP {LIp}
L_LR NLR V_IN4 {Nr}
R_RR V_IN3 NLR {RSr}
L_LS1 NLS1 V_OUT12 {Ns1}
R_RS1 NLS1 V_OUT11 {RSs1}
K_K2 L_LP L_LR L_LS1  1.0 core_model_K1
.model core_model_K1 AKO:core_model  CORE (GAP={Gap})
.model core_model CORE (LEVEL = 3 OD = 8.34 ID = 0 AREA = 0.404 GAP = 0 Br = 1200 Bm = 4900 Hc = 0.2)
.ends forconver
*$
```

**Table 6-2 Model parameters for forward converter transformers**

| Term.. | indicates... |
|---|---|
| Rsp | Primary Winding Resistance |
| Rs | Secondary Winding Resistance |
| Np | Number of turns in primary winding |
| Ns | Number of turns in secondary winding |
| LIp | Leakage inductance |
| GAP | air gap in the core (Not valid for forward transformer) |




Single switch topology with reset winding

**Figure 6-4 Schematic representation of forward converter transformer**

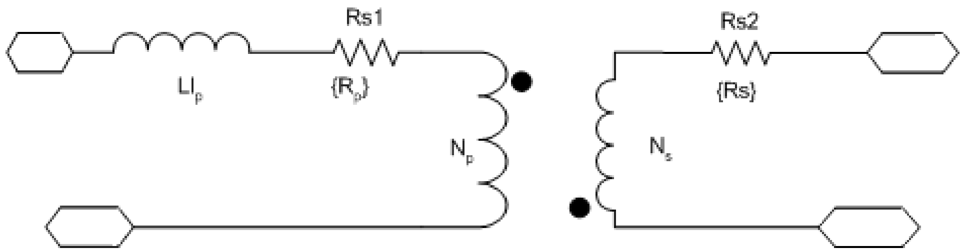
## Model for a Flyback Converter transformer

```
*$
*Generated by Magnetic Parts Editor on Tue Jun 28 08:36:15 2005
.subckt flybkconver V_IN1 V_IN2
+ V_OUT11 V_OUT12
+ V_OUT21 V_OUT22
+ PARAMS:  Np=15 RSp=0.0344185 Llp=3.06052e-006
+ Ns1=1 RSs1=0.000211096
+ Ns2=2 RSs2=0.00302596 Gap = 0.128547
L_LP NLP V_IN2 {Np}
R_RP NRP NLP {RSp}
L_Leak V_IN1 NRP {Llp}
L_LS1 NLS1 V_OUT12 {Ns1}
R_RS1 NLS1 V_OUT11 {RSs1}
L_LS2 NLS2 V_OUT22 {Ns2}
R_RS2 NLS2 V_OUT21 {RSs2}
K_K2 L_LP L_LS1 L_LS2  1.0 core_model_K1
.model core_model_K1 AKO:core_model  CORE (GAP={Gap})
.model core_model CORE ( LEVEL=3 OD=4.77 ID=0 AREA=0.86 GAP=0.128547 Br=1200 Bm=4900 Hc=0.2 )
.ends flybkconver
*$
```

**Table 6-3 Model parameters for flyback converter transformers**

| Term.. | indicates... |
|---|---|
| Rsp | Primary Winding Resistance |
| Rss | Secondary Winding Resistance |
| Np | Number of turns in primary winding |
| Ns1 | Number of turns in the first secondary winding |
| Ns2 | Number of turns in the second secondary winding |
| Llp | Primary inductance |
| GAP | length of the air gap in the core |

**Figure 6-5 Schematic representation of flyback converter transformer**




## DC Inductor model

```
*$
*|Generated by Magnetic Parts Editor on Tue Jun 28 08:38:34 2005
.subckt dcinduc V_IN V_OUT
+ PARAMS:  N=1 RS=0.00154614 Gap = 0.0144514
L_L NL V_OUT {N}
R_R V_IN NL {RS}
K_K1 L_L 1.0 core_model_K1
.model core_model_K1 AKO:core_model  CORE (GAP={Gap})
.model core_model CORE (LEVEL=3 OD=2.92 ID=0 AREA=0.115 GAP=0.0144514 Br=1200 Bm=4900 Hc=0.2 )
.ends dcinduc
*$
```

**Table 6-4 Model parameters for DC Inductors**

| Term.. | indicates... |
|---|---|
| Rs | Winding Resistance |
| N | Number of turns in the winding |
| GAP | air gap in the core (Not valid for power transformer) |

**Figure 6-6 Schematic representation of DC Inductor**


# Tweaking designs

At times you may need to redesign the transformer by modifying or adjusting the values of one or more design parameters. You can modify the design parameter values in the manufacturer report. When you edit a parameter value in the manufacturer report, the results are calculated and displayed immediately in the manufacturer report. Accordingly, the PSpice model for the transformer is also updated with appropriate parameter values.

## Editable design parameters

If required, you can change the values of the design parameters that have an asterisk symbol against them in the manufacturer report. The rest of the parameter values are read only and cannot be directly modified by you. This section lists the editable parameters in the manufacturer report.

### *Operating flux density (B)*

You can modify the operating flux density such that the modified value should be less than the saturation flux density, $B_{sat}$, for the selected core material.

**Note:** Magnetic Parts Editor compares the new value of B with the $B_{sat}$ value in the Magnetic Parts Editor database. If the new value is greater than the saturation flux density, $B_{sat}$, an error is displayed and the original value of B is retained.

### *Current Density (J)*

A change in the current density might cause you to redo wire gauge selection and winding design calculations. This may also influence the copper losses in the transformer.

*Tip*

Current density is inversely proportional to the size of the component and directly proportional to the copper loss. Therefore, in a transformer, an increase in current density will increase copper loss, and reduce the size of the transformer, causing a rise in the temperature.

### *Wire Gauge*

If you change the wire gauge for one or more windings, the winding design should be modified accordingly.

While changing the wire gauge selection, you must ensure that the selected wire has:

- cross-section area equal to or greater than the required area, and
- diameter less than two times the skin depth of the wire.

### *Insulation*

If you modify the insulation used in the transformer or a DC Inductor, winding build up needs to be calculated again. Reducing the insulation thickness will reduce the leakage. You can modify the following insulation properties.

- Insulation material
- End insulation
- Inter layer insulation
- Gap between windings

### *Number of wires in parallel*

If you are using Litz type of wire, you can change the number of strands of wires used in parallel.

In this case, wire gauge selection and winding design are modified accordingly.

### *Air gap (GAP)*

*Important*

Valid for flyback converters and DC Inductors only.

A change in the air gap results in recalculation of operating flux (B), AC flux density ($B_{ac}$), and magnetizing inductance, based on new value.

**Note:** You can specify the gap length as 0 cm, which will be treated as an infinitesimal number for all calculations.

## Modifying parameter values

Magnetic Parts Editor provides you with a facility of modifying the values of design parameters and viewing the results of your modification, in the manufacturer report itself.

### In original report

When you edit a parameter value in the manufacturer report, Magnetic Parts Editor creates a new view, *Modified:1*, and displays the modified results in the new view. Multiple views of the report provides you with the option of comparing your modified results to the original transformer design. Every time you modify a design parameter in the original report a new view is created. Magnetic Parts Editor supports a maximum of four views: *Modified:1*, *Modified:2*, *Modified:3*, and *Modified:4*. The *Modified* view displays the results in the Manufacturer Report tab and the PSpice model in the Model View tab.

### In modified report

In the modified view, you can change multiple design parameters and then update the transformer design with these changes at one go. Whenever you change the value of a design parameter in the modified view, the changed parameter value is displayed in red color. This is to indicate that the design is not yet updated with the changes.

#### *To update the design*

1. Modify the design parameter value and press Tab.

   The modified value appears in red.

2. From the View drop-down menu, choose Refresh Design.

   **Note:** Alternatively, you can also select the Refresh button from the toolbar.

   A message box appears asking you whether if the changes are to be made in the same view or a new view is to be created.

3. Select the appropriate button and view the results of the modification.

The PSpice model displayed in the Model View tab is also updated with new design values.

## Tips on modifying design parameters

You may want to modify your design in cases when one or more design requirements are not satisfied. For example, if the transformer efficiency calculated using Equation 4-13 on page 85 is less than the efficiency specified by you as one of the input parameters, you may want to change the design parameters such that transformer losses are reduced resulting in an increase in the transformer efficiency. Some of the common guidelines to be followed while modifying design parameters to achieve desired results, are listed below.

1. To reduce the core loss, reduce the value of operating flux density, B.
2. Copper loss can be reduced by reducing the current density, J.
3. An increase in the current density, J, reduces winding buildup, BLDP.
4. Overall size of a magnetic component can be decreased by reducing interlayer insulation and gap length.
5. Reducing gap length, $L_g$, causes a reduced fringing of the flux lines. As a result, FFC also decreases.
6. In case of DC inductors or flyback transformers, core loss can be reduced by increasing the gap length, $L_g$.

## Summary

In this chapter, you learnt about the manufacturer report and PSpice models generated by Magnetic Parts Editor at the end of the design process. When you send your design for production, you can send a copy of manufacturer report, containing all relevant information to the Vendor. The PSpice simulation model allows you to test the behavior of the magnetic component in an electrical circuit. To use the PSpice model in an electrical circuit, you first need to associate a symbol with it, and then use the symbol in a schematic design. To know how to associate symbols to PSpice models, see Chapter 9, "Using PSpice Models."

