

Introduction

One requirement for design engineers using programmable devices is the ability to calculate the power dissipation for a particular device used on a board. Lattice's ispLEVER® design tools include the Power Calculator tool, which allows designers to calculate the power dissipation for a given device. This technical note describes how to use the Power Calculator tool to calculate the power consumption of the LatticeXP2™ family of devices. General guidelines to reduce power consumption are also included.

Power Supply Sequencing and Hot Socketing

LatticeXP2 devices have been designed to ensure predictable behavior during power-up and power-down. Power supplies can be sequenced in any order. During power-up and power-down sequences, the I/Os remain in tri-state until the power supply voltage is high enough to ensure reliable operation. In addition, leakage into I/O pins is controlled to within the limits specified in the LatticeXP2 Family Data Sheet, allowing for easy integration with the rest of the system. These capabilities make the LatticeXP2 ideal for many multiple power supply and hot-swap applications.

Recommended Power-up Sequence

As described above, the supplies can be sequenced in any order. However, once internal power good is achieved (determined by VCC, VCCAUX, VCCIO Bank x) the device releases the I/Os from tri-state and the management of the I/Os becomes the designer's responsibility. To simplify a system design, it is recommended that supplies be sequenced in the following order: VCCIO, VCC, VCCAUX. If VCCIO is tied to VCC or VCCAUX, then it is recommended that VCCIO and the associated power supply are powered up before the remaining supply.

Please refer to the Hot Socketing section of the LatticeXP2 Family Data Sheet for more information.

Power Calculator Hardware Assumptions

Power consumption for a device can be coarsely broken down into the DC portion and the AC portion.

The Power Calculator reports the power dissipation in terms of:

1. DC portion of the power consumption.
2. AC portion of the power consumption.

The DC Power (or the Static power consumption) is the total power consumption of the used and the unused resources. These power components are fixed for each resource used and depends upon the number of resource units utilized. The DC component also includes the static power dissipation for the unused resources of the device.

The AC portion of power consumption is associated with the used resources. This is the dynamic part of the power consumption. Its power dissipation is directly proportional to the frequency at which the resource is running and the number of resource units used.

Power Calculation Equations

The following are the power equations used in the Power Calculator:

Total DC Power (Resource)

$$\begin{aligned}
 &= \text{Total DC Power of Used Portion} + \text{Total DC Power of Unused Portion} \\
 &= [\text{DC Leakage per Resource when Used} * N_{\text{RESOURCE}}] \\
 &\quad + [\text{DC Leakage per Resource when Unused} * (N_{\text{TOTAL RESOURCE}} - N_{\text{RESOURCE}})]
 \end{aligned}$$

Where:

$N_{\text{TOTAL RESOURCE}}$ is the total number of resources in a device
 N_{RESOURCE} is the number of resources used in the design

The total DC power consumption for all the resources as per the design data is the Quiescent Power in the Power Calculator.

The AC Power is governed by the following equation:

$$\begin{aligned}
 &\text{Total AC Power (Resource)} \\
 &= K_{\text{RESOURCE}} * f_{\text{MAX}} * AF_{\text{RESOURCE}} * N_{\text{RESOURCE}}
 \end{aligned}$$

Where:

$N_{\text{TOTALRESOURCE}}$ is the number of resources in a device
 N_{RESOURCE} is the number of resources used in the design
 K_{RESOURCE} is the power constant for the resource in mW/MHz
 f_{MAX} is the max frequency at which the resource is running. Frequency is measured in MHz.
 AF_{RESOURCE} is the activity factor for the resource group. The Activity Factor is a percentage of the switching frequency.

For example, the power consumption of the Slice portion is calculated in the following equation,

$$\begin{aligned}
 &\text{Total DC Power (Slice)} \\
 &= \text{Total DC Power of Used Portion} + \text{Total DC Power of Unused Portion} \\
 &= [\text{DC Leakage per Slice when Used} * N_{\text{SLICE}}] \\
 &\quad + [\text{DC Leakage per Slice when Unused} * (N_{\text{TOTALSLICE}} - N_{\text{SLICE}})]
 \end{aligned}$$

$$\begin{aligned}
 &\text{Total AC Power (Slice)} \\
 &= K_{\text{SLICE}} * f_{\text{MAX}} * AF_{\text{SLICE}} * N_{\text{SLICE}}
 \end{aligned}$$

Power Calculations

The Power Calculator allows users to estimate power consumption at three different levels:

1. Estimate of the utilized resources before completing place and route
2. Post place and route design
3. Post place and route, post trace, and post simulation

For the first level of estimation, the user provides estimates of device usage in the Power Calculator Wizard and the tool provides a rough estimate of the power consumption.

The second level is a more accurate approach. The user imports the actual device utilization by importing the post Place and Route netlist (NCD) file.

The third level brings even more accuracy to the calculation by importing the Trace (TWR) file to populate the maximum frequencies (f_{MAX}) into the tool. Users also have the option of importing the information from the post simulation (VCD) file and calculating the Activity Factor and Toggle Rates of various components.

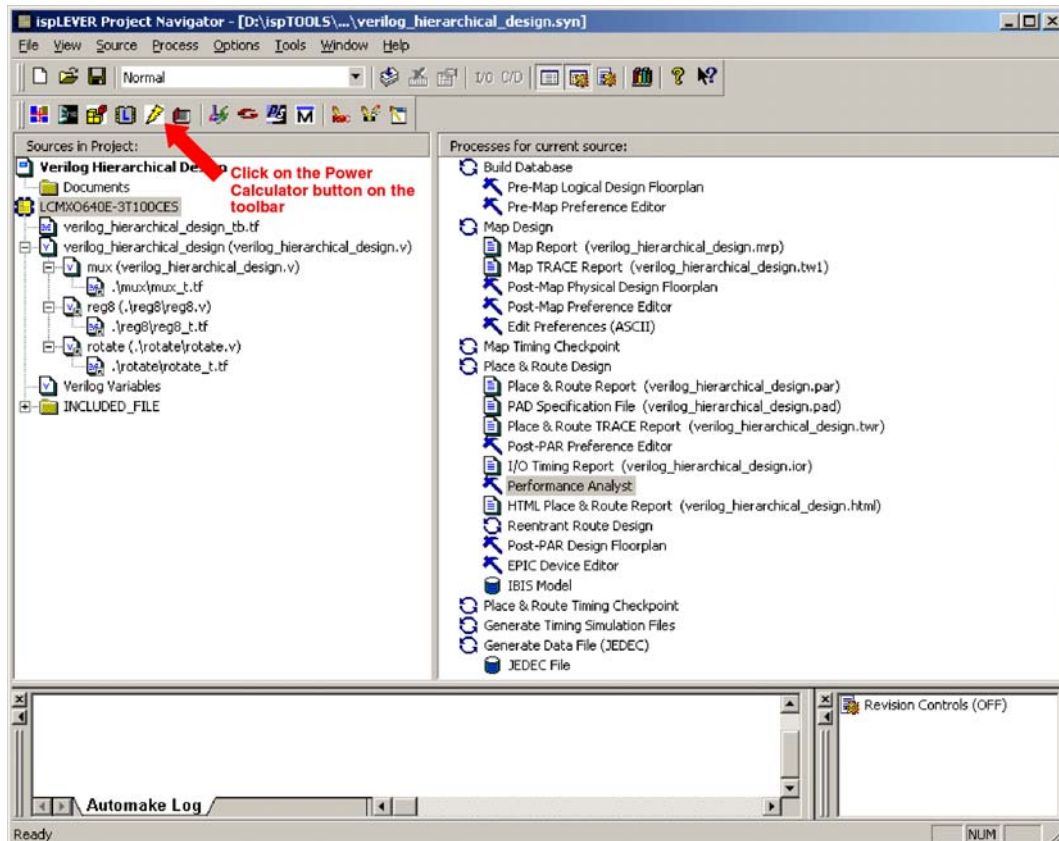
These three stages of power calculation are discussed in detail in the following sections of this document.

