Advanced Library Format
for
ASIC Cells & Blocks

containing
Power, Timing, Functional and Physical Information
for
Synthesis, Analysis and Test

Version 1.0.9
February 5, 1999

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<tr>
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<td>11/15/98</td>
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<tr>
<td>Version 1.0.8</td>
<td>1/12/99</td>
</tr>
<tr>
<td>Version 1.0.9</td>
<td>2/5/99</td>
</tr>
</tbody>
</table>
# Table of Contents

1 **Introduction** ......................................................... 1
   1.1 Motivation ......................................................... 1
   1.2 Goals ............................................................. 1
   1.3 Target Applications .............................................. 2
   1.4 Conventions ...................................................... 5
   1.5 Organization of this manual ..................................... 5

2 **Characterization and Modeling** ................................. 7
   2.1 Basic Concepts .................................................. 7
   2.2 Functional Modeling ............................................. 8
      2.2.1 Combinational Logic ...................................... 8
      2.2.2 Level Sensitive Sequential Logic ....................... 8
      2.2.3 Edge Sensitive Sequential Logic ....................... 8
      2.2.4 Vector-Sensitive Sequential Logic ..................... 11
   2.3 Modeling for Characterization .................................. 12
      2.3.1 Timing Modeling ........................................... 12
      2.3.2 Power Modeling ............................................ 13
   2.4 Physical modeling for synthesis and test .................... 15
      2.4.1 Cell modeling ............................................. 15
      2.4.2 Wire modeling ............................................. 16

3 **Library Format Specification** ................................... 17
   3.1 Object Model .................................................... 17
      3.1.1 Syntax conventions ...................................... 17
      3.1.2 Generic Objects ........................................... 18
      3.1.3 Library-specific objects ................................ 21
      3.1.4 Arithmetic models ....................................... 21
      3.1.5 Functions .................................................. 21
   3.2 Lexical rules .................................................... 24
      3.2.1 Character set .............................................. 24
      3.2.2 Lexical tokens ............................................. 25
      3.2.3 Whitespace Characters .................................. 25
      3.2.4 Reserved and Non-reserved Characters ................ 25
      3.2.5 Delimiters ................................................ 26
      3.2.6 Comments ................................................ 26
      3.2.7 Numbers .................................................. 26
3.2.8 Bit Literals 27
3.2.9 Based Literals 28
3.2.10 Edge Literals 29
3.2.11 Quoted Strings 29
3.2.12 Identifiers 30
3.2.13 Rules against parser ambiguity 31
3.2.14 Cross-reference of lexical tokens 31

3.3 Keywords 32
3.3.1 Keywords for Objects 32
3.3.2 Keywords for Operators 33
3.3.3 Context-Sensitive Keywords 33

3.4 Syntax Rules 33
3.4.1 Assignments 33
3.4.2 Expressions 34
3.4.3 Instantiations 35
3.4.4 Literals 35
3.4.5 Operators 36
3.4.6 Auxiliary Objects 38
3.4.7 Generic Objects 38
3.4.8 CELL 40
3.4.9 LIBRARY 40
3.4.10 PIN 40
3.4.11 PRIMITIVE 41
3.4.12 SUBLIBRARY 41
3.4.13 VECTOR 41
3.4.14 WIRE 42
3.4.15 Arithmetic Model 42
3.4.16 FUNCTION 43
3.4.17 Cross-reference of BNF items 44

3.5 Operators 47
3.5.1 Arithmetic operators 48
3.5.2 Boolean operators on scalars 48
3.5.3 Boolean operators on words 49
3.5.4 Vector operators 50
3.5.5 Operators for sequential logic 54
3.5.6 Operator priorities 54
3.5.7 Datatype mapping 55

3.6 Context-sensitive keywords 56
3.6.1 Containers for Annotations and Arithmetic Models 56
3.6.2 Keywords for referencing objects used as annotation 60
3.6.3 Annotations for a PIN object 60
3.6.4 Annotations for a VECTOR object 65
3.6.5 Annotations for a CELL object 67
3.6.6 Attributes 71
3.6.7 Annotations for arithmetic models 72
3.6.8 Keywords for arithmetic models 75
3.6.9 Keywords for arithmetic submodels 82
3.6.10 Special Annotations and Annotation Containers for Arithmetic Models 85
3.6.11 TIME and FREQUENCY in Analog Measurements and Waveforms 88

3.7 Library Organization 90
3.7.1 Scoping Rules 90
3.7.2 Use of multiple files 92

3.8 Referenceable objects 92
3.8.1 Referencing PRIMITIVES or CELLS 93
3.8.2 Referencing PINs in FUNCTIONs 93
3.8.3 Referencing PINs in VECTORs 96
3.8.4 Referencing multi-dimensional PINs 96
3.8.5 Referencing arithmetic models 98

3.9 Functional modeling styles and rules 99
3.9.1 Rules for combinational functions 100
3.9.2 Basic rules for sequential functions 101
3.9.3 Concurrency in combinational and sequential functions 103
3.9.4 Initial values for logic variables 106

3.10 Primitives 107
3.10.1 Concept of user-defined and predefined primitives 107
3.10.2 Predefined combinational primitives 108
3.10.3 Predefined tristate Primitives 112
3.10.4 Predefined multiplexor 114
3.10.5 Predefined flipflop 115
3.10.6 Predefined latch 116

3.11 Parametrizable Cells 118

4 Applications ........................................................... 123
4.1 Truth Table vs Boolean Equation 123
4.1.1 NAND gate 123
4.1.2 Flipflop 124
4.2 Use of primitives 124
4.2.1 D-Flipflop with asynchronous clear 124
4.2.2 JK-flipflop 125
4.2.3 D-Flipflop with synchronous load and clear 126
4.2.4 D-Flipflop with input multiplexor 126
4.2.5 D-latch 127
4.2.6 SR-latch 127
4.2.7 JTAG BSR 128
4.2.8 Combinational Scan Cell 128
4.2.9 Scan Flipflop 130
4.2.10 Quad D-Flipflop 131

4.3 Templates and vector-specific models 132
4.3.1 Vector specific delay and power Tables 132
4.3.2 Use of TEMPLATE 134
4.3.3 Vector description styles for timing arcs 136
4.3.4 Vectors for delay, power and timing constraints 137

4.4 Combining tables and equations 139
4.4.1 Table vs equation 139
4.4.2 Cell with Multiple Output Pins 140
4.4.3 PVT Derating 141

4.5 Use of Annotations 144
4.5.1 Annotations for a PIN 144
4.5.2 Annotations for a timing arc 144
4.5.3 Creating Self-explaining Annotations 145

4.6 Providing fallback position for applications 145
4.6.1 Use of DEFAULT 145

4.7 Bus Modeling 147
4.7.1 Tristate Driver 147
4.7.2 Bus with multiple drivers 149
4.7.3 Busholder 150

4.8 Wire models 150
4.8.1 Basic Wire Model 150
4.8.2 Wire select model 151

4.9 Megacell Modeling 152
4.9.1 Expansion of Timing Arcs 152
4.9.2 Two-port memory 153
4.9.3 Three-port memory 156
4.9.4 Annotation for pins of a bus 156
4.9.5 Skew for simultaneously switching signals on a bus 157

4.10 Special cells 158
4.10.1 Pulse generator 158
4.10.2 VCO 158

4.11 Core Modeling 159
4.11.1 Digital Filter 159
4.12 Connectivity 161
  4.12.1 External connections between pins of a cell 161
  4.12.2 Allowed connections for classes of pins 162
4.13 Signal Integrity 164
  4.13.1 I/V curves 164
  4.13.2 Driver resistance 166
4.14 Resistance and Capacitance on a Pin 169
  4.14.1 Self-Resistance and Capacitance on Input Pin 169
  4.14.2 Pullup and Pulldown Resistance on Input Pin 169
  4.14.3 Pin and Load Resistance and Capacitance on Output Pin 170
4.15 ALF/SDF cross reference 171
  4.15.1 SDF delays 171
  4.15.2 SDF timing constraints 176
  4.15.3 SDF conditions and labels for delays and timing constraints 184
Section 1
Introduction

1.1 Motivation

Design of digital integrated circuits has become an increasingly complex process. More functions get integrated into a single chip, yet the cycle time of electronic products and technologies has become considerably shorter. It would be impossible to successfully design a chip of today’s complexity within the time-to-market constraints without extensive use of EDA tools, which have become an integral part of the complex design flow. The efficiency of the tools and the reliability of the results for simulation, synthesis, timing analysis, and power analysis relies significantly on the quality of available information about the cells in the technology library.

New challenges in the design flow, e.g. power analysis, arise as the traditional tools and design flows hit their limits of capability in processing complex designs. As a result, new tools emerge, and libraries are needed in order to make them work properly. Library creation (generation) itself has become a very complex process and the choice or rejection of a particular application (tool) is often constrained or dictated by the availability of a library for that application. The library constraint may prevent designers from choosing an application program which is best suited for meeting specific design challenges. Similar considerations may inhibit the development and productization of such an application program altogether. As a result, competitiveness and innovation of the whole electronic industry may stagnate.

In order to remove these constraints, an industry-wide standard for library format, Advanced Library Format (ALF), is proposed. It enables the EDA industry to develop innovative products and the ASIC designers to chose the best product without library format constraints. Since ASIC vendors have to support a multitude of libraries according to the preferences of their customers, a common standard library is expected to significantly reduce the library development cycle and facilitate the deployment of new technologies sooner.

1.2 Goals

The basic goals of the proposed library standard are:

- **simplicity** - library creation process must be easy to understand and not become a cumbersome process only known by a few experts.

- **generality** - tools of any level of sophistication must be able to retrieve necessary information from the library.

- **expandability** - for early adoption and future enhancement possibilities
Introduction

Target Applications

- **flexibility** - the choice of keeping information in one library or in separate libraries must be in the hand of the user; it should not be dictated by the standard.

- **efficiency** - the complexity of the design information requires that the process of retrieving information from the library does not become a bottleneck. The right trade-off between compactness and verbosity must be found.

- **ease of implementation** - backward compatibility with existing libraries must be provided, and translation to the new library must be an easy task.

- **conciseness** - unambiguous description and accuracy of contents

- **acceptance** - preference for the new standard library over existing libraries.

### 1.3 Target Applications

The fundamental purpose of ALF is to serve as the primary database for all 3rd party applications of ASIC cells. In other words, it is an elaborate and formalized version of the databook.

In the early days, databooks provided all the information a designer needed for choosing a cell in a particular application: Logic symbols, schematics and truth table provided the functional specification for simple cells. For more complex blocks, the name of the cell (e.g. asynchronous ROM, synchronous 2-port RAM, 4-bit synchronous up-down counter) and timing diagrams conveyed the functional information. The performance characteristics of each cell were provided by the loading characteristics, delay and timing constraints, and some information about DC and AC power consumption. The designers chose the cell type according to the functionality, estimated the performance of the design, and eventually re-implemented it in an optimized way as necessary to meet performance constraints.

Design automation enabled tremendous progress in efficiency, productivity and the ability to deal with complexity, yet it did not change the fundamental requirements for ASIC design. Therefore, ALF needs to provide models with *functional* information and *performance* information, primarily including timing and power. Signal integrity characteristics, such as noise margin can also be included under performance category. Such information is typically found in any databook for analog cells. At deep sub-micron levels digital cells behave similar to analog cells as electronic devices bound by physical laws and therefore not infinitely robust against noise.

Table 1-1 shows a list of applications used in ASIC design flow and their relationship to ALF. The boundary between supported and not supported applications can be defined by the *physical* information provided by ALF. Information needed for area and performance estimation and
Optimization, notably by synthesis tools, is provided by ALF. On the other hand, layout information is only considered for front end application, such as RTL floorplanner.

Table 1-1 Target applications and models supported by ALF

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<th>physical model</th>
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<td>timing analysis</td>
<td>supported by ALF</td>
<td>supported by ALF</td>
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</tr>
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<td>power analysis</td>
<td>supported by ALF</td>
<td>supported by ALF</td>
<td>N/A</td>
</tr>
<tr>
<td>simulation</td>
<td>derived from ALF</td>
<td>derived from ALF</td>
<td>N/A</td>
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<td>synthesis</td>
<td>supported by ALF</td>
<td>supported by ALF</td>
<td>supported by ALF</td>
</tr>
<tr>
<td>scan insertion</td>
<td>supported by ALF</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>RTL floorplanner</td>
<td>N/A</td>
<td>N/A</td>
<td>planned for ALF</td>
</tr>
<tr>
<td>signal integrity</td>
<td>N/A</td>
<td>supported by ALF</td>
<td>N/A</td>
</tr>
<tr>
<td>layout</td>
<td>N/A</td>
<td>N/A</td>
<td>not supported by ALF</td>
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Historically, a functional model was virtually identical to a simulation model. A functional gate-level model was used by the proprietary simulator of the ASIC company, and it was easy to lump it together with a rudimentary timing model. Timing analysis was done through dynamic functional simulation. However, with the advanced level of sophistication of both functional simulation and timing analysis, this is no longer the case. The capabilities of the functional simulators have evolved far beyond the gate-level, and timing analysis has been decoupled from simulation.

The figure 1-1 shows how ALF provides information to various design tools.
The worldwide accepted standards for hardware description and simulation are VHDL and Verilog. Both languages have a wide scope of describing the design at various levels of abstraction: behavioral, functional, synthesizable RTL, gate level. There are many ways to describe gate-level functions. The existing simulators are implemented in such a way that some constructs are more efficient for simulation run time than others. Also, how the simulation model handles timing constraints is a trade-off between efficiency and accuracy. Developing efficient simulation models which are functionally reliable (i.e. pessimistic for detecting timing constraint violation) is a major development effort for ASIC companies.

Hence, the use of a particular VHDL or Verilog simulation model as primary source of functional description of a cell is not very practical. Moreover, the existence of two simulation standards makes it difficult to pick one as a reference with respect to the other. The purpose of a generic functional model is to serve as an absolute reference for all applications that require functional information. Applications such as synthesis, which need functional information merely for recognizing and choosing cell types, can use the generic functional model directly. For other applications such as simulation and test, the generic functional model enables...
automated simulation model and test vector generation and verification, which has a tremendous benefit for the ASIC industry.

With progress of technology, not only the cost constraints but also the set of physical constraints under which the design will function or not have increased dramatically. Therefore the requirements for detailed characterization and analysis of those constraints, especially timing and power in deep submicron design, are much more sophisticated than it used to be. Only a subset of the increasing amount of characterization data appears in today’s databooks.

ALF provides a generic format for all type of characterization data, without restriction to state-of-the-art timing models. Power models are the most immediate extension, and they have been the starter and primary driver for ALF.

Detailed timing and power characterization needs to take into account the mode of operation of the ASIC cell, which is related to the functionality. ALF introduces the concept of vector-based modeling, which is a generalization and a superset of today’s timing and power modeling approaches. All existing timing and power analysis applications can retrieve the necessary model information from ALF.

1.4 Conventions

The syntax for description of lexical and syntax rules uses following conventions.

::= definition of a syntax rule
| alternative definition
[item] an optional item
[item1 | item2 | ... ]
  optional item with alternatives
{item} optional item which can be repeated
{item1 | item2 | ... }
  optional items with alternatives which can be repeated
item item in boldface font is taken verbatim
item item in italic is for explanation purpose only

The syntax for explanation of semantics of expressions uses the following conventions.

=== left side and right side expressions are equivalent
<item> a placeholder for an item in regular syntax

Feature enhancements proposed for ALF 1.1 are written in blue font.

1.5 Organization of this manual

This document presents the Advanced Library Format (ALF), a new standard library format for ASIC cells, blocks and cores, containing power, timing, functional, and physical information.

In the first chapter, motivation and goals of ALF are defined.
The second chapter describes the underlying concepts for functional modeling, cell characterization for timing and power, and additional modeling features for synthesis and test.

The third chapter is the Language Reference Manual (LRM).

The fourth chapter provides application notes.
Section 2
Characterization and Modeling

This chapter elaborates on the basics of cell modeling and characterization, which is the primary source of library information.

2.1 Basic Concepts

The functional models within an ASIC library describe functions and algorithms of hardware components, as opposed to synthesizable functions or algorithms. The functional modeling language for the ASIC library is designed to make the description of existing hardware easy and efficient. The scope here is different from a hardware description language (HDL) or a programming language designed to specify functionality without other aspects of hardware implementation.

Functional description provides boolean functions or truth tables, including state variables for sequential logic. Boolean and arithmetic operators for scalars and vectors are also provided. Combinational and sequential logic cells, macrocells (e.g. adders, multipliers, comparators), and atomic megacells (e.g. memories) can be modeled with these capabilities.

Vectors describe the stimuli for characterization. This encompasses both the concept of timing arcs and logical conditions. An exhaustive set of vectors can be generated from functional information, although the complexity of the exhaustive set precludes it from practical usage. The characterizer makes a choice of the relevant subset for characterization.

Power characterization is a superset of timing characterization using the same set and range of characterization variables: load, input slew rate, skew between multiple switching inputs, voltage, temperature. Characterization measurements, such as delay, output slew rate, average current in time window, bounds of allowed skew for timing constraints, etc. can be described as functions of the characterization variables, either by equations or using lookup tables. More complicated calculation algorithms cannot be described explicitly in the library, but can be referenced using templates.

A core is not an atomic megacell, since it can be split up into smaller components. Templates provide the capability of defining and reusing blocks consisting of atomic constructs or of other blocks. Thus a hierarchical description of the complete core can be created in a simple and efficient way.

Abstraction is required for the characterization of megacells: vectors describe events on buses rather than on scalar pins; number and range of switching pins within a bus become additional characterization variables. Characterization measurements are expandable and can be extrapolated from scalar pin to bus.
2.2 Functional Modeling

2.2.1 Combinational Logic

Combinational logic can be described by continuous assignments of boolean values (True, False) to output variables as a function of boolean values of input variables. Such functions can be expressed in either equation format or table format\(^1\).

Let us consider an arbitrary continuous assignment

\[
z = f(a_1, \ldots, a_n)
\]

In a dynamic or simulation context, the left-hand side (LHS) variable \(z\) is evaluated whenever there is a change in one of the right-hand side (RHS) variables \(a_i\). No storage of previous states is needed for dynamic simulation of combinational logic.

2.2.2 Level Sensitive Sequential Logic

In sequential logic, an output variable \(z_j\) can also be a function of itself, i.e. of its previous state. The sequential assignment has the form

\[
z_j = f(a_1, \ldots, a_n, z_1, \ldots, z_m)
\]

The RHS cannot be evaluated continuously, since a change in the LHS as a result of a RHS evaluation will trigger a new RHS evaluation repeatedly, unless the variables attain stable values. Modeling capabilities of sequential logic with continuous assignments would be restricted to systems with oscillating or self-stabilizing behavior.

However, if we introduce the concept of triggering conditions for the LHS, we have everything we need for modeling level-sensitive sequential logic. The expression of a triggered assignment can look like this:

\[
\theta \ g(b_1, \ldots, b_k) \ z_j = f(a_1, \ldots, a_n, z_1, \ldots, z_m)
\]

The evaluation of \(f\) is activated whenever the triggering function \(g\) is true. The evaluation of \(g\) is self-triggered, i.e. at each time when an argument of \(g\) changes its value. If \(g\) is a boolean expression like \(f\), we can model all types of level-sensitive sequential logic.

During the time when \(g\) is true, the logic cell behaves exactly like combinational logic. During the time when \(g\) is false, the logic cell holds its value. Hence one memory element per state bit is needed.

2.2.3 Edge Sensitive Sequential Logic

In order to model edge-sensitive sequential logic, we need to introduce notations for logical transitions in addition to logical states.

If the triggering function \(g\) is sensitive to logical transitions rather than to logical states, the function \(g\) evaluates to true only for an infinitely small time, exactly at the moment when the

\(^1\) Rather than defining a new syntax for boolean equations, we are just adopting existing notations people are familiar with. Those notations can already be found in the ANSI C standard, and they are widely used in popular script languages such as PERL as well as in HDLs like VERILOG.
transition happens. The sole purpose of \( g \) is to trigger an assignment to the output variable through evaluation of the function \( f \) exactly at this time.

Edge-sensitive logic requires storage of the previous output state and the input state (to detect a transition). In fact, all implementations of edge-triggered flipflops require at least two storage elements. For instance, the most popular flipflop architecture features a master latch driving a slave latch.

Using transitions in the triggering function for value assignment, the functionality of a positive edge triggered flipflop can be described as follows in ALF:

\[
\begin{align*}
\& (01 \text{ CP}) \{ Q = D; \}
\end{align*}
\]

which reads “at rising edge of CP, assign Q the value of D”.