# 7

# Magnetic Parts Editor Database

While designing a transformer using the Magnetic Parts Editor provided by PSpice, you specify all your input and output requirements. Depending on your inputs, Magnetic Parts Editor generates a list of core parts that fulfill your selection criterion. To generate this list, Magnetic Parts Editor uses information from the Magnetic Parts Editor database.

The Magnetic Parts Editor database contains a list of core components that have different physical and electrical characteristics, and are readily available in the market. As a user, you can navigate through the database, add new records, and delete the obsolete records.

The basic material required to design a simple transformer is a core, wires (for primary and secondary windings), and an insulation material (to be used between core and wire & also between wire and wire). The Magnetic Parts Editor database contains information on all three components. All these components are readily available in the market, with different physical and electrical characteristics. Depending on your design requirement, you can select one of parts from the database, and design a transformer or a DC Inductor.

The topics covered in this chapter are:

# Configuring the database

When you install Magnetic Parts Editor, installer automatically configures the database shipped with Magnetic Parts Editor. You can view the configuration details using the Windows' Control Panel.

1. Open the Control Panel window.
2. Double-click Administrative Tools.
3. Double-click on DataSources (ODBC).
4. In the System DSN tab, the Magnetic Parts Editor database is configured as `magdes`.

In cases when your database has no records, you will receive an error message stating that no information is available in the database.

If required, you can configure your own database to be used with Magnetic Parts Editor. Before configuring a local database ensure that you have write permissions on the directory containing the `.mdb` file. This is required to ensure that you are able to modify database entries using Magnetic Parts Editor.

1. In the System DSN tab, select `magdes` and click Remove.
2. To add a new database, click Add.
3. In the Create New Data Source dialog box, choose Microsoft Access Driver (*.mdb) and click Finish.
4. In the ODBC Microsoft Access Setup dialog box, enter the Data Source Name and Description as `magdes`.

   **Note:** To ensure that you are able to read and modify the database using Magnetic Parts Editor, the Data Source Name must be `magdes`.
5. Click Select.
6. In the Select Database dialog box, navigate to the database location, select the database and click OK.
7. To complete the process to configuring data click OK.
8. The configured database appears in the System DSN tab. Click OK to save your changes.

Your database is now configured to be used with Magnetic Parts Editor.

## Navigating the database

1. Launch the Magnetic Parts Editor.
2. From the Tools drop-down menu, choose Data Entry.
3. Select the component for which you want to view, modify or edit the data.
4. In the dialog box that appears, navigate through all the records in the database using the navigation button at the bottom of the dialog box.

   The buttons and their functions are listed in the table given below.

<table>
<tr><th>Select this button...</th><th>to...</th></tr>
<tr><td>|<<</td><td>Jump to the first record in the navigation list</td></tr>
<tr><td><</td><td>View the record previous to the displayed record.</td></tr>
<tr><td>></td><td>Navigate to the next record in the database</td></tr>
<tr><td>>>|</td><td>Move to the last record in the navigation list</td></tr>
<tr><td>New</td><td>Add a new record to the database.</td></tr>
<tr><td>Save</td><td>Save the changes done to the displayed record.<br><br>Note: This button is enabled only if you are adding a new record.</td></tr>
<tr><td>Reset</td><td>Clear the information displayed in the dialog box.</td></tr>
</table>

| Select this button... | to... |
|---|---|
| Delete | Remove the current or the displayed record from the database. |
| Close | Close the dialog box. |

# Populating database

Using Magnetic Parts Editor, you can add information about:

- Core parts supplied by different vendors
- Wires, used for primary and secondary windings
- Insulation material, used between windings and also between core and windings

## Add core details

Adding information about a magnetic core part, you need to complete the steps listed below:

1. Add Vendor data.

   For detailed information, see Add vendor data on page 141.

2. Add Material information

   For detailed information, see Add material information on page 142.

3. Add core properties

   For detailed information, see Adding core properties on page 146.

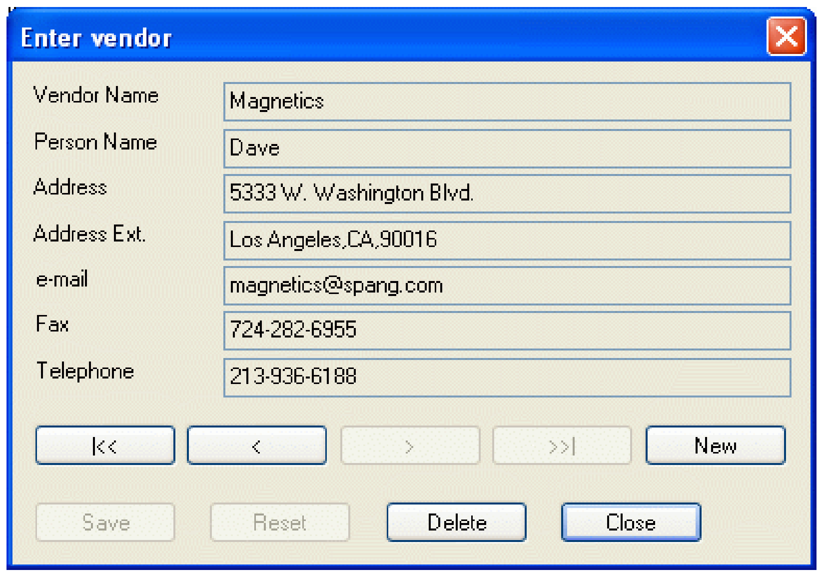
4. Add bobbin information

   For detailed information, see Add bobbin information on page 150.

Of the steps listed above, first three steps are mandatory. Adding bobbin information is optional. Therefore, there may be cases in the database where you have core part without bobbin data.

### Add vendor data

1. From the *Tools* menu, choose *Data Entry - Core Details - Vendor*.




2. In the Enter Vendor dialog box, select the New button.
3. Specify the details as required in the dialog box.

**Note:** To be able to successfully add the record to the database, you must specify the Vendor Name, Person Name, and Address (including Address Extension). Rest of the fields are optional.

*Tip*

Magnetic Parts Editor does not support the use of special characters in various field values. Therefore, while specifying the value for each field, you can only use alphanumeric characters, spaces, comma, and period.

4. To save the record for the new Vendor to the database, click Save.

*Caution*

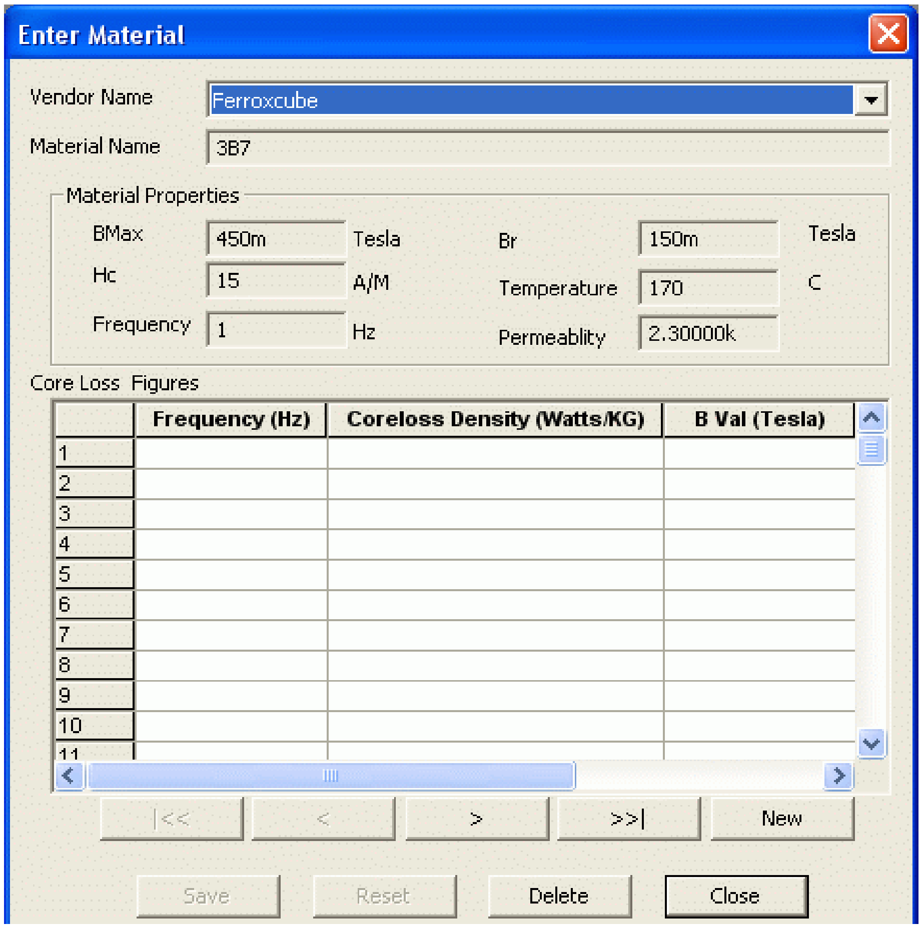
***Select Reset button, before you save the data will erase the data entered by you in all the fields of the dialog box.***

5. Select the Close button, to close the dialog box.

### Add material information

In this step, you add information about the material used for manufacturing the core. While designing transformers, properties such as switching frequency, operating flux density, core loss and operating temperatures, should be taken into considerations. These are the factors that influence the selection of material used for designing cores.

