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Seven Steps to an Accurate Worst-Case Power Analysis Using Xilinx Power Estimator (XPE)

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Power and cooling specifications for an FPGA design have to be determined early in the product's design cycle, often even before the logic within the FPGA has been designed. An accurate worst-case power analysis early on helps you avoid the pitfalls of overdesigning or underdesigning your product's power or cooling system.

The Xilinx Power Estimator (XPE) can perform a power analysis at any time during the design cycle. This White Paper describes a seven step procedure for analyzing your design's power requirements using the Xilinx Power Estimator.

Seven Steps to an Accurate Power Estimation

As a necessary step in any FPGA design, power and cooling specifications need to be properly set in order to create a functioning and reliable system. In most cases, these thermal and power specifications need to be set prior to PCB design and, due to the flexibility of FPGAs, often the FPGA design is not completed or sometimes even started prior to system design and/or PCB fabrication. This creates an interesting challenge for FPGA designers, since thermal and power characteristics can vary dramatically depending on the bitstream (design), clocking, and data put into the chip.

Underdesigning the power or thermal system can make the FPGA operate out of specification, which could result in the FPGA not operating at the expected performance or potentially other more serious consequences. Overdesigning the power system is generally less serious but still not desirable since it can add unnecessary cost and complexity to the overall FPGA design. The task of power estimation is not a trivial one prior to completing the design.

The purpose of this paper is to simplify this task by splitting it into seven steps in order to achieve an accurate power estimation prior to design completion. Note that this paper is primarily focused on power analysis. There are several techniques for power optimization that can be explored and applied during the analysis and can result in significant power savings. For more details on power optimization, see White Paper [WP285](#), *Virtex-5 FPGA System Power Design Considerations*, before performing power analysis.

Step 1: Obtain the latest version of Xilinx Power Estimator for the selected target device.

It is important to make sure you are using the latest version of the Xilinx Power Estimator (XPE) tool because power information is updated periodically to reflect the latest power modeling and characterization data. The latest version of XPE can be obtained from the Xilinx web site at <http://www.xilinx.com/power>. It is also helpful to check this web site occasionally during the design process to determine whether a new version has become available. If a new version is available, you may import the data from a previous version into the updated version using the **Import from XPE...** button on the updated version's Summary tab. Keeping the Xilinx Power Estimator up to date ensures the most current power information will be used in the power analysis at all times during the design cycle.

Step 2: Complete the Device information on the Summary tab.

Make sure each field in the Device section of the Summary tab is properly set since each can have a significant effect on the end power calculation, particularly in static and clocking power.

The screenshot shows the XPower Estimator (XPE) - 10.1.03 interface. The 'Device' section is highlighted with a red box, showing the following fields:

Field	Value
Part	XC5VLX60
Package	FF324
Grade	Commercial
Process	Typical
Speed Grade	-1
Stepping	Stepping - 1

Other sections visible in the interface include:

- Block Summary:** A table listing power blocks and their power consumption in Watts (W).
- Voltage Source Summary:** A table listing voltage sources, their voltages, and associated currents.
- Thermal Information:** Fields for Ambient Temp (50.0), Airflow (250), Heat Sink (None), Board Selection (Medium), etc.
- Thermal Summary:** Fields for Effective θ_{JA} (6.5), Max Ambient (79.0), and Junction Temp (56.0).
- Power Summary:** Fields for Optimization (None), Data (Production), Quiescent (0.444), Dynamic (0.471), and Total (0.915) power.