Using the Power Calculator

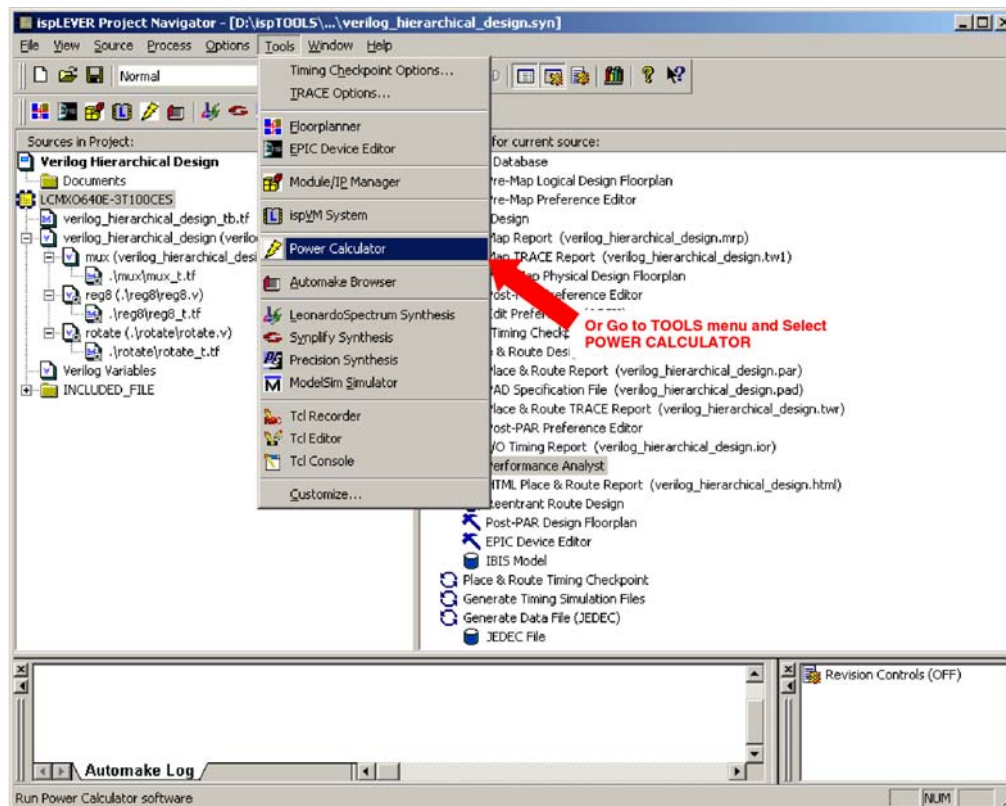
Starting the Power Calculator

The Power Calculator can be launched by one of two methods. The first method is to click the **Power Calculator button** in the toolbar as shown in Figure 12-1.

Figure 12-1. Starting Power Calculator from the Toolbar



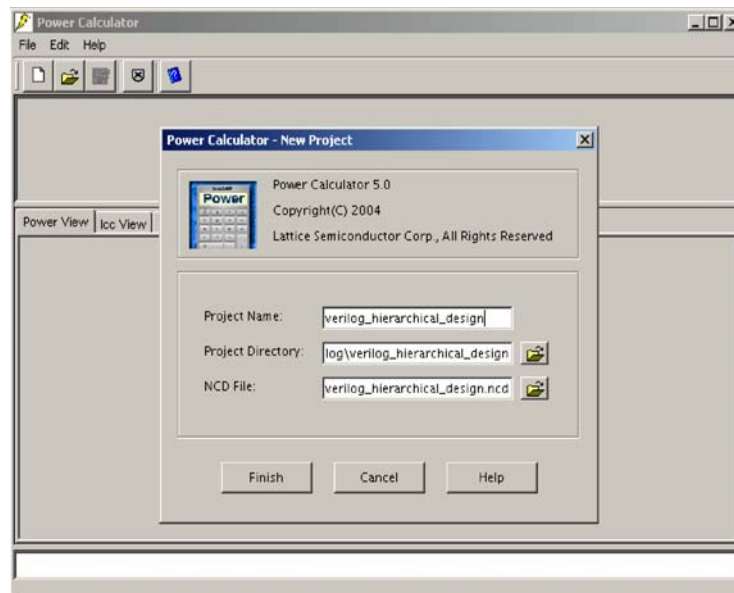
The Power Calculator can also be launched by going to the **Tools** menu and selecting the option **Power Calculator** as shown in Figure 12-2.

Figure 12-2. Starting Power Calculator from Tools Menu

Note: The Power Calculator does not support some older Lattice devices. The toolbar button and menu item are only present when supported devices are selected.

Creating a Power Calculator Project

After starting the Power Calculator, the Power Calculator window is displayed. Click on the **File** menu and select **New** to get to the **Start Project** window as shown in Figure 12-3.