If the flipflop also has an asynchronous direct clear pin (CD), the functional description consists of either two concurrent statements or two statements ordered by priority:

```aldf
// concurrent style
@ (!CD) {Q = 0;}
@ (01 CP && CD) {Q = D;}
// priority (if-then-else) style
@ (!CD) {Q = 0;} : (01 CP) {Q = D;}
```

**Figure 2-1: Model of a flipflop with asynchronous clear in ALF**

The following two examples show corresponding simulation models in Verilog and VHDL:

```verilog
// full simulation model
always @ (negedge CD or posedge CP) begin
    if ( ! CD ) Q <= 0;
    else if (CP && !CP_last_value) Q <= D;
    else Q <= 1’bx;
end
always @ (posedge CP or negedge CP) begin
    if (CP===0 | CP===1’bx) CP_last_value <= CP;
end
// simplified simulation model for synthesis
always @ (negedge CD or posedge CP) begin
    if ( ! CD ) Q <= 0;
    else Q <= D;
end
```

**Figure 2-2: Model of a flipflop with asynchronous clear in Verilog**
The following differences in modeling style can be noticed: VHDL and Verilog provide the list of sensitive signals at the begin of the process or always block, respectively. The information of level-or edge-sensitivity must be inferred by if-then-else statements inside the block. ALF shows the level-or-edge sensitivity as well as the priority directly in the triggering expression. Verilog has another particularity: The sensitivity list indicates whether at least one of the triggering signals is edge-sensitive, by the use of negedge or posedge. However, it does not indicate which one, since either none or all signals must have negedge or posedge qualifiers. Furthermore, posedge is any transition with 0 as initial state or 1 as final state. A positive-edge triggered flipflop will be inferred for synthesis, yet this flipflop will only work correctly if both the initial state is 0 and the final state is 1. Therefore a simulation model for verification must be more complex than the model in the synthesizeable RTL code. In Verilog, the extra non-synthesizeable code must also reproduce the relevant previous state of the clock signal, whereas VHDL has built-in support for last_value of a signal.

Other aspects of simulation models include performance and tradeoff between accuracy and runtime, timing annotation etc.

ALF provides a canonical, compact and highly self-explaining description of the functional specification of a cell, from which simulation models for various applications can be derived.
2.2.4 Vector-Sensitive Sequential Logic

In order to model generalized higher order sequential logic, the concept of vector expressions is introduced, an extension of the boolean expressions.

A vector expression describes sequences of logical events or transitions in addition to static logical states. A vector expression represents a description of a logical stimulus without timescale. It describes the order of occurrence of events.

Using the -> operator (followed by operator), we have a general capability of describing a sequence of events or a vector. For example, consider the following vector expression:

\[ 01 \text{ A} \rightarrow 01 \text{ B} \]

which reads “rising edge on A is followed by rising edge on B”.

A vector expression is evaluated by an event sequence detection function. Like a single event or a transition, this function evaluates true only at an infinitely short time when the event sequence is detected.

\[
g(A, B) = (01 \text{ A} \rightarrow 01 \text{ B})
\]

sequence \((01 \text{ A} \rightarrow 01 \text{ B})\) detected

The event sequence detection mechanism can be described as a queue that sorts events according to their order of arrival. The event sequence detection function evaluates true at exactly the time when a new event enters the queue and forms the required sequence, \(i.e.\) the sequence specified by the vector expression with its preceding events.

A vector-sensitive sequential logic can be called \((N+1)\) order sequential logic, where \(N\) is the number of events to be stored in the queue. The implementation of \((N+1)\) order sequential logic requires \(N\) memory elements for the event queue and 1 memory element for the output itself.

A sequence of events can also be gated with static logical conditions. For example,

\[ (01 \text{ CP} \rightarrow 10 \text{ CP}) \&\& \text{ CD} \]
the pin CD must have state 1 from some time before the rising edge at CP to some time after
the falling edge of CP. The pin CD can not go low (state 0) after the rising edge of CP and go
high again before the falling edge of CP because this would insert events into the queue, and
the sequence “rising edge on CP followed by falling edge on CP” would not be detected.

The formal calculation rules for general vector expressions featuring both states and transitions
will be introduced in Section 3.5.4.

The concept of vector expression supports functional modeling of devices featuring digital
communication protocols with arbitrary complexity.

2.3 Modeling for Characterization

2.3.1 Timing Modeling

The timing models of cells consists of two types: delay models for combinational and
sequential cells, and timing constraint models for sequential cells. Both types can be described
by timing arcs. A timing arc is a sequence of two events which can be described by a vector
expression “event \( e_1 \) is followed by event \( e_2 \)”.

For example, a particular input to output delay of an inverting logic cell is identified by the
following timing arc:

\[ \text{01 A} \rightarrow \text{10 Z} \]

which reads “rising edge on input A is followed by falling edge on output Z”.

A setup constraint between data and clock input of a positive edge triggered flipflop is
identified by the following timing arc:

\[ \text{01 D} \rightarrow \text{01 CP} \]

which reads “rising edge on input D is followed by rising edge on input CP”.

A crucial part in ASIC cell development is to characterize a model which describes the
behavior of each timing arc with sufficient accuracy in order to guarantee correct functional
behavior under all required operational conditions.

A delay model usually needs two output variables:

- \textit{intrinsic delay}, measured between a well-defined threshold value of the input signal and
  a well-defined threshold value of the output signal

- \textit{transition delay}, measured between two well-defined threshold values of the output
  signal. Hence the transition delay is a fraction of the total output transition time, also
called \textit{slew rate} or \textit{edge rate}.

A timing constraint model needs just one output variable:

- A timing constraint is the \textit{minimum or maximum allowed elapsed time} between two
  signals, measured between well-defined threshold values between those two signals. This
definition is similar to the intrinsic delay, except there is no input-output
relationship between the two signals. Both signals are usually inputs to the cell.
The actual values of transition times and load capacitances seen by each pin of a cell instance are calculated by a delay predictor. Delay prediction can be separated into two tasks:

1. Acquisition of information on pin capacitance, extracted or estimated layout parasitics for each net and fitting those into the load characterization model (lumped C, R, etc.)
2. Calculation of internal signal transition times based on the extracted internal load and on load and transition times at the boundaries of the system.

Lookup tables provide a general modeling capability without precluding any level of accuracy. Equations may feature polynomial expressions, exponentials and logarithms, and arbitrary transcendent functions. For practical purpose, only the four basic arithmetic operations (+, -, *, /) and exponentiation and logarithm will be supported for standard models.

Some models may require transcendent functions or complicated algorithms that cannot be expressed directly in equations. Other models and algorithms may need protection from being visible. In order to address needs that go beyond standard modeling features, a template-reference scheme is proposed: Any model which is neither in table nor in equation format needs to be a pointer to a customer-defined model which may reside outside the library.

### Table 2-1 Modeling choices for cell characterization library

<table>
<thead>
<tr>
<th>type of model</th>
<th>features</th>
<th>purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>table</td>
<td>discrete points, multidimensional</td>
<td>direct storage of characterization data, direct accuracy control through mesh granularity</td>
</tr>
<tr>
<td>equation</td>
<td>expressions with +, -, *, /, exponent, logarithm</td>
<td>analytical model, well-suited for optimization purpose, more compact than table, also usable for arithmetic operations on tabulated data (scale, add, subtract ..)</td>
</tr>
<tr>
<td>reference</td>
<td>pointer to any type of model</td>
<td>reuse of predefined model (which may be table or equation), protection of user-defined model</td>
</tr>
</tbody>
</table>

Regardless of which type of model is chosen, there is a need to specify explicitly the meaning of the variables and the units. The specification of variables and units can be made outside the model and independent of the chosen model.

Since the set of variables should not be restrictive in order to allow any enhancements (e.g. move from a lumped capacitance to an RC model), *context-sensitive keywords* are proposed (e.g. “load”, “slewrate”). The application parser need not know the meaning of the context-sensitive keyword, except that it is used as a variable in a model and that it has some unit attached to it, e.g. picofarad, nanosecond etc.

### 2.3.2 Power Modeling

A power model is an extension of the delay model for each timing arc using a third variable:
• *scaled average current*, measured by integrating and scaling the total transient current through the power supply of the cell for the specific timing arc or vector. The current measurement can start anytime before the first event of the vector starts and can end anytime after all transients of the vector have stabilized.

Variants of this model are scaled average power and energy, which are obtained by simple scaling of average current measurements:

\[
\text{power} = \text{current} \times V_{dd} \\
\text{energy} = \text{current} \times V_{dd} \times \text{integration time}
\]

The set of vectors causing power consumption within a cell is a superset of those vectors causing the cell output to switch. While only the vectors with switching output are needed for delay characterization, more vectors are needed for accurate power characterization.

For example, consider a flipflop, which consumes power at every edge of the clock, even if the output does not switch. The vectors for delay and power characterization can be described as follows:

\[
01 \text{ CP} \rightarrow 01 \text{ Q} \\
01 \text{ CP} \rightarrow 10 \text{ Q}
\]

The vectors for power characterization with only clock-switching can be described as follows:

\[
01 \text{ CP} \&\& Q==D \\
10 \text{ CP} \&\& Q==D
\]

The D input having the same value as the Q output is a necessary and sufficient condition that the output will not switch at the rising edge of CP and that the value transferred to the master latch at the falling edge of CP will be the same as already stored. Hence those two vectors capture the actual power dissipation only within the clock buffers. Additional power vectors can be defined to capture the power dissipation within the data buffers and the master latch etc.

For a 2-input AND gate with input pins \(A, B\) and output pin \(Z\) a *glitch* is observed if the event 01 \(A\) is detected and then the event 10 \(B\) is detected before the input-to-output delay elapses. It is possible to describe the glitch by a higher-order vector.

In dynamic simulation with *transport delay mode*, the glitch would appear as follows:

\[
01 \text{ A} \rightarrow 10 \text{ B} \rightarrow 01 \text{ Z} \rightarrow 10 \text{ Z}
\]

Simulation featuring *transport delay mode with invalid-value-detection* would exhibit the glitch as follows:\(^2\)

\[
01 \text{ A} \rightarrow 10 \text{ B} \rightarrow 'b0'bX \text{ Z} \rightarrow 'bX'b0 \text{ Z}
\]

Simulation with *inertial delay mode* would suppress the output transitions:

\[
(01 \text{ A} \rightarrow 10 \text{ B}) \&\& !Z
\]

The last expression can be used for each of the three simulation modes, since \(!Z\) is always true from beginning to end of the sequence 01 \(A\) \(\rightarrow\) 10 \(B\), in particular at the time when the sequence 01 \(A\) \(\rightarrow\) 10 \(B\) is detected.

---

2. *use based edge literals to avoid parser ambiguity.*
Each way of expressing vectors can be derived from the cell functionality. The different examples for delay vectors (i.e. timing arcs), power vectors, and glitch vectors emphasize the rich potential of modeling capabilities using vector expressions.

State-dependent *static power* is also within the scope of vector-based power models. Static power consumption is activated by a simulation model in the same way as level-sensitive logic in functional modeling by a boolean expression, whereas *transient power* consumption is activated similar to edge-sensitive logic by a vector expression.

The advantages of adding power models within each delay vector and providing extra power vectors are the following:

- straightforward extension of delay characterization
- capable of yielding the most detailed and accurate model on gate-level
- each vector defines a comprehensive stimulus for power measurements

More abstract vector expressions are provided for power modeling of complex blocks, where simplification is needed in order to deal with the complexity of characterization vectors.

## 2.4 Physical modeling for synthesis and test

### 2.4.1 Cell modeling

Physical modeling of cells requires annotating cell properties (e.g. area, height, width, aspect ratio). The set of annotated properties give an application such as synthesis a choice to pick one cell from a set of functionally equivalent cells, if one property is more desirable than another one under given synthesis goals and constraints.

Cell pins can also have annotated properties, such as pin capacitance, voltage swing, switching threshold etc.

Most of the modeling for test requirements are already fulfilled by the functional model. Declaration of pins and their direction (input, output, bidirectional) is already a generic requirement for cell modeling.

Scan insertion tools require specific annotations about cell and pin properties relevant for scan test. They also require reference to equivalent non-scan cells. An equivalent non-scan cell is a scan cell, when all scan specific hardware (e.g. multiplexor, scan clock) is removed.

The variables used in the functional model must have their counterpart in the pin declaration. Only primary input pins can be primary inputs of functions, while primary output pins, internal pins, or virtual pins can be primary or intermediate outputs of functions. Furthermore, test vectors for fault coverage can be derived from the functional model in a formal way.

The remainder of the modeling for test requirements can be covered by annotations of cell properties and cell pin properties. For instance, a cell can be labeled as a scan-flipflop, a pin can be labeled as scan input or mode select pin.
### 2.4.2 Wire modeling

The purpose of wire modeling is to get good estimates of parasitic resistance and capacitance as a function of fanout. These estimates are technology specific, and they depend on metal layer, sheet resistance, self capacitance per unit wirelength, fringe capacitance per unit wirelength, via resistance for wires routed through multiple layers.

The wires can be characterized by types, similar to cells. For example,

```plaintext
// wire with fanout < 5 routed in metal 1, 2
WIRE small_wire {
    ATTRIBUTE { metal1 metal2 }
    LIMIT { FANOUT { MAX = 5; } }
    /* fill in data */
}

// wire with 10 ≤ fanout ≤ 20 routed in metal 1, 2, 3, 4, 5
WIRE big_wire {
    ATTRIBUTE { metal1 metal2 metal3 metal4 metal5 }
    LIMIT { FANOUT { MIN = 10; MAX = 20; } }
    /* fill in data */
}
```

From a modeling standpoint, no particular language is required for performance modeling of wires that would be different from performance modeling of cells. The fanout will be an input variable, and capacitance and resistance would be output variables. The values can be expressed either in tables or in equations. Usually first order equations (with slope and intercept) are used for wire modeling.
This section discusses the object model used by ALF and provides the syntax rules for all objects. The syntax rules are provided in standard BNF form.

### 3.1 Object Model

A library consists of one or more objects. Each object is defined by a keyword and an optional name for the object and an optional value of the object.

A keyword defines the type of the object. Section 3.1.2 and Section 3.1.3 define various types of objects used in ALF and related keywords.

An optional identifier (also called name) following the keyword defines the name of the object. This name must be used while referencing an object inside other objects in the library. If an object is not referenced by name, then the object need not be named.

A literal defines an optional value associated with the object. An expression can be used when the value of the object cannot be expressed as a literal.

An object may contain one or more objects. The containing object is called a hierarchical object. The contained objects are called children objects. The children objects are defined and referenced inside curly braces ({} in the description of the hierarchical object. An object without children is called an atomic object.

Forward referencing of objects is not allowed. Therefore, all objects must be defined before they can be instantiated. This allows library parsers to be one-pass parsers.

#### 3.1.1 Syntax conventions

In order to make ALF easy to parse, we use syntax conventions which are followed by the existing syntax rules (see Section 3.4) and should also be followed for future extensions of the grammar.

The first token of the object is the object type identifier, followed by a name (mandatory or optional, depending on object type), followed by (mandatory or optional) = and value assignment, followed by (mandatory or optional) children objects enclosed by curly braces. Objects with more than one token (i.e. name and/or value) and without children are terminated with ;.

Examples:

1. unnamed object without value assignment:

   `MY_OBJECT_TYPE`
or

```c
MY_OBJECT_TYPE {
    //fill in children objects
}
```

2. unnamed object with value assignment:

```c
MY_OBJECT_TYPE = my_object_value;
```
or

```c
MY_OBJECT_TYPE = my_object_value {
    //fill in children objects
}
```

3. named object without value assignment:

```c
MY_OBJECT_TYPE my_object_name;
```
or

```c
MY_OBJECT_TYPE my_object_name {
    //fill in children objects
}
```

4. named object with value assignment:

```c
MY_OBJECT_TYPE my_object_name = my_object_value;
```
or

```c
MY_OBJECT_TYPE my_object_name = my_object_value {
    //fill in children objects
}
```

The objects in ALF are divided into four categories - generic objects, library-specific objects, arithmetic models, and functions.

### 3.1.2 Generic Objects

A generic object can appear at every level in the library within any scope. The semantics of a generic object must be understood by any ALF compiler if the generic object is within the scope of application for that compiler.

The following objects shall be considered generic objects:
### 3.1.2.1 CONSTANT

A **CONSTANT** object is a named object with value assignment and without children objects. Value is a number.

Example:

```al "
CONSTANT vdd = 3.3;
```

### 3.1.2.2 ALIAS

An **ALIAS** object is a named object with value assignment and without children objects. Value is a string.

Example:

```al "
ALIAS RAMPTIME = SLEWRATE;
```

### 3.1.2.3 INCLUDE

An **INCLUDE** object is a named object without value assignment and without children. The name is a quoted string containing the name of a file to be included.

Example:

```al "
INCLUDE "primitives.alf";
```

Since the file name is a quoted string, any special symbols (like ~ or *) are allowed within the filename. The interpretation of those (for file search path etc.) is up to the application.

### 3.1.2.4 CLASS

A **CLASS** object is a named object with optional value assignments and children objects. The name can be used by other objects to reference the class object.
Example:

```plaintext
CLASS my_class { ... }
...
MY_OBJECT_TYPE my_object {
    CLASS = my_class;
} // my_object belongs to my_class
```

### 3.1.2.5 ATTRIBUTE

An **ATTRIBUTE** object is an unnamed object without value, but has children objects. The attribute object shall be the child object of another object. The children of the attribute object are unnamed objects which can have other unnamed objects as children objects. The purpose of an attribute object is to provide free association of objects with attributes when there is no special category available for the attributes.

Examples:

```plaintext
CELL rr_8x128 {
    ATTRIBUTE {ROM ASYNCHRONOUS STATIC}
}
PIN read_write_select {
    ATTRIBUTE {READ{POLARITY=low;} WRITE{POLARITY=high;}}
}
```

### 3.1.2.6 TEMPLATE

A **TEMPLATE** object is a named object with one or more children objects. Any valid ALF object can be a child object of a template object. An identifier enclosed between `<` and `>` are recognized as placeholders. When a template object is used, each of its placeholders must be referenced by order or by explicit name association.

Example:

```plaintext
TEMPLATE std_table {
    CAPACITANCE {PIN=<pin1>; UNIT=pF; TABLE {0.02 0.04 0.08 0.16}}
    SLEWRATE {PIN=<pin2>; UNIT=ns; TABLE {0.1 0.3 0.9}}
}
```

An instantiation of the above template object with explicit reference to placeholders by name:

```plaintext
std_table{pin1=out; pin2=in;}
```

An instantiation of the above template object with implicit reference to placeholders by order:

```plaintext
std_table{out in}
```

If a symbol within a placeholder appears more than once in the template definition, the order for implicit reference is defined by the first appearance of the symbol. Explicit referencing improves the readability and is the recommended usage.

A template instantiation can appear at any place within a hierarchical object, as long as the template object contains the structure of valid objects inside. Hierarchical templates contain other template objects.
3.1.2.7 PROPERTY
A PROPERTY object is a named or an unnamed annotation container. It can be used at any level in the library. It is used for arbitrary parameter-value assignment.

Example:

```alp
PROPERTY items {
  parameter1=value1;
  parameter2=value2;
}
```

3.1.2.8 GROUP
A GROUP object is a set of elements with commonality between them. Thus the common characteristics can be defined once for the group instead of being repeated for each element.

Example:

```alp
GROUP time_measurements = {DELAY SLEWRATE SKEW JITTER}
```

Thus the statement

```alp
time_measurements { UNIT = ns; }
```

replaces the following statements:

```alp
DELAY { UNIT = ns; }
SLEWRATE { UNIT = ns; }
SKEW { UNIT = ns; }
JITTER { UNIT = ns; }
```

3.1.3 Library-specific objects

The library-specific objects define their nature and their relationship to each other by containment rules. For example, a library may contain a cell, but a cell may not contain a library. However, both the library object and the cell object may contain any generic object. A generic object defined at the library level makes it visible inside the scope of that library, defining it on the cell level makes it visible inside the scope of that cell and its children objects.

3.1.4 Arithmetic models

An arithmetic model is an object that describes characterization data, or more abstract, measurable relationships between physical quantities. The modeling language allows tabulated data as well as linear and non-linear equations. The equations consists of arithmetic expressions, for which the IEEE standards have been adopted.

3.1.5 Functions

A function is an object that describes the functional specification of a digital circuit (or a digital model of an analog or a mixed-signal circuit) in a canonical form. The modeling language allows behavioral models as well as statetables and structural models with primitives. The behavioral models contain boolean expressions, for which the IEEE standards have been adopted. Since boolean expressions are insufficient to describe sequential logic, ALF introduces new operators and symbols that can be used in conjunction with boolean operators.
and symbols. Expressions that use both the IEEE operators and the new operators, are called vector expressions.

The following figures describe the four types of objects and their relationships with each other.

Note that a function can contain a primitive and a primitive can contain a function. See figure 3-7 and syntax descriptions in Section 3.4.11 and Section 3.4.16.
library
arithmetic model
sublibrary
cell
wire
pin
vector
function
primitive

```
contains
contains
contains
```

Figure 3-5: Annotations

```
is a
is a
is a
is a
is a
is a
is a
is a
is a
```

library
sublibrary
cell
wire
pin
vector
annotation container
annotation
primitive

```
is a
```

Figure 3-6: Library-specific objects
Note that a function can contain a primitive and a primitive can contain a function. See figure 3-7 and syntax descriptions in Section 3.4.11 and Section 3.4.16.

### 3.2 Lexical rules

#### 3.2.1 Character set

Each graphic character corresponds to a unique code of the ISO eight-bit coded character set [ISO 8859-1 : 1987(E)], and is represented (visually) by a graphical symbol.
3.2.2 Lexical tokens

The ALF source text files shall be a stream of lexical tokens. Each lexical token is either a delimiter, a comment, a bit literal, a based literal, an edge literal, a number, a quoted string or an identifier.