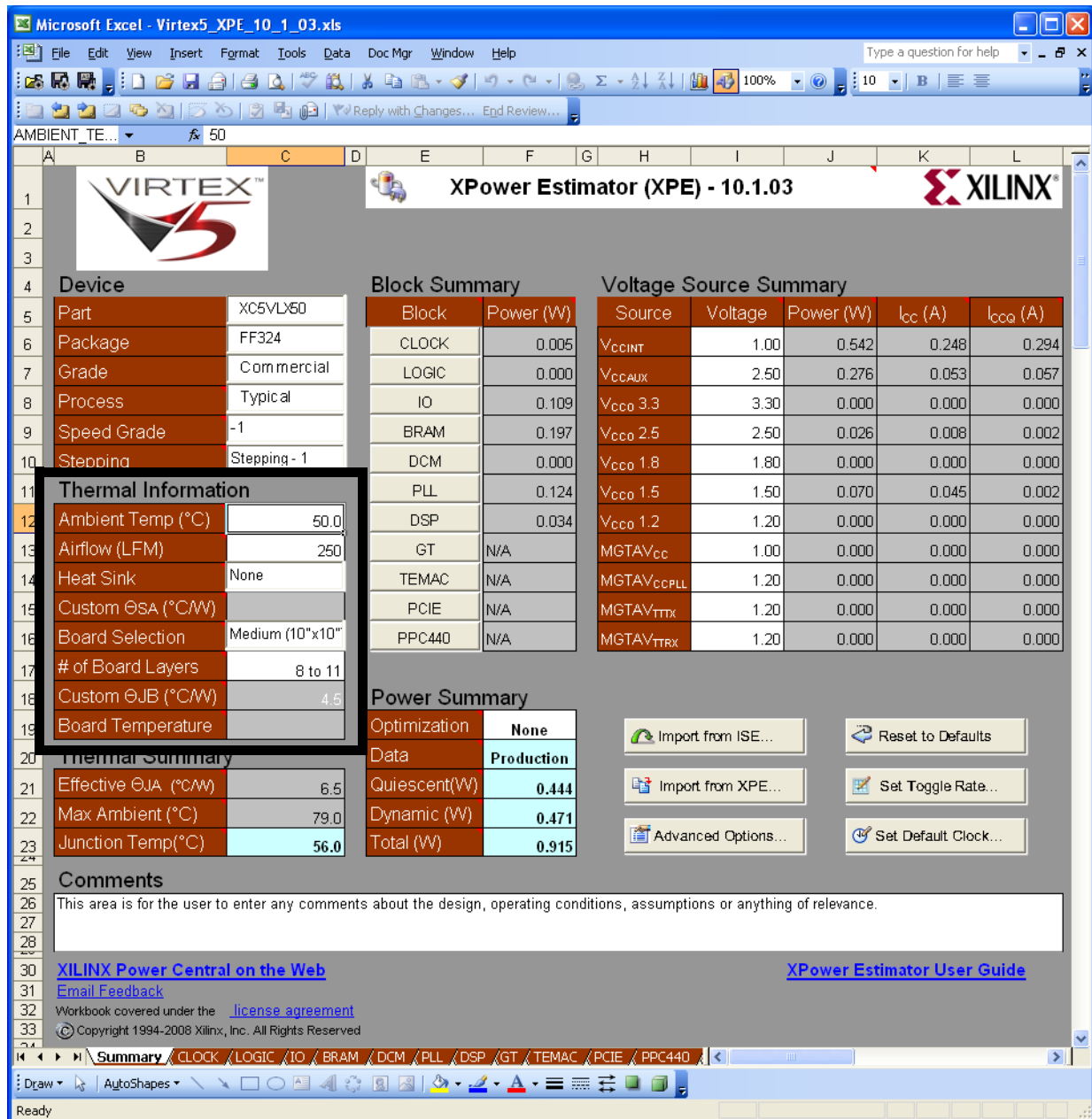
Figure 1: Device Information - Summary Tab

- **Part** – An improperly set part can lead to incorrect quiescent and dynamic power component estimations such as the dynamic power reported for clocks. An incorrect part setting will also result in improperly reported available resources.
- **Package** – The package selection can affect the device's heat dissipation and thus affect the end junction temperature. An incorrect junction temperature can result in an incorrect quiescent power calculation.

- **Grade** – Select the appropriate grade for the device (typically **Commercial** or **Industrial**). Some devices may have different quiescent power specifications depending on this setting. Setting this properly will also allow for the proper display of junction temperature limits for the chosen device.
- **Process** – For the purposes of a worst-case analysis, the recommended process setting is **Maximum**. The default setting of **Typical** will give a closer picture to what would be measured statistically, but changing the setting to **Maximum** will modify the power specification to worst-case values.
- **Speed Grade** (if available) – Some FPGA families may have different power specifications for different speed grades. For instance, the Virtex®-5 family has lower quiescent typical and maximum power specifications for the slowest (-1) speed grade.
- **Stepping** (if available) – Different steppings represent different silicon revisions that may have different power characteristics.