Figure 12-3. Power Calculator Start Project Window (Create New Project)

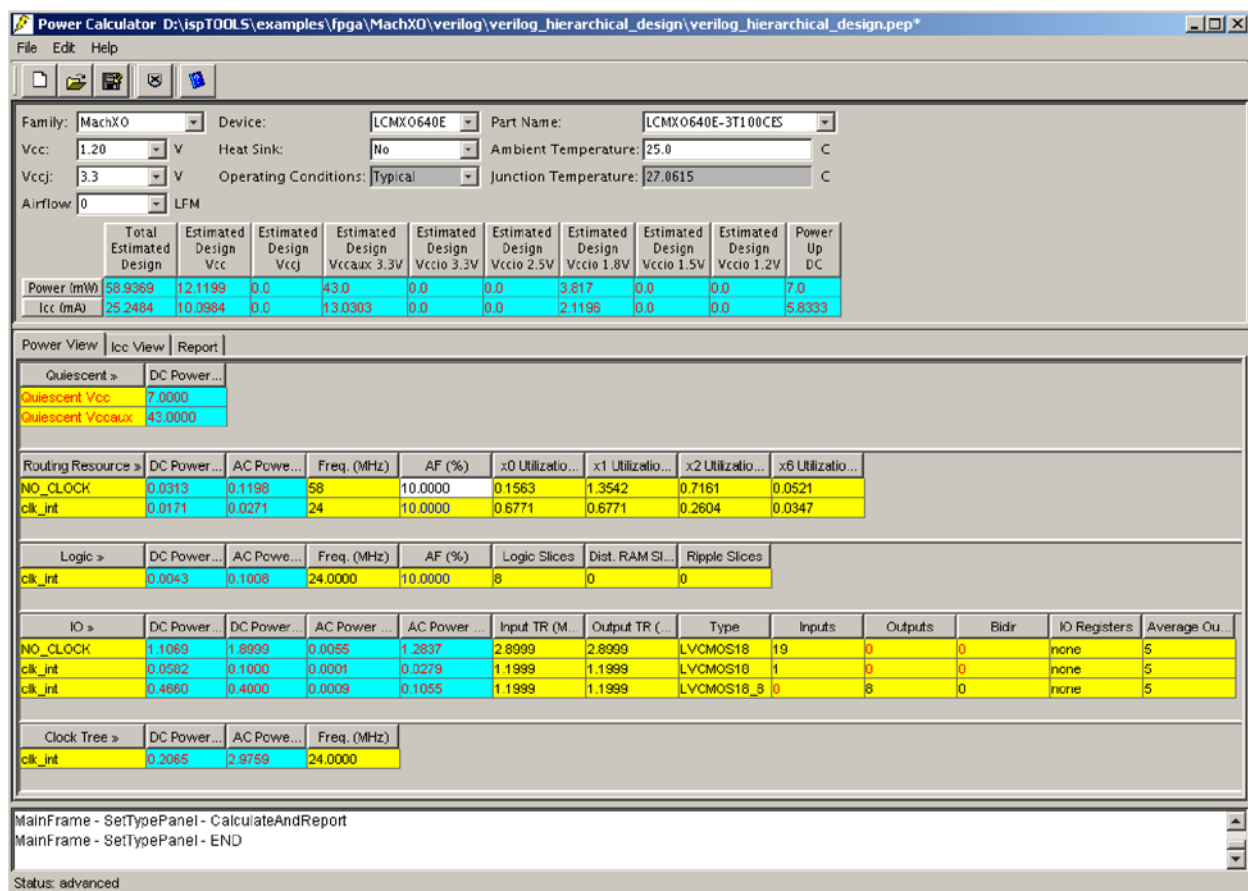
The Start Project window is used to create a new Power Calculator Project (*.pep project). Three pieces of data are entered into the Start Project window.

1. The Power Calculator project name by default is same as the Project Navigator project name. It can be changed, if desired.
2. Project Directory is where the Power Calculator project (*.pep) file will be stored. By default it is stored in the main project folder.
3. The NCD file is automatically selected, if available, or users can browse to the NCD file in a different location.

Power Calculator Main Window

The Power Calculator main window is shown in Figure 4.

Figure 12-4. Power Calculator Main Window (Type View)



The top pane of the window shows information about the device family, device and the part number as it appears in the Project Navigator. The VCC used for the power calculation is also listed. Users have the choice of selecting the core voltage VCC with +5% of the nominal value (or values). The option of selecting VCCJ is also available. Users can provide the ambient temperature, and the junction temperature is calculated based on that.

Users can also enter values for airflow in Linear Feet per Minute (LFM) along with heat sink to obtain the junction temperature.

The table near the top of the Power Calculator main window summarizes the currents and power consumption associated with each type of power supply for the device. This also takes into consideration the I/O power supplies.

In the middle pane of the window, there are three tabs:

1. Power View

The first tab is the Power view. This tab provides an interactive spreadsheet type interface with all values in terms of power consumption mW.

The first column breaks down the design in terms of clock domains. The second and third columns, which are shaded blue, provide the DC (static) and AC (dynamic) power consumption, respectively.

Next are four columns shaded blue. These provide information on the I/O DC and AC power, including core voltage, VCC and the I/O voltage supply, VCCIO.

The first three rows show the Quiescent Power for VCC, VCCAUX and VCCJ. These are DC power numbers for a blank device or device with no resource utilization.

Some of the cells are shaded yellow. These cells are editable cells and users can type in values such as frequency, activity factors and resource utilization. The second tab (the Report tab) is the summary of the Power View. This report is in text format and provides details of the power consumption.

2. ICC View

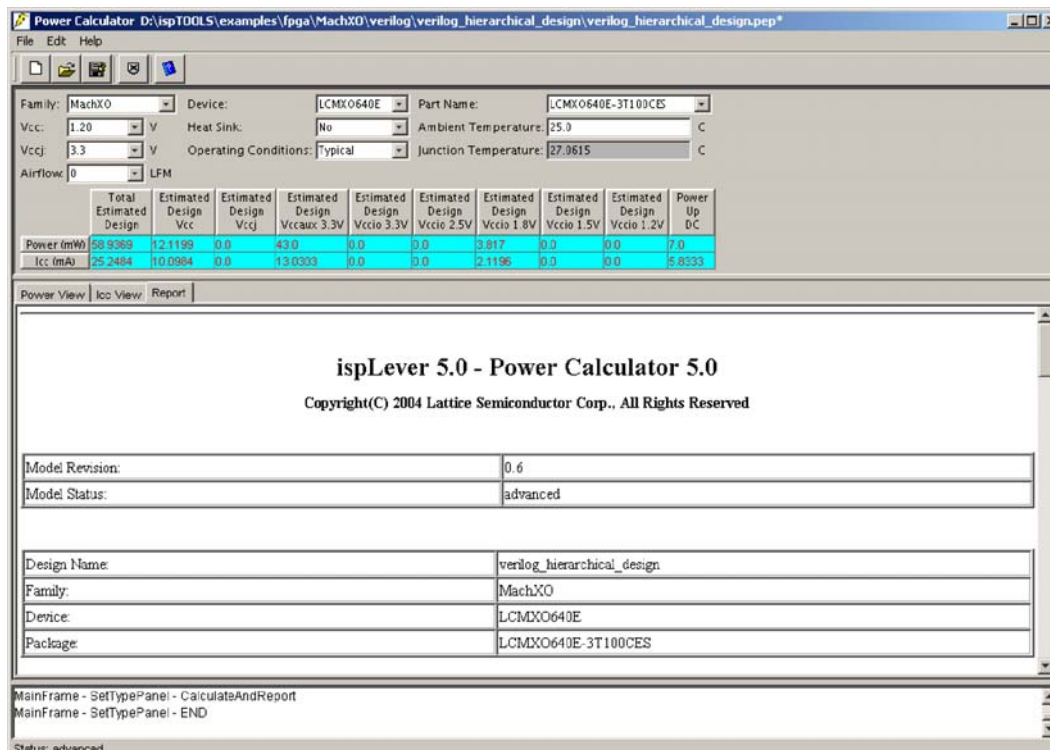
The second tab is the ICC view. This tab is exactly same as the Power View tab, except that all values are expressed in terms of current or mA.