1. From the *Tools* menu, choose *Data Entry ->Core Details -> Material*.




2. Select the New button.
3. From the Vendor Name drop-down list, select a vendor for which you want to add the data.
4. In Material Name text box, enter the name of the material used for creating core.

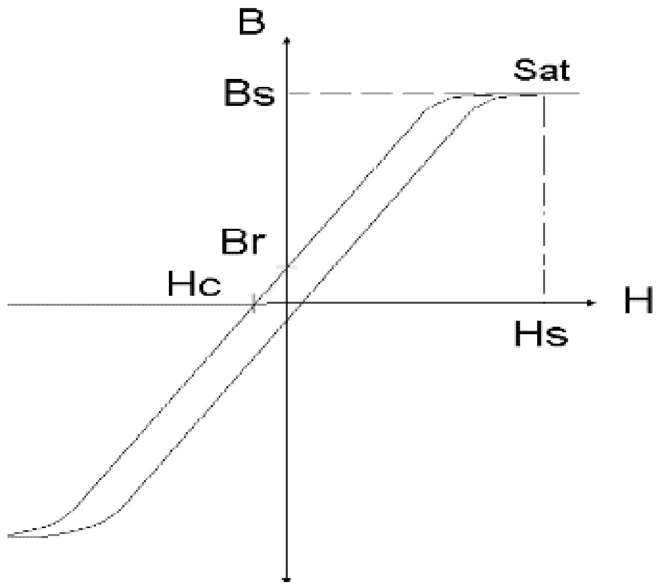
   **Note:** Material Name is available in the data sheets provided by the manufacturer.

5. Next you specify the material properties. Table 7-1 on page 144 lists the properties to be specified for a new material.

**Table 7-1 Material Properties**

| Property name.. | Means... |
|---|---|
| $B_{Max}$ | Saturation flux density |
| $B_r$ | Residual flux density<br>The magnetic flux density at which the magnetizing force is zero when the material is in a symmetrically magnetized condition.<br>Also known as remnant flux density.<br>You can obtain this value from:<br>■ Vendor-specific data sheets<br>■ B-H curve provided by vendors. See Figure 7-1 on page 145.<br>■ Calculate using the formula:<br>$B = \mu H$<br>where $\mu$ = relative permeability |
| $H_c$ | Coercive force<br>Magnetic force required to bring the flux density to zero.<br>See Figure 7-1 on page 145. |
| Frequency | Operating Frequency |
| Temperature | Curie temperature |
| Permeability | Initial permeability of the material<br>For a magnetic material, you can get these values from the vendor supplied data sheets. |

**Figure 7-1 B-H Curve**




6. Enter core loss information. The information you enter in this section will be used to derive an empirical formula using which core loss will be calculated at specified frequency.

   You can obtain core loss information from the data sheets provided by manufacturers.

   To successfully save your record to the database, you must enter the core loss information for at least two different frequencies. For each frequency, two core loss values are expected. So in all you need to specify at least four set of values. An example is shown in the table given below.

| Frequency | Core Loss | Operating Flux (B val) |
|---|---|---|
| 10K | 100m | 10m |
| 10K | 100m | 11m |
| 20K | 100m | 10m |
| 20K | 100m | 11m |

*Important*

The units used for specifying core loss information depends on the vendor for which you are adding the data.

| Vendor Name | Units used for specifying .... | | |
| --- | --- | --- | --- |
| | **Frequency** | **Core loss** | **Operating Flux (B Val)** |
| Magnetics | Hertz (Hz) | milli-watt-per-cubic centimeter ($mW/cm^3$) | Tesla |
| Ferroxcube | Hertz (Hz) | watt-per-kilogram (W/Kg) | Tesla |
| New Vendor | Hertz (Hz) | watt-per-kilogram (W/Kg) | Tesla |

**7.** To add the new record to the database, click Save.

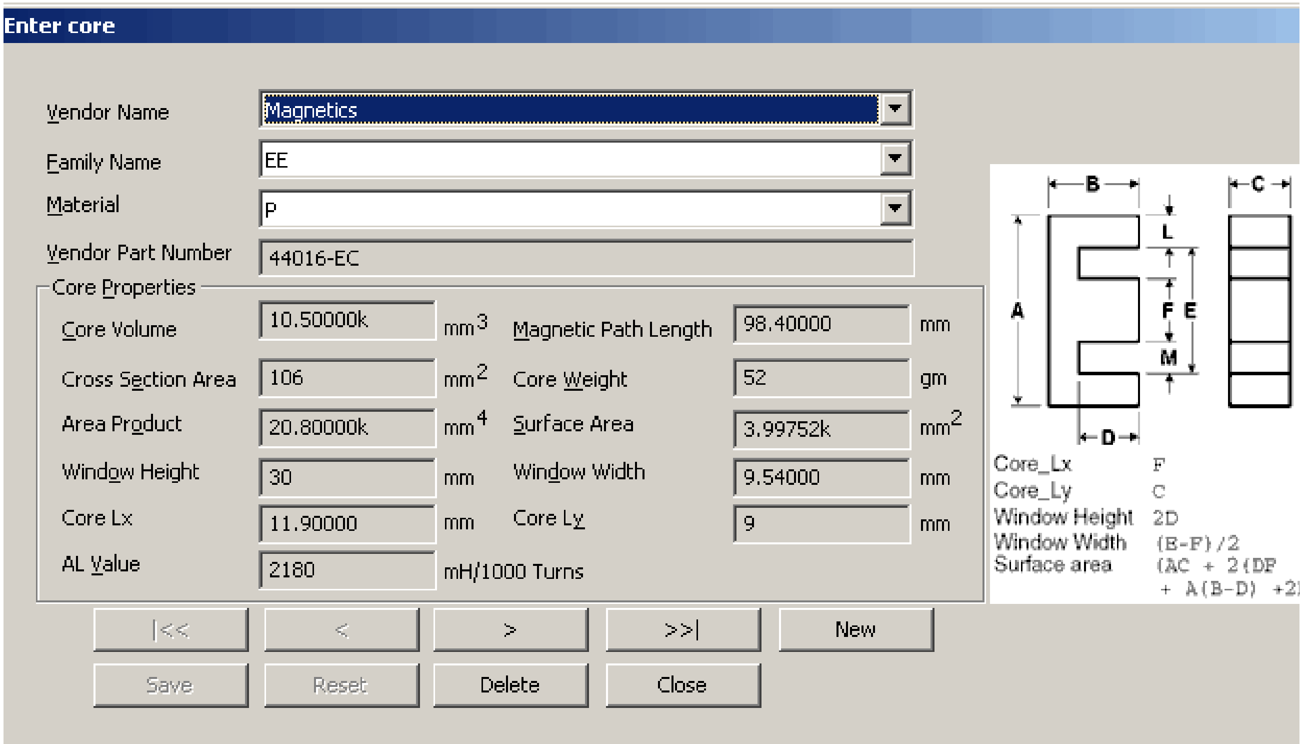
**8.** Close the dialog box.

### Adding core properties

When you select a core for creating a transformer or an inductor, you first decide the core family, followed by the core material to be used. Next you specify the properties of the core and the bobbin to be used with the core.

To add information about a new core part, you should follow the steps listed below.

1. From the *Tools* menu, choose *Data Entry ->Core Details -> Core*.




2. Select a vendor name.

   **Note:** In case you need to enter a new vendor name, follow the steps in the section, Add vendor data on page 141.

3. From the Family Name drop-down list, select the shape of the core for which data is to be added.

4. Select the material used for making the core.

   **Note:** If the required material is not available in the database, add material information to the database. To view the steps for adding material information to the database, see Add material information.

5. In the Vendor Part Number text box, enter the part number for which you want to enter information in the database.

6. Enter core properties using data sheets provided by the vendor.

7. To save the information to the database, click Save.