Step 3: Complete the Thermal Information on the Summary tab.

Set the proper thermal conditions in the Thermal Information section of the Summary tab.



The screenshot shows the XPower Estimator (XPE) - 10.1.03 Summary tab in Microsoft Excel. The Thermal Information section is highlighted with a red box. The Ambient Temp is set to 50.0°C, Airflow is 250 LFM, and Heat Sink is None. The Thermal Summary shows an Effective Theta JA of 6.5°C/W, Max Ambient of 79.0°C, and Junction Temp of 56.0°C.

Thermal Information	
Ambient Temp (°C)	50.0
Airflow (LFM)	250
Heat Sink	None
Custom θ_{SA} (°C/W)	
Board Selection	Medium (10"x10")
# of Board Layers	8 to 11
Custom θ_{JB} (°C/W)	4.5
Board Temperature	

Thermal Summary	
Effective θ_{JA} (°C/W)	6.5
Max Ambient (°C)	79.0
Junction Temp(°C)	56.0

Block Summary	
Block	Power (W)
CLOCK	0.005
LOGIC	0.000
IO	0.109
BRAM	0.197
DCM	0.000
PLL	0.124
DSP	0.034
GT	N/A
TEMAC	N/A
PCIE	N/A
PPC440	N/A

Voltage Source Summary				
Source	Voltage	Power (W)	I _{CC} (A)	I _{CCQ} (A)
V _{CCINT}	1.00	0.542	0.248	0.294
V _{CCAUX}	2.50	0.276	0.053	0.057
V _{CC0 3.3}	3.30	0.000	0.000	0.000
V _{CC0 2.5}	2.50	0.026	0.008	0.002
V _{CC0 1.8}	1.80	0.000	0.000	0.000
V _{CC0 1.5}	1.50	0.070	0.045	0.002
V _{CC0 1.2}	1.20	0.000	0.000	0.000
MGTAV _{CC}	1.00	0.000	0.000	0.000
MGTAV _{CCPLL}	1.20	0.000	0.000	0.000
MGTAV _{TTTX}	1.20	0.000	0.000	0.000
MGTAV _{TRRX}	1.20	0.000	0.000	0.000

Power Summary	
Optimization	None
Data	Production
Quiescent(W)	0.444
Dynamic (W)	0.471
Total (W)	0.915

Figure 2: Thermal Information - Summary Tab

- **Ambient Temp (°C)** – Specify the maximum possible temperature expected inside the enclosure that will house the FPGA design. This, along with airflow and other thermal dissipation paths (for example, the heatsink), will allow an accurate calculation of Junction Temperature which in turn will allow a more accurate calculation of quiescent current.
- **Airflow (LFM)** – The airflow across the chip is measured in Linear Feet per Minute (LFM). LFM can be calculated from the fan output in CFM (Cubic Feet per Minute) divided by the cross sectional area through which the air passes. Specific

placement of the FPGA and/or fan may have an effect on the effective air movement across the FPGA and thus the thermal dissipation. Note that the default for this parameter is 250 LFM. If you plan to operate the FPGA without active air flow (still air operation) then the 250 LFM default has to be changed to 0 LFM.

- **Heat Sink** (if available) – If a heatsink is used and more detailed thermal dissipation information is not available, choose an appropriate profile for the type of heatsink used. This, along with other entered parameters, will be used to help calculate an effective Θ_B , resulting in a more accurate junction temperature and quiescent power calculation. Note that some types of sockets may act as heatsinks, depending on the design and construction of the socket.
- **Board Selection and # of Board Layers** (if available) – Selecting an approximate size and stack of the board will help calculate the effective Θ_B by taking into account the thermal conductivity of the board itself.
- **Custom Θ_B ($^{\circ}\text{C}/\text{W}$)** – In the event more accurate thermal modeling of the board and system is available or in the case of Heatsink and Board parameters unavailable in the version of XPE being used, Custom Θ_B (printed circuit board thermal resistance) should be used in order to specify the amount of heat dissipation expected from the FPGA.

Note: In order to specify a Custom Θ_B , the Board Selection must be set to **Custom**. If you do specify a Custom Θ_B , you must also specify a Board Temperature for an accurate power calculation.

