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Standard for Property Specification Language (PSL)

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

The Institute of Electrical and Electronics Engineers, Inc
3 Park Avenue
US-New York, NY10016-5997
USA
Email: stds-info@ieee.org
Web: www.ieee.org

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STANDARD FOR PROPERTY SPECIFICATION LANGUAGE (PSL)

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IEEE Standard for

Property Specification Language (PSL)

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Approved 22 September 2005

IEEE-SA Standards Board

Grateful acknowledgment is made to Accellera Organization, Inc. for the permission to use the following source material:

Accellera Property Specification Language Reference Manual (version 1.1), Accellera

GDL: General Description Language, Accellera, Mar. 2005

Abstract: The IEEE Property Specification Language (PSL) is defined in this standard. PSL is a formal notation for specification of electronic system behavior, compatible with multiple electronic system design languages, including IEEE Std 1076™ (VHDL®), IEEE Std 1364™ (Verilog®), IEEE P1666™ (SystemC®), and IEEE P1800™ (SystemVerilog®), thereby enabling a common specification and verification flow for multi-language and mixed-language designs. PSL captures design intent in a form suitable for simulation, formal verification, formal analysis, and hybrid verification tools. PSL enhances communication among architects, designers, and verification engineers to increase productivity throughout the design and verification process. The primary audiences for this standard are the implementors of tools supporting the language and advanced users of the language.
Keywords: ABV, assertion, assertion-based verification, assumption, cover, model checking, property, PSL, specification, temporal logic, verification

IEEE Introduction

IEEE Std 1850 Property Specification Language (PSL) is based upon the Accellera Property Specification Language (Accellera PSL), a language for formal specification of electronic system behavior, which was developed by Accellera, a consortium of Electronic Design Automation (EDA), semiconductor, and system companies. IEEE Std 1850 PSL refines Accellera PSL version 1.1, addressing errata and a few minor technical issues and clarifying how PSL interfaces with various standard electronic system design languages.

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STANDARD FOR
PROPERTY SPECIFICATION VOLTAGE (PSL)

1. Overview

1.1 Scope

This standard defines the property specification language (PSL), which formally describes electronic system behavior. This standard specifies the syntax and semantics for PSL and also clarifies how PSL interfaces with various standard electronic system design languages.

1.2 Purpose

The purpose of this standard is to provide a well-defined language for formal specification of electronic system behavior, one that is compatible with multiple electronic system design languages, including IEEE Std 1076™ (VHDL), IEEE Std 1364™ (Verilog®), IEEE P1800™[1] (SystemVerilog®), and IEEE P1666™ (SystemC), to facilitate a common specification and verification flow for multi-language and mixed-language designs.

1.2.1 Background

The complexity of Very Large Scale Integration (VLSI) has grown to such a degree that traditional approaches have begun to reach their limitations, and verification costs have reached 60%–70% of development resources. The need for advanced verification methodology, with improved observability of design behavior and improved controllability of the verification process, has become critical. Over the last decade, a methodology based on the notion of “properties” has been identified as a powerful verification paradigm that can assure enhanced productivity, higher design quality and, ultimately, faster time to market and higher value to engineers and end-users of electronics products. Properties, as used in this context, are concise, declarative, expressive and unambiguous specifications of desired system behavior, that are used to guide the verification process. IEEE Std 1850 PSL is a standard language for specifying electronic system behavior using properties. PSL facilitates property-based verification using both simulation and formal verification, thereby enabling a productivity boost in functional verification.

[1]Numbers preceded by P are IEEE authorized standards projects that were not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining drafts, contact the Institute of Electrical and Electronics Engineers, Inc.

1.2.2 Motivation

Ensuring that a design's implementation satisfies its specification is the foundation of hardware verification. Key to the design and verification process is the act of specification. Yet historically, the process of specification has consisted of creating a natural language description of a set of design requirements. This form of specification is both ambiguous and, in many cases, unverifiable due to the lack of a standard machine-executable representation. Furthermore, ensuring that all functional aspects of the specification have been adequately *verified* (that is, covered) is problematic.

