Power Estimation and Management for MachXO Devices

September 2007 Technical Note TN1090

Introduction

One requirement for design engineers using programmable devices is to be able 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 provides users with details for using the Power Calculator to calculate the power consumption of the Lattice MachXO™ family of devices. General guidelines for reducing power consumption are also included.

Power Supply Sequencing and Hot Socketing

The MachXO 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 tristate until the power supply voltage is high enough to ensure reliable operation. In addition, leakage into I/O pins is controlled to within specified limits listed in the device data sheet. This allows for easy integration with the rest of the system. These capabilities make the MachXO ideal for many multiple power supply and hot-swap applications.

Recommended Power-up Sequence

As described in the previous paragraph, the supplies can be sequenced in any order. However, once internal power is achieved (determined by VCC, VCCAUX) the device releases I/Os from tristate and the management of I/Os becomes the designer's responsibility. Therefore, to simplify a system design it is recommended that supplies be sequenced VCCIO, VCC, VCCAUX. If VCCIO is tied to VCC or VCCAUX, 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 device data sheet for more information.

Power Calculator Hardware Assumptions

Power consumption of the device can be broken down coarsely 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 and depend 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 the power consumption is associated with the used resources and 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 Calculator

Power Calculator Equations

The power equations used in the Power Calculator are shown below.

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

Where,

$N_{TOTAL\ RESOURCE}$	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, on the other hand, is governed by the following equation.

Total AC Power (Resource)
= $K_{RESOURCE}$ * f_{MAX} * $AF_{RESOURCE}$ * $N_{RESOURCE}$

Where,

$N_{TOTAL\ RESOURCE}$	is the total 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. The units of this factor are 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. Activity factor is in terms of the percentage (%) of switching frequency.

Based on the above equations, if we wish to calculate the power consumption of the slice portion, it will be as shown below.

Total DC Power (Slice)
= Total DC Power of Used Portion + Total DC Power of Unused Portion
= [DC Leakage per Slice when Used * N_{SLICE}]
+ [DC Leakage per Slice when Unused * ($N_{TOTAL\ SLICE}$ - N_{SLICE})]

Total AC Power (Slice)
= K_{SLICE} * f_{MAX} * AF_{SLICE} * N_{SLICE}

Power Calculations

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

In the second level, a more accurate approach, the user imports the actual device utilization by importing the post place and route netlist (NCD) file.

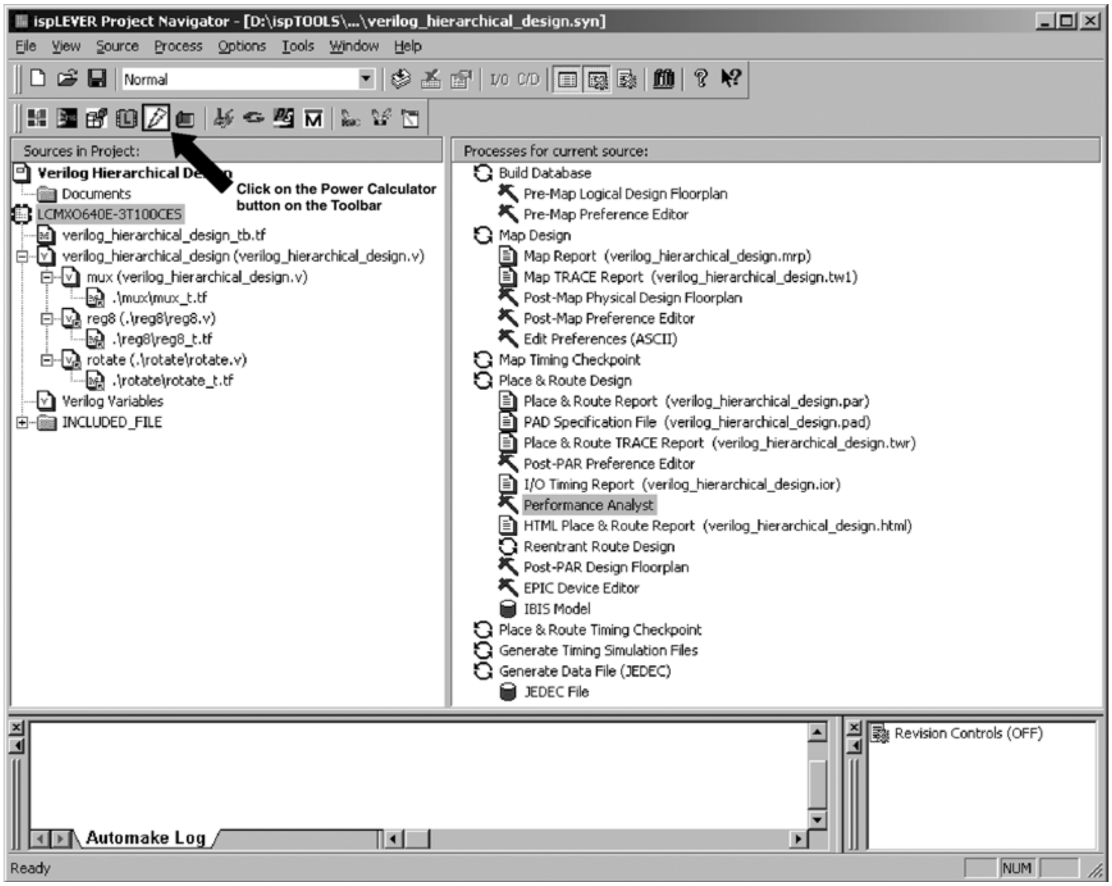
The third and final stage brings even more accuracy to the calculation, by importing the Trace (TWR) file to populate the maximum frequencies (f_{MAX}) into the tool. Users also have the option of importing the information from the post simulation (VCD) file and calculating the activity factor and toggle rates of various components.

These power calculations are discussed in detail in the following sections of this document.