3.2.3 Whitespace Characters

The following characters shall be considered whitespace characters:

<table>
<thead>
<tr>
<th>Character</th>
<th>ASCII code (hex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>space</td>
<td>20</td>
</tr>
<tr>
<td>vertical tab</td>
<td>0B</td>
</tr>
<tr>
<td>horizontal tab</td>
<td>09</td>
</tr>
<tr>
<td>line feed (new line)</td>
<td>0A</td>
</tr>
<tr>
<td>carriage return</td>
<td>0D</td>
</tr>
<tr>
<td>form feed</td>
<td>0C</td>
</tr>
</tbody>
</table>

Figure 3-8: List of whitespace characters

Comments are also considered white space (see Section 3.2.6).

A whitespace character shall be ignored except when it separates other lexical tokens or when it appears in a quoted string.

3.2.4 Reserved and Non-reserved Characters

The ASCII character set shall be divided in three categories - whitespace (Section 3.2.3), reserved characters, and non-reserved characters. The reserved characters are symbols that make up punctuation marks and operators. The non-reserved characters shall be used for creating identifiers and numbers.

reserved_character ::= & | | ^ | ~ | + | - | * | / | % | ? | ! | = | < | > | :
                     | ( | ) | [ | ] | { | } | @ | ; | , | . | ” | ’

nonreserved_character ::= letter | digit | _ | $

letter ::= a | b | c | d | e | f | g | h | i | j | k | l | m
      | n | o | p | q | r | s | t | u | v | w | x | y | z
      | A | B | C | D | E | F | G | H | I | J | K | L | M
      | N | O | P | Q | R | S | T | U | V | W | X | Y | Z

digit ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

escape_character ::= \
any_character ::=  
  reserved_character  
  | nonreserved_character  
  | escape_character  
  | whitespace

Figure 3-9: Reserved and non-reserved characters

ALF shall treat uppercase and lowercase characters as the same characters. In other words, ALF is a case-insensitive language.

3.2.5 Delimiters

A delimiter is either a reserved character or one of the following compound operators, each composed of two or three adjacent reserved characters:

delimiter ::=  
  reserved_character  
  | &&  
  | |  
  | ~&  
  | |  
  | ~^  
  | ==  
  | !=  
  | **  
  | >=  
  | <=  
  | ?!  
  | ?~  
  | ?-  
  | ??  
  | ->  
  | <->  
  | >-  
  | <<<

Figure 3-10: Tokens that make up delimiters

Each special character in a single character delimiter list shall be a single delimiter unless this character is used as a character in a compound operator or as a character in a quoted string.

3.2.6 Comments

ALF has two forms to introduce comments.

A single-line comment shall start with the two characters // and end with a new line.

A block comment shall start with /* and end with */. Comments shall not be nested. The single-line comment token // shall not have any special meaning in a block comment.

comment ::=  
  single_line_comment  
  | block_comment

Figure 3-11: Single-line and block comments

3.2.7 Numbers

Constant numbers can be specified as integer or real.

The integer is a decimal integer constant.

sign ::=  
  +  
  |  
  -
unsigned ::= digit { _ | digit }
integer ::= [ sign ] unsigned
number ::= [ sign ] non-negative-number

Figure 3-12: Integer and real numbers

3.2.8 Bit Literals
A bit literal shall represent a single bit constant.

bit_literal ::= numeric_bit_literal | alphabetic_bit_literal | dont_care_literal | random_literal
numeric_bit_literal ::= 0 | 1
alphabetic_bit_literal ::= X | Z | L | H | U | W | x | z | l | h | u | w
dont_care_literal ::= ?
random_literal ::= *

Table 3-1: Single bit constants

<table>
<thead>
<tr>
<th>Literal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>value is logic zero</td>
</tr>
<tr>
<td>1</td>
<td>value is logic one</td>
</tr>
<tr>
<td>X or x</td>
<td>value is unknown</td>
</tr>
<tr>
<td>L or l</td>
<td>value is logic zero with weak drive strength</td>
</tr>
<tr>
<td>H or h</td>
<td>value is logic one with weak drive strength</td>
</tr>
<tr>
<td>W or w</td>
<td>value is unknown with weak drive strength</td>
</tr>
<tr>
<td>Z or z</td>
<td>value is high-impedance</td>
</tr>
<tr>
<td>U or u</td>
<td>value is uninitialized</td>
</tr>
<tr>
<td>?</td>
<td>value is any of the above, yet stable</td>
</tr>
<tr>
<td>*</td>
<td>value may randomly change</td>
</tr>
</tbody>
</table>
3.2.9 Based Literals

A based literal is a constant expressed in a form that specifies the base explicitly. The base can be specified in binary, octal, decimal or hexadecimal format.

```
based_literal ::= binary_base { _ | binary_digit }
  | octal_base   { _ | octal_digit   }
  | decimal_base { _ | digit       }
  | hex_base     { _ | hex_digit    }

binary_base ::= 'B' | 'b'
octal_base ::= 'O' | 'o'
decimal_base ::= 'D' | 'd'
hex_base ::= 'H' | 'h'

binary_digit ::= bit_literal

octal_digit ::= binary_digit | 2 | 3 | 4 | 5 | 6 | 7

hex_digit ::= octal_digit | 8 | 9 | A | B | C | D | E | F | a | b | c | d | e | f
```

Figure 3-13: Based constants

The underscore (_) shall be legal anywhere in the number except as the first character, and this character is ignored. This feature can be used to break up long numbers for readability purposes. No white space shall be allowed between base and digit token in a based literal.

When an alphabetic bit literal is used as an octal digit, it shall represent 3 repeated bits with the same literal. When an alphabetic bit literal is used as a hex digit, it shall represent 4 repeated bits with the same literal.

For example,

'02xw0u is same as 'b010_xxx_www_000_uuu
'hLux is same as 'bLLLL_uuuu_xxxx
3.2.10 Edge Literals

An edge literal shall be constructed by two bit literals or two based literals. It shall describe the transition of a signal from one discrete value to another. No white space shall be allowed within (between) the two literals. An underscore shall be allowed.

```
edge_literal ::=  
    bit_edge_literal | word_edge_literal | symbolic_edge_literal  

bit_edge_literal ::=  
    bit_literal bit_literal  

word_edge_literal ::=  
    based_literal based_literal  

symbolic_edge_literal ::=  
    ?? | ?~ | ?! | ?- 
```

Figure 3-14: Edge literals

3.2.11 Quoted Strings

The quoted string shall be a sequence of zero or more characters enclosed between two quotation marks ("") and contained on a single line. Character escape codes are used inside the string literal to represent some common special characters. The characters that may follow the backslash (\) and their meanings are listed below in Table 3-2.

```
quoted_string ::=  
    " { any_character } "  
```

Figure 3-15: A quoted string

<table>
<thead>
<tr>
<th>Symbol</th>
<th>ASCII Code (octal)</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>\g</td>
<td>007</td>
<td>alert/bell</td>
</tr>
<tr>
<td>\h</td>
<td>010</td>
<td>backspace</td>
</tr>
<tr>
<td>\t</td>
<td>011</td>
<td>horizontal tab</td>
</tr>
<tr>
<td>\n</td>
<td>012</td>
<td>new line</td>
</tr>
<tr>
<td>\v</td>
<td>013</td>
<td>vertical tab</td>
</tr>
<tr>
<td>\f</td>
<td>014</td>
<td>form feed</td>
</tr>
<tr>
<td>\r</td>
<td>015</td>
<td>carriage return</td>
</tr>
<tr>
<td>&quot;</td>
<td>042</td>
<td>double quotation mark</td>
</tr>
</tbody>
</table>
A non-quoted string can not contain any reserved character. Therefore, when referencing file names (which typically contain a period character), use of a quoted string is necessary.

### 3.2.12 Identifiers

Identifiers are used in ALF as names of objects, reserved words and context-sensitive keywords. An identifier shall be any sequence of letters, digits, underscore (\_), and dollar sign ($\$) character. If an identifier is constructed from one or more non-reserved characters, it is called **non-escaped identifier**. A digit shall not be allowed as first character of a non-escaped identifier.

\[
\text{nonescaped_identifier ::= nonreserved_character \{ nonreserved_character \}}
\]

A sequence of characters starting with an escape_character is called an **escaped identifier**. The purpose of the escaped identifier is to legalize the use of a digit as first character of an identifier, the use of reserved_character anywhere in an identifier or to prevent the misinterpretation of an identifier as a keyword. The escape character shall be followed by at least one non-white space character to form an escaped identifier. The escaped identifier shall contain all characters up to first white space character.

\[
\text{escaped_identifier ::= escape_character escaped_characters}
\]

\[
\text{escaped_characters ::= escaped_character \{ escaped_character \}}
\]

\[
\text{escaped_character ::= nonreserved_character | reserved_character | escape_character}
\]

A **placeholder identifier** shall be a non-escaped identifier between the less-than character (<) and the greater-than character (>). No whitespace or delimiters are allowed between the non-escaped identifier and the placeholder characters (< and >). The placeholder identifier is used in template objects as a formal parameter, which is replaced by the actual parameter in template instantiation.

\[
\text{placeholder_identifier ::= < nonescaped_identifier >}
\]

Identifiers are treated in a case-insensitive way. They may be used in the definition of objects and in reference to already defined objects. A parser should preserve the case of an identifier in the definition of an object, since a downstream application may be case-sensitive.
3.2.13 Rules against parser ambiguity

The following rules shall apply when resolving ambiguity in parsing ALF source:

- In a context where both `bit_literal` and `identifier` are legal syntax items, `nonescaped_identifier` shall take priority over `alphabetic_bit_literal`.

- In a context where both `bit_literal` and `number` are legal syntax items, `number` shall take priority over `numeric_bit_literal`.

- In a context where both `edge_literal` and `identifier` are legal syntax items, `identifier` shall take priority over `bit_edge_literal`.

- In a context where both `edge_literal` and `number` are legal syntax items, `number` shall take priority over `bit_edge_literal`.

In such contexts, `based_literal` shall be used instead of `bit_literal`.

3.2.14 Cross-reference of lexical tokens

<table>
<thead>
<tr>
<th>Lexical token</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>alphabetic_bit_literal</td>
<td>3.2.8</td>
</tr>
<tr>
<td>any_character</td>
<td>3.2.4</td>
</tr>
<tr>
<td>based_literal</td>
<td>3.2.9</td>
</tr>
<tr>
<td>binary_base</td>
<td>3.2.9</td>
</tr>
<tr>
<td>binary_digit</td>
<td>3.2.9</td>
</tr>
<tr>
<td>bit_edge_literal</td>
<td>3.2.10</td>
</tr>
<tr>
<td>bit_literal</td>
<td>3.2.8</td>
</tr>
<tr>
<td>block_comment</td>
<td>3.2.6</td>
</tr>
<tr>
<td>comment</td>
<td>3.2.6</td>
</tr>
<tr>
<td>decimal_base</td>
<td>3.2.9</td>
</tr>
<tr>
<td>delimiter</td>
<td>3.2.5</td>
</tr>
<tr>
<td>digit</td>
<td>3.2.4</td>
</tr>
<tr>
<td>dont_care_literal</td>
<td>3.2.8</td>
</tr>
<tr>
<td>edge_literal</td>
<td>3.2.10</td>
</tr>
<tr>
<td>escape_character</td>
<td>3.2.4</td>
</tr>
<tr>
<td>escaped_identifier</td>
<td>3.2.12</td>
</tr>
<tr>
<td>hex_base</td>
<td>3.2.9</td>
</tr>
<tr>
<td>hex_digit</td>
<td>3.2.9</td>
</tr>
<tr>
<td>integer</td>
<td>3.2.7</td>
</tr>
<tr>
<td>nonescaped_identifier</td>
<td>3.2.12</td>
</tr>
<tr>
<td>non_negative_number</td>
<td>3.2.7</td>
</tr>
</tbody>
</table>
Keywords are case-insensitive non-escaped identifiers. For clarity, this document uses uppercase letters for keywords and lowercase letters elsewhere, unless otherwise mentioned.

Keywords are reserved for use as object identifiers, not for general symbols. To use an identifier that conflicts with the list of keywords, use the escape character, e.g. to declare a pin that is called `PIN`, use the form:

```
PIN \PIN {..}
```

A keyword can either be a reserved keyword (also called hard keyword) or a context-sensitive keyword (also called soft keyword). The hard keywords have fixed meaning, and must be understood by any parser of ALF. The soft keywords may be understood only by specific applications. For example, a parser for a timing analysis application can ignore objects which contain power related information described using soft keywords.

### 3.3.1 Keywords for Objects

The following keywords are used to identify object types:

```
ALIAS CLASS GROUP PIN SUBLIBRARY WIRE
ATTRIBUTE CONSTANT HEADER PRIMITIVE TABLE
BEHAVIOR EQUATION INCLUDE PROPERTY TEMPLATE
CELL FUNCTION LIBRARY STATETABLE VECTOR
```

**Figure 3-16: Keywords for objects**
3.3.2 Keywords for Operators

The following keywords are used for built-in arithmetic functions:

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>absolute value</td>
</tr>
<tr>
<td>EXP</td>
<td>natural exponential function</td>
</tr>
<tr>
<td>LOG</td>
<td>natural logarithm</td>
</tr>
<tr>
<td>MIN</td>
<td>minimum</td>
</tr>
<tr>
<td>MAX</td>
<td>maximum</td>
</tr>
</tbody>
</table>

Figure 3-17: Keywords for built-in arithmetic functions

3.3.3 Context-Sensitive Keywords

In order to address the need of extensible modeling, ALF provides a predefined set of public context-sensitive keywords. Additional private context-sensitive keywords can be introduced as long as they do not have the same name as any existing public keyword.

The public context-sensitive keywords and their semantic meaning is defined in Section 3.6. This set can be extended to include private context-sensitive keywords.

3.4 Syntax Rules

The formal syntax of ALF language is described using Backus-Naur Form (BNF).

3.4.1 Assignments

```
unnamed_assignment_base ::= 
context_sensitive_keyword = value

unnamed_assignment ::= 
unnamed_assignment_base ;

unnamed_assignments ::= 
unnamed_assignment { unnamed_assignment }

named_assignment_base ::= 
context_sensitive_keyword identifier = value

named_assignment ::= 
named_assignment_base ;

named_assignments ::= 
named_assignment { named_assignment }

assignment_base ::= 
named_assignment_base 
| unnamed_assignment_base

multi_value_assignment ::= 
identifier { values }
```
assignment ::= 
  named_assignment 
  | unnamed_assignment 
  | multi_value_assignment

pin_assignment ::= 
  pin_identifier [index] = pin_identifier [index] ; 
  | pin_identifier [index] = logic_constant ; 
  | logic_constant = pin_identifier [index] ;

pin_assignments ::= 
  pin_assignment { pin_assignment }

arithmetic_assignment ::= 
  identifier = arithmetic_expression ;

3.4.2 Expressions

arithmetic_expression ::= 
  ( arithmetic_expression ) 
  | number 
  | [ arithmetic_unary_operator ] identifier 
  | arithmetic_expression arithmetic_binary_operator 
  | arithmetic_function_operator 
  | arithmetic_expression { , arithmetic_expression }

boolean_expression ::= 
  ( boolean_expression ) 
  | logic_constant 
  | logic_variable 
  | boolean Unary_operator boolean_expression 
  | boolean_expression boolean_binary_operator boolean_expression 
  | boolean_expression boolean_condition_operator boolean_expression 
  | boolean_else_operator boolean_expression

vector_expression ::= 
  ( vector_expression ) 
  | vector Unary_operator boolean_expression 
  | vector_expression vector_binary_operator vector_expression 
  | vector_expression boolean or operator vector_expression 
  | vector_expression boolean_and_operator vector_expression 
  | vector_expression boolean_and_operator boolean_expression 
  | boolean_expression boolean_and_operator vector_expression 
  | boolean_expression boolean_and_operator boolean_expression 
  | boolean_expression boolean_or_operator vector_expression 
  | boolean_expression boolean_or_operator boolean_expression 
  | boolean_expression boolean_else_operator vector_expression 
  | boolean_expression boolean_else_operator boolean_expression
3.4.3 Instantiations

cell_instantiation ::=  
    cell_identifier { logic_values }  
    | cell_identifier { pin_assignments }  

primitive_instantiation ::=  
    primitive_identifier [ identifier ] { logic_values }  
    | primitive_identifier [ identifier ] { logic_assignments }  
    | primitive_identifier [ identifier ] { pin_assignments }  

template_instantiation ::=  
    template_identifier ;  
    | template_identifier [ = static ] { values }  
    | template_identifier [ = static ] { all_purpose_items }  
    | template_identifier = dynamic { values }  
    | template_identifier = dynamic { dynamic_instantiation_items }  

dynamic_instantiation_items ::=  
    dynamic_instantiation_item { dynamic_instantiation_item }  

dynamic_instantiation_item ::=  
    all_purpose_item  
    | arithmetic_model  
    | arithmetic_assignment  

3.4.4 Literals

context_sensitive_keyword ::=  
    nonescaped_identifier  

edge_literal ::=  
    bit_edge_literal  
    | word_edge_literal  
    | symbolic_edge_literal  

edge_literals ::=  
    edge_literal { edge_literal }  

identifier ::=  
    nonescaped_identifier  
    | escaped_identifier  
    | placeholder_identifier  

idicators ::=  
    identifier { identifier }  

index ::=  
    [ unsigned ]  
    | [ unsigned : unsigned ]
logic_value ::= logic_constant | logic_variable
logic_values ::= logic_value { logic_value }
logic_constant ::= bit_literal | based_literal
logic_constants ::= logic_constant { logic_constant }
statetable_value ::= logic_constant | edge_literal | ( [!] logic_variable )
statetable_values ::= statetable_value { statetable_value }
logic_variable ::= pin_identifier [ index ]
logic_variables ::= logic_variable { logic_variable }
numbers ::= number { number }
string ::= quoted_string | identifier
value ::= number | string | logic_value
values ::= value { value }

3.4.5 Operators

arithmetic_binary_operator ::= + | - | * | / | ** | %
arithmetic_function_operator ::= abs
Syntax Rules

| exp    |
| log    |
| min    |
| max    |

arithmetic_unary_operator ::= 
   + | -

boolean_binary_operator ::= 
   boolean_and_operator | boolean_or_operator | boolean_logic_compare_operator | boolean_case_compare_operator | boolean_arithmetic_operator

boolean_and_operator ::= 
   & | &&

boolean_or_operator ::= 
   | | ||

boolean_logic_compare_operator ::= 
   ^ | ~^    

boolean_case_compare_operator ::= 
   != | == | >= | <= | > | <

boolean_arithmetic_operator ::= 
   + | - | * | / | % | >> | <<

boolean_condition_operator ::= 

boolean_else_operator ::= 

vector_if_operator ::= 

vector_elsif_operator ::= 

boolean_unary_operator ::= 
   ! | ~ | & | ~& | | | ~ | ^ | ~^    

vector_binary_operator ::= 
   -- > | <-> | &> | <&> | ~> 

vector_unary_operator ::= 
   edge_literal

See Section 3.5 for semantics of operators.
### 3.4.6 Auxiliary Objects

all_purpose_item ::=  
  annotation  
  | annotation_container  
  | generic_object  
  | template_instantiation  
  | cell_instantiation

all_purpose_items ::=  
  all_purpose_item { all_purpose_item }

annotation ::=  
  assignment  
  | assignment_base { all_purpose_items }

annotation_container ::=  
  context_sensitive_keyword { all_purpose_items }

generic_object ::=  
  alias  
  | attribute  
  | constant  
  | class  
  | group  
  | include  
  | property  
  | template

library_specific_object ::=  
  annotation  
  | annotation_container  
  | cell  
  | function  
  | library  
  | pin  
  | primitive  
  | sublibrary  
  | vector  
  | wire

source_text ::=  
  ALF_REVISION version_string library

### 3.4.7 Generic Objects

alias ::=  
  ALIAS identifier = identifier ;

attribute ::=  
  ATTRIBUTE { attribute_items }
attribute_item ::= 
    identifier [ { unnamed_assignments } ]

attribute_items ::= 
    attribute_item { attribute_item }

class ::= 
    CLASS identifier ;
    | CLASS identifier { class_items }

class_item ::= 
    all_purpose_item
    | logic_assignment
    | vector_assignment

class_items ::= 
    class_item { class_item }

constant ::= 
    CONSTANT identifier = number ;
    | CONSTANT identifier = logic_constant ;

group ::= 
    GROUP group_identifier { identifiers }
    | GROUP group_identifier { numbers }
    | GROUP group_identifier { edge_literals }
    | GROUP group_identifier { logic_constants }
    | GROUP group_identifier { logic_variables }
    | GROUP group_identifier { integer : integer }

include ::= 
    INCLUDE quoted_string ;

property ::= 
    PROPERTY [ identifier ] { unnamed_assignments }

template_item ::= 
    all_purpose_item
    | library_specific_object
    | arithmetic_model
    | header
    | table
    | equation
    | behavior_item

template_items ::= 
    template_item { template_item }

template ::= 
    TEMPLATE template_identifier { template_items }
### 3.4.8 CELL

```plaintext
cell ::= 
  CELL cell_identifier { cell_items }
  |  CELL cell_identifier ;
  |  cell_template_instantiation

cell_item ::= 
  all_purpose_item
  |  pin
  |  primitive
  |  function
  |  arithmetic_model
  |  vector
  |  wire

cell_items ::= 
  cell_item {cell_item}
```