The more accurately Custom Θ_B can be specified, the more accurate the estimated junction temperature will be, thus affecting quiescent power calculations.

Step 4: Set worst-case voltages for all supplies.

By default, each voltage rail for a particular device is set to its nominal value. In order to get an accurate power estimation, the worst-case or highest voltage value seen at the FPGA device needs to be specified. This can be generally calculated using the nominal output value and tolerances from supplies/regulators to each rail. If any significant IR (voltage) drop may be seen, particularly with supplies that are unregulated, the voltage drop should be accounted for in the maximum voltage calculation.

If you are not using some of the V_{CCO} or MGT voltage sources, leave the default values in the rows for those voltage sources..

Note: If you are targeting a Virtex-5 LXT, SXT or FXT FPGA, the default value for $MGTAV_{CCPLL}$ is the typical value for FXT (1.0V) but out of the 1.14V to 1.26V range for LXT or SXT. Make sure the proper voltage is set, particularly for this rail, when targeting those devices.

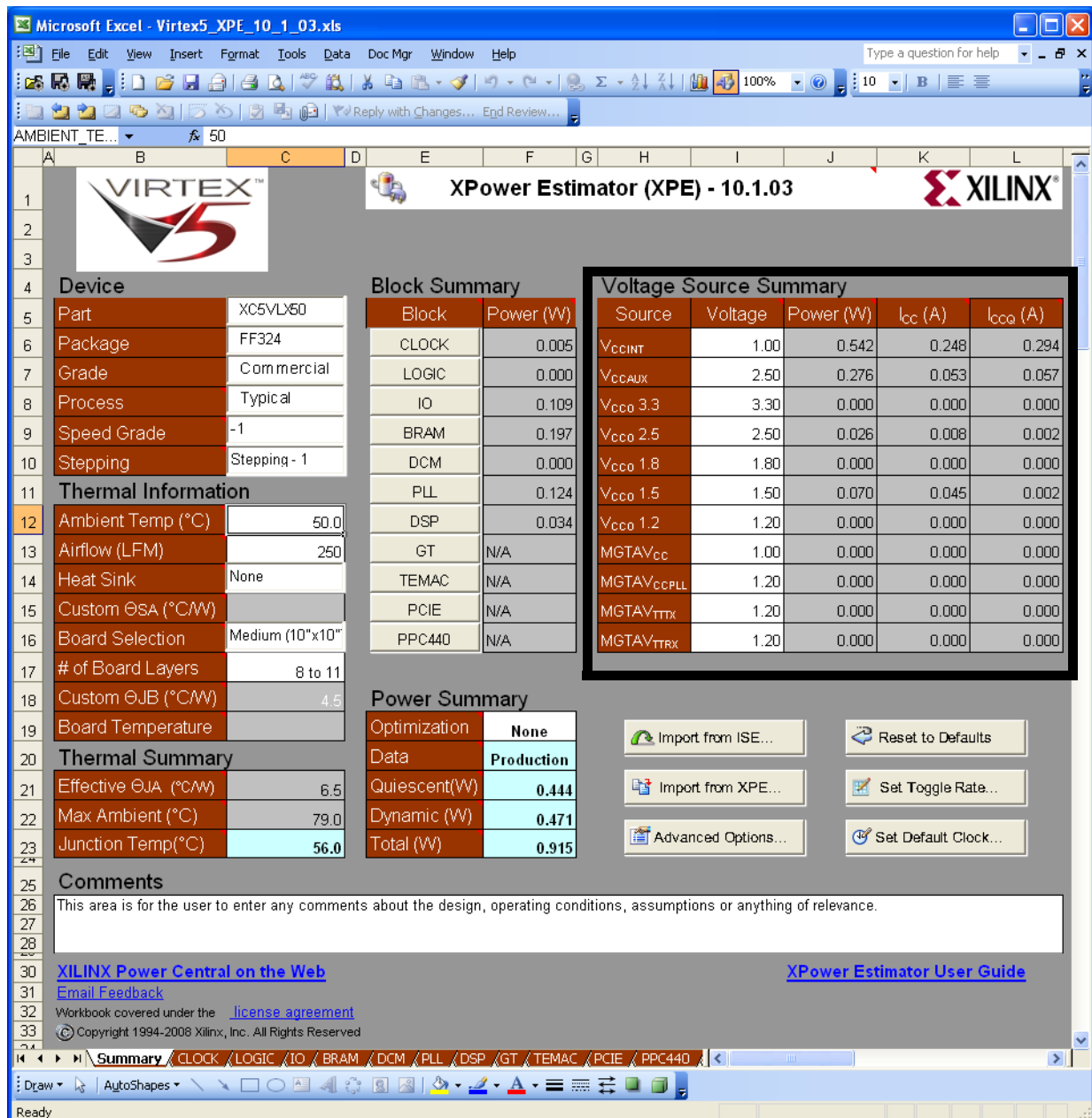


Figure 3: Voltage Source Summary - Summary Tab

- **DSP/Multiplier Power** – Complete the DSP or Multiplier tab of XPE. Note that the DSP blocks can be used for purposes other than multipliers, such as counters, barrel shifters, MUXs and other common functions.

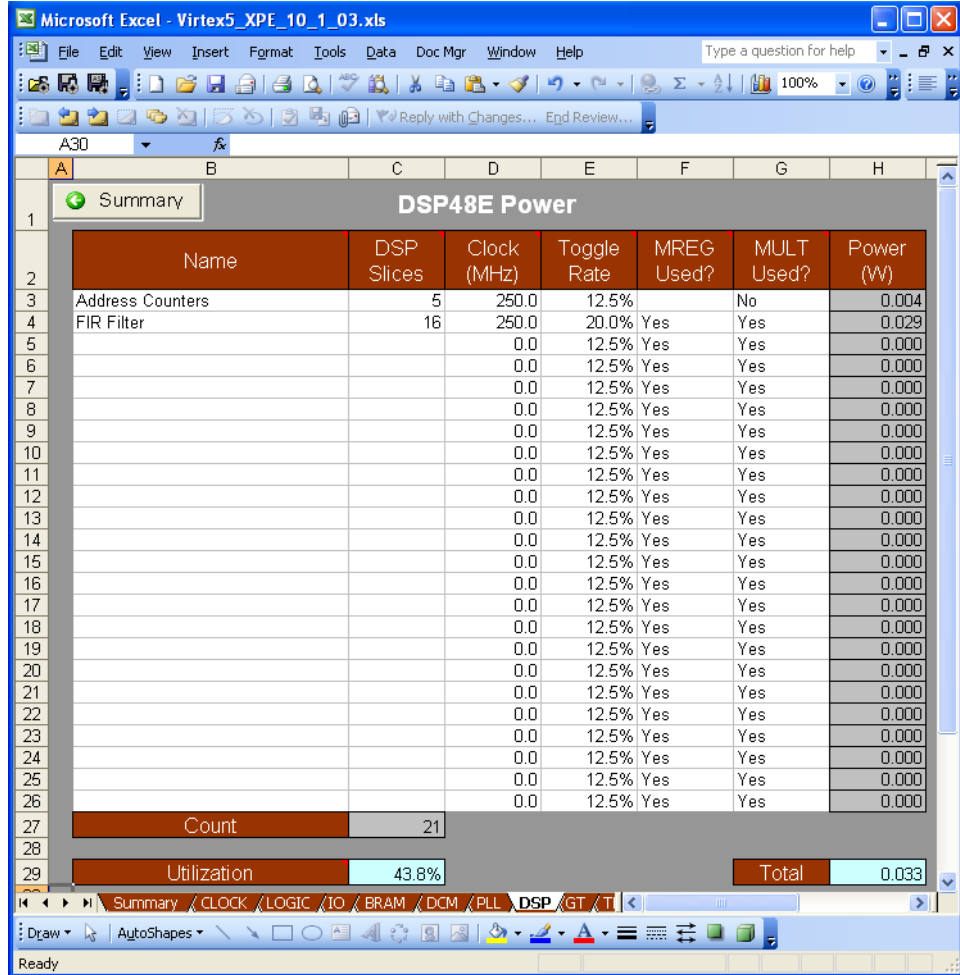
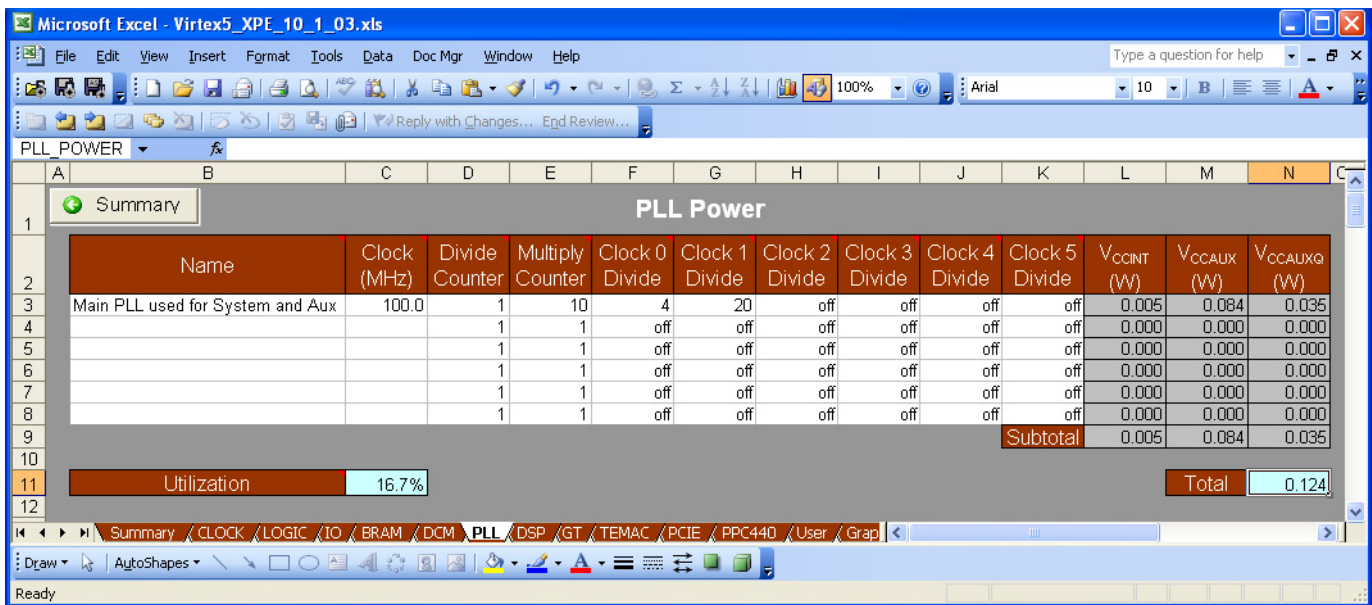