3. Report View

The third and final tab is the Report view. This is an HTML type of Power Calculator report. It summarizes the contents of the Power and ICC views.

The final pane, the lower pane of the window, is the log pane where users can see a log of the various operations in the Power Calculator.

Figure 12-5. Power Calculator Main Window (Power Report View)

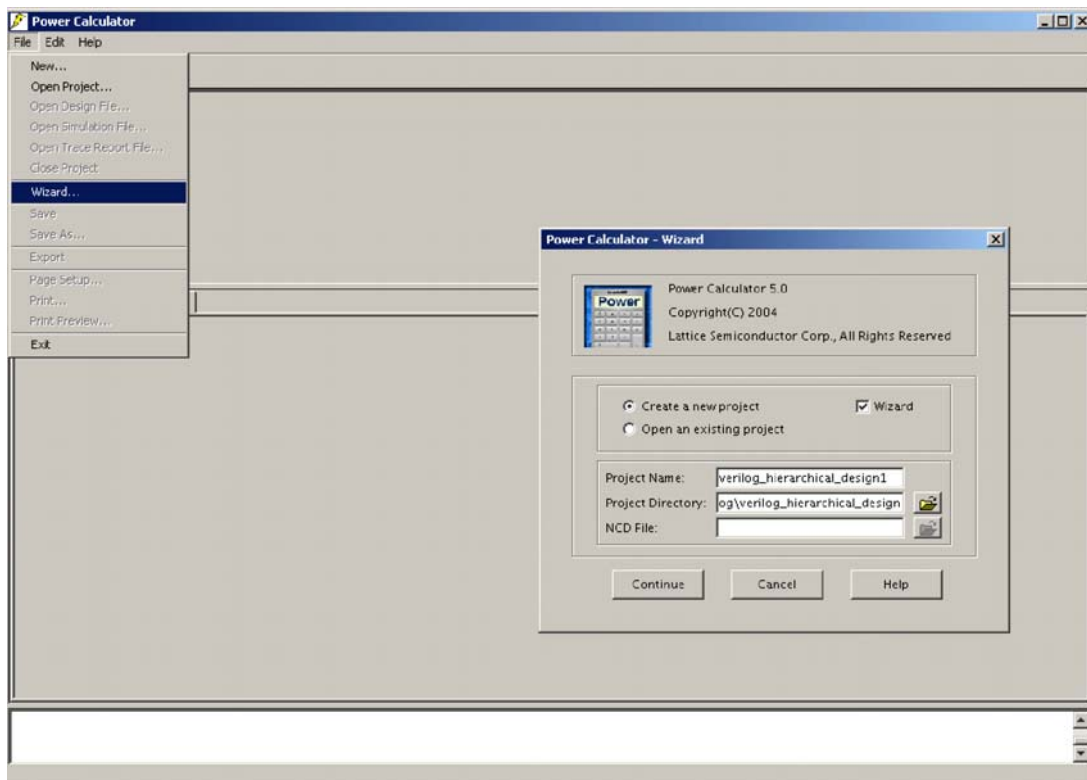


Power Calculator Wizard

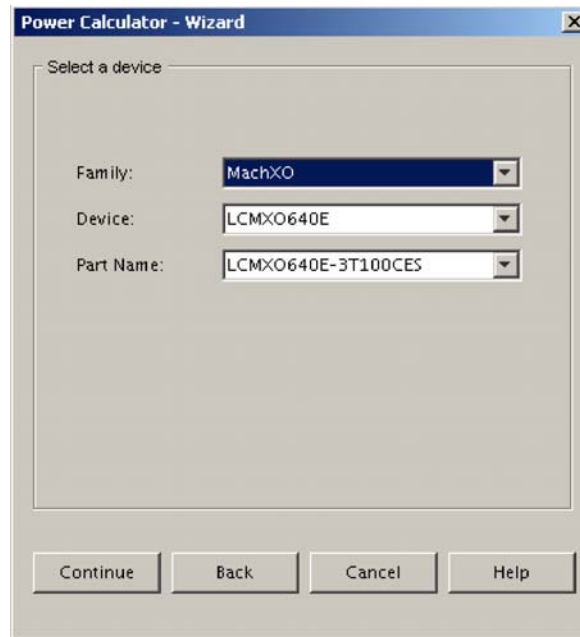
The Power Calculator Wizard allows users to estimate the power consumption of a design. This estimation is done before the design is created. It is important for the user to understand the logic requirements of the design. The wizard allows the user to provide the required parameters and then estimates the power consumption of the device.

To start the Power Calculator in the wizard mode, go to the **File** menu and select **Wizard**. Alternatively, you can click on the **Wizard button** to see the Power Calculator - Wizard window as shown in Figure 12-6. Select the option **Create a new Project** and check the **Wizard check box** in the Power Calculator Start Project window. Provide the project name and the project folder and click **Continue**. Since this is power estimation before the actual design, no NCD file is required.

Figure 12-6. Power Calculator Start Project Window (Using the New Project Window Wizard)



In the next screen, the device family, device, and part number are chosen. After making the proper selections, click **Continue**. This is shown in Figure 7.

Figure 12-7. Power Calculator Wizard Mode Window - Device Selection

In the following screens (Figures 8-12) users can select additional resources, such as I/O types, clock name, frequency at which the clock is running and other parameters by selecting the appropriate resource using the pull-down **Type** menu.