8. Close the dialog box.

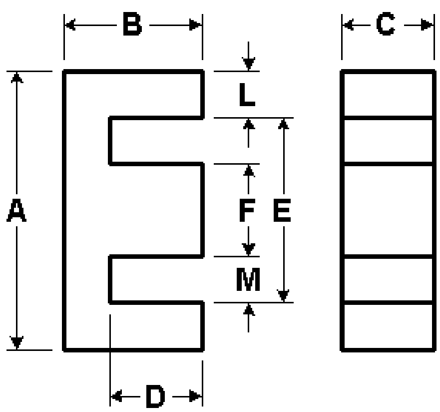
### *Types of core supported by Magnetic Parts Editor*

The core types supported by Magnetic Parts Editor are:

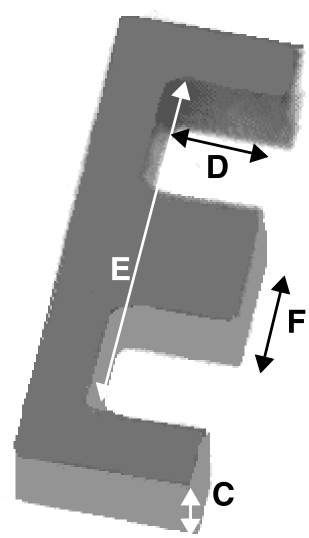
1. EE
2. TOROID, see Figure 7-3 on page 150
3. UU, see Figure 7-2 on page 149

### E Core

**Figure 7-2 E core**




*Two dimensional view of an E Core*




*Three dimensional view of an E Core*

**(7-1)** $$\text{WindowWidth} = \frac{E-F}{2}$$

$$WindowHeight = 2 \cdot D \quad (7\text{-}2)$$

**Table 7-2 Mapping of database entries to E dimensions**

| Entry in database.. | Corresponds to.. |
|---|---|
| Core_Lx | F |
| Core_Ly | C |
| Core Cross-section area, $A_e$ | F*C |
| | Core_$l_x$*Core_$l_y$ |
| Window Height ($H_w$) | 2D |
| Window Width ($W_w$) | (E-F)/2 or M |
| Surface area | (AC + 2(DF +A(B-D) +2DL) +2BC) |

### *UU Core*

**Figure 7-2 U Core diagram**

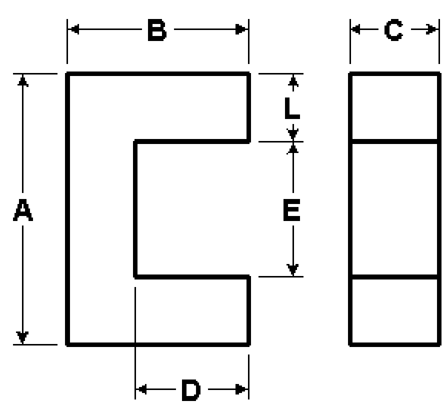



**Table 7-3 Mapping of database entries to UU dimensions**

| Entry in database.. | Corresponds to.. |
|---|---|
| Core_Lx | L |
| Core_Ly | C |
| Window Height ($H_w$) | 2D |
| Window Width ($W_w$) | E |

**Table 7-3 Mapping of database entries to UU dimensions**

| Entry in database.. | Corresponds to.. |
|---|---|
| SurfaceArea | `(AC + 2(A(B-D) +2DL) +2BC)` |

### *Toroid Core*

**Figure 7-3 Lateral and Cross-sectional view of toroid core**

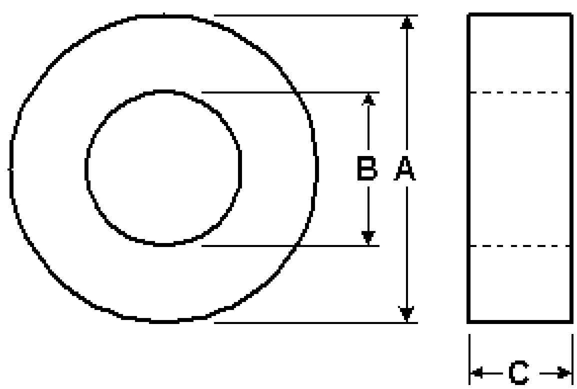



**Table 7-4 Mapping of database entries to core dimensions**

| Entry in database.. | Corresponds to.. |
|---|---|
| Outer diameter | A |
| Inner diameter | B |
| Height | C in Figure 7-3 on page 150) |
| Surface Area | $\pi*[C*A + C*B + 0.5*(A^2-B^2)]$ |

**(7-3)** Window Height = $\pi*B$

**(7-4)** Window Width = $B/2$

### Add bobbin information

1. From the *Tools* menu, choose *Data Entry ->Core Details -> Bobbin*.

2. From the Vendor Name drop-down list box, select the name of the vendor that has provided the bobbin data.
3. From the Family Name drop-down list box, select the type of core for which bobbin information is to be added.
4. Enter bobbin properties.

   **Note:** To know about the properties of EE and UU core, see EE and UU cores. To know about the properties of a toroid core, see Toroid cores.
5. Click the Save button.

### *EE and UU cores*

The properties to be added for EE and UU cores, are:

**a.** Window Width, $W_w$

Bobbin window width is same as the window width available for winding.

**b.** Window Height, $H_w$

Bobbin window height is an indication of the window height available for winding.

**c.** Bobbin $L_x$ and Bobbin $L_y$

Bobbin $L_x$ and $L_y$, are used while calculating mean turn length, MTL, for the winding wire.

**(7-5)** $$\text{Bobbin cross section area} = \text{Bobbin } L_x * \text{Bobbin } L_y$$

### *Toroid cores*

The properties to be added for Toroid cores, are:

**a.** Outer diameter

**b.** Inner diameter

**c.** Height

## Add wire information

1. From the *Tools* menu, choose *Data Entry ->Wire*.
2. To add a new record to the database, click New.
3. From the Wire Type drop-down list, select the convention used for specifying wire properties.

   The supported wire types are:

   a. AWG, American Wire Gauge

   b. SWG, Standard Wire Gauge

4. Enter the wire gauge number in the Wire Gauge field.

*Important*

The wire gauge number specified by you has different meaning for different Wire Types. For example, for a SWG wire, gauge number 20 refers to a wire of `0.0360 inches` diameter, whereas in AWG it will be a wire of `0.0320 inches` diameter.

5. Next, enter the copper cross-section area of the wire in $mm^2$.
6. Enter the diameter of the copper wire.
7. Specify the diameter of the wire including the insulation thickness.
8. Save the record in the database.

## Add Insulation information

1. From the *Tools* menu, choose *Data Entry ->Insulation*.
2. Click the New button.
3. In the Material Name text box, enter the name of the insulation material.
4. Enter the breakdown strength of the material in Volt per millimeter.
5. In the Thickness list box, enter the values in which this insulation material is commercially available.

6. Click Save to save the records to the database.

## Summary

This chapter provided you an overview of the Magnetic Parts Editor database. The Magnetic Parts Editor database contains information about the components required for manufacturing a transformer or an inductor. The database shipped with Magnetic Parts Editor contains data about cores (provided by Magnetics and Ferroxcube), winding wire, and insulation material. Magnetic Parts Editor uses entries in the database to design a transformer or a DC Inductor. You can keep the database updated by adding data about the new components and deleting obsolete information.

# 8

# Template Files

This chapter lists the default values of the properties that are read from the template files. For each type of magnetic supported by Magnetic Parts Editor, a template file is available that has default values for some of the fields, such as Utilization factor, and Current density. These are the values that can be modified by you from within the Magnetic Parts Editor. The template files used by Magnetic Parts Editor are shipped in the Template folder. The Templates folder is located at *<install_dir>*\tools\pspice.

Some of design parameter values that are defined in the templates file and used for calculations in the transformer design process are not visible to you. For example, bobbin thickness, read from the templates file is used to calculate the window area available for winding. Table 8-1 on page 155 lists the entries in a template file, along with the default values for each entry.

**Table 8-1 Properties read from the template file**

| Property Name | Default Values.. | Comments.. |
|---|---|---|
| INSULATION_MATERIAL | NYLON | The value assigned to this property will appear as the default insulation material. The possible values are:<br>❑ NYLON<br>❑ MYLER<br>❑ TEFLON<br>❑ KAPTON |
| CURRENT_DENSITY | 3 | Enter any positive value that you want to be used as the value of current density, J.<br>The value you specify should be in $A/mm^2$. |

**Table 8-1 Properties read from the template file,** *continued*

| Property Name | Default Values.. | Comments.. |
|---|---|---|
| VENDOR | Magnetics | As of now Magnetic Parts Editor database is populated with information from the Magnetics and Ferroxcube. Therefore, the possible values are Magnetics and Ferroxcube.<br><br>If you add a value that is not present in core database, it will be ignored and Magnetics will be the default vendor. |
| FAMILY | EE | Specifies the default value of the core family or the core geometry used for designing a transformer or an inductor. The geometries currently supported are:<br>■ EE<br>■ UU<br>■ TOROID |
| WIRETYPE | AWG | Depending on the value assigned to this property AWG or SWG wires will be selected for winding design.<br><br>The possible values are AWG and SWG. |
| WINDING_GAP | 1 | The gap between primary and secondary winding in millimeters (mm). You can specify any positive number as the winding gap. |

**Table 8-1 Properties read from the template file,** *continued*

| Property Name | Default Values.. | Comments.. |
|---|---|---|
| UTIL_FACTOR | = 0.6<br>(for power transformer)<br><br>=0.112<br>(for forward converter)<br><br>= 0.3<br>(for flyback converter)<br><br>=0.5<br>(for DC inductor) | Utilization factor used in core selection.<br><br>Default values used for different transformer types is indicated, but you can specify any value which is greater than 0 and less than 1. |
| RESISTIVITY | 1.6 7E-05 | Used to specify the resistivity of copper wire used to calculate resistance of winding.<br><br>The value of this property is used to calculated winding resistance. |
| FOIL_WIDTH | 0.00 | For the 10.5 release, this parameter will be ignored. |
| BOBIN_THICK | 1 | By default, bobbin wall thickness is assumed to be 1 mm.<br><br>Bobbin wall thickness is used in situations where no matching bobbins are available in the database for the selected core. Magnetic Parts Editor uses bobbin thickness to calculate the window area available for winding.<br><br>**Note:** This value cannot be modified through the Magnetic Parts Editor. You need to modify it directly in the template file. |

**Table 8-1 Properties read from the template file,** *continued*

| Property Name | Default Values.. | Comments.. |
|---|---|---|
| STRAND_FACTOR | 1 | For the 10.5 release, this parameter will be ignored. |
| WINDING_LAYOUT | NO_SPLIT | Indicates the winding type used. For the 10.5 release, Magnetic Parts Editor does not support any kind of split winding, therefore any changes to this field will be ignored. |
| PARALLEL_CORES | 1 | For the 10.5 release, Magnetic Parts Editor can use only one core at a time. Therefore, any changes to this field will be ignored. |
| KADJ | 1 | This property specifies the default value of the accommodation factor, $K_{adj}$. Accommodation factor is used while calculating the number of turns per layer. |

## Modifying Template properties

To edit or modify the values in the Magnetic Parts Editor template files, open the template file in a text editor, make the required changes and save the file with `.mgt` extension.