### 3.4.9 LIBRARY

```plaintext
library ::= 
  LIBRARY library_identifier { library_items [sublibraries] }
  |  LIBRARY library_identifier ;
  |  library_template_instantiation

libraries ::= 
  library { library }

library_item ::= 
  all_purpose_item
  |  arithmetic_model
  |  cell
  |  primitive
  |  wire

library_items ::= 
  library_item { library_item }
```

### 3.4.10 PIN

```plaintext
pin ::= 
  PIN [ index ] pin_identifier { pin_items }
  |  PIN [ index ] pin_identifier ;
  |  pin_template_instantiation

pins ::= 
  pin { pin }

pin_item ::= 
  all_purpose_item
  |  arithmetic_model
```
pin_items ::= 
   pin_item { pin_item }

3.4.11 PRIMITIVE

primitive ::= 
   PRIMITIVE primitive_identifier { primitive_items }
   | PRIMITIVE primitive_identifier ;
   | primitive_template_instantiation

primitives ::= 
   primitive { primitive }

primitive_item ::= 
   all_purpose_item
   | pin
   | function

primitive_items ::= 
   primitive_item { primitive_item }

3.4.12 SUBLIBRARY

sublibrary ::= 
   SUBLIBRARY library_identifier { library_items }
   | SUBLIBRARY library_identifier ;
   | sublibrary_template_instantiation

sublibraries ::= 
   sublibrary { sublibrary }

3.4.13 VECTOR

vector ::= 
   VECTOR ( vector_expression ) { vector_items }
   | VECTOR ( boolean_expression ) { vector_items }
   | VECTOR ( vector_expression ) ;
   | VECTOR ( boolean_expression ) ;
   | vector_template_instantiation

vector_item ::= 
   all_purpose_item
   | arithmetic_model
   | logic_assignment
   | vector_assignment

vector_items ::= 
   vector_item { vector_item }

vector_assignment ::= 
   context_sensitive_keyword = ( vector_expression )


### 3.4.14 WIRE

wire ::=  
  WIRE wire_identifier { wire_items }  
  | WIRE wire_identifier ;  
  | wire_template.instantiation

wire_item ::=  
  all_purpose_item  
  | arithmetic_model

wire_items ::=  
  wire_item { wire_item }

### 3.4.15 Arithmetic Model

arithmetic_model ::=  
  context_sensitive_keyword [ identifier ]  
  { [ all_purpose_items ] [ header ] body }  
  | context_sensitive_keyword [ identifier ]  
  = value ;  
  | context_sensitive_keyword [ identifier ]  
  = value [ all_purpose_items ]  
  | context_sensitive_keyword [ identifier ]  
  { arithmetic_submodels }  
  | arithmetic_model_template.instantiation

arithmetic_models ::=  
  arithmetic_model { arithmetic_model }

arithmetic_model_container ::=  
  context_sensitive_keyword { arithmetic_models }

arithmetic_submodel ::=  
  context_sensitive_keyword  
  { [ all_purpose_items ] [ header ] body }  
  | context_sensitive_keyword  
  = value ;  
  | context_sensitive_keyword  
  = value [ all_purpose_items ]  
  | context_sensitive_keyword  
  { arithmetic_submodels }  
  | arithmetic_submodel_template.instantiation

arithmetic_submodels ::=  
  arithmetic_submodel { arithmetic_submodel }

header ::=  
  HEADER { [ all_purpose_items ] arithmetic_models }  
  | header_template.instantiation
body ::= 
  table 
  | equation 
  | table equation 

table ::= 
  \textbf{TABLE} \{ table\_items \} 
  | table\_template\_instantiation 

table\_item ::= 
  number 
  | identifier 

table\_items ::= 
  table\_item \{ table\_item \} 

equation ::= 
  \textbf{EQUATION} \{ arithmetic\_expression \} 
  | equation\_template\_instantiation 


\section{3.4.16 \textbf{FUNCTION}}

function ::= 
  \textbf{FUNCTION} [ identifier ] 
  \{ [all\_purpose\_items] [primitives] behavior \} 
  | \{ [all\_purpose\_items] [primitives] [behavior] statetables \} 
  | function\_template\_instantiation 

statetable ::= 
  \textbf{STATETABLE} [ identifier ] \{ statetable\_header statetable\_body \} 

statetables ::= 
  statetable \{ statetable \} 

statetable\_body ::= 
  statetable\_values : statetable\_values 
  \{ statetable\_values : statetable\_values \} 

statetable\_header ::= 
  logic\_variables : logic\_variables ; 

behavior ::= 
  \textbf{BEHAVIOR} [ identifier ] \{ behavior\_items \} 

behavior\_item ::= 
  logic\_assignment 
  | sequential\_logic\_statement 
  | primitive\_instantiation 

behavior\_items ::= 
  behavior\_item \{ behavior\_item \}
logic_assignment ::= 
    identifier [index] = boolean_expression ;

logic_assignments ::= 
    logic_assignment { logic_assignment }

sequential_logic_statement ::= 
    vector_if_operator ( vector_expression | boolean_expression )
    { logic_assignments } { vector_elsif_operator ( vector_expression | boolean_expression )
    { logic_assignments } }

3.4.17 Cross-reference of BNF items

Note: A BNF item with singular name is defined in the same section as the BNF item with the plural name. A plural item name implies one or more items with the corresponding singular name.

<table>
<thead>
<tr>
<th>BNF item</th>
<th>Section</th>
<th>Short semantic explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>alias</td>
<td>3.4.7</td>
<td>statement defining an alias</td>
</tr>
<tr>
<td>all_purpose_item(s)</td>
<td>3.4.6</td>
<td>item(s) that can appear inside any hierarchical object</td>
</tr>
<tr>
<td>annotation</td>
<td>3.4.6</td>
<td>parameter-value assignment inside an object, may be nested</td>
</tr>
<tr>
<td>annotation_container</td>
<td>3.4.6</td>
<td>unnamed object containing annotations</td>
</tr>
<tr>
<td>arithmetic_assignment</td>
<td>3.4.1</td>
<td>statement assigning an arithmetic expression to a variable</td>
</tr>
<tr>
<td>arithmetic_binary_operator</td>
<td>3.4.5</td>
<td>arithmetic operator requiring two operands</td>
</tr>
<tr>
<td>arithmetic_expression</td>
<td>3.4.2</td>
<td>expression involving arithmetic operations</td>
</tr>
<tr>
<td>arithmetic_function_operator</td>
<td>3.4.5</td>
<td>arithmetic operator prefixing a list of arguments</td>
</tr>
<tr>
<td>arithmetic_model(s)</td>
<td>3.4.15</td>
<td>statement(s) for description of characterization data using single numbers, tables or equations</td>
</tr>
<tr>
<td>arithmetic_model_container</td>
<td>3.4.15</td>
<td>unnamed object containing arithmetic models</td>
</tr>
<tr>
<td>arithmetic_submodel(s)</td>
<td>3.4.15</td>
<td>statement(s) inside an arithmetic model statement for categorizing the characterization data</td>
</tr>
<tr>
<td>arithmetic_unary_operator</td>
<td>3.4.5</td>
<td>arithmetic operator requiring one operand</td>
</tr>
<tr>
<td>assignment</td>
<td>3.4.1</td>
<td>terminated statement for single value assignment to an object</td>
</tr>
<tr>
<td>assignment_base</td>
<td>3.4.1</td>
<td>unterminated statement for single value assignment to an object</td>
</tr>
<tr>
<td>attribute</td>
<td>3.4.7</td>
<td>statement associating attributes to an object</td>
</tr>
<tr>
<td>attribute_item(s)</td>
<td>3.4.7</td>
<td>item(s) inside an attribute statement</td>
</tr>
<tr>
<td>behavior</td>
<td>3.4.16</td>
<td>statement describing the logic function of a digital circuit in a behavioral language</td>
</tr>
<tr>
<td>behavior_item(s)</td>
<td>3.4.16</td>
<td>item(s) inside a behavior statement</td>
</tr>
</tbody>
</table>
### Table 3-4: Cross-reference of BNF items with short semantic explanation

<table>
<thead>
<tr>
<th>BNF item</th>
<th>Section</th>
<th>Short semantic explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>body</td>
<td>3.4.15</td>
<td>table or equation defining characterization data for an arithmetic model</td>
</tr>
<tr>
<td>boolean_and_operator</td>
<td>3.4.5</td>
<td>boolean AND operator</td>
</tr>
<tr>
<td>boolean_arithmetic_operator</td>
<td>3.4.5</td>
<td>operator for boolean arithmetic</td>
</tr>
<tr>
<td>boolean_binary_operator</td>
<td>3.4.5</td>
<td>boolean operator requiring two operands</td>
</tr>
<tr>
<td>boolean_case_compare_operator</td>
<td>3.4.5</td>
<td>binary boolean operator for magnitude comparison</td>
</tr>
<tr>
<td>boolean_condition_operator</td>
<td>3.4.5</td>
<td>boolean postfix operator evaluating the preceeding boolean expression (if-clause)</td>
</tr>
<tr>
<td>boolean_else_operator</td>
<td>3.4.5</td>
<td>boolean infix operator separating if-and else-clauses</td>
</tr>
<tr>
<td>boolean_expression</td>
<td>3.4.5</td>
<td>expression involving boolean operations</td>
</tr>
<tr>
<td>boolean_logic_compare_operator</td>
<td>3.4.5</td>
<td>binary boolean operator for logic comparison</td>
</tr>
<tr>
<td>boolean_or_operator</td>
<td>3.4.5</td>
<td>boolean OR operator</td>
</tr>
<tr>
<td>boolean_unary_operator</td>
<td>3.4.5</td>
<td>boolean operator requiring one operand</td>
</tr>
<tr>
<td>cell(s)</td>
<td>3.4.8</td>
<td>statement(s) describing the entire model of a digital or analog circuit</td>
</tr>
<tr>
<td>cell_item(s)</td>
<td>3.4.8</td>
<td>item(s) inside a cell statement</td>
</tr>
<tr>
<td>cell_instantiation</td>
<td>3.4.3</td>
<td>statement inside a cell, describing a reference to another cell with pin-to-pin correspondence</td>
</tr>
<tr>
<td>class</td>
<td>3.4.7</td>
<td>statement describing a class for the use of reference and inheritance by other objects</td>
</tr>
<tr>
<td>class_item(s)</td>
<td>3.4.6</td>
<td>item(s) inside a class statement, which will be inherited by any object refering to the class</td>
</tr>
<tr>
<td>constant</td>
<td>3.4.7</td>
<td>statement defining a numeric constant</td>
</tr>
<tr>
<td>context_sensitive_keyword</td>
<td>3.4.4</td>
<td>identifier of an object for which the semantic meaning is established by its context</td>
</tr>
<tr>
<td>dynamic_instantiation_item(s)</td>
<td>3.4.3</td>
<td>item(s) inside a dynamic instantiation of a template</td>
</tr>
<tr>
<td>edge_literal(s)</td>
<td>3.4.4</td>
<td>symbol(s) describing a transition between two states</td>
</tr>
<tr>
<td>equation</td>
<td>3.4.15</td>
<td>statement inside arithmetic model containing an arithmetic expression for the calculation of characterization data</td>
</tr>
<tr>
<td>function</td>
<td>3.4.16</td>
<td>statement describing the logic function of a circuit in a canonical way, using behavior and/or statetable statement</td>
</tr>
<tr>
<td>generic_object</td>
<td>3.4.6</td>
<td>statement with the sole purpose of being used by other objects</td>
</tr>
<tr>
<td>group</td>
<td>3.4.7</td>
<td>statement allowing expansion of one object to multiple objects</td>
</tr>
<tr>
<td>header</td>
<td>3.4.15</td>
<td>statement inside arithmetic model containing a list of parameters of the arithmetic model</td>
</tr>
<tr>
<td>identifier(s)</td>
<td>3.4.4</td>
<td>literal(s) defining a keyword or a name or a string value</td>
</tr>
<tr>
<td>include</td>
<td>3.4.7</td>
<td>statement defining the inclusion of a file</td>
</tr>
<tr>
<td>BNF item</td>
<td>Section</td>
<td>Short semantic explanation</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>index</td>
<td>3.4.4</td>
<td>symbol defining an integer or a range of integers for the use as indices</td>
</tr>
<tr>
<td>library (libraries)</td>
<td>3.4.9</td>
<td>statement(s) describing the entire contents of a library</td>
</tr>
<tr>
<td>library_item(s)</td>
<td>3.4.9</td>
<td>item(s) inside a library statement</td>
</tr>
<tr>
<td>library_specific_object</td>
<td>3.4.6</td>
<td>statement describing an object which is part of the library</td>
</tr>
<tr>
<td>logic_assignment(s)</td>
<td>3.4.1</td>
<td>statement(s) assigning a logic expression to a logic variable</td>
</tr>
<tr>
<td>logic_value(s)</td>
<td>3.4.4</td>
<td>variable(s) or constant logic value(s)</td>
</tr>
<tr>
<td>logic_constant(s)</td>
<td>3.4.4</td>
<td>constant logic value(s)</td>
</tr>
<tr>
<td>logic_variable(s)</td>
<td>3.4.4</td>
<td>variable(s) containing a logic value</td>
</tr>
<tr>
<td>multi_value_assignment</td>
<td>3.4.1</td>
<td>statement for assignment of multiple values to an object</td>
</tr>
<tr>
<td>named_assignment</td>
<td>3.4.1</td>
<td>terminated statement for single value assignment to a named object</td>
</tr>
<tr>
<td>named_assignment_base</td>
<td>3.4.1</td>
<td>unterminated statement for single value assignment to a named object</td>
</tr>
<tr>
<td>number(s)</td>
<td>3.4.4</td>
<td>integer or floating point number(s)</td>
</tr>
<tr>
<td>pin(s)</td>
<td>3.4.10</td>
<td>statement(s) describing a pin inside a cell</td>
</tr>
<tr>
<td>pin_item(s)</td>
<td>3.4.10</td>
<td>item(s) inside a pin statement</td>
</tr>
<tr>
<td>pin_assignment(s)</td>
<td>3.4.1</td>
<td>statement(s) defining a correspondence between two pins or between a pin and a constant logic value</td>
</tr>
<tr>
<td>primitive(s)</td>
<td>3.4.11</td>
<td>statement(s) describing a technology-independent cell</td>
</tr>
<tr>
<td>primitive_instantiation</td>
<td>3.4.3</td>
<td>statement inside a behavior statement for logic function description by reference to a primitive</td>
</tr>
<tr>
<td>primitive_item(s)</td>
<td>3.4.11</td>
<td>item(s) inside a primitive statement</td>
</tr>
<tr>
<td>property</td>
<td>3.4.7</td>
<td>statement describing private properties without standardized semantics</td>
</tr>
<tr>
<td>sequential_logic_statement</td>
<td>3.4.1</td>
<td>statement inside a behavior statement for logic function description with storage elements</td>
</tr>
<tr>
<td>source_text</td>
<td>3.4.6</td>
<td>contents of a self-sufficient file in ALF</td>
</tr>
<tr>
<td>statetable(s)</td>
<td>3.4.16</td>
<td>statement(s) describing the logic function of a digital circuit in table format</td>
</tr>
<tr>
<td>statetable_body</td>
<td>3.4.16</td>
<td>list of values inside a statetable</td>
</tr>
<tr>
<td>statetable_header</td>
<td>3.4.16</td>
<td>list of variables inside a statetable</td>
</tr>
<tr>
<td>statetable_value(s)</td>
<td>3.4.4</td>
<td>literal(s) inside a statetable</td>
</tr>
<tr>
<td>string</td>
<td>3.4.4</td>
<td>identifier consisting of a restricted set of characters or quoted string containing arbitrary characters</td>
</tr>
<tr>
<td>sublibrary (sublibraries)</td>
<td>3.4.12</td>
<td>statement(s) describing the contents of a sub-library inside a library</td>
</tr>
<tr>
<td>table</td>
<td>3.4.15</td>
<td>statement inside arithmetic model containing a list of characterization data</td>
</tr>
<tr>
<td>table_item(s)</td>
<td>3.4.15</td>
<td>item(s) inside a table statement</td>
</tr>
</tbody>
</table>
Table 3-4: Cross-reference of BNF items with short semantic explanation

<table>
<thead>
<tr>
<th>BNF item</th>
<th>Section</th>
<th>Short semantic explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>template</td>
<td>3.4.7</td>
<td>statement defining an object with placeholders</td>
</tr>
<tr>
<td>template_instantiation</td>
<td>3.4.3</td>
<td>statement referring to a template and filling the placeholders</td>
</tr>
<tr>
<td>template_item(s)</td>
<td>3.4.7</td>
<td>statement(s) inside a template statement</td>
</tr>
<tr>
<td>unnamed_assignment(s)</td>
<td>3.4.1</td>
<td>terminated statement(s) for single value assignment to an unnamed object</td>
</tr>
<tr>
<td>unnamed_assignment_base</td>
<td>3.4.1</td>
<td>unterminated statement for single value assignment to an unnamed object</td>
</tr>
<tr>
<td>value(s)</td>
<td>3.4.4</td>
<td>number(s) or string(s) or logic value(s)</td>
</tr>
<tr>
<td>vector(s)</td>
<td>3.4.13</td>
<td>statement(s) describing event sequence and data for characterisation of a circuit</td>
</tr>
<tr>
<td>vector_binary_operator</td>
<td>3.4.5</td>
<td>operator used for description of an event sequence requiring two operands</td>
</tr>
<tr>
<td>vector_expression</td>
<td>3.4.2</td>
<td>expression describing an event sequence</td>
</tr>
<tr>
<td>vector_elsif_operator</td>
<td>3.4.5</td>
<td>operator indicating a lower-priority logic state or event sequence</td>
</tr>
<tr>
<td>vector_if_operator</td>
<td>3.4.5</td>
<td>operator indicating a top-priority logic state or event sequence</td>
</tr>
<tr>
<td>vector_item(s)</td>
<td>3.4.13</td>
<td>item(s) inside a vector statement</td>
</tr>
<tr>
<td>vector_unary_operator</td>
<td>3.4.5</td>
<td>operator used for description of an event sequence requiring one operand</td>
</tr>
<tr>
<td>wire(s)</td>
<td>3.4.14</td>
<td>statement(s) describing a wireload model</td>
</tr>
<tr>
<td>wire_item(s)</td>
<td>3.4.14</td>
<td>item(s) inside wire statement</td>
</tr>
</tbody>
</table>

3.5 Operators

The operators are divided into four groups:

- Arithmetic operators
- Boolean operators on scalars, i.e. single bits
- Boolean operators on words, i.e. arrays of bits
- Vector operators
3.5.1 Arithmetic operators

Table 3-5, Table 3-6, and Table 3-7 list unary, binary and function arithmetic operators.

Table 3-5 : Unary arithmetic operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>positive sign (for integer or number)</td>
</tr>
<tr>
<td>-</td>
<td>negative sign (for integer or number)</td>
</tr>
</tbody>
</table>

Table 3-6 : Binary arithmetic operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>addition (integer or number)</td>
</tr>
<tr>
<td>-</td>
<td>subtraction (integer or number)</td>
</tr>
<tr>
<td>*</td>
<td>multiplication (integer or number)</td>
</tr>
<tr>
<td>/</td>
<td>division (integer or number)</td>
</tr>
<tr>
<td>**</td>
<td>exponentiation (integer or number)</td>
</tr>
<tr>
<td>%</td>
<td>modulo division (integer or number)</td>
</tr>
</tbody>
</table>

Table 3-7 : Function arithmetic operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOG</td>
<td>natural logarithm (argument is + integer or number)</td>
</tr>
<tr>
<td>EXP</td>
<td>natural exponential (argument is integer or number)</td>
</tr>
<tr>
<td>ABS</td>
<td>absolute value (argument is integer or number)</td>
</tr>
<tr>
<td>MIN</td>
<td>minimum (all arguments are integer or number)</td>
</tr>
<tr>
<td>MAX</td>
<td>maximum (all arguments are integer or number)</td>
</tr>
</tbody>
</table>

Function operators with one argument (such as \( \text{log}, \text{exp} \) and \( \text{abs} \)) or multiple arguments (such as \( \text{min} \) and \( \text{max} \)) must have the arguments within parenthesis, e.g. \( \text{min}(1.2, -4.3, 0.8) \).

3.5.2 Boolean operators on scalars

Table 3-8, Table 3-9 and Table 3-10 list unary, binary and ternary boolean operators on scalars.

Table 3-8 : Unary boolean operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>!, ~</td>
<td>logical inversion</td>
</tr>
</tbody>
</table>
Combinational if-then-else clauses are constructed as follows:

\[
<\text{cond1}> ? <\text{value1}> : <\text{cond2}> ? <\text{value2}> : <\text{cond3}> ? <\text{value3}> : <\text{default_value}>
\]

If \text{cond1} evaluates to boolean \text{TRUE} then \text{value1} is the result, else if \text{cond2} evaluates to boolean \text{TRUE} then \text{value2} is the result, else if \text{cond3} evaluates to boolean \text{TRUE} then \text{value3} is the result, else \text{default_value} is the result of this clause.