1. Routing Resources
2. Logic
3. EBR
4. I/O
5. PLL
6. Clock Tree

The number in these windows refers to the number of clocks and the index corresponds to each of the clocks. By default, the clock names are clk_1, clk_2, and so on. Clock names can be changed by typing in the Clock Name text box. For each clock domain and resource, parameters such as Frequency and Activity Factor can be specified. In the final window, click the **Create** button for each clock driven resource to include the parameters specified for it.

Figure 12-8. Power Calculator Wizard Mode Window - Resource Specification

Power Calculator - Wizard

Type of Resource:

Logic

Number of Clock Domains:

Routing Resource

Logic

IO

Clock Tree

Clock Domain:

Clock Name:

clk_1

Frequency (MHz):

0.0

Activity Factor (%):

0.0

Number of Slices in Logic Mode:

0

Number of Slices in Dist. RAM Mode:

0

Number of Slices in Ripple Mode:

0

Finish

Back

Cancel

Help

These parameters are then used in the Power Type View window, which can be seen upon clicking on **Finish** (see Figure 9).

Figure 12-9. Power Calculator Wizard Mode - Main Window

Power Calculator

D:\ispTOOLS\examples\fpga\MachXO\verilog\verilog_hierarchical_design\verilog_hierarchical_design1.pep

File Edit Help

Family: MachXO Device: LCMX0640E Part Name: LCMX0640E-3T100CS

Vcc: 1.20 V Heat Sink: No Ambient Temperature: 25.0 C

Vccj: 3.3 V Operating Conditions: Typical Junction Temperature: 27.4395 C

Airflow: 0 LFM

	Total Estimated Design	Estimated Design Vcc	Estimated Design Vccj	Estimated Design Vccaux 3.3V	Estimated Design Vccio 3.3V	Estimated Design Vccio 2.5V	Estimated Design Vccio 1.8V	Estimated Design Vccio 1.5V	Estimated Design Vccio 1.2V	Power Up DC
Power (mW)	69.7693	26.4215	0.0	43.0	0.0	0.0	0.3477	0.0	0.0	7.0
Icc (mA)	35.2402	22.0172	0.0	13.0303	0.0	0.0	0.1927	0.0	0.0	5.8333

Power View

Icc View

Report

Quiescent >

DC Power ...

Quiescent Vcc 7.0000

Quiescent Vccaux 43.0000

Routing Resource >	DC Power ...	AC Power ...	Freq. (MHz)	AF (%)	x0 Utilizatio...	x1 Utilizatio...	x2 Utilizatio...	x6 Utilizatio...
clk_1	0.0061	0.0252	100.0000	5.0000	0.7000	0.8900	0.0000	0.0000

Logic >

DC Power ...

AC Power ...

Freq. (MHz)

AF (%)

Logic Slices

Dist. RAM Sl...

Ripple Slices

clk_1	0.0560	0.5519	100.0000	12.0000	100	2	0
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IO >

DC Power ...

DC Power ...

AC Power ...

AC Power ...

Input TR (M...

Output TR (...

Type

Inputs

Outputs

BiDir

IO Registers

Average Ou...

clk_1	0.1747	0.1500	0.0017	0.1979	5.0	6.0	LVCMS018_8	7	3	0	sdr	5
-------	--------	--------	--------	--------	-----	-----	------------	---	---	---	-----	---

Clock Tree >

DC Power ...

AC Power ...

Freq. (MHz)

clk_1	0.2065	12.3999	100.0000
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MainFrame - SetTypePanel - CalculateAndReport
MainFrame - SetTypePanel - END
Status: advanced

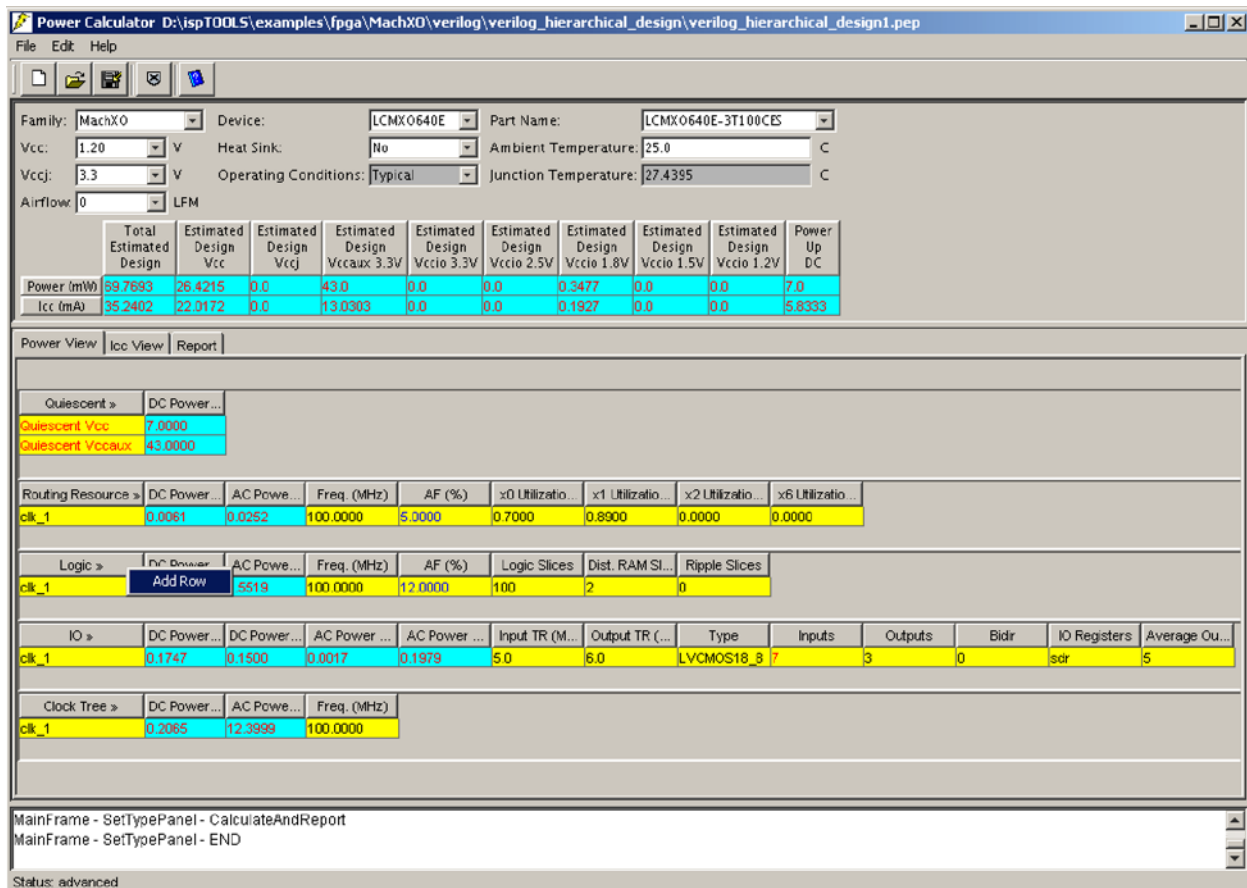
Creating a New Project Without the NCD File

A new project can be started without the NCD file, either by using the wizard (as discussed above) or by selecting the **Create a New Project** option in the Power Calculator - Start Project. The project name and project directory must be provided. After clicking **Continue** the Power Calculator main window will be displayed.