Starting the Power Calculator

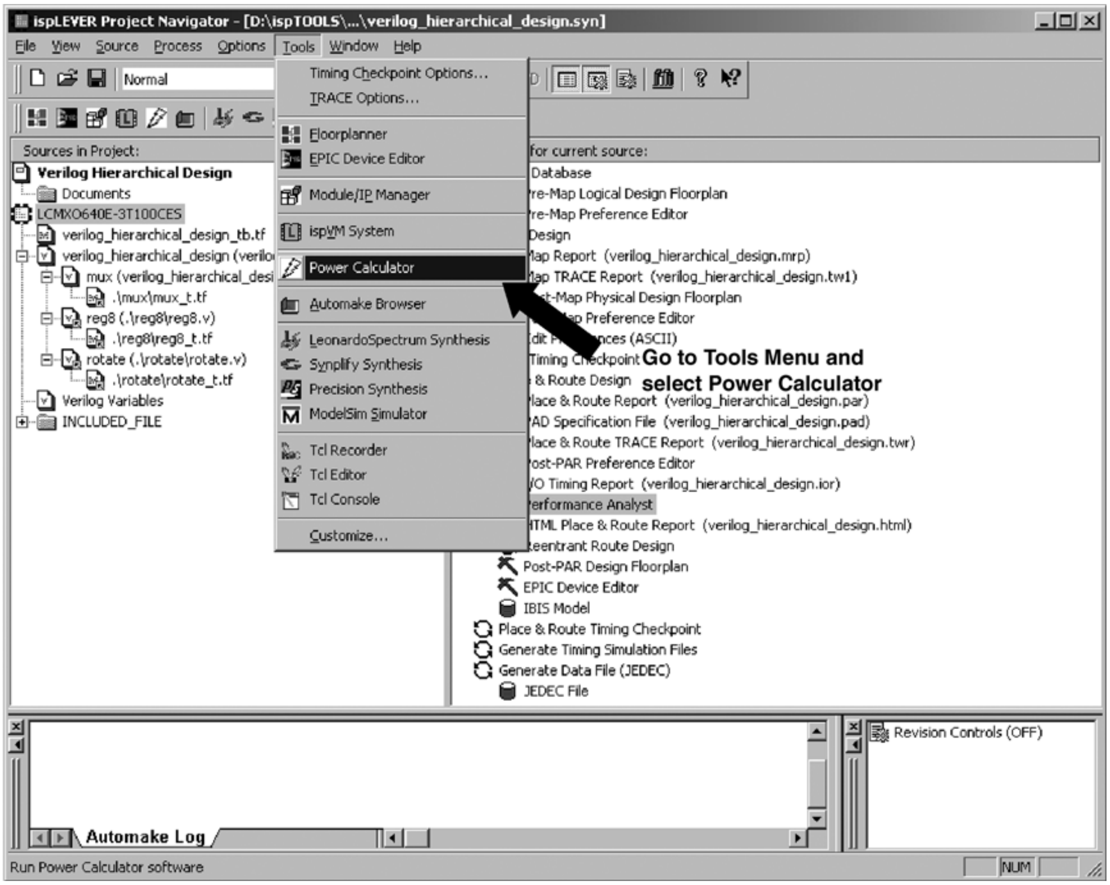
The user may launch the Power Calculator using one of two methods. The first method is by clicking the **Power Calculator button** in the toolbar as shown in Figure 11-1.

Figure 11-1. Starting Power Calculator From the Toolbar



Alternatively, users can launch the Power Calculator by going to the **Tools** menu and selecting **Power Calculator** as shown in Figure 11-2.

Figure 11-2. Starting Power Calculator from Tools Menu

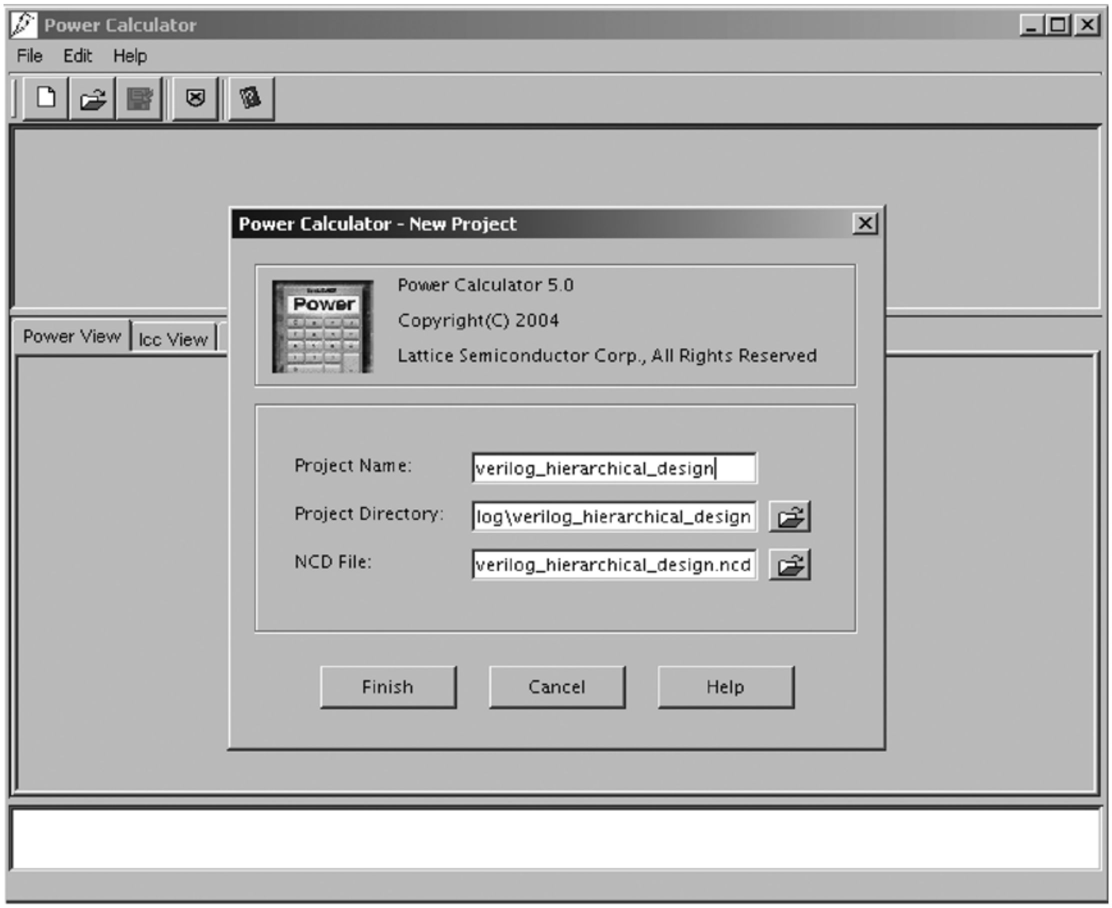


The Power Calculator does not support some of Lattice's older devices. The toolbar button and menu item is only present when supported devices are selected.

Creating a Power Calculator Project

After starting the Power Calculator, the user will see the Power Calculator window. Click on **File -> Menu** and select **New** to get to the Start Project window, as shown in Figure 11-3.