### Table 3-9: Binary boolean operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;&amp;, &amp;</td>
<td>logical AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>logic equivalence (XNOR)</td>
</tr>
<tr>
<td>^</td>
<td>logic antivalence (XOR)</td>
</tr>
</tbody>
</table>

### Table 3-10: Ternary operator

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>boolean condition operator for construction of combinational if-then-else clause</td>
</tr>
<tr>
<td>:</td>
<td>boolean else operator for construction of combinational if-then-else clause</td>
</tr>
</tbody>
</table>

### Table 3-11: Unary reduction operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>AND all bits</td>
</tr>
<tr>
<td>~&amp;</td>
<td>NAND all bits</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>~</td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>XOR all bits</td>
</tr>
<tr>
<td>^</td>
<td>XNOR all bits</td>
</tr>
</tbody>
</table>

### Table 3-12: Binary reduction operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>equality for case comparison</td>
</tr>
<tr>
<td>!=</td>
<td>non-equality for case comparison</td>
</tr>
<tr>
<td>&gt;</td>
<td>greater</td>
</tr>
<tr>
<td>&lt;</td>
<td>smaller</td>
</tr>
</tbody>
</table>
The arithmetic operations addition, subtraction, multiplication, and division shall be \textit{unsigned} if all the operands have the datatype \textit{unsigned}. If any of the operands have the datatype signed, the operation shall be \textit{signed}. See Table 3.6.3.13 for DATATYPE definition.

### 3.5.4 Vector operators

A transition operation is defined using unary operators on a scalar net. The scalar constants (see figure 3-13) shall be used to indicate the start and end states of a transition on a scalar net.
bit bit // apply transition from bit value to bit value

For example,

01 is a transition from 0 to 1.

No whitespace shall be allowed between the two scalar constants. The transition operators shown in Table 3-16 shall be considered legal:

Table 3-16 : Unary vector operators on bits

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>signal toggles from 0 to 1</td>
</tr>
<tr>
<td>10</td>
<td>signal toggles from 1 to 0</td>
</tr>
<tr>
<td>00</td>
<td>signal remains 0</td>
</tr>
<tr>
<td>11</td>
<td>signal remains 1</td>
</tr>
<tr>
<td>0?</td>
<td>signal remains 0 or toggles from 0 to arbitrary value</td>
</tr>
<tr>
<td>1?</td>
<td>signal remains 1 or toggles from 1 to arbitrary value</td>
</tr>
<tr>
<td>?0</td>
<td>signal remains 0 or toggles from arbitrary value to 0</td>
</tr>
<tr>
<td>?1</td>
<td>signal remains 1 or toggles from arbitrary value to 1</td>
</tr>
<tr>
<td>??</td>
<td>signal remains constant or toggles between arbitrary values</td>
</tr>
<tr>
<td>0*</td>
<td>a number of arbitrary signal transitions, including possibility of constant value, with the initial value 0</td>
</tr>
<tr>
<td>1*</td>
<td>a number of arbitrary signal transitions, including possibility of constant value, with the initial value 1</td>
</tr>
<tr>
<td>?*</td>
<td>a number of arbitrary signal transitions, including possibility of constant value, with arbitrary initial value</td>
</tr>
<tr>
<td>*0</td>
<td>a number of arbitrary signal transitions, including possibility of constant value, with the final value 0</td>
</tr>
<tr>
<td>*1</td>
<td>a number of arbitrary signal transitions, including possibility of constant value, with the final value 1</td>
</tr>
<tr>
<td>*?</td>
<td>a number of arbitrary signal transitions, including possibility of constant value, with arbitrary final value</td>
</tr>
</tbody>
</table>

Unary operators for transitions can also appear in `STATETABLE`.

Transition operators are also defined on words (can appear in `STATETABLE` as well):

'base word 'base word

In this context, the transition operator shall apply transition from first word value to second word value.

For example,

'hA'h5 is a transition of a 4-bit signal from 'b1010 to 'b0101.

No whitespace shall be allowed between `base` and `word`. 
The unary and binary operators for transition, listed in Table 3-17 and Table 3-18 respectively, are defined on bits and words:

**Table 3-17 : Unary vector operators on bits or words**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>?–</td>
<td>no transition occurs</td>
</tr>
<tr>
<td>??</td>
<td>apply arbitrary transition, including possibility of constant value</td>
</tr>
<tr>
<td>?!</td>
<td>apply arbitrary transition, excluding possibility of constant value</td>
</tr>
<tr>
<td>?~</td>
<td>apply arbitrary transition with all bits toggling</td>
</tr>
</tbody>
</table>

The following canonical binary operators are necessary to define sequences of transitions:

- sequential event AND for completely specified sequence of events
- simultaneous event AND
- alternative event OR
- sequential event AND for incompletely specified sequence of events

The symbols for the boolean operators for AND, OR, are overloaded for simultaneous event AND, alternative event OR, respectively. New symbols are introduced for the followed-by operators.

**Table 3-18 : Canonical Binary vector operators**

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operands</th>
<th>LHS, RHS commutative</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>-&gt;</code></td>
<td>2 vector expressions</td>
<td>no</td>
<td>Left-hand side (LHS) transition is followed by Right-hand side (RHS) transition, no other transition may occur in-between</td>
</tr>
<tr>
<td><code>&amp;&amp;</code> or <code>&amp;</code></td>
<td>2 vector expressions</td>
<td>yes</td>
<td>LHS and RHS transition occur simultaneously</td>
</tr>
<tr>
<td>`</td>
<td></td>
<td><code>or</code></td>
<td>`</td>
</tr>
<tr>
<td><code>-&gt;</code></td>
<td>2 vector expressions</td>
<td>no</td>
<td>Left-hand side (LHS) transition is followed by Right-hand side (RHS) transition, other transitions may occur in-between</td>
</tr>
</tbody>
</table>

Per definition, the `->`, `~>` operators shall not be commutative, whereas the `&&`, `||` operators on events shall be commutative.

```
01 a && 01 b === 01 b && 01 a
01 a || 01 b === 01 b || 01 a
```

The `||` operator allows also to reduce the set of edge operators (unary vector operators) to canonical and non-canonical operators.

```
(?? a)           === (?! a) || (?~ a)   //a does or does not change its value
```
Hence `??` is non-canonical, since it can be defined by other operators.

If `<value1><value2>` is an edge operator consisting of two based literals `value1` and `value2` and `word` is an expression which can take the value `value1` or `value2`, then the following vector expressions are considered equivalent:

```
<value1><value2> <word>
```

```plaintext
=== 10 (<word> == <value1>) && 01 (<word> == <value2>)
=== 01 (<word> != <value1>) && 01 (<word> == <value2>)
=== 10 (<word> == <value1>) && 10 (<word> != <value2>)
=== 01 (<word> != <value1>) && 10 (<word> != <value2>)
```

// all expressions describe the same event:
// <word> makes a transition from <value1> to <value2>

Hence vector expressions with edge operators using based literals can be reduced to vector expressions using only the edge operators `01, 10`.

Complex binary vector operators are also defined. Vector expressions using those operators can be decomposed into vector expressions using only canonical operators.

### Table 3-19: Complex Binary vector operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operands</th>
<th>LHS, RHS commutative</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;-&gt;</td>
<td>2 vector expressions</td>
<td>yes</td>
<td>LHS transition follows or is followed by RHS transition</td>
</tr>
<tr>
<td>&amp;&gt;</td>
<td>2 vector expressions</td>
<td>yes</td>
<td>LHS transition is followed by or occurs simultaneously with RHS transition</td>
</tr>
<tr>
<td>&lt;&amp;&gt;</td>
<td>2 vector expressions</td>
<td>yes</td>
<td>LHS transition follows or is followed by or occurs simultaneously with RHS transition</td>
</tr>
<tr>
<td>&amp;&amp; or &amp;</td>
<td>1 vector expression, 1 boolean expression</td>
<td>yes</td>
<td>boolean expression (LHS or RHS) is true while sequence of transitions, defined by vector expression (RHS or LHS) occurs</td>
</tr>
</tbody>
</table>

The following expressions shall be considered equivalent:

```
(01 a <-> 01 b) === (01 a -> 01 b) || (01 b -> 01 a)
(01 a &> 01 b) === (01 a -> 01 b) || (01 a && 01 b)
(01 a <&> 01 b) === (01 a -> 01 b) || (01 b -> 01 a) || (01 a && 01 b)
```

By their symmetric definition, the `<->`, `<&>` operators are commutative.

```
01 a <-> 01 b === 01 b <-> 01 a
01 a <&> 01 b === 01 b <&> 01 a
```

The definition of the `&&` operator is also overloaded to describe a `conditional vector expression` (conditional event AND), involving a boolean expression and a vector expression.

Example:

```
(01 a && !b)  // a rises while b==0
```
The order of the operands in a conditional vector expression shall not matter.

\[
<vector_expr> \&\& <boolean_expr> === <boolean_expr> \&\& <vector_expr>
\]

The \&\& operator is still commutative in this case, although one operand is a boolean expression defining a static state, the other operand is a vector expression defining an event or a sequence of events. However, since the operands are distinguishable per se, it is not necessary to impose a particular order of the operands.

A conditional vector expression can be reduced to a canonical vector expression in the following way:

\[
<vector_expr> \&\& <boolean_expr>
=== *1 <boolean_expr> -> <vector_expr> -> 1* <boolean_expr>
\]

Every binary vector operator may be applied to a conditional vector expression.

### 3.5.5 Operators for sequential logic

#### Table 3-20 : Operators for sequential logic

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>@</td>
<td>vector if operator, followed by a boolean logic expression (for level-sensitive assignment) or by a vector expression (for edge-sensitive assignment)</td>
</tr>
<tr>
<td>:</td>
<td>vector elsif operator, followed by a boolean logic expression (for level-sensitive assignment) or by a vector expression (for edge-sensitive assignment) with lower priority</td>
</tr>
</tbody>
</table>

Sequential assignments are constructed as follows:

```plaintext
@ ( <trigger1> ) { <action1> } : ( <trigger2> ) { <action2> } : ( <trigger3> ) { <action3> } 
```

If `trigger1` event is detected then `action1` is performed, else if `trigger2` event is detected then `action2` is performed, else if `trigger3` event is detected then `action3` is performed as a result of this clause.

### 3.5.6 Operator priorities

The priority of binding operators to operands shall be from strongest to weakest in the following order:

1. unary vector operators (edge literals)
2. binary vector operators (->, <<- ,&>, <&>, ~>)
3. unary arithmetic operator (+, -) and unary boolean operator (!, ~, & , ~& , |, ~|, ^, ~^)
4. XNOR (~^), XOR (^), relational (> , <, >=, <= , == , != ), exponentiation (**), shift (<<, >>)
5. AND ( &, &&), NAND (~&), multiplication (*), division (/), modulo division (%)

6. OR ( |, ||), NOR (~ |), addition (+), subtraction (-)

The priority applies also to the overloaded boolean operators in vector expressions.

Operators with equal priority are evaluated strictly in order of occurrence from left to right. The parenthesis () shall be used for changing the priority of binding operators to operands.

### 3.5.7 Datatype mapping

Logical operations can be applied to scalars and words. For that purpose, the values of the operands are reduced to a system of 3 logic values in the following way:

- **H** has the logic value 1
- **L** has the logic value 0
- **W, Z, U** have the logic value X

A word has the logic value 1, if the unary OR reduction of all bits results in 1.
A word has the logic value 0, if the unary OR reduction of all bits results in 0.
A word has the logic value X, if the unary OR reduction of all bits results in X.

Case comparison operations can also be applied to scalars and words. For scalars, they are defined in the following way:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>A==B</th>
<th>A!=B</th>
<th>A&gt;B</th>
<th>A&lt;B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>L</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>W, U, Z, X</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>W, U, Z, X</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>L</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>0</td>
<td>W, U, Z, X</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>L</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L</td>
<td>W, U, Z, X</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
</tbody>
</table>

**Table 3-21: Case comparison operators**
For word operands, the operations > and < are performed after reducing all bits to the 3-value system first, and then interpreting the resulting number according to the datatype of the operands. For example, if datatype is signed, 'b1111 is smaller than 'b0000; if datatype is unsigned, 'b1111 is greater than 'b0000. If two operands have the same value 'b1111 and a different datatype, the unsigned 'b1111 is greater than the signed 'b1111.

The operations >= and <= are defined in the following way:

\[
(a \geq b) === (a > b) \quad \text{||} \quad (a == b)
\]
\[
(a \leq b) === (a < b) \quad \text{||} \quad (a == b)
\]

### 3.6 Context-sensitive keywords

The context-sensitive keywords permit legal extensions to ALF syntax. An ALF parser shall either accept or ignore when an unknown keyword or annotation is encountered. The purpose of context-sensitive keywords is to have a vocabulary of keywords with already well-defined semantic meaning. That means, an ALF compiler for an application must understand those keywords needed (used) by the application. For example, a compiler that needs SLEWRATE must understand the keyword SLEWRATE and not expect a keyword RAMPTIME.

#### 3.6.1 Containers for Annotations and Arithmetic Models

Any object with children objects may contain annotations. In addition, the following objects are defined only for the purpose of unnamed annotation containers.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCAN</td>
<td>contains information relevant to design for test</td>
</tr>
<tr>
<td>FROM</td>
<td>contains start point of timing measurement or timing constraint</td>
</tr>
</tbody>
</table>
3.6.1.1 Scan container
A SCAN container may be used inside a CELL or a PIN object and may contain annotations which are allowed inside a CELL (Section 3.6.5) or a PIN object (Section 3.6.3) for limiting the scope of those annotations.

Example:

```
PIN clk1 { signaltype = master_clock; SCAN {signaltype = slave_clock;} }
PIN clk2 { SCAN {signaltype = master_clock;} }
```

In normal mode, `clk1` is master clock, `clk2` is unused. In scan mode, `clk2` is master clock, `clk1` is slave clock.

3.6.1.2 FROM and TO container
A FROM container and a TO container may be used inside a DELAY or SLEWRATE object (Section 3.6.7.5). It may contain a PIN annotation (Section 3.6.3) and/or a THRESHOLD annotation (Section 3.6.7.5) or a THRESHOLD annotation container. The THRESHOLD annotation container may contain RISE and/or FALL annotations (Section 3.6.7.5).

Example:

```
DELAY {
  FROM {PIN = data_in;  THRESHOLD { RISE = 0.4; FALL = 0.6;} }
  TO   {PIN = data_out; THRESHOLD = 0.5;}
}
```

The delay is measured from pin `data_in` to pin `data_out`. The threshold for `data_in` is 0.4 for rising signal and 0.6 for falling signal. The threshold for `data_out` is 0.5.

3.6.1.3 LIMIT container
A LIMIT container may be used inside a library-specific object (Section 3.4.6). It may contain annotation containers defined by keywords for arithmetic models (Section 3.6.7.5). Those annotation containers must contain arithmetic models identified by MIN and/or MAX (Section 3.6.7.6)

---

### Table 3-22: Unnamed annotation containers

<table>
<thead>
<tr>
<th>Objects</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TO</td>
<td>contains end point of measurement or timing constraint</td>
</tr>
<tr>
<td>LIMIT</td>
<td>contains arithmetic models for limit values</td>
</tr>
<tr>
<td>EARLY</td>
<td>contains arithmetic models for timing measurements relevant for early signal arrival time</td>
</tr>
<tr>
<td>LATE</td>
<td>contains arithmetic models for timing measurements relevant for late signal arrival time</td>
</tr>
<tr>
<td>VIOLATION</td>
<td>contains items relevant to timing violations</td>
</tr>
<tr>
<td>INFORMATION</td>
<td>contains purely informational items</td>
</tr>
</tbody>
</table>
Example:

```
PIN data_in {
  LIMIT {
    SLEWRATE { UNIT = ns; MIN = 0.05; MAX = 5.0;}
  }
}
```

The minimum slewrate allowed at pin `data_in` is 0.05 ns, the maximum is 5.0 ns.

```
PIN data_in {
  LIMIT {
    SLEWRATE {
      UNIT = ns;
      MAX {
        HEADER { FREQUENCY { UNIT=megahz;} }
        EQUATION { 250 / FREQUENCY }
      }
    }
  }
}
```

The maximum allowed slewrate is frequency-dependent, e.g. the value is 0.25ns for 1GHz.

### 3.6.1.4 EARLY and LATE container

The EARLY and LATE containers define the boundaries of timing measurements in one single analysis. Only applicable to DELAY and SLEWRATE. Both of them must appear in both containers.

The quadruple

```
EARLY {
  DELAY { FROM {...} TO { ...} /* data */ }
  SLEWRATE { /* data */ }
LATE {
  DELAY { FROM {...} TO { ...} /* data */ }
  SLEWRATE { /* data */ }
}
```

is used to calculate the envelope of the timing waveform at the TO point of a delay arc with respect to the timing waveform at the FROM point of a delay arc.

The EARLY DELAY is of course a smaller number (or a set of smaller numbers) than the LATE DELAY. However, the EARLY SLEWRATE is not necessarily smaller than the LATE SLEWRATE, since the SLEWRATE of the EARLY signal may be larger than the SLEWRATE of the LATE signal.

### 3.6.1.5 VIOLATION container

A VIOLATION container may be inside a SETUP, HOLD, RECOVERY, REMOVAL, PULSEWIDTH, PERIOD, or NOCHANGE object. It may contain the BEHAVIOR object.
(Section 3.4.16), since the behavior in case of timing constraint violation cannot be described in the FUNCTION. It may also contain the following annotations:

### Table 3-23: Violation annotation container

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MESSAGE_TYPE</td>
<td>string</td>
<td>specifies the type of the message. It can be one of information, warning, error.</td>
</tr>
<tr>
<td>MESSAGE</td>
<td>string</td>
<td>specifies the message itself.</td>
</tr>
</tbody>
</table>

Example:

```alp
VECTOR (01 d <&> 01 cp) {
    SETUP {
        VIOLATION {
            MESSAGE_TYPE = error;
            MESSAGE = "setup violation 01 d <&> 01 cp";
            BEHAVIOR {q = 'bx;}
        }
    }
}
```

### 3.6.1.6 INFORMATION container

An INFORMATION container may be inside a LIBRARY, SUBLIBRARY, CELL, or WIRE object. It may also be in PRIMITIVE objects inside a LIBRARY or SUBLIBRARY, but not in the locally defined primitives inside cells or functions. It may contain the following annotations:

### Table 3-24: Information annotation container

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERSION</td>
<td>string</td>
<td>version of the object containing this INFORMATION block</td>
<td>“v1r3_2”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“1.3.2”</td>
</tr>
<tr>
<td>TITLE</td>
<td>string</td>
<td>title or comment related this object</td>
<td>“0.2u StdCell Library”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“2-input NAND, 4x drive”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“3-layer metal, best case, wireload model”</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>string</td>
<td>product related to the object</td>
<td>“vsc1083”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“vsm10rs111”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“0.2u technology family”</td>
</tr>
<tr>
<td>AUTHOR</td>
<td>string</td>
<td>originator or modifier of the object</td>
<td>“<a href="mailto:user@system.com">user@system.com</a>”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Imn N. Gineer”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“An ASIC Vendor, Inc.”</td>
</tr>
<tr>
<td>DATETIME</td>
<td>string</td>
<td>date/time stamp related to the object</td>
<td>“Wed Aug 19 08:13:01 MST 1998”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“July 4, 1998”</td>
</tr>
</tbody>
</table>
Example:

LIBRARY major_ASIC_vendor {
  INFORMATION {
    version = "v2.1.0";
    title = "0.35 standard cell";
    product = p35sc;
    author = "Major Asic Vendor, Inc.";
    datetime = "Wed Jul 23 13:50:12 MST 1997";
  }
}

3.6.2 Keywords for referencing objects used as annotation

The following object references may be used as annotations:

Table 3-25: Object references as annotation

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELL</td>
<td>string</td>
<td>reference to a declared CELL object</td>
</tr>
<tr>
<td>PRIMITIVE</td>
<td>string</td>
<td>reference to a declared PRIMITIVE object</td>
</tr>
<tr>
<td>PIN</td>
<td>string</td>
<td>reference to a declared PIN object</td>
</tr>
<tr>
<td>CLASS</td>
<td>string</td>
<td>reference to a declared CLASS object</td>
</tr>
</tbody>
</table>

The syntax is as follows:

object_keyword = string ;

3.6.3 Annotations for a PIN object

A PIN object may contain the following annotations:

3.6.3.1 VIEW annotation

VIEW = string ;

annotates the view where the pin appears, which can take the following values:

Table 3-26: VIEW annotations for a PIN object

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>functional</td>
<td>pin appears in functional netlist</td>
</tr>
<tr>
<td>physical</td>
<td>pin appears in physical netlist</td>
</tr>
<tr>
<td>both (default)</td>
<td>pin appears in both functional and physical netlist</td>
</tr>
<tr>
<td>none</td>
<td>pin does not appear in netlist</td>
</tr>
</tbody>
</table>

3.6.3.2 PINTYPE annotation

PINTYPE = string ;
context-sensitive keywords

Library Format Specification

annotes the type of the pin, which can take the following values:

### Table 3-27: PINTYPE annotations for a PIN object

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>digital (default)</td>
<td>digital signal pin</td>
</tr>
<tr>
<td>analog</td>
<td>analog signal pin</td>
</tr>
<tr>
<td>supply</td>
<td>power supply or ground pin</td>
</tr>
</tbody>
</table>

#### 3.6.3.3 SIGNALTYPE annotation

SIGNALTYPE = string;

annotes the type of the signal connected to the pin, which can take the following values:

### Table 3-28: SIGNALTYPE annotations for a PIN object

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>data (default)</td>
<td>general data signal</td>
</tr>
<tr>
<td>scan_data</td>
<td>scan data signal</td>
</tr>
<tr>
<td>control</td>
<td>general control signal</td>
</tr>
<tr>
<td>select</td>
<td>select signal of a multiplexer</td>
</tr>
<tr>
<td>enable</td>
<td>enable signal</td>
</tr>
<tr>
<td>out_enable</td>
<td>output enable signal</td>
</tr>
<tr>
<td>scan_enable</td>
<td>scan enable signal</td>
</tr>
<tr>
<td>scan_out_enable</td>
<td>scan output enable signal</td>
</tr>
<tr>
<td>clear</td>
<td>clear signal of a flipflop or latch</td>
</tr>
<tr>
<td>set</td>
<td>set signal of a flipflop or latch</td>
</tr>
<tr>
<td>write</td>
<td>write signal for memory, register file</td>
</tr>
<tr>
<td>read</td>
<td>read signal for memory, register file</td>
</tr>
<tr>
<td>clock</td>
<td>clock signal of a flipflop or latch</td>
</tr>
<tr>
<td>scan_clock</td>
<td>scan clock signal of a flipflop or latch</td>
</tr>
<tr>
<td>master_clock</td>
<td>master clock signal of a flipflop or latch</td>
</tr>
<tr>
<td>slave_clock</td>
<td>slave clock signal of a flipflop or latch</td>
</tr>
<tr>
<td>address</td>
<td>address signal of a memory</td>
</tr>
</tbody>
</table>

#### 3.6.3.4 DRIVETYPE annotation

DRIVETYPE = string;
annotates the drive type for the pin, which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cmos (default)</td>
<td>standard cmos signal</td>
</tr>
<tr>
<td>nmos</td>
<td>nmos or pseudo nmos signal</td>
</tr>
<tr>
<td>pmos</td>
<td>pmos or pseudo pmos signal</td>
</tr>
<tr>
<td>nmos_pass</td>
<td>nmos passgate signal</td>
</tr>
<tr>
<td>pmos_pass</td>
<td>pmos passgate signal</td>
</tr>
<tr>
<td>cmos_pass</td>
<td>cmos passgate signal, i.e. full transmission gate</td>
</tr>
<tr>
<td>ttl</td>
<td>TTL signal</td>
</tr>
<tr>
<td>open_drain</td>
<td>open drain signal</td>
</tr>
<tr>
<td>open_source</td>
<td>open source signal</td>
</tr>
</tbody>
</table>

3.6.3.5 DIRECTION annotation

DIRECTION = string ;
annotates the direction of the pin, which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td>input pin</td>
</tr>
<tr>
<td>output</td>
<td>output pin</td>
</tr>
<tr>
<td>both</td>
<td>bidirectional pin</td>
</tr>
<tr>
<td>none</td>
<td>no direction can be assigned to the pin</td>
</tr>
</tbody>
</table>

3.6.3.6 SCOPE annotation

SCOPE = string ;
annotates modeling scope of a pin, which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>behavior</td>
<td>can be used for modeling functional behavior</td>
</tr>
<tr>
<td>measure</td>
<td>measurements can be done related to this pin, e.g. timing or power characterization</td>
</tr>
<tr>
<td>both (default)</td>
<td>can be used for function as well as for characterization measurements</td>
</tr>
<tr>
<td>none</td>
<td>no model, only pin exists</td>
</tr>
</tbody>
</table>
3.6.3.7  **ACTION annotation**

\[
\text{ACTION} = \text{string} ;
\]

annotates action of the signal, which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>synchronous</td>
<td>signal acts in synchronous way</td>
</tr>
<tr>
<td>asynchronous</td>
<td>signal acts in asynchronous way</td>
</tr>
</tbody>
</table>

3.6.3.8  **POLARITY annotation**

\[
\text{POLARITY} = \text{string} ;
\]

annotates the polarity of the pin signal.

The polarity of an input pin (i.e. `DIRECTION = input;`) can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>signal active high or to be driven high</td>
</tr>
<tr>
<td>low</td>
<td>signal active low or to be driven low</td>
</tr>
<tr>
<td>rising_edge</td>
<td>signal sensitive to rising edge</td>
</tr>
<tr>
<td>falling_edge</td>
<td>signal sensitive to falling edge</td>
</tr>
<tr>
<td>double_edge</td>
<td>signal sensitive to any edge</td>
</tr>
</tbody>
</table>

The polarity of an output pin (i.e. `DIRECTION = output;`) can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>inverted</td>
<td>polarity change between input and output</td>
</tr>
<tr>
<td>non_inverted</td>
<td>no polarity change between input and output</td>
</tr>
<tr>
<td>both</td>
<td>polarity may change or not (e.g. XOR) (default)</td>
</tr>
<tr>
<td>none</td>
<td>polarity has no meaning (e.g. analog signal)</td>
</tr>
</tbody>
</table>

3.6.3.9  **ENABLE_PIN annotation**

\[
\text{ENABLE_PIN} = \text{string} ;
\]

references an output enable pin (i.e. a pin with `SIGNALTYPE = out_enable;`).

3.6.3.10  **PULL annotation**

\[
\text{PULL} = \text{string} ;
\]
which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>up</td>
<td>pullup device connected to pin</td>
</tr>
<tr>
<td>down</td>
<td>pulldown device connected to pin</td>
</tr>
<tr>
<td>both</td>
<td>pullup and pulldown device connected to pin</td>
</tr>
<tr>
<td>none (default)</td>
<td>no pull device</td>
</tr>
</tbody>
</table>

Table 3-35 : PULL annotations for a PIN object

3.6.3.11 ORIENTATION annotation

ORIENTATION = string ;

which can take the following pin orientation values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>left</td>
<td>pin is on the left side</td>
</tr>
<tr>
<td>right</td>
<td>pin is on the right side</td>
</tr>
<tr>
<td>top</td>
<td>pin is at the top</td>
</tr>
<tr>
<td>bottom</td>
<td>pin is at the bottom</td>
</tr>
</tbody>
</table>

Table 3-36 : ORIENTATION annotations for a PIN object

3.6.3.12 CONNECT_CLASS annotation

CONNECT_CLASS = identifier ;

annotates a declared class object for connectivity determination.

3.6.3.13 DATATYPE annotation

DATATYPE = string ;

is only relevant for bus pins, which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>signed</td>
<td>result of arithmetic operation is signed 2’s complement</td>
</tr>
<tr>
<td>unsigned</td>
<td>result of arithmetic operation is unsigned</td>
</tr>
</tbody>
</table>

Table 3-37 : DATATYPE annotations for a PIN object

3.6.3.14 SCAN_POSITION annotation

SCAN_POSITION = unsigned ;

annotates position in scan chain.

3.6.3.15 STUCK annotation

STUCK = string ;
which can be

### Table 3-38: STUCK annotations for a PIN object

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>stuck_at_0</td>
<td>pin can have stuck-at-0 fault</td>
</tr>
<tr>
<td>stuck_at_1</td>
<td>pin can have stuck-at-1 fault</td>
</tr>
<tr>
<td>both (default)</td>
<td>pin can have both stuck-at-0 and stuck-at-1 faults</td>
</tr>
<tr>
<td>none</td>
<td>pin can not have stuck-at faults</td>
</tr>
</tbody>
</table>

#### 3.6.3.16 OFF_STATE annotation

OFF_STATE = string;

which can be

### Table 3-39: OFF_STATE annotations for a PIN object

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>inverted</td>
<td>pin is inverted when in off state</td>
</tr>
<tr>
<td>non_inverted</td>
<td>pin is not inverted when in off state</td>
</tr>
</tbody>
</table>

#### 3.6.4 Annotations for a VECTOR object

A VECTOR object may contain the following annotations:

#### 3.6.4.1 LABEL annotation

LABEL = string;

to be used to ensure SDF matching with conditional delays across Verilog, VITAL etc.

#### 3.6.4.2 EXISTENCE_CONDITION

EXISTENCE_CONDITION = boolean_expression;

For false-path analysis tools, the existence condition shall be used to eliminate the vector from further analysis if and only if the existence condition evaluates to “false”. For applications other than false-path analysis, the existence condition shall be treated as if the boolean expression was a cofactor to the vector itself. Default existence condition is “true”.

Example:

```plaintext
VECTOR (01 a -> 01 z & (c | !d) ) {
    EXISTENCE_CONDITION = !scan_select;
    DELAY { FROM { PIN=a; } TO { PIN=z; } /* data */ }
}
VECTOR (01 a -> 01 z & (!c | d) ) {
    EXISTENCE_CONDITION = !scan_select;
    DELAY { FROM { PIN=a; } TO { PIN=z; } /* data */ }
}
```
Each vector contains state-dependent delay for the same timing arc. If "!scan_select" evaluates "true", both vectors are eliminated from timing analysis.

3.6.4.3 EXISTENCE_CLASS

EXISTENCE_CLASS = string ;

Reference to the same existence class by multiple vectors has the following effects:

- A common mode of operation is established between those vectors, which can be used for selective analysis, for instance mode-dependent timing analysis. Name of the mode is the name of the class.
- A common existence condition is inherited from that existence class, if there is one.

Example:

CLASS non_scan_mode {
  EXISTENCE_CONDITION = !scan_select;
}
VECTOR (01 a -> 01 z & (c | !d)) {
  EXISTENCE_CLASS = non_scan_mode;
  DELAY { FROM { PIN=a; } TO { PIN=z; } /* data */ }
}
VECTOR (01 a -> 01 z & (!c | d)) {
  EXISTENCE_CLASS = non_scan_mode;
  DELAY { FROM { PIN=a; } TO { PIN=z; } /* data */ }
}

Each vector contains state-dependent delay for the same timing arc. If the mode "non_scan_mode" is turned off or if "!scan_select" evaluates "true", both vectors are eliminated from timing analysis.

3.6.4.4 CHARACTERIZATION_CONDITION

CHARACTERIZATION_CONDITION = boolean_expression ;

For characterization tools, the characterization condition shall be treated as if the boolean expression was a cofactor to the vector itself. For all other applications, the characterization condition shall be disregarded. Default characterization condition is “true”.

Example:

VECTOR (01 a -> 01 z & (c | !d)) {
  CHARACTERIZATION_CONDITION = c & !d;
  DELAY { FROM { PIN=a; } TO { PIN=z; } /* data */ }
}

The delay value for the timing arc applies for any of the following conditions (c & !d) or (c & d) or (!c & !d), since they all satisfy (c | !d).

However, the only condition chosen for delay characterization is (c & !d).
3.6.4.5 CHARACTERIZATION_VECTOR

CHARACTERIZATION_VECTOR = ( vector_expression );

The characterization vector is provided for the case that the vector expression cannot be constructed using the vector and a boolean cofactor. The use of the characterization vector is restricted to characterization tools in the same way as the use of the characterization condition. Either a characterization condition or a characterization vector may be provided, but not both. If none is provided, the vector itself will be used by the characterization tool.

Example:

VECTOR (01 A -> 01 Z) {
    CHARACTERIZATION_VECTOR = ((01 A & 10 inv_A) -> (01 Z & 10 inv_Z));
}

Analysis tools see the signals "A" and "Z". The signals "inv_A" and "inv_Z" are visible to the characterization tool only.

3.6.4.6 CHARACTERIZATION_CLASS

CHARACTERIZATION_CLASS = string ;

Reference to the same characterization class by multiple vectors has the following effects:

- A commonality is established between those vectors, which can be used for selective characterization in a way defined by the library characterizer, for instance to share the characterization task between different teams or jobs or tools ...
- A common characterization condition or characterization vector is inherited from that characterization class, if there is one.

3.6.5 Annotations for a CELL object

A CELL object may contain the following annotations:

3.6.5.1 CELLTYPE annotation

CELLTYPE = string ;

which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>buffer</td>
<td>cell is a buffer</td>
</tr>
<tr>
<td>combinational</td>
<td>cell is a combinational logic element</td>
</tr>
<tr>
<td>multiplexor</td>
<td>cell is a multiplexor</td>
</tr>
<tr>
<td>flipflop</td>
<td>cell is a flip-flop</td>
</tr>
<tr>
<td>latch</td>
<td>cell is a latch</td>
</tr>
<tr>
<td>memory</td>
<td>cell is a memory element</td>
</tr>
</tbody>
</table>
3.6.5.2 **BUFFERTYPE** annotation

BUFFERTYPE = string ;

which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td>cell is an input buffer</td>
</tr>
<tr>
<td>output</td>
<td>cell is an output buffer</td>
</tr>
<tr>
<td>inout</td>
<td>cell is an inout (bidirectional) buffer</td>
</tr>
<tr>
<td>internal</td>
<td>cell is an internal buffer</td>
</tr>
</tbody>
</table>

3.6.5.3 **DRIVERTYPE** annotation

DRIVERTYPE = string ;

which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>predriver</td>
<td>cell is a predriver</td>
</tr>
<tr>
<td>slotdriver</td>
<td>cell is a slotdriver</td>
</tr>
<tr>
<td>both</td>
<td>cell is both a predriver and a slot driver</td>
</tr>
</tbody>
</table>

3.6.5.4 **PARALLEL_DRIVE** annotation

PARALLEL_DRIVE = unsigned ;

which specifies the number of parallel drivers.

3.6.5.5 **SCAN_TYPE** annotation

SCAN_TYPE = string ;
which can take the following values:

**Table 3-43: SCAN_TYPE annotations for a CELL object**

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>muxscan</td>
<td>There is a multiplexer for normal data and scan data</td>
</tr>
<tr>
<td>clocked</td>
<td>There is a special scan clock</td>
</tr>
<tr>
<td>lssd</td>
<td>combination between flipflop and latch with special clocking (level sensitive scan design)</td>
</tr>
<tr>
<td>control_0</td>
<td>combinational scan cell, controlling pin must be 0 in scan mode</td>
</tr>
<tr>
<td>control_1</td>
<td>combinational scan cell, controlling pin must be 1 in scan mode</td>
</tr>
</tbody>
</table>

**3.6.5.6 SCAN_USAGE annotation**

```
SCAN_USAGE = string ;
```

which can take the following values:

**Table 3-44: SCAN_USAGE annotations for a CELL object**

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>input</td>
<td>primary input in a chain of cells</td>
</tr>
<tr>
<td>output</td>
<td>primary output in a chain of cells</td>
</tr>
<tr>
<td>hold</td>
<td>holds intermediate value in the scan chain</td>
</tr>
</tbody>
</table>

**3.6.5.7 NON_SCAN_CELL annotation**

```
NON_SCAN_CELL [ identifier ] = cell_identifier { pin_assignments }
NON_SCAN_CELL [ identifier ] = primitive_identifier { pin_assignments }
```

This annotation shall define non-scan cell equivalency to the scan cell in which this annotation is contained. A cell instantiation form (Section 3.4.3) is used to reference the library cell which defines the non-scan functionality of the current cell. If no such cell is available or defined, or if an explicit reference to such a cell is not desired, then a primitive instantiation form (Section 3.4.3) may reference a primitive, either ALF- or user-defined, for such use. In either case, constant values may appear on either the left-hand side or right-hand side of the pin connectivity relationships. A constant on the left-hand side defines the value the scan cell pins (appearing on the right-hand side) must have in order for the primitive to perform with the same functionality as does the instantiated reference. Multiple non-scan cells may be referenced within the same scope by giving a name to each one.
Example:

```plaintext
CELL my_flipflop {
    PIN q   ( DIRECTION=output; )
    PIN d   ( DIRECTION=input; )
    PIN clk ( DIRECTION=input; )
    PIN clear { DIRECTION=input; polarity=low; }
    // followed by function, vectors etc.
}

CELL my_other_flipflop {
    // declare the pins
    // followed by function, vectors etc.
}

CELL my_scan_flipflop {
    PIN data_out { DIRECTION=output; }
    PIN data_in  { DIRECTION=input; }
    PIN clock   { DIRECTION=input; }
    PIN scan_in  { DIRECTION=input; }
    PIN scan_sel { DIRECTION=input; }
    NON_SCAN_CELL first_choice = my_flipflop {
        q = data_out;
        d = data_in;
        clk = clock;
        clear = 'b1;       // scan cell has no clear
        'b0 = scan_in;    // non-scan cell has no scan_in
        'b0 = scan_sel;   // non-scan cell has no scan_sel
    }
    NON_SCAN_CELL second_choice = my_other_flipflop {
        // put in the pin assignments
    }
    // followed by function, vectors etc.
}
```

### 3.6.5.8 SWAP_CLASS annotation

```plaintext
SWAP_CLASS = string ;
```

The value is the name of a declared CLASS. Multi-value annotation may be used. Cells referring to the same CLASS may be swapped for certain applications.

Cell-swapping is only allowed under the following conditions:

- The RESTRICT_CLASS annotation (see next) authorizes usage of the cell
- The cells to be swapped are compatible from an application standpoint (functional compatibility for synthesis, physical compatibility for layout)

### 3.6.5.9 RESTRICT_CLASS annotation

```plaintext
RESTRICT_CLASS = string ;
```

The value is the name of a declared CLASS. Multi-value annotation may be used. Cells referring to a particular class may be used in design tools identified by the value.
User-defined values are also possible. If a cell has no or only unknown values for RESTRICT_CLASS, the application tool may not modify any instantiation of that cell in the design. However, the cell must still be considered for analysis.

Example:

```plaintext
CLASS foo;
CLASS bar;
CELL c1 {
    SWAP_CLASS = foo;
    RESTRICT_CLASS = synthesis;
}
CELL c2 {
    SWAP_CLASS = foo;
    RESTRICT_CLASS { synthesis scan bar }
}
```

Supposed that the cells c1 and c2 are compatible from an application standpoint, the cells c1 and c2 can be used for synthesis, where they may be swapped which each other. The cell c2 can be also used for scan insertion and for the user-defined application “bar”.

### 3.6.6 Attributes

Identifiers inside ATTRIBUTE can be used to add information which does not fit into the annotation scheme. The syntax for specifying ATTRIBUTE is

```
ATTRIBUTE { attribute_items }
```

where attribute_items is a list of predefined or user-defined attributes.

#### 3.6.6.1 ATTRIBUTE within a PIN object

The following attributes can be used within a PIN object:

<table>
<thead>
<tr>
<th>Attribute item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHMITT</td>
<td>Schmitt trigger signal</td>
</tr>
<tr>
<td>TRISTATE</td>
<td>tristate signal</td>
</tr>
<tr>
<td>XTAL</td>
<td>crystal/oscillator signal</td>
</tr>
<tr>
<td>PAD</td>
<td>pad going off-chip</td>
</tr>
</tbody>
</table>
The following attributes within a PIN object can also have \texttt{POLARITY} annotation:

<table>
<thead>
<tr>
<th>Attribute item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIE</td>
<td>signal that needs to be tied to a fixed value</td>
</tr>
<tr>
<td>READ</td>
<td>read enable mode</td>
</tr>
<tr>
<td>WRITE</td>
<td>write enable mode</td>
</tr>
</tbody>
</table>

Example:

```
PIN rw {
  ATTRIBUTE {
    WRITE { POLARITY = high; }
    READ  { POLARITY = low ; }
  }
}
```

### 3.6.6.2 \texttt{ATTRIBUTE} within a \texttt{CELL} object

The following attributes can be used within a \texttt{CELL} object:

<table>
<thead>
<tr>
<th>Attribute item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>ROM</td>
<td>Read Only Memory</td>
</tr>
<tr>
<td>CAM</td>
<td>Content Addressable Memory</td>
</tr>
<tr>
<td>static</td>
<td>static device (e.g. static CMOS, static RAM)</td>
</tr>
<tr>
<td>dynamic</td>
<td>dynamic device (e.g. dynamic CMOS, dynamic RAM)</td>
</tr>
<tr>
<td>asynchronous</td>
<td>asynchronous operation</td>
</tr>
<tr>
<td>synchronous</td>
<td>synchronous operation</td>
</tr>
</tbody>
</table>

### 3.6.7 Annotations for arithmetic models

The following four annotations shall be recognized within arithmetic models:

#### 3.6.7.1 \texttt{DEFAULT} annotation

The default annotation allows use of the default value instead of the arithmetic model, if the arithmetic model is beyond the scope of the application tool.

```
DEFAULT = number ;
```

Restrictions may apply for the allowed type of \texttt{number}. For instance, if the arithmetic model allows only \texttt{non_negative_number}, then the default is restricted to \texttt{non_negative_number}. 

3.6.7.2 UNIT annotation

The unit annotation associates units with the value computed by the arithmetic model.