However, in this case there are no resources added. The power estimation row for the routing resources is always available in the Power Calculator. Additional information such as the Slice, EBR, I/O, PLL, and clock tree utilization must be provided to calculate the power consumption.

For example, if the user wants to add the logic resources shown in Figure 10, right-click on **Logic >>** and then select **Add Row** in the menu that pops up.

Figure 12-10. Power Calculator Main Window - Adding Resources



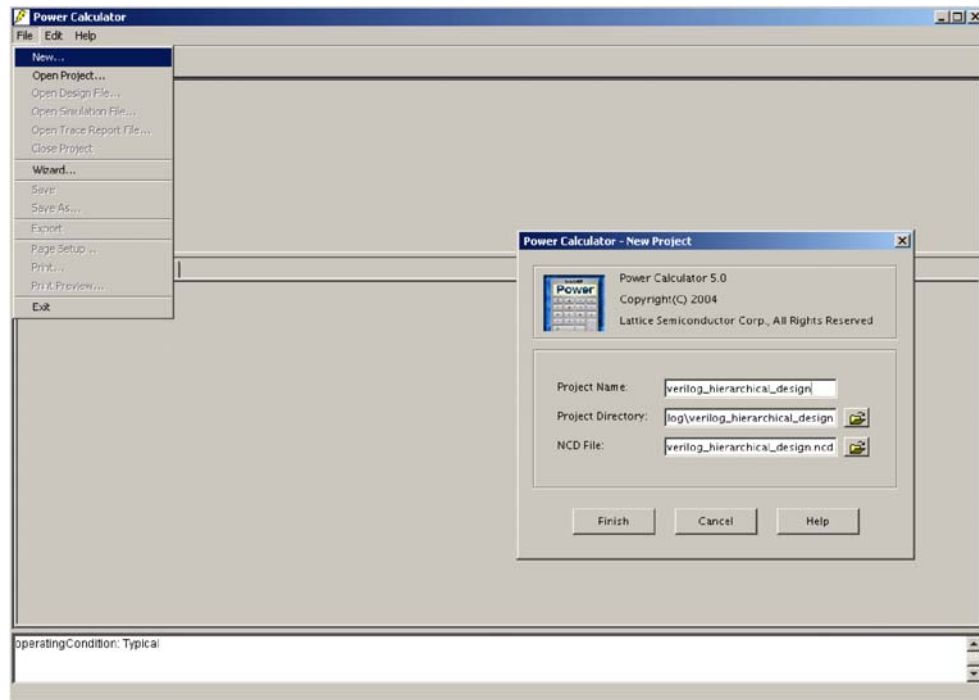
This adds a new row for the logic resource utilization with clock domain named clk_1.

Similarly, other resources like EBR, I/Os, PLLs and routing can be added. Each of these resources is used for AC power estimation and categorized by clock domains.

Creating a New Project with the NCD File

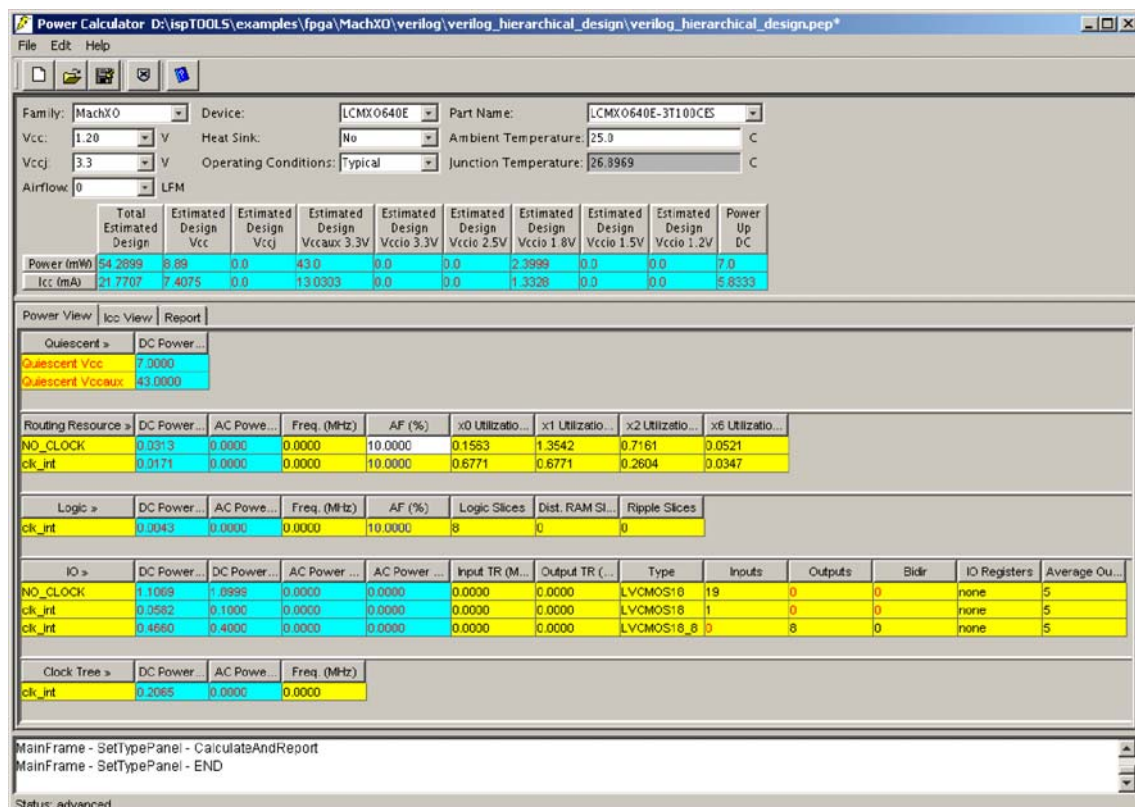
If the post place and routed NCD file is available, the Power Calculator can use it to import accurate information about the design data and resource utilization for power calculation. After starting the Power Calculator, the NCD file is automatically placed in the NCD File option, if it is available in the project directory. Otherwise, browse to the NCD file using the Power Calculator.