Figure 11-3. Power Calculator Start Project Window (Create New Project)



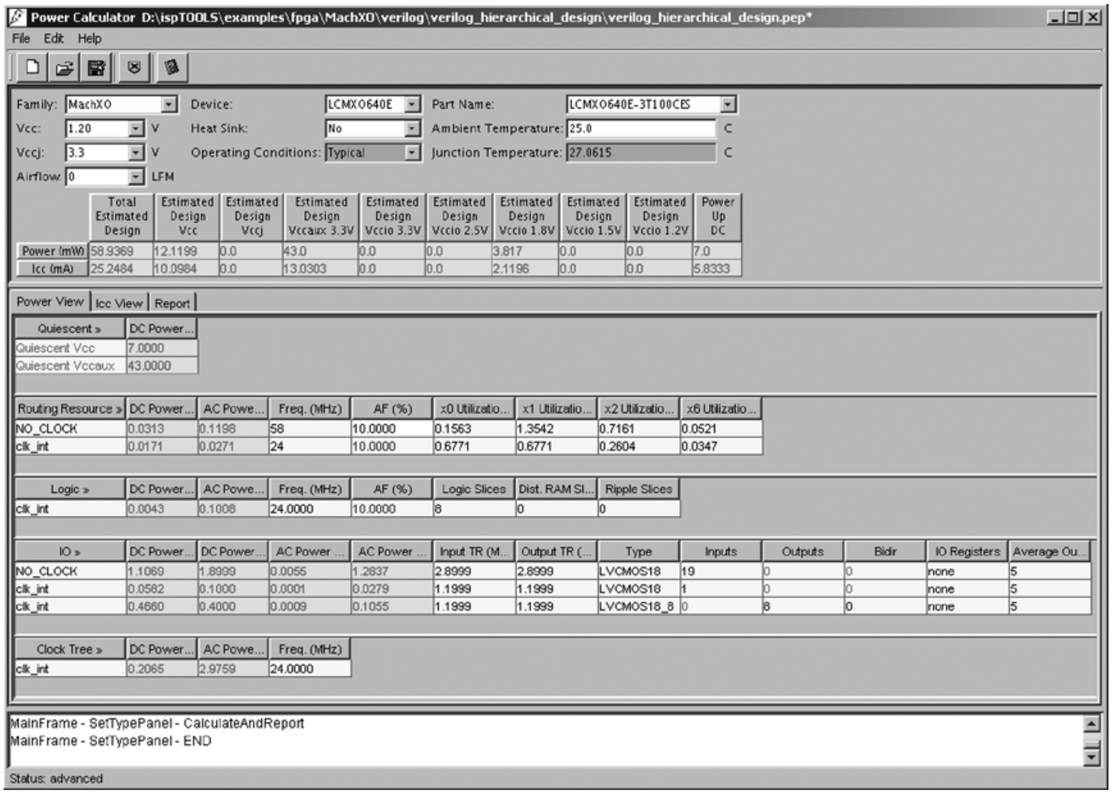
The Start Project window is used to create a new Power Calculator project (*.pep project). Three pieces of data must be input into the Start Project window:

1. The Power Calculator project name by default is the same as the Project Navigator project name. This can be changed, if desired.
2. The 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 main Power Calculator window is shown in Figure 11-4.

Figure 11-4. 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 V_{CC} used for the power calculation is also listed. Users have a choice of selecting the core voltage, V_{CC} with +5% of the nominal value (or values). The option of selecting V_{CCJ} is also available. Users 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 get the junction temperature.

A table in the top part of the Power Calculator 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. Under this tab, the Power Calculator tool has 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 in the tool, provide the DC (or static) and AC (or dynamic) power consumption, respectively.

   In case of the I/Os, there are four columns that are shaded blue. These provide the DC and AC power for I/Os for the core voltage, V_{CC} and the I/O voltage supply, V_{CCIO}.

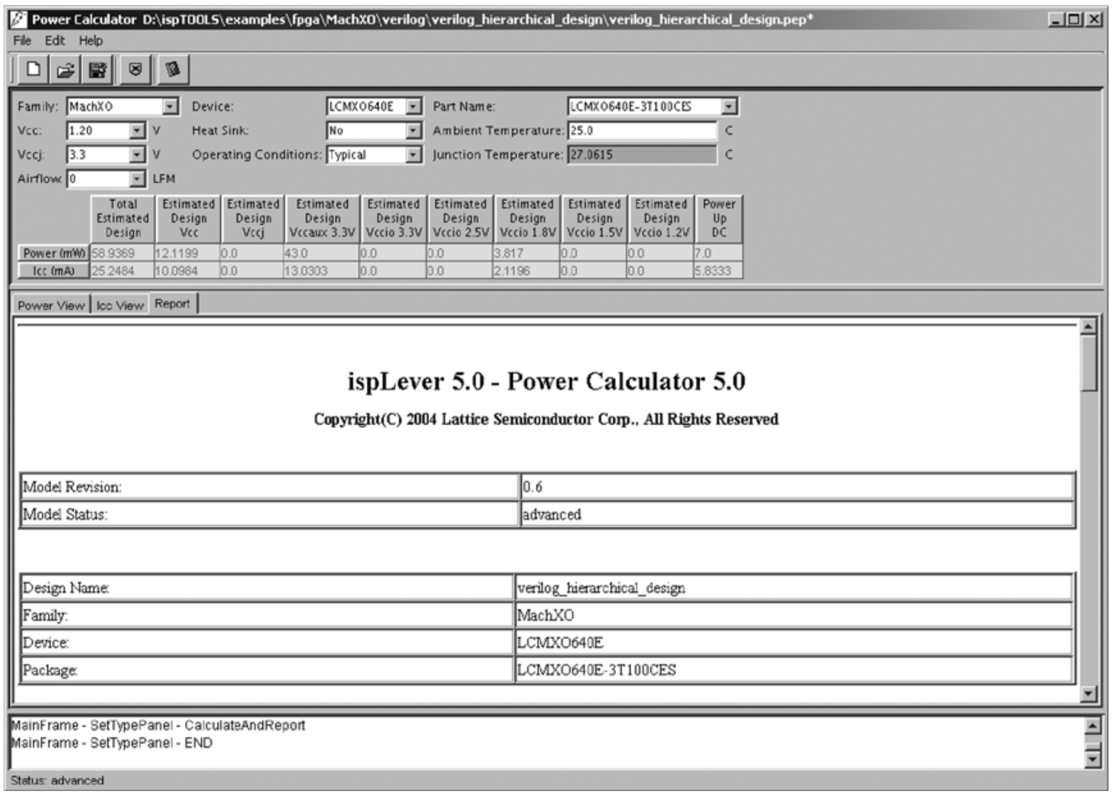
   The first three rows show the Quiescent Power for V_{CC}, V_{CCAUX} and V_{CCJ}. These are DC power numbers for a blank device or a device with no resource utilization.

