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DELAY AND POWER CALCULATION STANDARDS –

Part 4: Design and Verification of Low-Power, Energy-Aware Electronic Systems

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IEEE Standard for Design and Verification of Low-Power, Energy-Aware Electronic Systems

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Abstract: A method is provided for specifying power intent for an electronic design, for use in verification of the structure and behavior of the design in the context of a given power-management architecture, and for driving implementation of that power-management architecture. The method supports incremental refinement of power intent specifications required for IP-based design flows.

Keywords: corruption semantics, IEEE 1801™, interface specification, IP reuse, isolation, level-shifting, power-aware design, power domains, power intent, power modes, power states, progressive design refinement, retention, retention strategies

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IEEE Introduction

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The purpose of this standard is to provide portable, low-power design specifications that can be used with a variety of commercial products throughout an electronic system design, analysis, verification, and implementation flow.

When the electronic design automation (EDA) industry began creating standards for use in specifying, simulating, and implementing functional specifications of digital electronic circuits in the 1980s, the primary design constraint was the transistor area necessary to implement the required functionality in the prevailing process technology at that time. Power considerations were simple and easily assumed for the design as power consumption was not a major consideration and most chips operated on a single voltage for all functionality. Therefore, hardware description languages (HDLs) such as VHDL (IEC 61691-1-1/ IEEE Std 1076™[1]) and SystemVerilog (IEEE Std 1800™[2]) provided a rich set of capabilities necessary for capturing the functional specification of electronic systems, but no capabilities for capturing the power architecture (how each element of the system is to be powered).

As the process technology for manufacturing electronic circuits continued to advance, power (as a design constraint) continually increased in importance. Even above the 90 nm process node size, dynamic power consumption became an important design constraint as the functional size of designs increased power consumption at the same time battery-operated mobile systems, such as cell phones and laptop computers, became a significant driver of the electronics industry. Techniques for reducing dynamic power consumption—the amount of power consumed to transition a node from a `0` to `1` state or vice versa—became commonplace. Although these techniques affected the design methodology, the changes were relatively easy to accommodate within the existing HDL-based design flow, as these techniques were primarily focused on managing the clocking for the design (more clock domains operating at different frequencies and gating of clocks when logic in a clock domain is not needed for the active operational mode). Multi-voltage power-management methods were also developed. These methods did not directly impact the functionality of the design, requiring only level-shifters between different voltage domains. Multi-voltage power domains could be verified in existing design flows with additional, straightforward extensions to the methodology.

With process technologies below 90 nm, static power consumption has become a prominent and, in many cases, dominant design constraint. Due to the physics of the smaller process nodes, power is leaked from transistors even when the circuitry is quiescent (no toggling of nodes from `0` to `1` or vice versa). New design techniques have been developed to manage static power consumption. Power gating or power shut-off turns off power for a set of logic elements. Back-bias techniques are used to raise the voltage threshold at which a transistor can change its state. While back bias slows the performance of the transistor, it greatly reduces leakage. These techniques are often combined with multi-voltages and require additional functionality: power-management controllers, isolation cells that logically and/or electrically isolate a shutdown power domain from “powered-up” domains, level-shifters that translate signal voltages from one domain to another, and retention registers to facilitate fast transition from a power-off state to a power-on state for a domain.

The Unified Power Format (UPF) was developed to enable modeling of these new power-management techniques and to facilitate automation of design, verification, and implementation tools that must account for power-management aspects of a design. The initial version of UPF, developed by the Accellera Systems Initiative, focused primarily on modeling power distribution and its effects on the behavior of a system. In

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May 2007 that initial version was donated to the IEEE, and in March 2009 a new version, IEEE Std 1801, was released. That update of UPF added many new features, including the concept of successive refinement, more abstract modeling of system-power states, and more abstract modeling of supply networks.

This document, the latest revision of IEEE Std 1801, makes available further enhancements to UPF, including enhanced concepts for modeling power states and transitions at all levels of aggregation, enhanced support for methodologies such as successive refinement and bottom-up implementation, and a detailed information model that serves as the basis for enhanced package UPF functions and query functions. This current version also provides support for component power modeling for system-level power analysis in virtual prototyping applications.

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IEEE Standard for Design and Verification of Low-Power, Energy-Aware Electronic Systems

1. Overview

1.1 Scope

This standard defines the syntax and semantics of a format used to express power intent in energy-aware electronic system design. *Power intent* includes the concepts and information required for specification and validation, implementation and verification, and modeling and analysis of power-managed electronic systems. This standard also defines the relationship between the power intent captured in this format and design intent captured via other formats (e.g., standard hardware description languages and cell libraries).

1.2 Purpose

The standard enables portability of power intent across a variety of commercial products throughout an electronic system design, analysis, verification, and implementation flow.