Figure 12-11. Power Calculator Start Project Window with Post PAR NCD File



The information from the NCD file is automatically inserted into the correct rows and Power Calculator uses the Clock names from the design as shown in Figure 12-12.

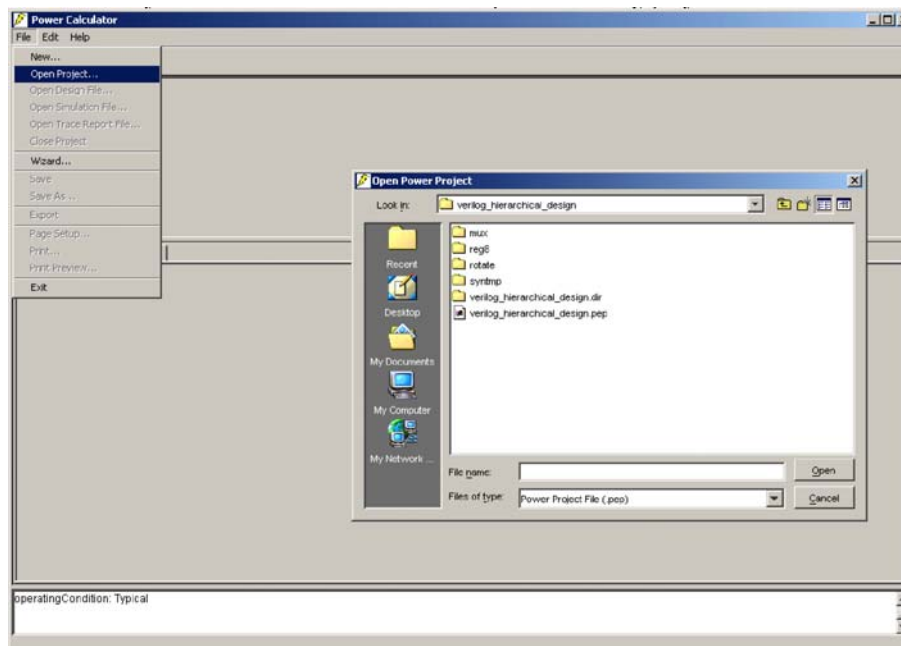
Figure 12-12. Power Calculator Main Window - Resource Utilization Picked Up from the NCD File



Opening an Existing Project

The Power Calculator - Start Project window also allows users to open an existing project. Select **Open Existing Project** and browse to the *.pep project file and click **Continue**. This opens the existing project in windows similar to those discussed above (see Figure 12-13).

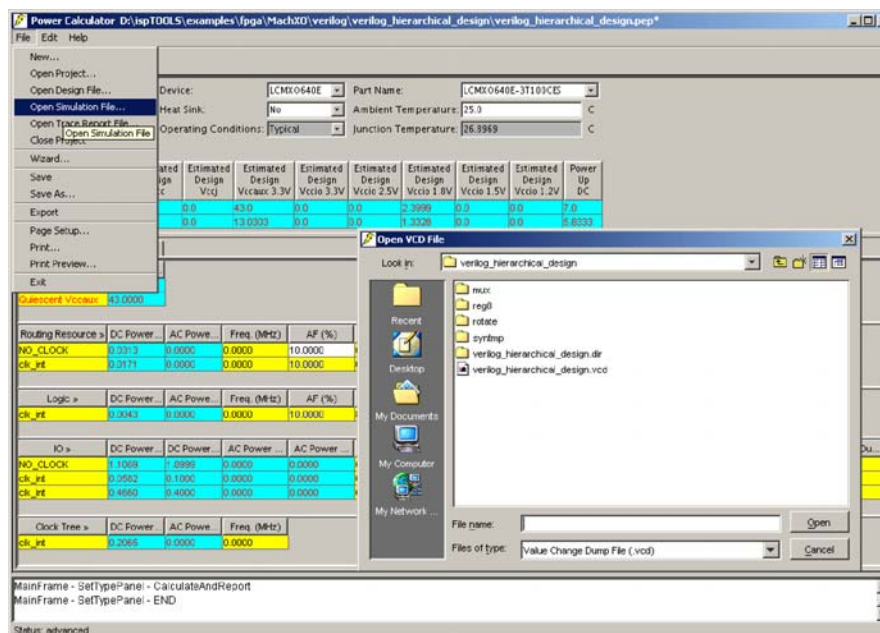
Figure 12-13. Opening an Existing Project in Power Calculator



Importing a Simulation File (VCD)

A post simulation VCD file can be imported into the Power Calculator project to estimate a design's activity factors. Under the **File** menu, select **Open Simulation File** and browse to the VCD file location and select **Open**. All AF and Toggle Rate fields are then populated with the information from this file, as shown in Figure 12-14.

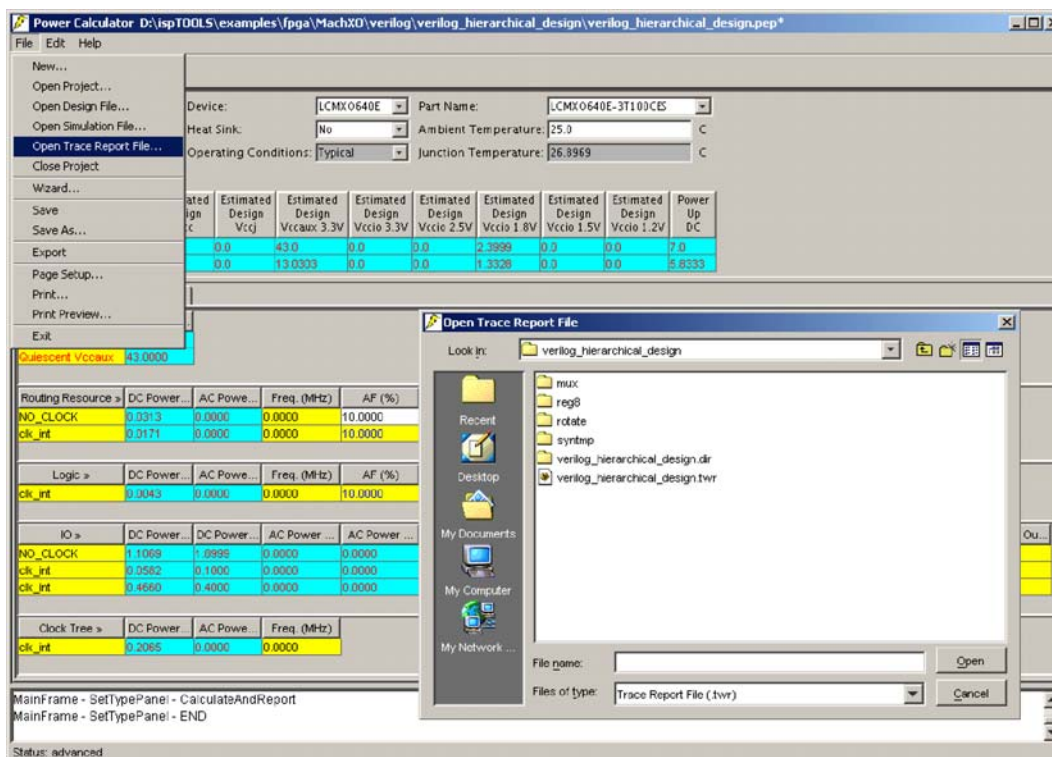
Figure 12-14. Importing a Simulation File in an Existing Power Calculator Project