Some of the cells are shaded yellow in the tool. 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 the details of the power consumption.

2. **I_{CC} View:** The second tab is the I_{CC} view. This tab is exactly same as the Power View tab, except that all values are in terms of current or mA.
3. **Report:** 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 I_{CC} views.

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

Figure 11-5. Power Calculator Main Window (Power Report View)

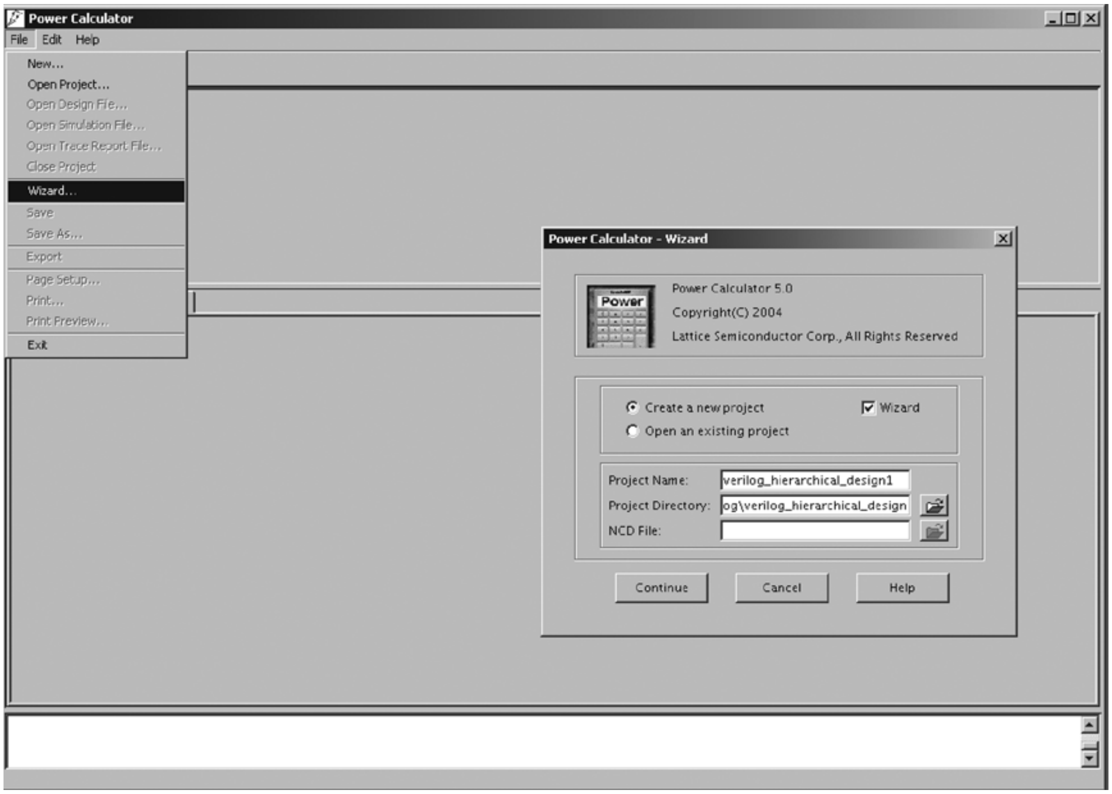


Power Calculator Wizard

The Power Calculator Wizard estimates the power consumption of a given design. This estimation is done before a design is created. The user must understand the logic requirements of the design. The wizard allows the user to provide these 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, click on the **Wizard** button to get the **Power Calculator - Wizard window** as shown in Figure 11-6. Select the option **Create a New Project** and check the **Wizard** check box in the **Power Calculator Start Project** window. Users are required to provide the project name and the project folder. Click **Continue**. Since this is power estimation before the actual design, no NCD file is required.

Figure 11-6. Power Calculator Start Project Window (Using the New Project Window Wizard)



The next screen allows users to select the device family, device and appropriate part number for which users plan to estimate power. After making the proper selections, click “Continue” (see Figure 11-7).

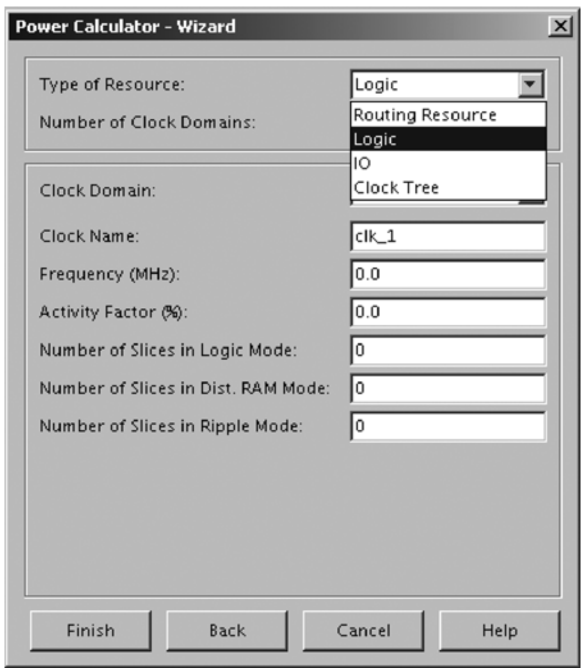
Figure 11-7. Power Calculator Wizard Mode Window - Device Selection

In the following screens, as shown in Figures 8-12, users can select further resources, like I/O types, clock name, frequency at which the clock is running, and other parameters, by selecting the appropriate resource using the pull-down menu:

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

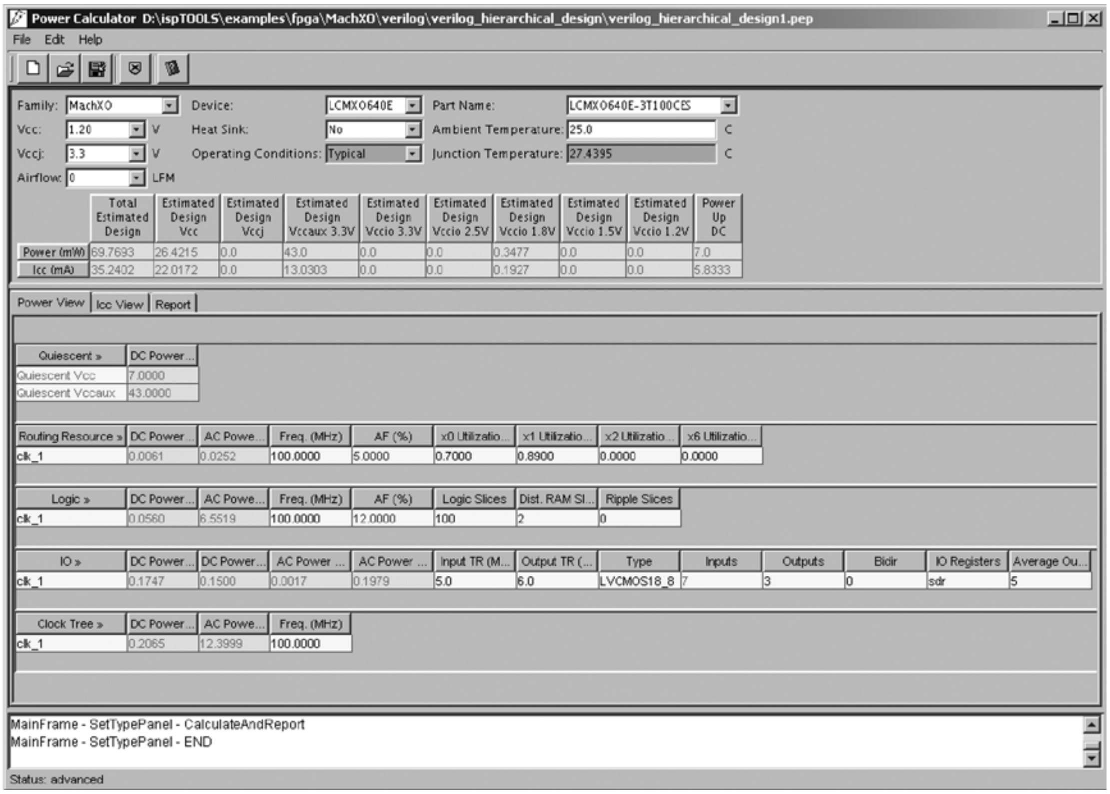
The numbers in these windows refer to the number of clocks and the index corresponds to each clock. By default, the clock names are clk_1, clk_2, and so on. Users can change the name of each clock by typing in the **Clock Name** text box. For each clock domain and resource, users can specify parameters such as frequency, activity factor, etc. In the final window, users must click the **Create** button for each clock-driven resource to include the parameters they have specified for it.

Figure 11-8. Power Calculator Wizard Mode Window - Resource Specification



These parameters are then used in the **Power Type View** window, which can be seen upon clicking on **Finish** (Figure 11-9).

Figure 11-9. Power Calculator Wizard Mode - Main Window



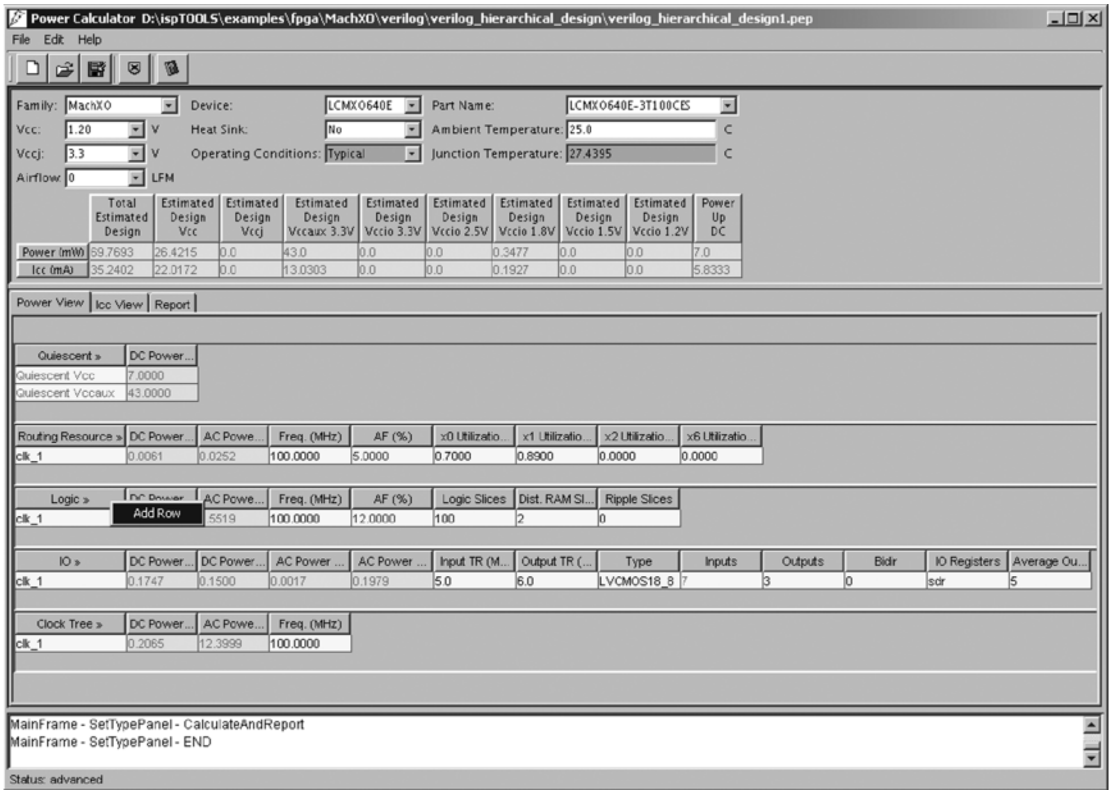
Power Calculator - Creating a New Project Without the NCD File

When starting a new project without the NCD file, begin either by using the **Wizard** (as discussed above) or by selecting the **Create a New Project** option in the **Power Calculator -> Start Project**. Users are required to provide a project name and project directory. 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. Users are required to add more information like the slice, EBR, I/O, PLL and clock tree utilization to calculate the power consumption.

For example, if the user wants to add the logic resources as shown in Figure 11-10, right-click on **Logic** and select **Add Row** in the pop-up menu.