Figure 8: DSP Power Tab

- **DCM/PLL Power** – If a DCM and/or PLL is used in the design, specify the use and configuration of each.



Name	Clock (MHz)	Divide Counter	Multiply Counter	Clock 0 Divide	Clock 1 Divide	Clock 2 Divide	Clock 3 Divide	Clock 4 Divide	Clock 5 Divide	VCCINT (W)	VCCAUX (W)	VCCAUXQ (W)
Main PLL used for System and Aux	100.0	1	10	4	20	off	off	off	off	0.005	0.084	0.035
		1	1	off	off	off	off	off	off	0.000	0.000	0.000
		1	1	off	off	off	off	off	off	0.000	0.000	0.000
		1	1	off	off	off	off	off	off	0.000	0.000	0.000
		1	1	off	off	off	off	off	off	0.000	0.000	0.000
		1	1	off	off	off	off	off	off	0.000	0.000	0.000
										0.005	0.084	0.035
Subtotal										0.005	0.084	0.035
Utilization											16.7%	
Total											0.124	

Figure 9: PLL Power Tab

- **Other** – Complete any other tabs with the usage and configuration of any additional elements used in the design.

Step 6: Set the toggle and connectivity parameters.

For each tab of the tool containing a Toggle Rate, Average Fanout or Enable Rate, review the set value. For toggle and enable rates, in the absence of any other information or knowledge, we generally suggest leaving these settings at their defaults. However if you determine that the default may not represent the characteristics of this design, make the necessary adjustments. For instance, if you know that a memory interface has a training pattern routine that exercises a sustained high toggle rate on that interface, the Toggle Rate may need to be raised to reflect this additional activity. Alternatively, if a portion of a circuit is clock enabled in a way that reduces the overall activity of the circuit, the toggle rate may need to be reduced. More information on methods to determine toggle rate can be found in [UG440, Xilinx Power Estimator User Guide](#).

For clock fanout, the easiest way to specify this in XPE is to create an equation which will SUM all of the synchronous elements for any particular clock domain. For instance, in the Fanout field for a given clock, type **=SUM(** and then select all of the cells which specify the number of synchronous elements sourced by that clock (that is, BRAMs, FFs, Shift Registers, Select RAMs, etc.). When completed, close the parenthesis and this will populate the Fanout cell with the appropriate number. This method of entering clock fanout not only is often the easiest, but also has the added advantage of automatically updating when adjustments are made to the spreadsheet resource counts. The resulting Excel equation would be similar to this:

```
=SUM(LOGIC!E3:G3, IO!E3:G3, BRAM!C4, MULT!C3)
```

For logic fanout, the nature of the data and control paths need to be thought out. In designs with well structured sequential data paths, such as DSP designs, fanouts generally tend to be lower than the set default. In designs with many data execution paths, such as in some embedded designs, higher fanouts may be seen. As with toggle

rates, if this information is not known it is best to leave the setting at the default and adjust later if needed.

For I/O Output Load, enter a simple capacitive load for each design output. This will affect the dynamic power of the driven output. The Output Load value is primarily made up from the sum of the individual input capacitances of each device connected to that output. The input capacitance can generally be obtained from the datasheets of the devices to which the FPGA I/O is connected.

Step 7: Analyze the results.

Before you analyze the results, update Steps 1 through 6, if necessary. After completing these steps, analyze the results. Make sure the junction temperature is not exceeded and the power drawn is within the desired budget for the project. If the thermal dissipation or power characteristics are not within targets, adjustments should be made to either the environmental characteristics (that is, more airflow, a heatsink, etc.) or the resource and power characteristics of the design until an acceptable result is reached. Many times, trade-offs can be made to derive the desired functionality with a tighter power budget, and the best time to explore these options is early in the design process. Once the data is completely entered and the part is operating within the thermal limits of the selected grade, the power reported by XPE can be used to specify the rails for the design. If your confidence in the data entered is not very high, additional padding to the numbers may be used to circumvent the possibility of underdesigning the power system for the FPGA. If, however, you are fairly certain of the data entered, no additional padding above the data reported by the tool is necessary.

As the design matures, continue to review and update the information in the spreadsheet to reflect the latest requirements and implementation details. This will present the most current picture of the power used in the design and could potentially allow early identification of adjustments to the power budgeting up or down depending on the current power trends of the design.

Conclusion

With accurate data entered into the Xilinx Power Estimator, accurate power estimations can be made. It can be difficult to determine the exact power requirements of an FPGA system prior to implementing it. However, with the seven steps laid out in this document, the problem can now be broken down into smaller, easier to define and understand phases which should allow for improved data entry and improved data accuracy. In order to help ensure that no step is missed, a checklist is attached to this document ([Figure 10](#)). Please feel free to use this checklist for your next power estimation task.

More detail on the Xilinx Power Estimator can be found in [UG440](#), *Xilinx Power Estimator User Guide*.

Xilinx Power Estimator (XPE) Checklist

- Device Information
 - Target Device
 - Package
 - Grade
 - Process
 - Speed Grade (if available)
 - Stepping (if applicable)
- Thermal Information
 - Ambient Temperature
 - Airflow (if available)
 - Heatsink (if available)
 - Board Selection
 - # of Layers (if available)

OR

- Custom Θ_{JB}

- Resource Information
- Clock
- IO
- BRAM
- DCM/PLL
- DSP/Mult
- Other {
 - _____
 - _____
 - _____
- Toggle/Connectivity Information
- Toggle Rate
 - Logic
 - I/O
 - BRAM
 - DSP/Mult
- Enable Rate
 - I/O
 - BRAM
- Fanout
 - Clock
 - Logic
- Output Load

X11008

Figure 10: Xilinx Power Estimator (XPE) Checklist