Magnetic Parts Editor provides one template file for each of the supported topology. For example, `FLYBACKTRANSFORMER.mgt` is the template file for flyback converter transformers. Similarly, you have one file for other three topologies as well. You can use these template files to define default values of parameters for each topology.

## Summary

This chapter introduced you to the template files used with Magnetic Parts Editor. These files are located in the `<install_dir>\tools\pspice\Templates` folder, and are read by Magnetic Parts Editor to populate the default values of the design parameters in the Magnetic Parts Editor interface. For each transformer topology, you can modify the respective template file and customize the default values for design parameters such as utilization factor, and core geometry.

# 9

# Using PSpice Models

This chapter provides you an overview of steps involved in using Magnetic Parts Editor generated PSpice models in your schematic design.

To be able to use the transformer models generated by Magnetic Parts Editor, you need to complete the steps listed below.

1. Associate symbols to the model generated by Magnetic Parts Editor
2. Use the symbol in your design

## Associating symbols and models

The model-symbol association can be done in two ways. First, is when you have a symbol and want to associate a model to it. Second, is when you have a model and you need to look for a symbol to be associated with that model. For the first scenario, where you have a symbol and need to associate a model to it, you use OrCAD Capture, whereas for the second method you use Model Editor.

### Using Model Editor

Using Model Editor, you can attach symbols to a single model or to all the models in the PSpice library. Model Editor provides you two methods for associating symbols to your models. These are:

- Attaching symbols in a batch mode
- Attaching symbols in an interactive mode

### *To attach symbols in a batch mode*

1. From the File menu, choose Export to Capture Part Library.
2. In the Create Parts for Library dialog box, specify the name of the input model library and output part library.
3. Click OK.

   Model Editor will create symbols for all the models in the specified PSpice library.

*Tip*

Different part symbols are generated for different schematic editors. Use the Options dialog box to specify the schematic editor for which symbols are to be generated.

To know more about associating symbols in the batch mode, see *Creating parts for models* chapter of *PSpice User Guide*.

### *To attach symbols in an interactive mode*

In the interactive mode of part creation, you can view the shape of the symbol being associated with a PSpice model. If required you can specify a different symbol.

1. From the File menu, choose Model Import Wizard.
2. In the first page of the wizard, specify the name of the input model library and output part library.
3. In the subsequent pages, provide relevant information.

   Model Editor will create symbols for all the models in the specified PSpice library.

*Tip*

Different part symbols are generated for different schematic editors. Use the Options dialog box to specify the schematic editor for which symbols are to be generated.

To know more about associating symbols in interactive mode, see *Creating parts for models* chapter of *PSpice User Guide*.

### Using Capture

This flow is useful when you create a transformer symbol in Capture and then associate the transformer model generated by Magnetic Parts Editor to the new symbol.

#### *To associate a transformer model to a Capture symbol*

1. Open the part library (.OLB) containing the symbol to which the PSpice model is to be associated.
2. From the Tools menu, choose Associate PSpice Model.

   **Note:** Alternatively, right-click on the symbol name and from the pop-up menu, choose Associate PSpice Model.
3. In the Select Matching page of the Model Import Wizard, specify the PSpice library containing the transformer symbol.
4. Select the transformer model to be associated with the symbol created in Capture.
5. Complete the mapping of symbol pin to the relevant model terminals and click Finish.

The required PSpice model is now associated with the PSpice symbol. You can now use this symbol in your schematic design to simulate the transformer behavior.

## Example

This example describes the steps required to associate a symbol to a Magnetic Parts Editor generated PSpice model using Model Editor. In this example, the PSpice model for the power transformer with two secondary windings will be associated to a Capture symbol, XFRMER, using the interactive mode of operation. The Capture symbol was created by copying the XFRM_NONLIN/CT-SEC part from BREAKOUT.OLB and is saved in TRANSFORMER.OLB.

### Using Model Editor

To associate an existing Capture symbol, `XFRMER` from to the generated PSpice model, `PWRXMER`.

1. Open Magnetic Parts Editor generated `.lib` in Model Editor.
2. From the Tools menu, choose Options.
3. In the Options dialog box, select the schematic editor as Capture and click OK to close the dialog box.
4. From the File menu, choose Model Import Wizard [Capture].
5. Specify the location of the input library containing the PSpice model, `PWRXMER`, and the location of the output part library, `PWRXMER.OLB`.
6. Specify the location of the `.olb` containing XFRMER symbol.
7. Complete the pin-port mapping and click Finish.

The symbol XFRMER is not associated with the `PWRXMER` PSpice model.

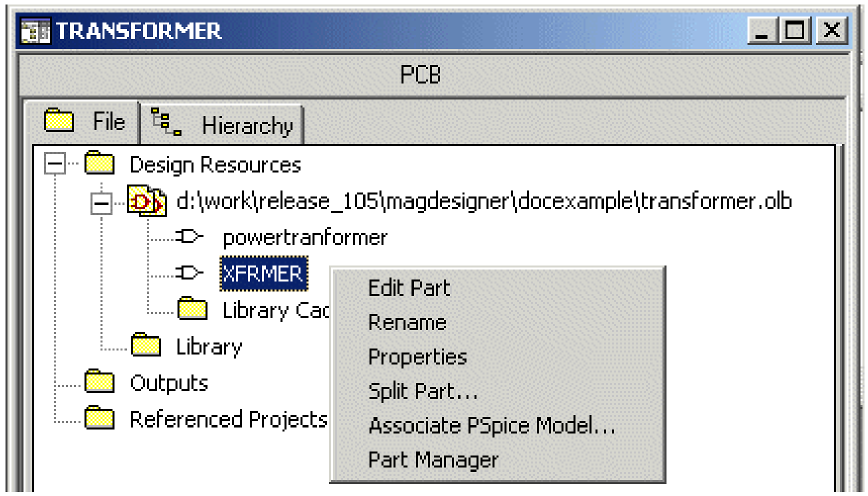
## Using Capture

This example explains the steps required to associate the Magnetic Parts Editor generated PSpice model for the power transformer with two secondary windings, to a Capture symbol, XFRMER. The Capture symbol was created by copying the XFRM_NONLIN/CT-SEC part from BREAKOUT.OLB and is saved in the TRANSFORMER.OLB.

### *To associate PSpice model*

1. Open TRANSFORMER.OLB in OrCAD Capture.
2. Select the symbol.
3. From the Tools menu, choose Associate PSpice Model.

   **Note:** Alternatively, right-click on the symbol name and from the pop-up menu, choose Associate PSpice Model.




4. In the Select Matching page of the Model Import Wizard, specify the location of the Magnetic Parts Editor generated library.
5. Complete the pin to port mapping, and click Finish.

You have successfully associated the PSpice model to the Capture symbol.

## B-H Curve

When you use the PSpice model of a transformer, generated by Magnetic Parts Editor in a circuit, you can view the B-H curve for the transformer in the Probe window. Magnetic Parts Editor generates a .SUBCKT model for the transformer. To display the B-H curve for the designed transformer in the Probe window, complete the steps listed below.

To display the B-H curve, complete the steps listed below.

1. Edit the simulation profile.
   a. From the Simulation menu, choose Edit Profile.
   b. In the Simulation Setting dialog box, select the Data Collection tab.
   c. Set the data collection option for Currents to All.
   d. Click OK to close the dialog box.

2. Simulate the design.
3. Plot the H values on the X-axis.
    a. From the Plot menu, choose Axis Settings.
    b. In the X Axis tab of the Axis Settings dialog box, click Axis Variable button.
    c. From the list of Simulation Output Variables in the X Axis Variables dialog box, select H and click OK.

       **Note:** The variable H will be available in the Simulation Output Variables list only if the Subcircuit Nodes check box is selected. By default, this check box will be enabled and selected only when the design contains a .SUBCKT model and the data collection option is set to *All*.
4. Add the trace for the B curve.
    d. From the Simulation Output Variables list in the Add Traces dialog box, select the B curve and click OK.

       **Note:** The variable B will be available in the Simulation Output Variables list only if the Subcircuit Nodes check box is enabled and selected.

## Summary

In this chapter, you learnt how to use Magnetic Parts Editor generated symbol for a transformer or a DC inductor in a schematic design. Table 9-1 on page 167 lists the concise steps to be followed, before you can use the PSpice models generated by Magnetic Parts Editor, in your schematic designs.

**Table 9-1 Methods of associating symbols to transformer models**

| **Methods** | **Steps** |
|---|---|
| Associate PSpice models to existing Capture symbols and use the symbol in a schematic design | ■ Open the symbol library in Capture<br>■ Use the Associate PSpice Model command to attach Magnetic Parts Editor generated PSpice model to the selected symbol.<br>■ Instantiate the symbol in a schematic design. |
| Attaching Capture symbols to PSpice models and use the symbol in a schematic design | ■ Open the library containing the transformer model, generated by Magnetic Parts Editor, in Model Editor<br>■ Using one of the commands listed below, attach symbol to the transformer model.<br>❑ Export To Capture part library command<br>❑ Model Import Wizard [Capture] command<br>■ Instantiate the symbol in a schematic design. |

# A

# Example

This chapter uses sample inputs values to explain the complete design flow used by Magnetic Parts Editor while designing a power transformer. The values used in this design example, do not depict an actual transformer.