Figure 11-10. Power Calculator Main Window - Adding Resources



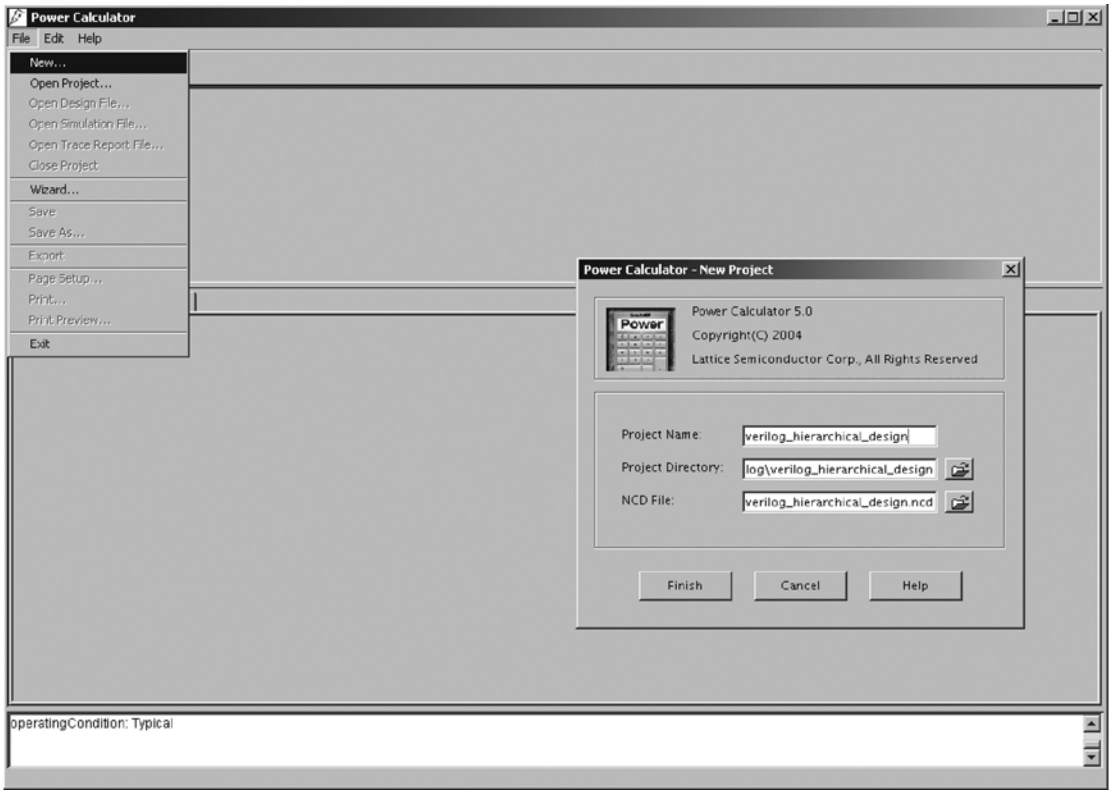
This adds a new row for the logic resource utilization with clock domain as clk_1.

Similarly, users can add other resources like EBR, I/Os, PLLs, routing, etc. Each of these resources is for the AC power estimation and categorized by clock domains.

Power Calculator - Creating a New Project with the NCD File

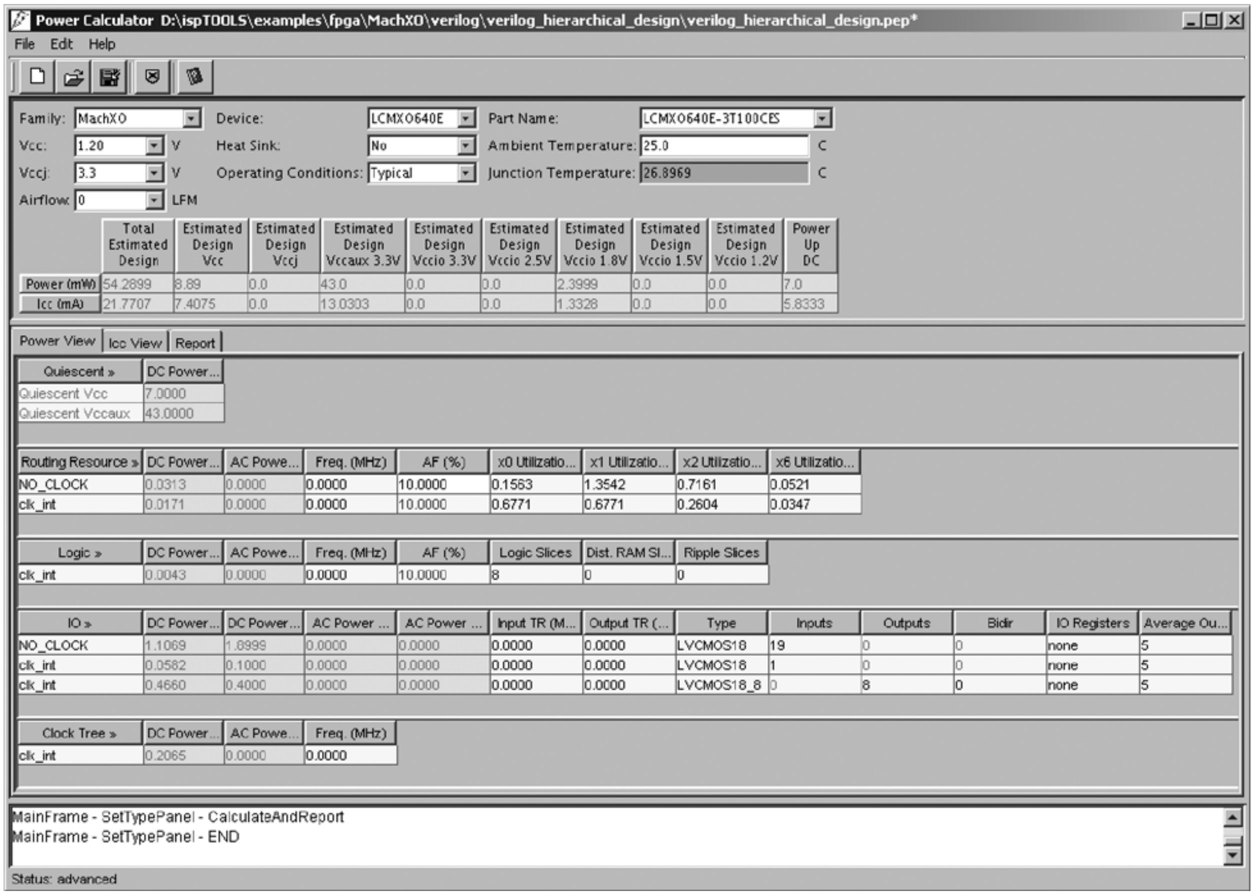
If the post place and routed NCD file is available, the Power Calculator can use this file to import accurate information about the design data and resource utilization and calculate the power. When the Power Calculator is started, the NCD file is automatically placed in the NCD File option, if it is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

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



The information from the NCD file is automatically inserted into the correct rows. Power Calculator uses the clock names from the design as shown in Figure 11-12.