1.3 Key characteristics of the Unified Power Format

The Unified Power Format (UPF) provides the ability for electronic systems to be designed with power as a key consideration early in the process. UPF accomplishes this by allowing the specification of what was traditionally physical implementation-based power information early in the design process—at the register transfer level (RTL) or earlier. Figure 1 shows UPF supporting the entire design flow. UPF provides a consistent format to specify power-design information that may not be easily specifiable in a hardware description language (HDL) or when it is undesirable to directly specify the power semantics in an HDL, as doing so would tie the logic specification directly to a constrained power implementation. UPF specifies a set of HDL attributes and HDL packages to facilitate the expression of power intent in HDL when appropriate (see Table 4 and 11.2). UPF also defines consistent semantics across verification and implementation to check that what is implemented is the same as what has been verified.

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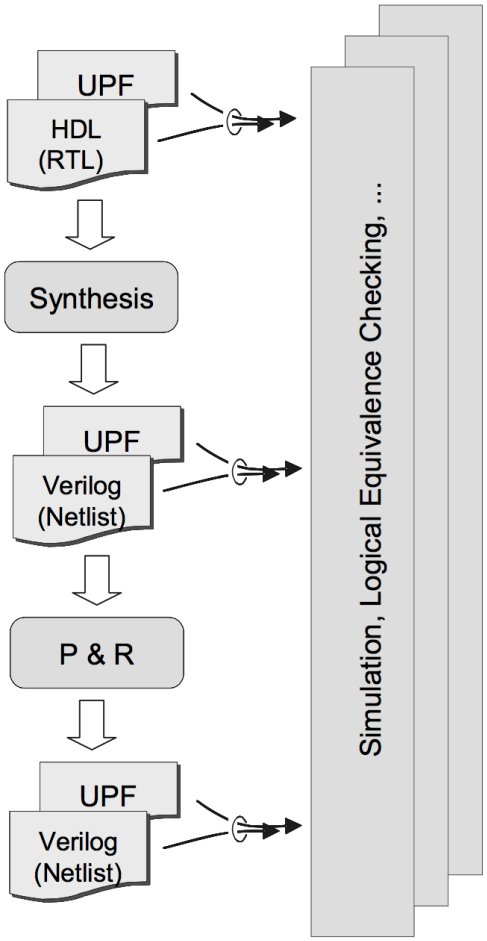


Figure 1—UPF tool flow

As indicated in Figure 1, UPF files are part of the design source and, when combined with the HDL, represent a complete design description: the HDL describing the logical intent and the UPF describing the power intent. Combined with the HDL, the UPF files are used to describe the intent of the designer. This collection of source files is the input to several tools, e.g., simulation tools, synthesis tools, and formal verification tools. UPF supports the successive refinement methodology (see 4.9) where power intent information grows along the design flow to provide needed information for each design stage.

— Simulation tools can read the HDL/UPF design input files and perform RTL power-aware simulation. At this stage, the UPF might only contain abstract models such as power domains and supply sets without the need to create the power and ground network and implementation details.

— A user may further refine the UPF specification to add implementation-related information. This further-refined specification may then be processed by synthesis tools to produce a netlist and optionally update the UPF fileset accordingly.

— In those cases where design object names change, a UPF file with the new names is needed. A UPF-aware logical equivalence checker can read the full design and UPF filesets and perform the checks to ensure power-aware equivalence.

— Place and route tools read both the netlist and the UPF files and produce a physical netlist, potentially including an output UPF file.

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UPF is a concise, power intent specification capability. Power intent can be easily specified over many elements in the design. A UPF specification can be included with the other deliverables of intellectual property (IP) blocks and reused along with the other delivered IP. UPF supports various methodologies through carefully defined semantics, flexibility in specification, and, when needed, defined rational limitations that facilitate automation in verification and implementation.

1.4 Contents of this standard

The organization of the remainder of this standard is as follows:

- Clause 2 provides references to other applicable standards that are presumed or required for this standard.
- Clause 3 defines terms and acronyms used throughout the different specifications contained in this standard.
- Clause 4 describes the basic concepts underlying UPF.
- Clause 5 describes the language basics for UPF and its commands.
- Clause 6 details the syntax and semantics for each UPF power intent command.
- Clause 7 details the syntax and semantics for each UPF power-management cell command.
- Clause 8 defines a reference model for UPF command processing.
- Clause 9 defines simulation semantics for various UPF commands.
- Clause 10 defines the UPF information model.
- Clause 11 defines the UPF information model application programmable interface (API).
- Annex A lists potentially useful additional reference material.
- Annex B lists the predefined value conversion tables (VCTs) for use in power intent specifications.
- Annex C provides sample Tcl procs for retrieving power intent information.
- Annex D summarizes deprecated and legacy commands.
- Annex E provides an overview of UPF tool flows and use model with an illustrative example.
- Annex F provdes a summary of UPF power-management cell command semantics and Liberty mappings.
- Annex G provides examples of UPF power-management cell modeling.
- Annex H provides an overview of UPF use model for system-level IP power modeling.
- Annex I defines the Switching Activity Interchange Format (SAIF) for representing power-related activity in a design.

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2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 61691-1-1/IEEE Std 1076™, Behavioural languages—Part 1-1: VHDL Language Reference Manual.[10, 11, 12]

IEEE Std 1800™, IEEE Standard for SystemVerilog—Unified Hardware Design, Specification, and Verification Language.

ISO/IEC 19501:2005, Information technology—Open Distributed Processing—Unified Modeling Language (UML) Version 1.4.2.

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