## Designing Power Transformer

The input specifications used for designing a sine wave power transformer are listed in the table given below.

| | |
|---|---|
| Number of secondary windings | 2 |
| Insulation Material | NYLON |
| Current Density, $J$ | 3 amp-per-mm$^2$ |
| Efficiency | 90 |
| Regulation | 95 |
| Input Voltage, | 100V |
| Core Material | P (from Magnetics) |
| Core shape | UU core |
| Window utilization, k | 0.5 |
| Voltage across first secondary, $V_{s1}$ | 50 volts |
| Current across first secondary, $I_{s1}$ | 1 amp |
| Voltage across 2$^{nd}$ secondary, $V_{s2}$ | 40 volts |
| Current across 2$^{nd}$ secondary, $I_{s2}$ | 1.25 amp |

### Step 1: Calculate output power, $P_{out}$

You can calculate current using the equations given below.

$$P_{out} = V_{s1} \times I_{s1} + V_{s2} \times I_{s2}$$

$$P_{out} = 50 \times 1 + 40 \times 1.25$$

$$P_{out} = 50 + 50$$

$$P_{out} = 100 \text{ watts}$$

### Step 2: Calculate Window Area product, $W_aA_e$

Magnetic Parts Editor calculates Window Area product using Equation 2-1 on page 38.

$$W_aA_e = (P \cdot 10^4)/(K \cdot J \cdot B \cdot f)$$

$$W_aA_e = \frac{100 \cdot 10^4}{0.5 \cdot 300 \cdot 375 \cdot 10^{-3} \cdot 100 \cdot 10^3}$$

$$W_aA_e = 0.177778 \text{ cm}^4$$

$$W_aA_e = 0.177778 \times 10^4 \text{ mm}^4$$

$$W_aA_e = 1777.78 \text{ mm}^4$$

The properties of the UU- core with the nearest area product are listed in the table given below.

**Table A-1 Properties for selected core**

| Property | Value | Property | Value |
|---|---|---|---|
| Part Number | 42515-UC | Area Product | 6.3K $mm^4$ |

**Table A-1 Properties for selected core,** *continued*

| Property | Value | Property | Value |
|---|---|---|---|
| core cross-section area | 40.40 $mm^2$ | core volume | 3.37 k mm3 |
| Window height | 18.54 mm | Window width | 12.70 mm |
| core_Lx | 6.35 mm | core _Ly | 6.35mm |
| MPL | 83.4 mm | core weight | 17 |

### Step 3: Calculations using bobbin dimensions

The core selected in the previous step in an UU core. Bobbin dimensions calculated using the default value of bobbin thickness, T, are listed in Table A-2 on page 171.

**Table A-2 Bobbin Properties**

| Property | Value |
|---|---|
| Bobbin Thickness, `T` | 1 mm |
| Bobbin $L_x$ | `Core` $L_x$ `+ 2T` |
| | `= 6.35 + 2*1` |
| | `= 8.35 mm` |
| Bobbin $L_y$ | `Core` $L_y$ `+ 2T` |
| | `= 6.35 + 2*1` |
| | `= 8.35 mm` |
| Window Width ($W_w$) available for winding | $W_w$`-T` |
| (this is same as bobbin window width) | `= 12.70-1` |
| | `= 11.70 mm` |
| Window Height ($H_w$ or `G`) available for winding | $H_w$`-2T` |
| (this is same as bobbin window height) | `= 18.54-2*1` |
| | `= 16.54 mm` |

### Step 4: Calculating input power

You can calculate current using the equations given below.

$$P_{in} = P_{out}/\eta$$

$$P_{in} = 100/0.9$$

$P_{in} = 111.111$ watts

### Step 5: Calculating primary winding currents

Magnetic Parts Editor uses Equation on page 172

$$I_p = \frac{P_{in}}{V_{in}}$$

$$I_p = \frac{100/0.9}{100}$$

$I_p = 1.111$ amp

### Step 6: Calculate turns in primary winding, $N_p$

Using Equation 2-9 on page 43, Magnetic Parts Editor first calculates volts per turn for the primary winding.

$$E_{tp} = 4 \cdot F \cdot B \cdot f \cdot A$$

$$E_{tp} = 4 \cdot 1.11 \cdot 375\times10^{-3} \cdot 100\times10^{3} \cdot 40.40\times10^{-6}$$

$E_{tp} = 67266\times10^{-4}$ volts

$$E_{tp} = 6.7266 \text{ volts}$$

$$N_p = \mathrm{CEIL}\left(\frac{V_p}{E_{tp}}\right)$$

$$N_p = \mathrm{CEIL}\left(\frac{100}{6.7266}\right)$$

$$N_p = \mathrm{CEIL}(14.866)$$

$$N_p = 15$$

For $N_p = 15$, voltage per turn is calculated as:

$$E'_{tp} = 100/15 \text{ volts}$$

### Step 7: Turns in secondary winding, $N_s$

Turns in the secondary winding is calculated using the equation given below.

$$N_s = \frac{V_s}{E_{ts}}$$

For power transformer, $E_{ts} = E_{tp}$

$$N_{s1} = \frac{V_{s1}}{E_{ts}}$$

$$N_{s1} = \frac{50}{100/15}$$

$$N_{s1} = \frac{15}{2}$$

$$N_{s1} = 7.5$$

Taking the ceiling value for 8.5, we get $N_{s1} = 8$

Similarly, $N_{s2} = \dfrac{40}{100/15}$

$$N_{s2} = 6$$

**Step 8: End Insulation for primary (P0)**

Using Equation 3-1 on page 72, Magnetic Parts Editor calculates end insulation as:

$$\text{nsulationThickness} = \frac{V_{peak}}{V_{InsulatorBreakdo}}$$

For sine wave $V_{ppeak} = \sqrt{2} \cdot V_{prms}$

$$\text{nsulationThickness} = \frac{\sqrt{2} \times 10}{700}$$

$\text{nsulationThickness} = 0.20203$ mm

In the database, insulation material is available in thickness of 0.2 mm, 0.5 mm, and 1 mm. Therefore, end insulation thickness will be calculated as **0.4 mm**.

**Step 9: Winding details for P0 winding**

Magnetic Parts Editor uses Equation 2-44 on page 65, to calculate the required cross-section area of the foil to be used as transformer winding.

$$A_{crosssection} = \frac{10/9}{3}$$

$$A_{crosssection} = \frac{10}{27}$$

$$A_{crosssection} = 0.3703\text{ mm}^2$$

$$FoilThickness = \frac{FoilCrossSectionArea}{AvailableWindowHeight}$$

$$FoilThickness = \frac{10/27}{16.54 - 2(0.4}$$

$$FoilThickness = \frac{10/27}{15.74}$$

$$FoilThickness = 0.0235305\text{ mm}$$

Using Equation 2-49 on page 68, width of the foil is calculated as:

$$FoilWidth = AvailableWindowWidth - 2EndInsulatio$$

$$FoilWidth = 16.54 - 2 \times 0.4$$

$$FoilWidth = 15.74\text{ mm}$$

### Step 10: End Insulation for first secondary (S0)

$$InsulationThickness = \frac{V_{peak}}{V_{InsulatorBreakdo}}$$

For sine wave $V_{ppeak} = \sqrt{2} \cdot V_{prms}$

$$V_{ppeak} = \sqrt{2} \cdot 50$$

$$nsulationThickness = \frac{\sqrt{2} \times 5}{700}$$

$$nsulationThickness = \frac{\sqrt{}}{1}$$

$$ısulationThickness = 0.1010152$$ mm

In the database, insulation material is available in thickness of 0.2 mm, 0.5 mm, and 1 mm. Therefore, end insulation thickness will be calculated as **0.2 mm**.

### Step 11: End Insulation for second secondary (S1)

$$ısulationThickness = \frac{V_{peak}}{V_{InsulatorBreakdo}}$$

For sine wave $V_{ppeak} = \sqrt{2} \cdot V_{prms}$

$$V_{ppeak} = \sqrt{2} \cdot 40$$

$$nsulationThickness = \frac{\sqrt{2} \times 4}{700}$$

$$nsulationThickness = \frac{2\sqrt{}}{35}$$

$$ısulationThickness = 0.080812$$ mm

In the database, insulation material is available in thickness of 0.2 mm, 0.5 mm, and 1 mm. Therefore, end insulation thickness will be calculated as **0.2 mm**.

### Step 12: Winding details for S0 winding

Magnetic Parts Editor uses Equation 2-44 on page 65, to calculate the required cross-section area of the foil to be used as the secondary winding.