The IEEE PSL was developed to address these shortcomings. It gives the design architect a standard means of specifying design properties using a concise syntax with clearly-defined formal semantics. Similarly, it enables the RTL implementer to capture design intent in a verifiable form, while enabling the verification engineer to validate that the implementation satisfies its specification through *dynamic* (that is, simulation) and *static* (that is, formal) verification means. Furthermore, it provides a means to measure the quality of the verification process through the creation of functional coverage models built on formally specified properties. In addition, it provides a standard means for hardware designers and verification engineers to create a rigorous and machine-executable design specification.

1.2.3 Goals

PSL was specifically developed to fulfill the following general hardware functional specification requirements:

— Easy to learn, write, and read
— Concise syntax
— Rigorously well-defined formal semantics
— Expressive power, permitting specifications of a large class of real-world design properties
— Known efficient underlying algorithms in simulation, as well as formal verification

1.3 Usage

PSL is a language for the formal specification of hardware. It is used to describe properties that are required to hold in the design under verification. PSL provides a means to write specifications that are both easy to read and mathematically precise. It is intended to be used for functional specification on the one hand and as input to functional verification tools on the other. Thus, a PSL specification is an executable specification of a hardware design.

1.3.1 Functional specification

PSL can be used to capture requirements regarding the overall behavior of a design, as well as assumptions about the environment in which the design is expected to operate. PSL can also capture internal behavioral requirements and assumptions that arise during the design process. Both enable more effective functional verification and reuse of the design.

One important use of PSL is for documentation, either in place of or along with an English specification. A PSL specification can describe simple invariants (for example, signals `read_enable` and `write_enable` are never asserted simultaneously) as well as multi-cycle behavior (for example, correct behavior of an interface with respect to a bus protocol or correct behavior of pipelined operations).

A PSL specification consists of *assertions* regarding *properties* of a design under a set of *assumptions*. A *property* is built from three kinds of elements: *Boolean expressions*, which describe behavior over one cycle; *sequential expressions*, which can describe multi-cycle behavior; and *temporal operators*, which describe

temporal relationships among Boolean expressions and sequences. For example, consider the following Verilog Boolean expression:

```
ena || enb
```

This expression describes a cycle in which at least one of the signals `ena` and `enb` are asserted. The PSL sequential expression

```
{req; ack; !cancel}
```

describes a sequence of cycles, such that `req` is asserted in the first cycle, `ack` is asserted in the second cycle, and `cancel` is deasserted in the third cycle. The following property, obtained by applying the temporal operators `always` and `|=>` to these expressions,

```
always {req;ack;!cancel} |=> (ena || enb)
```

means that always (that is, in every cycle), if the sequence `{req;ack;!cancel}` occurs, then either `ena` or `enb` is asserted one cycle after the sequence ends. Adding the directive `assert` as follows:

```
assert always {req;ack;!cancel} |=> (ena || enb);
```

completes the specification, indicating that this property is expected to hold in the design and that this expectation needs to be verified.

1.3.2 Functional verification

PSL can also be used as input to verification tools, for both verification by simulation, as well as formal verification using a model checker or a theorem prover. Each of these is discussed in the subclauses that follow.

1.3.2.1 Simulation

A PSL specification can also be used to automatically generate checks of simulated behavior. This can be done, for example, by directly integrating the checks in the simulation tool; by interpreting PSL properties in a testbench automation tool that drives the simulator; by generating HDL monitors that are simulated alongside the design; or by analyzing the traces produced during simulation.

For instance, the following PSL property:

```
Property 1: always (req -> next !req)
```

states that signal `req` is a pulsed signal, i.e., if it is high in some cycle, then it is low in the following cycle. Such a property can be easily checked using a simulation checker written in some HDL that has the functionality of the finite state machine (FSM) shown in Figure 1.