UNIT = string | non_negative_number;

A unit specified by a string can take the following values (* indicates wildcard):

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f* or F*</td>
<td>equivalent to 1E-15</td>
</tr>
<tr>
<td>p* or P*</td>
<td>equivalent to 1E-12</td>
</tr>
<tr>
<td>n* or N*</td>
<td>equivalent to 1E-9</td>
</tr>
<tr>
<td>u* or U*</td>
<td>equivalent to 1E-6</td>
</tr>
<tr>
<td>m* or M*</td>
<td>equivalent to 1E-3</td>
</tr>
<tr>
<td>1*</td>
<td>equivalent to 1E+0</td>
</tr>
<tr>
<td>k* or K*</td>
<td>equivalent to 1E+3</td>
</tr>
<tr>
<td>meg* or MEG*</td>
<td>equivalent to 1E+6</td>
</tr>
<tr>
<td>g* or G*</td>
<td>equivalent to 1E+9</td>
</tr>
</tbody>
</table>

Arithmetic models are context-sensitive, i.e. the units for their values can be determined from the context. If UNIT annotation for such a context does not exist, default units are applied to the value (Section 3.6.7.5).

Example:

```plaintext
TIME { UNIT = ns; }
FREQUENCY { UNIT = gigahz; }
```

If the unit is a string, then only the first character (respectively the first 3 characters in case of MEG) is interpreted. The reminder of the string can be used to define base units. Metric base units are assumed, but not verified, in ALF.

There is no semantic difference between

```plaintext
unit = 1sec;
```

and

```plaintext
unit = 1volt;
```

Therefore, if the unit is specified as

```plaintext
unit = meg;
```

the interpretation is 1E+6. However, for

```plaintext
unit = 1meg;
```

the interpretation is 1 and not 1E+6.
Units in a non-metric system can only be specified with numbers, not with strings. For instance, if the intent is to specify inch instead of meter as base unit, the following specification will not meet the intent:

\[
\text{unit} = 1\text{inch};
\]
since the interpretation is 1 and meters are assumed.

The correct way of specifying inch instead of meter is

\[
\text{unit} = 26E-3;
\]
since 1 inch is 26 millimeters.

### 3.6.7.3 MEASUREMENT annotation

The *measurement annotation* indicates the type of measurement used for the computation in arithmetic model.

\[
\text{MEASUREMENT} = \text{string};
\]

where measurement string can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>transient</td>
<td>measurement is a transient value</td>
</tr>
<tr>
<td>static</td>
<td>measurement is a static value</td>
</tr>
<tr>
<td>average</td>
<td>measurement is an average value</td>
</tr>
<tr>
<td>rms</td>
<td>measurement is an RMS value</td>
</tr>
<tr>
<td>peak</td>
<td>measurement is a peak value</td>
</tr>
</tbody>
</table>

### 3.6.7.4 CONNECT_RULE annotation

The *connect_rule annotation* may only be inside a CONNECTIVITY object. It specifies connectivity requirement.

\[
\text{CONNECT\_RULE} = \text{string};
\]

which can take the following values:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>must_short</td>
<td>short connection required</td>
</tr>
<tr>
<td>can_short</td>
<td>short connection allowed</td>
</tr>
<tr>
<td>cannot_short</td>
<td>short connection disallowed</td>
</tr>
</tbody>
</table>

### 3.6.7.5 RISE/FALL annotation

This section will be superseeded by 3.6.9.1.
A *RISE annotation* and a *FALL annotation* may be inside a DELAY, SLEWRATE, or THRESHOLD object, which are used as annotation containers (Section 3.6.7.5). The value for RISE and/or FALL annotation is a number.

\[
\text{RISE} = \text{number} ; \\
\text{FALL} = \text{number} ;
\]

### 3.6.7.6 MIN/TYP/MAX annotation

This section will be superseeded by 3.6.9.2.

A *MIN annotation*, a *TYP annotation*, and a *MAX annotation* may be inside an annotation container defined by a keyword for arithmetic models (Section 3.6.7.5).

\[
\text{MIN} = \text{number} ; \\
\text{TYP} = \text{number} ; \\
\text{MAX} = \text{number} ;
\]

The keyword for arithmetic models itself may be inside a LIMIT container (Section 3.6.1.3). In that case, only MIN and MAX have a semantic meaning.

### 3.6.8 Keywords for arithmetic models

The following keywords shall identify arithmetic model objects inside a LIBRARY, a SUBLIBRARY, a CELL, a WIRE or a VECTOR object, i.e. output variables of an arithmetic model. Inside an arithmetic model object, the same keywords identify arguments, i.e. input variables to the arithmetic model. This gives virtually unlimited choice of combination of variables for characterization. The keywords for arithmetic models can also be used

- for simple annotations
- as annotation container

The annotations or annotation containers identified by keywords for arithmetic models can be interpreted as *reduced* arithmetic models, since they don’t contain a header or a body, whereas *full* arithmetic models always contain a header and a body (table or equation).

All the keywords for arithmetic models are considered context-sensitive keywords. In the following sections, these arithmetic models are described along with the type of the value they can have. If the quantity associated with the arithmetic model is a measurement, default units and base units are also noted. The default units are applied when the unit is not specified.
### 3.6.8.1 Models for interpolateable tables and equations

The following tables list the keywords that identify arithmetic models which can be used as interpolateable table indices and/or as equations.

#### Table 3-52: Timing measurements

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELAY</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>time between two threshold crossings within two consecutive events on two pins</td>
</tr>
<tr>
<td>RETAIN</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>time between two threshold crossings within two consecutive events on two pins, in conjunction with DELAY</td>
</tr>
<tr>
<td>SLEWRATE</td>
<td>non-negative number</td>
<td>Second</td>
<td>n (nano)</td>
<td>time between two threshold crossings within one event on one pin</td>
</tr>
</tbody>
</table>

#### Table 3-53: Timing constraints

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOLD</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit for hold between two threshold crossings within two consecutive events on two pins</td>
</tr>
<tr>
<td>NOCHANGE</td>
<td>optional(^a) non-negative number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit between two threshold crossings within two arbitrary consecutive events on one pin, in conjunction with SETUP and HOLD</td>
</tr>
<tr>
<td>PERIOD</td>
<td>non-negative number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit between two identical events within a sequence of periodical events on one pin</td>
</tr>
<tr>
<td>PULSEWIDTH</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit between two threshold crossings within two consecutive and complementary events on one pin</td>
</tr>
<tr>
<td>RECOVERY</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit for recovery between two threshold crossings within two consecutive events on two pins</td>
</tr>
<tr>
<td>REMOVAL</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit for removal between two threshold crossings within two consecutive events on two pins</td>
</tr>
<tr>
<td>SETUP</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>minimum time limit for setup between two threshold crossings within two consecutive events on two pins</td>
</tr>
<tr>
<td>SKEW</td>
<td>number</td>
<td>Second</td>
<td>n (nano)</td>
<td>absolute value is maximum time limit between two threshold crossings within two consecutive events on two pins, the sign indicates positive or negative direction</td>
</tr>
</tbody>
</table>
a. The associated SETUP and HOLD measurements provide data. NOCHANGE itself need not provide data.

**Table 3-54: Analog measurements**

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURRENT</td>
<td>number</td>
<td>Ampere</td>
<td>m (milli)</td>
<td>electrical current</td>
</tr>
<tr>
<td>ENERGY</td>
<td>number</td>
<td>Joule</td>
<td>p (pico)</td>
<td>electrical energy</td>
</tr>
<tr>
<td>FREQUENCY</td>
<td>non-negative number</td>
<td>Hz</td>
<td>meg (mega)</td>
<td>frequency</td>
</tr>
<tr>
<td>JITTER</td>
<td>non-negative number</td>
<td>Second</td>
<td>n (nano)</td>
<td>uncertainty of arrival time</td>
</tr>
<tr>
<td>POWER</td>
<td>number</td>
<td>Watt</td>
<td>u (micro)</td>
<td>electrical power</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>number</td>
<td>°Celsius</td>
<td>l (unit)</td>
<td>temperature</td>
</tr>
<tr>
<td>TIME</td>
<td>number</td>
<td>Second</td>
<td>l (unit)</td>
<td>time point for waveform modeling, time span for average, RMS, peak modeling</td>
</tr>
<tr>
<td>VOLTAGE</td>
<td>number</td>
<td>Volt</td>
<td>l (unit)</td>
<td>voltage</td>
</tr>
<tr>
<td>FLUX</td>
<td>non-negative number</td>
<td>Coloumb per Square Meter</td>
<td>l (unit)</td>
<td>amount of hot electrons in units of electrical charge per gate oxide area</td>
</tr>
<tr>
<td>FLUENCE</td>
<td>non-negative number</td>
<td>Second times Coloumb per Square Meter</td>
<td>l (unit)</td>
<td>integral of FLUX over time</td>
</tr>
</tbody>
</table>

**Table 3-55: Electrical components**

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPACITANCE</td>
<td>non-negative number</td>
<td>Farad</td>
<td>p (pico)</td>
<td>pin, wire, load, or net capacitance</td>
</tr>
<tr>
<td>INDUCTANCE</td>
<td>non-negative number</td>
<td>Henry</td>
<td>n (nano)</td>
<td>pin, wire, load, or net resistance</td>
</tr>
<tr>
<td>RESISTANCE</td>
<td>non-negative number</td>
<td>Ohm</td>
<td>K (kilo)</td>
<td>pin, wire, load, or net resistance</td>
</tr>
</tbody>
</table>
### Table 3-56: Layout data

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>non-negative number</td>
<td>Square</td>
<td>p (pico)</td>
<td>area in square microns (pico = micro²)</td>
</tr>
<tr>
<td>DISTANCE</td>
<td>number</td>
<td>Meter</td>
<td>u (micro)</td>
<td>distance between two points in microns</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>non-negative number</td>
<td>Meter</td>
<td>u (micro)</td>
<td>x-or y- dimension of a placeable object (e.g. cell, block)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x-, y-, or z- dimension of a routable object (e.g. wire) measured in orthogonal direction to the route</td>
</tr>
<tr>
<td>LENGTH</td>
<td>non-negative number</td>
<td>Meter</td>
<td>u (micro)</td>
<td>x-, y-, or z- dimension of a routable object (e.g. wire) measured in parallel direction to the route</td>
</tr>
<tr>
<td>WIDTH</td>
<td>non-negative number</td>
<td>Meter</td>
<td>u (micro)</td>
<td>x-or y- dimension of a placeable object (e.g. cell, block)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x-, y-, or z- dimension of a routable object (e.g. wire) measured in orthogonal direction to the route</td>
</tr>
</tbody>
</table>

### Table 3-57: Abstract measurements

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVE_STRENGTH</td>
<td>non-negative number</td>
<td>None</td>
<td>1 (unit)</td>
<td>drive strength of a pin, abstract measure for (drive resistance)⁻¹</td>
</tr>
<tr>
<td>SIZE</td>
<td>non-negative number</td>
<td>None</td>
<td>1 (unit)</td>
<td>abstract cost function for actual or estimated area of a cell or a block</td>
</tr>
</tbody>
</table>
Actual values for discrete measurements are always integer numbers, however, estimated values may be non-integer numbers (e.g. average fanout of a net =2.4 ).

3.6.8.2 Models for non-interpolateable tables
The following keywords identify arithmetic models which can only be used as non-interpolateable tables. The values in the table may not be used in equations.

The following table describes connectivity data:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Value type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONNECTIVITY</td>
<td>boolean literal</td>
<td>connectivity function</td>
</tr>
<tr>
<td>DRIVER</td>
<td>string</td>
<td>argument of connectivity function</td>
</tr>
<tr>
<td>RECEIVER</td>
<td>string</td>
<td>argument of connectivity function</td>
</tr>
</tbody>
</table>

Table 3-38 : Normalized measurements

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>THRESHOLD</td>
<td>non-negative</td>
<td>Normalized</td>
<td>1 (unit)</td>
<td>Fraction of signal voltage swing, specifying a reference point for timing measurement data. The threshold is the voltage for which the timing measurement is taken.</td>
</tr>
<tr>
<td>NOISE_MARGIN</td>
<td>number</td>
<td>Normalized</td>
<td>1 (unit)</td>
<td>Fraction of signal voltage swing, specifying the noise margin. The noise margin is a deviation of the actual voltage from the expected voltage for a specified signal level.</td>
</tr>
</tbody>
</table>

Table 3-39 : Discrete measurements

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Value type</th>
<th>Base Units</th>
<th>Default Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWITCHING_BITS</td>
<td>non-negative</td>
<td>None</td>
<td>1</td>
<td>number of switching bits on a bus</td>
</tr>
<tr>
<td>FANOUT</td>
<td>non-negative</td>
<td>None</td>
<td>1</td>
<td>number of receivers connected to a net</td>
</tr>
<tr>
<td>FANIN</td>
<td>non-negative</td>
<td>None</td>
<td>1</td>
<td>number of drivers connected to a net</td>
</tr>
<tr>
<td>CONNECTIONS</td>
<td>non-negative</td>
<td>None</td>
<td>1</td>
<td>number of pins connected to a net, where CONNECTIONS = FANIN+FANOUT</td>
</tr>
</tbody>
</table>

Table 3-40 : Connectivity data
The connectivity function specifies the allowed and disallowed connections amongst drivers or receivers in 1-dimensional tables, or between drivers and receivers in 2-dimensional tables. A CONNECTIVITY object requires a CONNECT_RULE annotation (3.6.7.4). The boolean literals in the table have the following meaning:

<table>
<thead>
<tr>
<th>Boolean literal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CONNECT_RULE is true</td>
</tr>
<tr>
<td>0</td>
<td>CONNECT_RULE is false</td>
</tr>
<tr>
<td>?</td>
<td>CONNECT_RULE is don’t care</td>
</tr>
</tbody>
</table>

The arguments of the connectivity functions are tables of strings, which refer to user-definable classes. Pins which are subject to a particular CONNECT_RULE refer to the relevant class via a CONNECT_CLASS annotation (see section 3.6.3.12).

Example:

CLASS power;
CLASS ground;
CONNECTIVITY {
  CONNECT_RULE = must_short;
  HEADER {
    RECEIVER r1 { TABLE { power ground } }
    RECEIVER r2 { TABLE { power ground } }
  }
  TABLE { 1 0 0 1 }
}

All pins of the power and ground class must be connected amongst themselves, but power and ground class must not be shorted together.

### 3.6.8.3 Models for non-interpolateable tables and equations

The following keywords identify arithmetic models which may be used directly as non-interpolateable tables and indirectly as equations. The use of those models as equations requires that a non-interpolateable table establishes a relationship between a symbolic identifier and a number.

The following table describes process data:

<table>
<thead>
<tr>
<th>Annotation string</th>
<th>Value type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DERATE_CASE</td>
<td>string</td>
<td>derating case coefficient</td>
</tr>
<tr>
<td>PROCESS</td>
<td>string</td>
<td>process derating coefficient</td>
</tr>
</tbody>
</table>

The following identifiers can be used as predefined processes:

- ?n?p — process definition with transistor strength
where ? can be

s  strong
w  weak

The possible process name combinations are

<table>
<thead>
<tr>
<th>Process name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>snsp</td>
<td>strong NMOS, strong PMOS</td>
</tr>
<tr>
<td>snwp</td>
<td>strong NMOS, weak PMOS</td>
</tr>
<tr>
<td>wnsn</td>
<td>weak NMOS, strong PMOS</td>
</tr>
<tr>
<td>wnwp</td>
<td>weak NMOS, weak PMOS</td>
</tr>
</tbody>
</table>

The following identifiers can be used as predefined derating cases:

nom          nominal case
bc?          prefix for best case
wc?          prefix for worst case

where ? can be

com          suffix for commercial case
ind          suffix for industrial case
mil          suffix for military case

The possible derating case combinations are

<table>
<thead>
<tr>
<th>Derating case</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bccom</td>
<td>best case commercial</td>
</tr>
<tr>
<td>bcind</td>
<td>best case industrial</td>
</tr>
<tr>
<td>bcmil</td>
<td>best case military</td>
</tr>
<tr>
<td>wccom</td>
<td>worst case commercial</td>
</tr>
<tr>
<td>wcind</td>
<td>worst case military</td>
</tr>
<tr>
<td>wcmil</td>
<td>worst case military</td>
</tr>
</tbody>
</table>

Example:

- Direct use of PROCESS in a non-interpolateable table:

```plaintext
DELAY {
  UNIT = ns;
  HEADER {
    PROCESS { TABLE { nom snsp wnwp } }
  }
  TABLE { 0.4 0.3 0.6 }
}
```

The delay is 0.4 ns for nominal process, 0.3 ns for snsp, 0.6 ns for wnwp.
• **Indirect use of** `PROCESS` **in an equation:**

```plaintext
DELAY {
    UNIT = ns;
    HEADER {
        PROCESS { HEADER { nom snsp wnwp } TABLE {0.0 -0.25 0.5} }
    }
    EQUATION { (1 + PROCESS)*0.4 }
}
```

The equation uses the derating factors 0.0 for nominal, -0.25 for `snsp`, 0.5 for `wnwp`.

### 3.6.9 Keywords for arithmetic submodels

Arithmetic submodels are for the purpose of distinguishing different measurement conditions for the same model. The root of an arithmetic model may contain nested arithmetic submodels. The header of an arithmetic model may contain nested arithmetic models, but not arithmetic submodels.

#### 3.6.9.1 MIN/TYP/MAX

MIN, TYP, MAX provide 3 distinct sets of data

```plaintext
<model_keyword> { MIN /*data*/ TYP /*data*/ MAX /*data*/ }
```
as opposed to a single set of data

```plaintext
<model_keyword> /*data*/
```

The MIN, TYP, MAX represent a statistical distribution of data without specifying or implying a particular cause of the distribution. If process corners or derate cases are not modeled explicitly, MIN, TYP, MAX can be used for representing the distribution of data across processes or derate cases. If process corners or delay cases are modeled explicitly, MIN, TYP, MAX can be used for representing the distribution of data within each process corner or derate case.

Note: The arithmetic model root containing MIN, TYP, MAX must not contain HEADER or TABLE or EQUATION. Instead, the MIN, TYP, MAX models may contain HEADER or TABLE or EQUATION.

```plaintext
<model_keyword> {
    MIN {
        HEADER { <model_keyword> /*data*/ .. <model_keyword> /*data*/ }
        TABLE /* or equation */ { <numbers> }
    }
    TYP {
        HEADER { <model_keyword> /*data*/ .. <model_keyword> /*data*/ }
        TABLE /* or equation */ { <numbers> }
    }
    MAX {
        HEADER { <model_keyword> /*data*/ .. <model_keyword> /*data*/ }
        TABLE /* or equation */ { <numbers> }
    }
}
```
Within the scope of a LIMIT container, MIN and MAX contain the data for a lower or upper limit, respectively. There must be at least one limit, lower or upper, in each model, but not necessarily both, as shown in the example below.

```plaintext
LIMIT {
    <model_keyword1> { MIN /*data*/ } // lower limit
    <model_keyword2> { MAX /*data*/ } // upper limit
    <model_keyword3> { MIN /*data*/ MAX /*data*/ } // lower and upper limit
}
```

Note: The arithmetic model root inside LIMIT must not contain HEADER or TABLE or EQUATION. Instead, the MIN or MAX models may contain HEADER or TABLE or EQUATION.

```plaintext
LIMIT {
    <model_keyword> {
        MIN {
            HEADER{ <model_keyword> /*data*/ .. }
            TABLE { <numbers> } /* or equation */
        }
        MAX {
            HEADER{ <model_keyword> /*data*/ .. }
            TABLE { <numbers> } /* or equation */
        }
    }
}
```

MIN, MAX inside a model inside a HEADER define the validity limits of the data. The model inside the HEADER may contain TABLE or EQUATION. It may also contain HEADER, which represents a nested arithmetic model.

If MIN, MAX is not defined and the data is in a TABLE, the boundaries of the data in the TABLE shall be considered as validity limits.

Note: The MIN and MAX numbers qualify the data of the arithmetic model in the HEADER, they do not represent the data itself.

```plaintext
<model_keyword> {
    HEADER {
        <model_keyword> {
            MIN = <number> ; // minimum value for valid extrapolation
            MAX = <number> ; // maximum value for valid extrapolation
            TABLE { <numbers> } // data for inter-and extrapolation
        }
    }
    TABLE { <numbers> }
}
```

**3.6.9.2 RISE/FALL and HIGH/LOW**

RISE, FALL contain data for transient measurements. HIGH, LOW contain data for static measurements.

```plaintext
<model_keyword> { RISE /*data*/ FALL /*data*/ }
<model_keyword> {HIGH /*data*/ LOW /*data*/ }
```
It is generally not required that both RISE and FALL or both HIGH and LOW, respectively, appear in the arithmetic model root.

The arithmetic model root containing RISE, FALL or HIGH, LOW must not contain MIN, TYP, MAX, HEADER, TABLE or EQUATION. Instead, the RISE, FALL or HIGH, LOW models may either contain HEADER, TABLE, EQUATION or contain MIN, TYP, MAX which may contain HEADER, TABLE, EQUATION themselves.

```plaintext
<model_keyword> {  
  <RISE or FALL or HIGH or LOW> {  
    HEADER { <model_keyword> /*data*/ .. }  
    TABLE { <numbers> } /* or equation */  
  }  
}
```

or

```plaintext
<model_keyword> {  
  <RISE or FALL or HIGH or LOW> {  
    MIN /*data*/  
    TYP /*data*/  
    MAX /*data*/  
  }  
}
```

Semantic meaning for RISE and FALL is provided for the following measurements:

- **DELAY:**
  RISE, FALL is the switching direction on the PIN specified in the TO field.