$$crosssection = \frac{I}{J}$$

$$crosssection = \frac{1}{3}\ mm^2$$

$$crosssection = 0.3333\ mm^2$$

$$oilThickness = \frac{FoilCrossSectionArea}{AvailableWindowHeight}$$

$$oilThickness = \frac{1/3}{16.54 - 2(0.2}$$

$$FoilThickness = \frac{1/3}{16.14}$$

$$oilThickness = 0.0206526\ mm$$

Using Equation 2-49 on page 68, width of the foil is calculated as:

$$oilWidth = AvailableWindowWidth - 2EndInsulatio$$

$$FoilWidth = 16.54 - 2 \times 0.2$$

$$FoilWidth = 16.14\ mm$$

**Step 13: Winding details for S1 winding**

Using Equation 2-44 on page 65

$$crosssection = \frac{I}{J}$$

$$crosssection = \frac{1.2}{3}\ mm^2$$

$$\text{crosssection} = 0.41666\text{ mm}^2$$

$$\text{oilThickness} = \frac{\text{FoilCrossSectionArea}}{\text{AvailableWindowHeight}}$$

$$\text{oilThickness} = \frac{1.25/3}{16.54 - 2(0.2}$$

$$\text{oilThickness} = \frac{1.25/}{16.14}$$

$$\text{oilThickness} = 0.0258157\text{ mm}$$

Using Equation 2-49 on page 68, width of the foil is calculated as:

$$\text{oilWidth} = \text{AvailableWindowWidth} - 2\text{EndInsulatio}$$

$$\text{oilWidth} = 16.54 - 2 \times 0.$$

$$\text{oilWidth} = 16.14\text{ mm}$$

**Step 14: Interlayer insulation P0 winding**

Using Equation 3-5 on page 77,

$$\text{erLayerInsulation} = \frac{\text{VoltageBuildup}}{\text{InsulationBreakdownVolta}}$$

For any transformer with foil winding, number of turns per layer is 1. As a result, voltage buildup between two layers is calculated using the equation given below.

$$\text{VoltageBuildup} = 2\sqrt{2} \times E'_{\text{tr}}$$

$$\text{VoltageBuildup} = 2\sqrt{2} \times \frac{100}{15}\text{ volts}$$

$$\text{nterLayerInsulation} = \frac{2\sqrt{2} \times 100/1}{700}$$

$$\mathrm{nterLayerInsulation} = \frac{2\sqrt{\ }}{10}$$

$$\mathrm{nterLayerInsulation} = 0.02693' \text{ mm}$$

Insulation material, nylon, is available in the minimum thickness of 0.2 mm. Therefore, inter layer insulation is **0.2 mm**.

For this design example, volts per turn is same for all three windings, Therefore, interlayer insulation for both secondary windings is calculated as **0.2 mm**.

### Step 15: Calculating winding buildup

Winding buildup for each winding is calculated as:

$$\mathrm{LDP} = N_L \times \mathrm{FoilThickness} + (N_L - 1) \times \mathrm{InterLayerInsulatio}$$

#### *Buildup for P0*

$$\mathrm{BLDP} = 15 \times 0.02353052 + 14 \times 0.2$$

$$\mathrm{BLDP} = 0.3529578 + 2.8$$

$$\mathrm{BLDP} = 3.1529578 \text{ mm}$$

#### *Buildup for S0*

$$\mathrm{BLDP} = 8 \times 0.02065262 + 7 \times 0.2$$

$$\mathrm{BLDP} = 0.16522096 + 1.4$$

$$\mathrm{BLDP} = 1.56522096 \text{ mm}$$

#### *Buildup for S1*

$$\mathrm{BLDP} = 6 \times 0.02581578 + 5 \times 0.2$$

$$\mathrm{BLDP} = 0.15489468 + 1$$

$\mathrm{BLDP} = 1.15489468$ mm

Total winding buildup is the sum of individual winding buildup and the voltage isolations between the windings.

$$\mathrm{TotalBLDP} = 3.1529578 + 1.56522096 + 1.15489468 + 2 \times 1$$

$\mathrm{TotalBLDP} = 7.87307344$ mm

### Step 16: Calculating window occupied

Percentage window occupied or the Window Utilization is calculated as

$$\mathrm{WindowOccupied} = \frac{\mathrm{AreaOccupiedbyCopper}}{\mathrm{TotalWindowArea}} \times 100$$

#### *Area occupied by Copper for P0*

$$\mathrm{Area}_{cu} = \mathrm{NumberOfLayers} \times (\mathrm{FoilThickness} \times \mathrm{FoilWidth}$$

$$\mathrm{Area}_{cu} = 15 \times (0.02353052 \times 15.74)$$

$$\mathrm{Area}_{cu} = 15 \times 0.37037038$$

$\mathrm{Area}_{cu} = 5.5555557$ mm²

#### *Area occupied by Copper for S0*

$$\mathrm{Area}_{cu} = 8 \times (0.02605262 \times 16.14)$$

$$\mathrm{Area}_{cu} = 8 \times 0.333333$$

$\mathrm{Area}_{cu} = 2.666666$ mm²

#### *Area occupied by Copper for S1*

$$\mathrm{Area}_{cu} = 6 \times (0.02581578 \times 16.14)$$

$$Area_{cu} = 6 \times 0.41666668$$

$$Area_{cu} = 2.500000 \text{ mm}^2$$

***Total area occupied by copper***

$$= (5.555555 + 2.666666 + 2.50000)$$

$$= 10.7222219 \text{ mm}^2$$

***Total area available for winding***

$$= WindowHeight \times WindowWidth$$

$$= 16.54 \times 11.7$$

$$= 193.518 \text{ mm}^2$$

$$WindowUtilization = \frac{10.7222219}{193.518} \times 100$$

$$WindowUtilization = 0.0554068 \times 100$$

$$WindowUtilization = 5.540\%$$

**Step 17: Calculating winding length**

***Winding length for P0***

The mean turn length for the first layer is calculated as:

$$2\,[Bobbin\_L_x + Bobbin\_L_y + 2 * FoilThickness]$$

$$= 2 \times (8.35 + 8.35 + 2 \times 0.02353052) \text{ mm}$$

$$= 2 \times 16.74706$$

$$= 33.494 \text{ mm}$$

Similarly, mean turn length of the second layer is:

2 [Bobbin_L$_x$ +Bobbin_L$_y$+2WireDiaInsu+4 (InterlayerInsulation+FoilThickness)]

$= 2 \times (8.35 + 8.35 + 2 \times 0.02353052) + 8 \times (0.2 + 0.02353052)$

$= 2 \times (8.35 + 8.35 + 2 \times 0.02353052) + 8 \times (0.2 + 0.02353052)$

$= 33.494 + 8 \times 0.22353052$

$= 33.494 + 1.78224416$

$= 35.27636$ mm

Similarly, you can calculate the mean turn length of all 15 layers and add them together to get the total length of the primary winding. The formula used is:

2 [Bobbin_L$_x$ + Bobbin_L$_y$ + 2FoilThickness + `4*i`(FoilThickness + InterlayerInsulation)]

where `i = n-1` for the $n^{th}$ layer

Using the procedure specified above, winding lengths are calculated as

| | |
|---|---|
| **Length of P0** | **688.766 mm** |
| **Length of S0** | **582.415 mm** |
| **Length of S1** | **549.97 mm** |

### Step 18: Calculating winding resistance

#### *Resistance for P0*

Using Equation 4-2 on page 80,

$$R = \frac{\zeta L}{A}$$

$$R = \frac{1.67\times10^{-5}\times688.766}{10/27}$$

$$R = 31056.46\times10^{-6}\Omega$$

$$R = 0.031056\Omega$$

***Resistance for S0***

$$R = \frac{1.67\times10^{-5}\times582.415}{1/3}$$

$$R = 2917.899\times10^{-5}\Omega$$

$$R = 0.029179\Omega$$

***Resistance for S1***

$$R = \frac{1.67\times10^{-5}\times549.97}{1.25/3}$$

$$R = \frac{2755.3497\times10^{-5}}{1.25}$$

$$R = 2204.278\times10^{-5}\Omega$$

$$R = 0.02204278\Omega$$

### Step 19: Calculating voltage drop

#### *Voltage drop across P0*

$= \frac{10}{9} \times 0.031056$

$= 0.034506$ volts

#### *Voltage drop across S0*

$= 1 \times 0.029179$

$= 0.029179$ volts

#### *Voltage drop across S1*

$= 1.25 \times 0.02204278$

$= 0.0275534$ volts

### Step 20: Calculating copper loss

Expanding Equation 4-1 on page 79 to this design example,

$$P_{cu} = I_p^{\ 2} \cdot R_p + I_{s0}^{\ 2} \cdot R_{so} + I_{s1}^{\ 2} \times R_{s1}$$

$$P_{cu} = \left(\frac{10}{9}\right)^2 \cdot 0.031056 + 1^2 \cdot 0.029179 + 1.25^2 \times 0.02204278$$

$$P_{cu} = \frac{3.1056}{81} + 0.029179 + 1.5625 \times 0.02204278$$

$$P_{cu} = 0.0383407 + 0.029179 + 0.03444187$$

$$P_{cu} = 0.10196162 \text{ watts}$$

### Step 21: Calculating core loss

In this design example, we have used core provided by Magnetics, which provides core loss information in $mW/cm^3$. Therefore, equations used for calculating core loss are:

$$CoreLoss = CoreVolume \times (mW)/cm^3$$

$$(mW)/cm^3 = a \cdot f^c \cdot B_{ac}{}^d$$

For P-type material at 100K frequency, the values of a, c, and d are listed in the table given below.