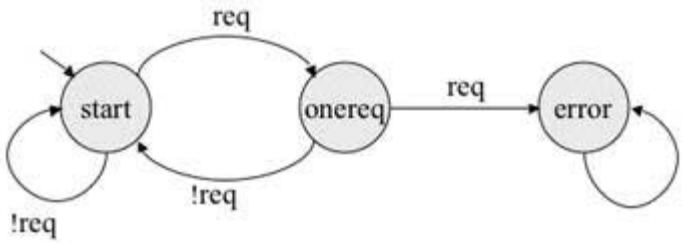

Figure 1—A simple (deterministic) FSM that checks Property 1

For properties more complicated than the property shown in Figure 1, manually writing a corresponding checker is painstaking and error-prone, and maintaining a collection of such checkers for a constantly changing design under development is a time-consuming task. Instead, a PSL specification can be used as input to a tool that automatically generates simulatable checkers.

Although in principle, all PSL properties can be checked for finite paths in simulation, the implementation of the checks is often significantly simpler for a subset called the *simple subset* of PSL. Informally, in this subset, composition of temporal properties is restricted to ensure that time *moves forward* from left to right through a property, as it does in a timing diagram. (See 4.4.4 for the formal definition of the simple subset.) For example, the property

Property 2: `always (a -> next[3] b)`

which states that, if `a` is asserted, then `b` is asserted three cycles later, belongs to the simple subset, because `a` appears to the left of `b` in the property and also appears to the left of `b` in the timing diagram of any behavior that is not a violation of the property. Figure 2 shows an example of such a timing diagram.

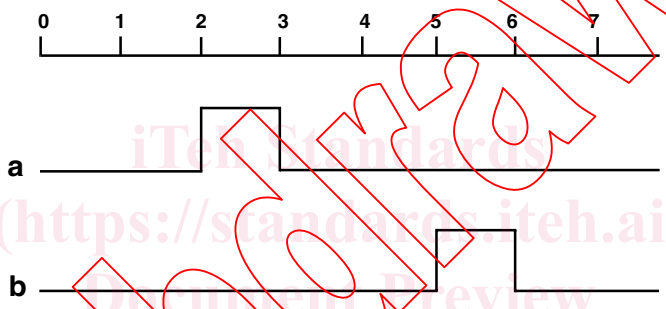

Figure 2—A trace that satisfies Property 2

An example of a property that is not in this subset is the property

Property 3: `always ((a && next[3] b) -> c)`

which states that, if `a` is asserted and `b` is asserted three cycles later, then `c` is asserted (in the same cycle as `a`). This property does not belong to the simple subset, because although `c` appears to the right of `a` and `b` in the property, it appears to the left of `b` in a timing diagram that is not a violation of the property. Figure 3 shows an example of such a timing diagram.

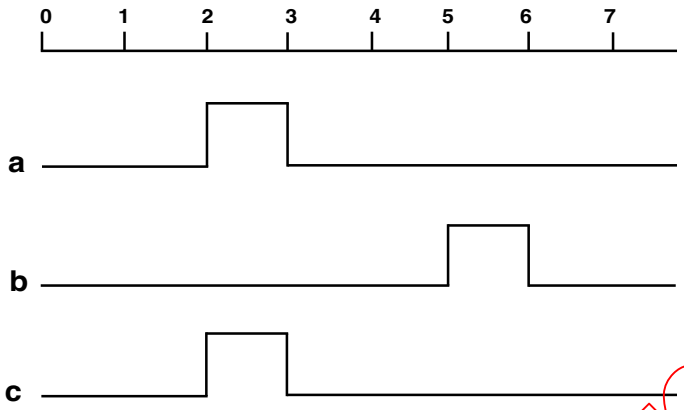

Figure 3—A trace that satisfies Property 3

1.3.2.2 Formal verification

PSL is an extension of the standard temporal logics Linear-Time Temporal Logic (LTL) and Computation Tree Logic (CTL). A specification in the PSL Foundation Language (respectively, the PSL Optional Branching Extension) can be *compiled down* to a formula of pure LTL (respectively, CTL), possibly with some auxiliary HDL code, known as a *satellite*.