Importing a Trace Report File (TWR)

Post Trace TWR file can be imported into the Power Calculator project to estimate a design's activity factors. Under the **File** menu, select **Open Trace Report File**, browse to the TWR file location and select **Open**. All Freq. (MHz) fields are then populated with the information from this file, as shown in Figure 12-15.

Figure 12-15. Importing a Trace Report File to a Power Calculator Project



Activity Factor and Toggle Rate

Activity Factor% (or AF%) is defined as the percentage of frequency (or time) that a signal is active or toggling of the output. Most of the resources associated with a clock domain are running or toggling at some percentage of the frequency at which the clock is running. Users must provide this value as a percentage under the AF% column in the Power Calculator tool.

Another term used is the I/O Toggle Rate or the I/O Toggle Frequency. The AF% is applicable to the PFU, routing and memory read write ports, etc. The activity of the I/Os is determined by the signals provided by the user (for inputs) or as an output of the design (for outputs). Therefore, the rates at which I/Os toggle define their activity. The Toggle Rate (or TR) in MHz of the output is defined by the following equation:

$$\text{Toggle Rate (MHz)} = 1/2 * f_{\text{MAX}} * \text{AF\%}$$

Users must provide the TR (MHz) value for the I/O instead of providing the Frequency and AF% in case of other resources. The AF can be calculated for each routing resource, output or PFU. However, it involves long calculations. The general recommendation for a design occupying roughly 30% to 70% of the device is an AF% of 15% to 25%. This is an average value that can be seen most of the design. An accurate value for an activity factor depends upon clock frequency, stimulus to the design and the final output.

Ambient and Junction Temperatures and Airflow

A common method of characterizing a packaged device's thermal performance is with thermal resistance, or Θ . For a semiconductor device, thermal resistance indicates the steady state temperature rise of the die junction above a given reference for each watt of power (heat) dissipated at the die surface. Its units are $^{\circ}\text{C}/\text{W}$.

The most common examples are Θ_{JA} , Thermal Resistance Junction-to-Ambient (in $^{\circ}\text{C}/\text{W}$) and Θ_{JC} , Thermal Resistance Junction-to-Case (also in $^{\circ}\text{C}/\text{W}$). Another factor is Θ_{JB} , Thermal Resistance Junction-to-Board (in $^{\circ}\text{C}/\text{W}$).

Knowing the reference (i.e. ambient, case, or board) temperature, the power, and the relevant Θ value, the junction temp can be calculated by the following equations.

$$T_J = T_A + \Theta_{JA} * P \quad (1)$$

$$T_J = T_C + \Theta_{JC} * P \quad (2)$$

$$T_J = T_B + \Theta_{JB} * P \quad (3)$$

While T_J , T_A , T_C and T_B are the Junction, Ambient, Case (or Package) and Board temperatures (in $^{\circ}\text{C}$) respectively, P is the total power dissipation of the device.

Θ_{JA} is commonly used with natural and forced convection air-cooled systems. Θ_{JC} is useful when the package has a high conductivity case mounted directly to a PCB or heatsink. And Θ_{JB} applies when the board temp adjacent to the package is known.

The Power Calculator utilizes the Ambient Temperature ($^{\circ}\text{C}$) to calculate the Junction Temperature ($^{\circ}\text{C}$) based on the Θ_{JA} for the targeted device, per Equation 1 above. Users can also provide the Airflow values (in LFM) to get a more accurate value of the Junction temperature.

Managing Power Consumption

One of the most critical design factors today is the reduction of system power consumption, especially for modern handheld devices and electronics. There are several design techniques that can significantly reduce overall system power consumption. Some of these include:

1. Reducing operating voltage.
2. Operating within the specified package temperature limitations.
3. Using the optimum clock frequency to reduce power consumption, since dynamic power is directly proportional to the frequency of operation. Designers must determine if a portion of their design can be clocked at a lower rate that will reduce power.
4. Reducing the span of the design across
5. Reducing the voltage swing of the I/Os where possible.
6. Using optimum encoding where possible. For example, a 16-bit binary counter has, on average, only 12% Activity Factor and a 7-bit binary counter has an average of 28% Activity Factor. On the other hand, a 7-bit Linear Feedback Shift Register could toggle as much as 50% Activity Factor, which causes higher power consumption. A gray code counter, where only one bit changes at each clock edge, will use the least amount of power, as the Activity Factor would be less than 10%.
7. Minimize the operating temperature, by the following methods:
 - a. Use packages that can better dissipate heat. For example, packages with lower thermal impedance.
 - b. Place heat sinks and thermal planes around the device on the PCB.
 - c. Better airflow techniques using mechanical airflow guides and fans (both system fans and device mounted fans).

Power Calculator Assumptions

The following are the assumptions made by the Power Calculator:

1. The Power Calculator tool is based on equations with constants based on a room temperature of 25°C.
2. The user can define the Ambient Temperature (T_A) for device Junction Temperature (T_J) calculation based on the power estimation. T_J is calculated from user-entered T_A and power calculation of typical room temperature.
3. I/O power consumption is based on output loading of 5pF. Users can change this capacitive loading.
4. The Power Calculator provides an estimate of the power dissipation and current for each of the following types of power supplies: VCC, VCCIO, VCCJ and VCCAUX.
5. The nominal VCC is used by default to calculate power consumption. A lower or higher VCC can be chosen from a list of available values.
6. Airflow in Linear Feet per Minute (LFM) can be entered by the user along with the Heat Sink option to calculate the Junction Temperature.
7. The default value of the I/O types is LVCMOS12, 6mA.
8. The Activity Factor (AF) is defined as the toggle rate of the registered output. For example, assuming that the input of a flip-flop is changing at every clock cycle, 100% AF of a flip-flop running at 100MHz is 50MHz.

Technical Support Assistance

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Revision History

Date	Version	Change Summary
February 2007	01.0	Initial release.