| | |
|---|---|
| a = | 0.0434 |
| d = | 2.62 |
| c = | 1.63 |

$$(mW)/cm^3 = 0.0434 \cdot 100^{1.63} \cdot (375 \times 10^{-3} \times 10)^{2.62}$$

$$(mW)/cm^3 = 0.0434 \cdot 1819.70085 \cdot 3.75^{2.62}$$

$$(mW)/cm^3 = 0.0434 \cdot 1819.70085 \cdot 31.912580$$

$$(mW)/cm^3 = 2520.29658$$

$$CoreLoss = CoreVolume \times (mW)/cm^3$$

$$CoreLoss = 3.37 \times 10^3 \times 10^{-3} \times 2520.29658$$

$$CoreLoss = 8493.39949 \text{ mW}$$

$$CoreLoss = 8.4933995 \text{ W}$$

**Step 22: Calculating temperature rise**

$$T_{rise} = 450 \times \left(\frac{TotalLoss}{CoreSurfaceArea}\right)^{0.82}$$

total loss = copper loss + core loss

$$TotalLoss = 0.10196162 + 8.4933995 \text{ watts}$$

$$TotalLoss = 8.5953611 \text{ watts}$$

$$T_{rise} = 450 \times \left(\frac{8.5953611}{1.87096 \times 10^3 \times 10^{-2}}\right)^{0.826}$$

$$T_{rise} = 450 \times \left(\frac{8.5953611}{18.7096}\right)^{0.826}$$

$$T_{rise} = 236.695°C$$

**Step 23: Calculating magnetizing inductance**

Magnetizing Inductance

$$= N_p^2 \times AL \times 10^{-6}$$

$$= 15^2 \times 1 \times 10^{-6} \text{ Henry}$$

$$= 0.000225 \text{ Henry}$$

### Step 24: Calculating transformer efficiency, $\eta$

$$\eta = \frac{P_{out}}{CopperLoss + CoreLoss + P_{out}}$$

$$\eta = \frac{100}{8.5953611 + 100}$$

$$\eta = 0.920849$$

$$\eta = 92.085\%$$

### Step 25: Calculating leakage inductance

$$L_{leak} = \left(\mu_0 \cdot 10^{-2} \cdot N_p{}^2 \cdot \frac{MLT}{H_{wdg}}\right) \times \frac{BLDP}{3}$$

$$L_{leak} = \left(4\pi\times10^{-7} \cdot 10^{-2} \cdot 15^2 \cdot \frac{MLT}{16.54}\right) \times \frac{7.87307\times10^{-1}}{3}$$

MLT for this design example evaluates to 62.89mm

$$L_{leak} = \left(4\pi\times10^{-7} \cdot 10^{-2} \cdot 15^2 \cdot \frac{62.89}{16.54}\right) \times \frac{0.787307}{3}$$

$$L_{leak} = \left(9\pi\times10^{-7} \cdot \frac{62.89}{16.54}\right) \times \frac{0.787307}{3}$$

$$L_{leak} = 28.2027\times10^{-7}$$

$L_{leak} = 2.8202\times10^{-6}$ Henry

### Step 26: Calculating voltage regulation

$$\text{VoltageRegulation} = \frac{V_{noload} - V_{fullload}}{V_{noload}}$$

Using Equation 4-18 on page 87, calculate effective resistance transferred to the primary.

$$R_{wdg} = R_p + R_{so} \cdot \left(\frac{V_p}{V_{so}}\right)^2 + R_{s1} \cdot \left(\frac{V_p}{V_{s1}}\right)^2$$

But $\frac{V_p}{V_{so}} = \frac{N_p}{N_{so}}$ and $\frac{V_p}{V_{s1}} = \frac{N_p}{N_{s1}}$

$$R_{wdg} = 0.031056 + 0.029179 \cdot \left(\frac{15}{8}\right)^2 + 0.02204278 \cdot \left(\frac{15}{6}\right)^2$$

$$R_{wdg} = 0.031056 + 0.10258242 + 0.13776738$$

$$R_{wdg} = 0.271405\Omega$$

Leakage reactance is calculated using Equation 4-19 on page 87.

$$X_{leak} = 2\pi f L_{leak}$$

$$X_{leak} = 2\pi 100\times 10^3 \times 2.8203\times 10^{-6}$$

$$X_{leak} = 17.71\times 10^{-1}$$

$$X_{leak} = 1.771\Omega$$

Using Equation 4-20 on page 88, impedance is calculated as,

$$Z_{final} = \sqrt{0.271405^2 + 1.771}$$

$$Z_{final} = \sqrt{0.271405^2 + 1.771}$$

$$Z_{final} = 1.791675\Omega$$

Therefore, using Equation 4-21 on page 88,

$$V_{drop} = 1.1111 \times 1.791675$$

$$V_{drop} = 1.99075\Omega$$

$$oltageRegulation = \left(1 - \frac{1.99075}{100}\right) \times 10\%$$

$$oltageRegulation = 98.0\,\%$$

# Glossary

**AWG**

American Wire Gauge. AWG is sometimes known as Brown and Sharpe (B&S) Wire Gauge. A gauging system used to size magnet wire.

**bobbin**

The injection molded form upon which the coil is wound on many cores and laminations.

**breakdown**

Breakdown of a insulation material in the voltage applied per unit length that will

**breakdown strength**

It is the maximum electric field strength that a material can withstand and still function like an insulator. Breakdown strength of an insulator material is measured in Volt per millimeter.

**CEIL(x)**

Ceiling value of x, is the nearest integer greater than x.

**coercive force, Hc**

The value of demagnetizing force that reduces residual induction to zero. The maximum coercive force, as measured on a saturated magnet, is proportional to the remanent flux density. It is expressed in oersteds or kiloAmps per meter (kA/m).

**core loss**

Core loss is the power loss or heat generated by a magnetic material subjected to an alternating magnetic field. It is measures in Watts. Core loss for a material changes with change in the operating frequency and operating flux density. Therefore, this information is critical for selecting a part.

**FFC**

Fringing flux coefficient (FFC) is the measure of how much flux redistributes when magnetic lines pass from a high permeability material (ferrite core) to a low permeability material (air gap).

**FLOOR(x)**

FLOOR(x), is the nearest integer smaller than x.

**fringing field**

The magnetic field associated with the divergence of the magnetic flux lines from the shortest path between two poles in a magnetic circuit.

**fringing flux**

When you have an air gap in the magnetic path length, the magnetic flux bulges at the air-gap. This bulging flux, which increases the effective area of the air gap to a value greater than the core cross-section area, is called fringing flux. Flux redistribution occurs whenever flux lines pass from a high permeability into a lower permeability material.

**impedance**

The effective electrical resistance that inductors, capacitors, and resistors present to current flow in a circuit.

**inductance factor ($A_L$)**

Core constant used to calculate inductance based on the number of winding turns squared. Value is given in millihenries per 1000 turns squared, which is the same as nanohenries per turn squared

**leakage flux**

Flux linking to the winding that does not pass through the magnetic path length. measured using leakage inductance.

**leakage inductance**

The inductance associated with the leakage flux of a core coil.

**litz wire**

A type of wire that consists of multiple strands of wire are used in parallel to form a single conductor. Litz wires reduce skin effect and offers advantages over single strand at high frequency.

### magnetics

Passive components, such as transformers and inductors, that use an internal magnetic field to change the phase of electrical current.

### Magnetic Path Length, MPL

The length of the closed path that magnetic flux follows around a magnetic circuit. Magnetic path length (MPL) is determined by the Ampere's Law.

### Permeability

The ratio of the ability of a material to carry magnetic flux in comparison to air or a vacuum, the permeability of which is, by definition, one.

### skin effect

Skin effect is the tendency of radio frequency current to be concentrated at the surface of the conductor.

### skin depth

Depth below the surface of the conductor at which the current is 1/e (about 0.37) times the current at the surface. Calculated using the formula given below.

$$d = \sqrt{\frac{2\rho}{\omega\mu}}$$

where

$\rho$ = resistivity of conductor
= $1.67\text{x}10^{-5}$ Ohm-mm for copper

$\omega$ = angular frequency of current
= $2\pi \times$ frequency in MegaHertz

$\mu$ = absolute magnetic permeability of conductor
= 1 for copper

### SWG

Imperial Standard Wire Gauge, (British legal standard)

### transformer

An electrical device that transfers energy from one electrical circuit to another by magnetic coupling with no moving parts. It is often used to convert between high and low voltages and accordingly between low and high currents.

**voltage regulation**

It is the measure of how well a power transformer can maintain constant secondary voltage given a constant primary voltage and wide variance in load current. The lower the percentage (closer to zero), the more stable the secondary voltage and the better the regulation it will provide.

Inductance because of the leakage flux.

**Watt Density**

Wattage concentration on the surface of the core.

**wire gauge**

It is the measure of the bare copper (without insulation) cross-section area of a wire.

# Index

## F



## G



## I



## K



## L



## M

## N



## P



## R



## S



## T



## U



## V



## W