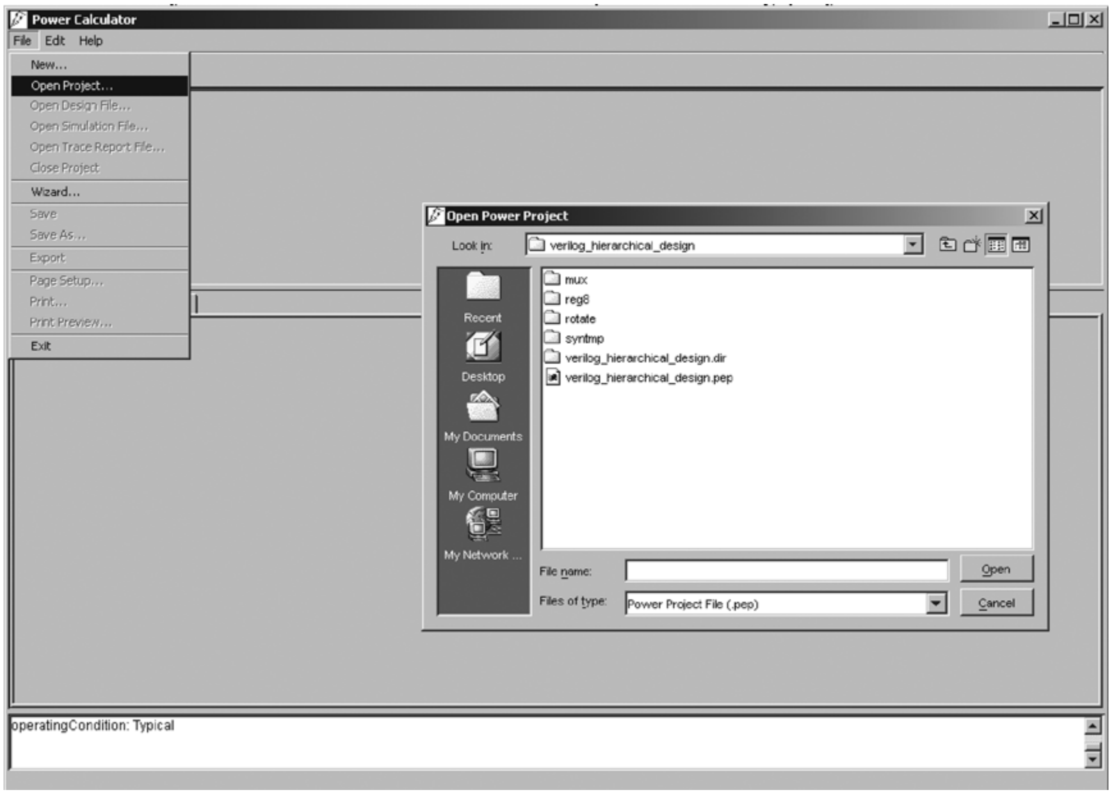
Figure 11-12. Power Calculator Main Window - Resource Utilization Picked up from the NCD File



Power Calculator - Open Existing Project

The Power Calculator - Start Project window also allows users to open an existing project. Select the option **Open Existing Project**, browse to the *.pep project file and click **Continue**. This opens the existing project in similar windows, as discussed above. This is shown in Figure 11-13.

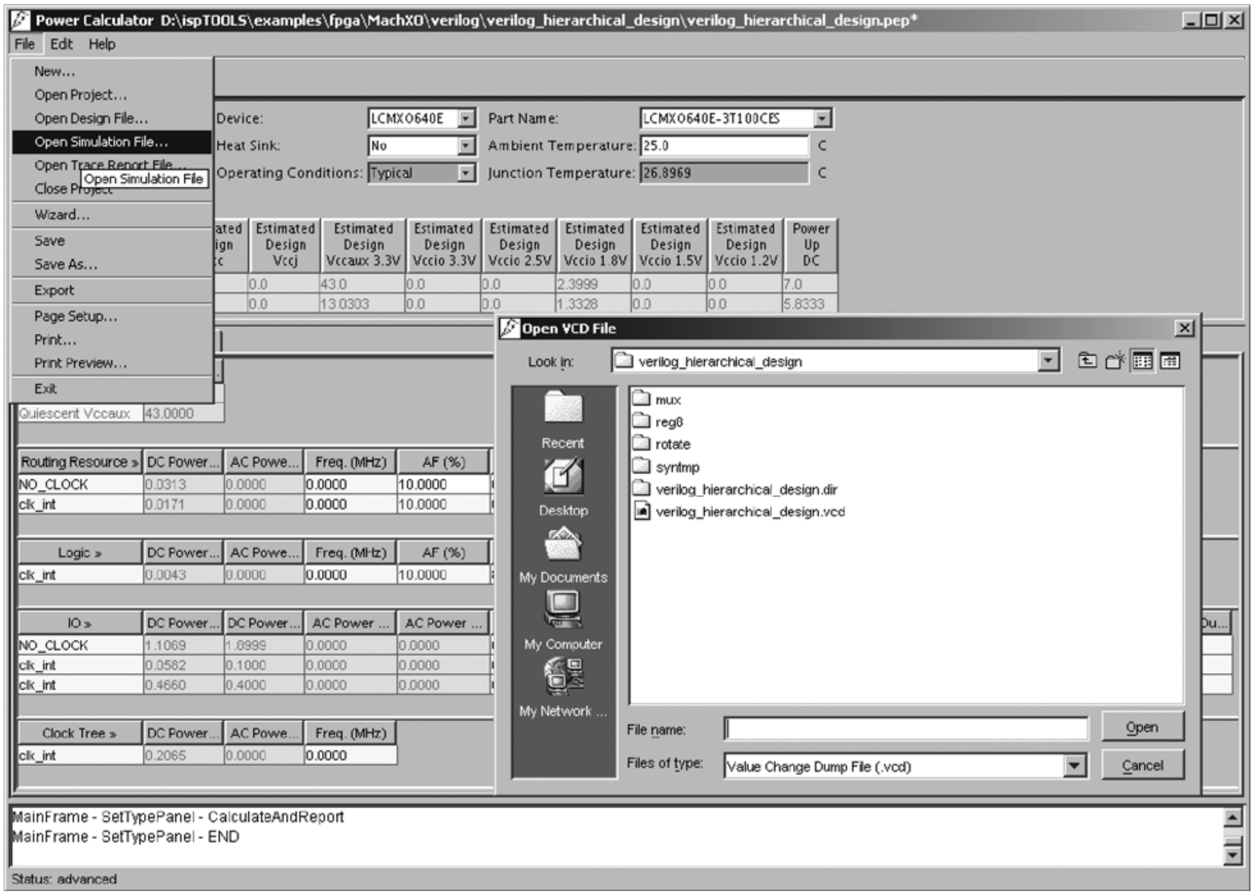
Figure 11-13. Opening an Existing Project in the Power Calculator



Power Calculator - Importing Simulation File (VCD) to the Project

Users can import the post simulation VCD file into the power calculator project to estimate their design's activity factors. Select **Open Simulation File** option under the **File** menu, browse to the VCD file location and select **Open**. All AF and toggle rate fields are populated with the information from this file. This is shown in Figure 11-14.

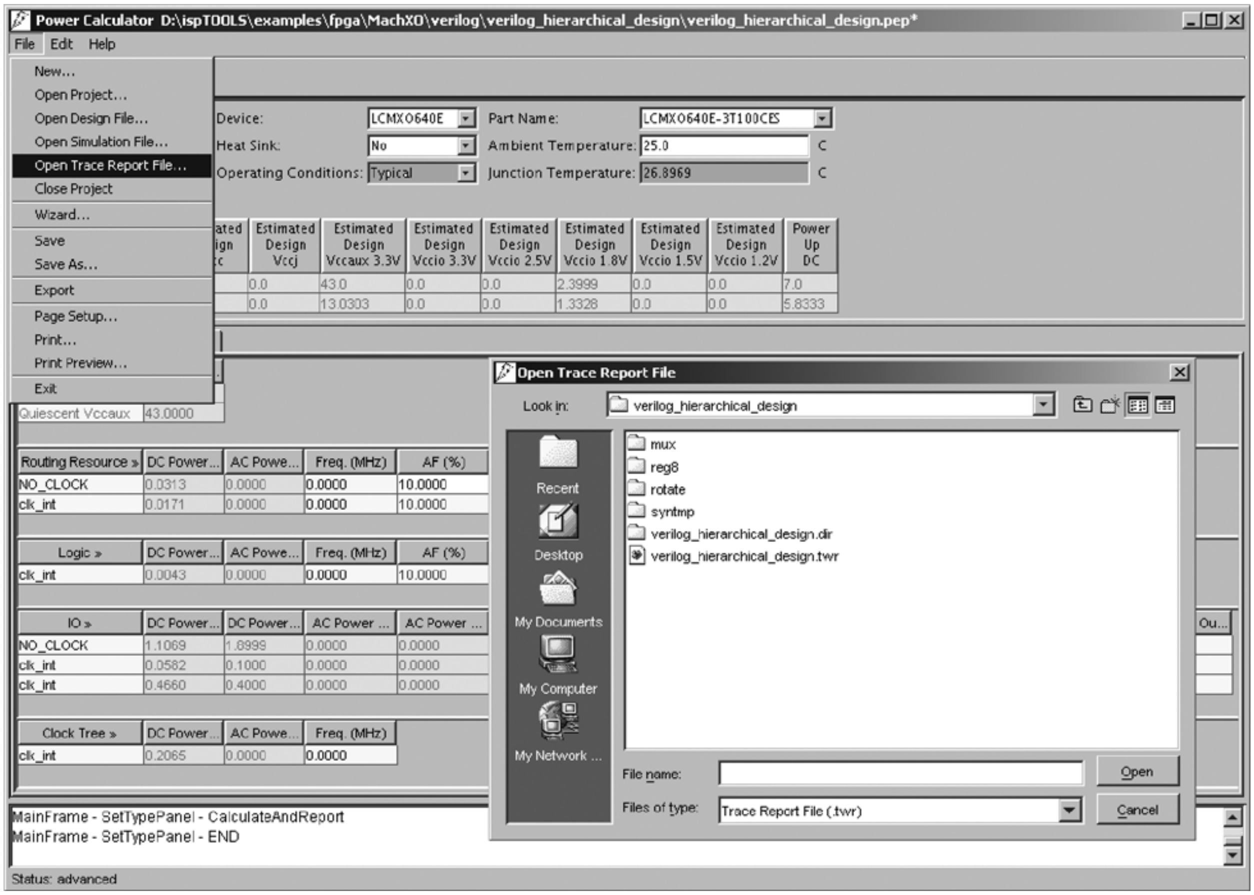
Figure 11-14. Importing Simulation File in the Existing Project in the Power Calculator



Power Calculator - Importing Trace Report File (TWR) to the Project

Users can import the post Trace TWR file into the Power Calculator project to estimate their design's activity factors. Select **Open Trace Report File** option under the **File** menu, browse to the TWR file location and select **Open**. All Freq. (MHZ) fields are populated with the information from this file. This is shown in Figure 11-15.

Figure 11-15. Importing Trace Report File in the Existing Project in the Power Calculator



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 are required to provide this value as a percentage under the AF% column in the Power Calculator tool.

Another term used for I/Os 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 I/Os is determined by the signals provided by the user (in the case of inputs) or as an output of the design (in the case of outputs). So, the rates at which I/Os toggle defines their activity. The Toggle Rate (or TR) in MHz of the output is defined as:

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

Users are required to 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 of a design occupying roughly 30% to 70% of the device is that the AF% used can be between 15% to 25%. This is an average value that can be seen most of the design. The accurate value of an AF depends upon clock frequency, stimulus to the design and the final output.

Ambient and Junction Temperature and Airflow

A common method of characterizing a packaged device's thermal performance is with Thermal Resistance, 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 °C/W.

The most common examples are θ_{JA}, Thermal Resistance Junction-to-Ambient (in °C/W) and θ_{JC}, Thermal Resistance Junction-to-Case (also in °C/W). Another factor is θ_{JB}, Thermal Resistance Junction-to-Board (in °C/W).

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

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

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

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

Where T_J, T_A, T_C and T_B are the junction, ambient, case (or package) and board temperatures (in °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.

Power Calculator utilizes the ambient temperature (°C) to calculate the junction temperature (°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 reducing system power consumption, especially for modern handheld devices and electronics. There are several design techniques that designers can use to significantly reduce overall system power consumption. Some of these include:

1. Reducing operating voltage.
2. Operating within the specified package temperature limitations.
3. Using optimum clock frequency reduces power consumption, as the 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 which will reduce power.
4. Reducing the span of the design across the device. A more closely placed design utilizes fewer routing resources for less power consumption.
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 in the Power Calculator:

1. The Power Calculator tool is based on equations with constants based on 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. The I/O power consumption is based on output loading of 5pF. Users have ability to change this capacitive loading.
4. The current version of the Power Calculator allows users to get an estimate of the power dissipation and the current for each type of power supplies, that are V_{CC}, V_{CCIO}, V_{CCJ} and V_{CCAUX}.
5. The nominal V_{CC} is used by default to calculate power consumption. Users can choose a lower or higher V_{CC} from a list of available values.
6. The current versions also allow users to enter an airflow in Linear Feet per Minute (LFM) along with the heat sink option to calculate the junction temperature.
7. The default value of the I/O types for the devices is LVCMOS12, 6mA.
8. The Activity Factor 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
July 2005	01.0	Initial release.
September 2007	01.1	Document title changed to: "Power Estimation and Management for MachXO Devices."