  If the TO field does not exist (a special case for port delay), RISE, FALL is the switching direction on the PIN specified in the FROM field.

- **CAPACITANCE, RESISTANCE, INDUCTANCE, CURRENT, ENERGY, POWER, SLEWRATE, THRESHOLD:**
  RISE, FALL is the switching direction on the PIN. Either the PIN is specified as annotation inside the model, or the model is inside a PIN.

Semantic meaning for HIGH and LOW is provided for the following measurements:

- **CAPACITANCE, RESISTANCE, INDUCTANCE, CURRENT, ENERGY, POWER, VOLTAGE, NOISE_MARGIN:**
  HIGH, LOW is the state on the PIN. Either the PIN is specified as annotation inside the model, or the model is inside a PIN.

The arithmetic model root containing RISE, FALL or HIGH, LOW may be inside a LIMIT container with the following rule: A model containing RISE, FALL or HIGH, LOW must not contain MIN or MAX. Instead, the RISE, FALL or HIGH, LOW model must contain MIN or MAX.

```plaintext
LIMIT {  
  <model_keyword> {  
    <RISE or FALL or HIGH or LOW> { MIN /*data*/ MAX /*data*/ }  
  }  
}
```
The arithmetic model root containing RISE, FALL may be inside EARLY, LATE containers with the following rules:

If only RISE appears in one model, only RISE must appear in all models.
If only FALL appears in one model, only FALL must appear in all models.
If both RISE and FALL appear in one model, both RISE and FALL must appear in all models.

```
EARLY {
    DELAY { RISE /*data*/ FALL /*data*/ }
    SLEWRATE { RISE /*data*/ FALL /*data*/ }
}
LATE {
    DELAY { RISE /*data*/ FALL /*data*/ }
    SLEWRATE { RISE /*data*/ FALL /*data*/ }
}
```

Semantic meaning for RISE and FALL is provided for the following LIMIT specifications, EARLY or LATE measurements:

- **DELAY**: RISE, FALL is the switching direction on the PIN specified in the TO field. Only if the TO field does not exist (a special case for port delay), RISE, FALL is the switching direction on the PIN specified in the FROM field (since the switching direction of the unspecified PIN in the TO field will be the same).
- **SLEWRATE**: RISE, FALL is the switching direction on the PIN. Either the PIN is specified as annotation inside the model, or the model is inside a PIN.

Semantic meaning for HIGH and LOW is provided for the following LIMIT specifications:

- **CURRENT, ENERGY, POWER, VOLTAGE**: HIGH, LOW is the state on the PIN. Either the PIN is specified as annotation inside the model, or the model is inside a PIN.

### 3.6.10 Special Annotations and Annotation Containers for Arithmetic Models

Annotations and annotation containers described in this chapter are relevant for the semantic interpretation of the arithmetic models. Annotations and annotation containers not described in this chapters can be interpreted as simple properties or attributes of the arithmetic models.

#### 3.6.10.1 FROM, TO annotation container

Annotation container used inside arithmetic models for timing measurement and timing constraints.
If said models apply for two pins, the FROM, TO containers shall each contain the PIN annotation. These annotations shall define the sense of measurement.

```plaintext
<model_keyword> {
    FROM { PIN = <pin_name> ; }  
    TO { PIN = <pin_name> ; }  
    /* data */
}
```

Otherwise, if said models apply only for one pin, the same PIN annotation may be repeated in both containers or the PIN annotation may be outside the FROM, TO container.

```plaintext
<model_keyword> {
    PIN = <pin_name> ;  
    /* data */
}
```

If thresholds are needed for exact definition of the model data, the FROM, TO containers shall each contain the annotation or an arithmetic model for THRESHOLD.

```plaintext
<model_keyword> {
    FROM { THRESHOLD /*data*/ }  
    TO { THRESHOLD /*data*/ }  
    /* data */
}
```

An annotation or arithmetic model for THRESHOLD outside a FROM or TO container shall only have a semantic meaning, if said annotation or arithmetic model contains a PIN annotation itself and this PIN annotation matches a PIN annotation in a FROM or TO container.

Example:

```plaintext
DELAY {
    FROM {
        PIN = pin1;  
        THRESHOLD /*data*/
    }  
    TO {
        PIN = pin2;  
    }  
    HEADER {
        THRESHOLD {
            PIN = pin2;  
            TABLE { <numbers> }
        }  
        TABLE { <numbers> }
    }
}
```

Note: The data of the THRESHOLD at pin1 is calculated independently of DELAY, whereas DELAY is calculated as a function of THRESHOLD at pin2.

### 3.6.10.2 PIN annotation

The use of PIN annotation in arithmetic models other than timing measurements and timing constraints is defined here.
If the PIN annotation appears inside an arithmetic model within the scope of a HEADER or a LIMIT, the physical quantity identified by the model keyword is *applied* to the PIN. Otherwise, if the PIN annotation appears inside an arithmetic model root which is not within the scope of a LIMIT, the physical quantity identified by the model keyword is *measured* at the PIN.

Example:

```plaintext
// intrinsic capacitance of pin1
CAPACITANCE {
    PIN = pin1;
/*data*/
}

// maximum allowed capacitance on a net connected to pin2
LIMIT {
    CAPACITANCE {
        PIN = pin2;
        MAX /*data*/
    }
}

// delay measured as function of capacitance on a net connected to pin3
DELAY {
    HEADER {
        CAPACITANCE {
            PIN = pin3;
        }
    }
/*data*/
}
```

If the arithmetic model is within the scope of a PIN object, a PIN annotation is illegal according to the visibility rules of ALF, since a PIN cannot be visible inside another PIN, with the following exception: The PIN outside the arithmetic model is a bus, and the PIN annotation inside the arithmetic model refers to a bit of the bus.

Example:

```plaintext
PIN [1:2] bus_pin {
    // intrinsic capacitance of bus_pin[1]
    CAPACITANCE {
        PIN = bus_pin[1];
/*data*/
    }

    // maximum allowed capacitance on a net connected to bus_pin[2]
    LIMIT {
        CAPACITANCE {
            PIN = bus_pin[2];
/*data*/
        }
    }
}
```

If an arithmetic model root appears within the scope of a LIMIT inside a PIN, the physical quantity identified by the model keyword is *applied* to the PIN. Otherwise, if an arithmetic
model root appears directly inside a PIN, the physical quantity identified by the model keyword is *measured* at the PIN.

Example:

```alp
PIN scalar_pin {
  // intrinsic capacitance of scalar_pin
  CAPACITANCE {
    /*data*/
  }
  // maximum allowed capacitance on a net connected to scalar_pin
  LIMIT {
    CAPACITANCE {
      /*data*/
    }
  }
}
```

An arithmetic model inside a bus or an arithmetic model with a PIN annotation refering to a bus shall apply to the entire bus, not to each individual scalar pin of the bus.

Example:

```alp
PIN [1:10] large_bus {
  CAPACITANCE = 1 { unit = pf; }
}
```

The total pin capacitance of `large_bus` is 1 pf, not 10 pf. The capacitance of individual scalar pins `large_bus[1] .. large_bus[10]` is not defined.

### 3.6.11 TIME and FREQUENCY in Analog Measurements and Waveforms

Arithmetic models describing analog measurements (see Table 3-54) can have a MEASUREMENT annotation (see Table 3-50). In this context, *either* TIME *or* FREQUENCY can also be used as annotations.

The semantics are defined as follows:

<table>
<thead>
<tr>
<th>MEASUREMENT annotation</th>
<th>Semantic meaning of TIME annotation</th>
<th>Semantic meaning of FREQUENCY annotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>transient</td>
<td>integration of analog measurement is done during that time window</td>
<td>integration of analog measurement is repeated with that frequency</td>
</tr>
<tr>
<td>static</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>average</td>
<td>average value is measured over that time window</td>
<td>average value measurement is repeated with that frequency</td>
</tr>
<tr>
<td>rms</td>
<td>root-mean-square value is measured over that time window</td>
<td>root-mean-square measurement is repeated with that frequency</td>
</tr>
<tr>
<td>peak</td>
<td>peak value occurs during that time window</td>
<td>observation of peak value is repeated with that frequency</td>
</tr>
</tbody>
</table>

In all applicable cases, the interpretation FREQUENCY = 1 / TIME is valid.
The values for average measurements and for rms measurements scale linearly with FREQUENCY and 1 / TIME, respectively. For transient measurements and for peak measurements, the TIME or FREQUENCY annotations are purely informational. The values do not scale with TIME or FREQUENCY.

Examples:

- transient measurement of ENERGY
- static measurement of VOLTAGE, CURRENT, POWER
- average measurement of POWER, CURRENT
- rms measurement of POWER, CURRENT
- peak measurement of VOLTAGE, CURRENT, POWER

Both FREQUENCY and TIME can also be used in the HEADER of arithmetic models. In particular, TIME in the HEADER describes waveforms of analog measurements. The initial and final values of the measurement, respectively, apply to the time before the first measurement and after the last measurement, respectively.

The semantics are defined as follows:

<table>
<thead>
<tr>
<th>MEASUREMENT annotation</th>
<th>Semantic meaning of TIME in HEADER</th>
<th>Use of FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>transient</td>
<td>piece-wise linear waveform of instantaneous value over time</td>
<td>allowed in HEADER or as annotation, boundary restrictions apply (see below)</td>
</tr>
<tr>
<td>static</td>
<td>N/A</td>
<td>allowed in HEADER only, no restriction</td>
</tr>
<tr>
<td>average</td>
<td>incremental average value, measured from the previous time point to the actual time point</td>
<td>allowed in HEADER or as annotation, boundary restrictions apply</td>
</tr>
<tr>
<td>rms</td>
<td>incremental rms value, measured from the previous time point to the actual time point</td>
<td>allowed in HEADER or as annotation, boundary restrictions apply</td>
</tr>
<tr>
<td>peak</td>
<td>peak value encountered between the previous time point and the actual time point</td>
<td>allowed in HEADER or as annotation, boundary restrictions apply</td>
</tr>
</tbody>
</table>

In the context of analog measurement versus TIME description, FREQUENCY may still be used either as complementary argument in the HEADER or as annotation. The interpretation FREQUENCY = 1 / TIME is not valid. Instead, the following boundary restrictions apply:

- The initial measurement value and the final measurement value must be the same.
- The overall time window between the first and the last measurement must be bound by 1 / FREQUENCY

These restrictions make sure that there is a physical interpretation of measurements as a function of TIME and FREQUENCY.

Examples:
• transient waveform, average, rms, peak of CURRENT vs. TIME, VOLTAGE vs. TIME. Resonance effects (parasitic oscillators) may influence the measurement results in a certain FREQUENCY range.

• static measurement of POWER vs. FREQUENCY. FREQUENCY of a voltage-controlled oscillator is statically controlled by a DC voltage. Measurement could also be expressed as power versus control voltage, but the control voltage may not be observable in simulation, whereas the frequency of the oscillating output signal is observable.

Figure 3-18: Illustration of Waveforms

\[
\begin{align*}
\text{avg}(T0) &= E0 \\
\text{avg}(T1) &= \frac{(E0+E1)}{2} \\
\text{avg}(T2) &= \frac{(E1+E2)}{2} \\
\text{avg}(T3) &= \frac{(E2+E3)}{2} \\
\text{avg}(T4) &= E3 \\
\text{rms}(T0) &= \sqrt{\frac{E0^2}{3}} \\
\text{rms}(T1) &= \sqrt{\frac{(E0^2+E0E1+E1^2)}{3}} \\
\text{rms}(T2) &= \sqrt{\frac{(E1^2+E1E2+E2^2)/3}{3}} \\
\text{rms}(T3) &= \sqrt{\frac{(E2^2+E2E3+E3^2)/3}{3}} \\
\text{rms}(T4) &= \sqrt{E3^2} \\
\end{align*}
\]

**T4 - T0 \leq 1 / \text{FREQUENCY}**

### 3.7 Library Organization

#### 3.7.1 Scoping Rules

The following scope rules shall apply to all library objects and its usage.

**Rule 1:** An object shall be defined before it is referenced.
**Rule 2:** An ALF object shall be known (referenceable) inside the parent object, inside all objects defined after that object within the same parent object, and inside all the children of those objects.

**Rule 3:** An object definition with only a keyword but without an object identifier implies that the content of this definition will be applied to all objects identified by this keyword at the current scope and the underlying levels of hierarchy.

Example:

```alure
LIBRARY my_library {
  CAPACITANCE {UNIT = pF;}  // default capacitance units for all
  ...  // cells in my_library
  CELL cell1 {
    CAPACITANCE {UNIT = pF;} // capacitance units specific to cell1
    PIN A {CAPACITANCE = 10.5;}
    ...
  }
  CELL cell2 {
    PIN A {CAPACITANCE = 0.010;} // default capacitance units
    ...
  }
}
```

The capacitance of pin A of cell1 is 10.5 fF. The capacitance of pin A of cell2 is 0.010 pF.

**Rule 4:** An object shall not be defined again at the same level of scope. A definition of an object is considered duplicate, if both keyword and object identifier are identical.

Example:

It is illegal to write the following:

```alure
LIBRARY my_library {
  CAPACITANCE {UNIT = fF;}
  ...  // duplicate definition
  CELL cell1 {
    pin A {CAPACITANCE = 10.5;}
    ...
  }
  CELL cell2 {
    pin A {CAPACITANCE = 0.010;}
    ...
  }
}
```

There are three possible ways capacitance units can be set to fF for some of the cells in the library and pF for other cells in the same library:

1. put each set of cells in a different sublibrary,
2. define templates for the different units and reference them appropriately, or
3. define the units locally inside each cell.
3.7.2 Use of multiple files

Sometimes it is inconvenient or impractical to include all of the data for a technology library in a single file. The INCLUDE keyword is used to compose a library from multiple files.

An INCLUDE statement may be used within any context, but any included file shall contain at least a valid object definition to be considered a legal ALF file. It shall begin with a keyword, otherwise it may be ignored by a generic parser.

In general the effect of using the INCLUDE statement is to be considered equivalent to inserting the contents of the included file at that point in the parent file.

For example, a top-level ALF library file may contain only the following statements, where each file contains appropriate data to make up the entire library.

```plaintext
LIBRARY mylib {
    INCLUDE "libdata.alf";
    INCLUDE "templates.alf";
    INCLUDE "cells.alf";
    INCLUDE "wiremodels.alf";
}
```

A complete ALF library definition must begin with the LIBRARY keyword. A list of cell definitions shall not be considered a full, legal ALF library database.

3.8 Referenceable objects

General referenceable objects within the scope of visibility are TEMPLATE and GROUP. Library-specific referenceable objects are PIN, PRIMITIVE and arithmetic model. The figure 3-19 shows relationships between these objects and where they can be referenced.

![Diagram showing relationships between ALF objects]

Figure 3-19: Referencing rules for ALF objects
The TEMPLATE and GROUP objects are referenceable only by their respective instantiation. The TEMPLATE definitions may contain instantiation of previously defined templates, which allows construction of reusable objects.

The arithmetic models can be referenced by other arithmetic models, if they are contained within each other. This allows hierarchical modeling and a mix of table and equation based models.

The PIN objects are referenced within FUNCTION and VECTOR objects and within any annotation container inside the same CELL object.

The PRIMITIVES are referenceable by a CELL in order to define pins and functionality or within a FUNCTION to define functionality only or within an annotation container, e.g. SCAN.

3.8.1 Referencing PRIMITIVEs or CELLS

A PRIMITIVE referenced in a CELL may replace the complete set of PIN and FUNCTION definition. PINS may be declared before the reference to the PRIMITIVE, in order to provide supplementary annotations that cannot be inherited from the PRIMITIVE. However, the CELL must be pin-compatible with the PRIMITIVE.

If the PRIMITIVE or a CELL is referenced in an annotation container such as SCAN, only the subset of PINS used in the non-scan cell must be compatible with the PINS of the cell.

The pin names can be referenced by order or by name. In the latter case, the LHS is the pin name of the referenced PRIMITIVE or CELL (e.g. the non-scan cell), the RHS is the pin name of the actual cell. A constant logic value can also appear at the LHS or RHS, indicating that a pin needs to be tied to a constant value. If this information is already specified in an annotation inside the PIN object itself, referencing between a pin name and a constant value is not necessary.

PRIMITIVES can also be instantiated inside BEHAVIOR.

3.8.2 Referencing PINS in FUNCTIONs

Inside a CELL object, the PIN objects with the PINTYPE digital define variables for FUNCTION objects inside the same CELL. A primary input variable inside a FUNCTION must be declared as a PIN with DIRECTION=input or both (since DIRECTION=both is a bidirectional pin). However, it is not required that all declared pins are used in the function. Output variables inside a FUNCTION need not be declared pins, since they are implicitly declared when they appear at the left-hand side (LHS) of an assignment.
Example:

```java
CELL my_cell {
  PIN A {DIRECTION = input;}
  PIN B {DIRECTION = input;}
  PIN C {DIRECTION = output;}
  FUNCTION {
    BEHAVIOR {
      D = A && B;
      C = !D;
    }
  }
}
```

C and D are output variables that need not be declared prior to use. After implicit declaration, D is reused as an input variable. A and B are primary input variables.

Inside BEHAVIOR, variables which appear at the LHS of an assignment conditionally controlled by a vector expression, as opposed to an unconditional continuous assignment, will hold their values, when the vector expression evaluates false. Those variables are considered to have latch-type behavior.

Examples:

```java
BEHAVIOR {
  @(G)
  Q = D; // both Q and QN have latch-type behavior
  QN = !D;
}

BEHAVIOR {
  @(G)
  Q = D; // only Q has latch-type behavior
  QN = !Q;
}
```

The functional description can be supplemented by a STATETABLE, the first row of which contains the arguments that are object IDs of declared PINs. The arguments appear in two fields, first is input, second is output. The fields are separated by colon (:). The rows are separated by (;). The arguments may appear in both fields, if the PINs have attribute direction=output or direction=both. If direction=output, then the argument has latch-type behavior. The argument on the input field is considered previous state, and the argument on the output field is considered the next state. If direction=both, then the argument on the input field applies for input direction, and the argument on the output field applies for output direction of the bidirectional PIN.
Example:

CELL ff_sd {
    PIN q {DIRECTION=output;}
    PIN d {DIRECTION=input;}
    PIN cp {DIRECTION=input;
        SIGNALTYPE=clock;
        POLARITY=rising_edge;}
    PIN cd {DIRECTION=input; SIGNALTYPE=clear; POLARITY=low;}
    PIN sd {DIRECTION=input; SIGNALTYPE=set; POLARITY=low;}
    FUNCTION {
        BEHAVIOR {
            @(!cd) (q = 0;); (:!sd) (q = 1;) : (01 cp) {q = d;}
        }
        STATETABLE {
            cd sd cp d q : q ;
            0 ? ?? ? ? : 0 ;
            1 0 ?? ? ? : 1 ;
            1 1 1? ? 0 : 0 ;
            1 1 ?0 ? 1 : 1 ;
            1 1 1? ? 0 : 0 ;
            1 1 ?0 ? 1 : 1 ;
            1 1 01 ? ? :(d);
        }
    }
}

If the output variable with latch-type behavior depends only on the previous state of itself as opposed to the previous state of other output variables with latch-type behavior, it is not necessary to use that output variable in the input field. This allows a more compact form of the STATETABLE.

Example:

STATETABLE {
    cd sd cp d q : q ;
    0 ? ?? ? ? : 0 ;
    1 0 ?? ? ? : 1 ;
    1 1 1? ? 0 : 0 ;
    1 1 ?0 ? 1 : 1 ;
    1 1 1? ? 0 : 0 ;
    1 1 ?0 ? 1 : 1 ;
    1 1 01 ? ? :(d);
}

A generic ALF parser must make the following semantic checks:

- Are all variables of a FUNCTION declared either by declaration as PIN names or through assignment?
- Does the STATETABLE exclusively contain declared PINS?
- Is the format of the STATETABLE, i.e. the number of elements in each field of each row, consistent?
- Are the values consistently either state or transition digits?
• Is the number of digits in each **TABLE** entry compatible with the signal bus width?

A more sophisticated checker for complete verification for logical consistency of a **FUNCTION**
given in both equation and tabular representation is out of scope for a generic ALF parser,
which checks only syntax and compliance to semantic rules. However, formal verification
algorithms can be implemented in special-purpose ALF analyzers or model generators/compilers.

### 3.8.3 Referencing PINs in **VECTORS**

A **VECTOR** defines state, transition, or sequence of transitions of pins which are controllable and
observable for characterization.

The set of **PINs** of a **CELL** with **PINTYPE=**digital and **SCOPE=**both (i.e. both **behavior** and
**measure**) is the **default** set of variables in the event queue for vector expressions relevant for
**VECTOR objects** and **BEHAVIOR** statements.

For detection of a sequence of transitions it is necessary to observe the set of variables in the
event queue. For instance, if the set of pins consists of A, B, C, D, the vector expression

\[(01 A \rightarrow 01 B)\]

implies, that no transition on A, B, C, D occurs between the transitions 01 A and 01 B.

The default set of pins applies only for vector expressions without conditions. The conditional
event AND operator limits the set of variables in the event queue. In this case, only the state of
the condition and the variables appearing in the vector expression are observed.

**Example:**

\[(01 A \rightarrow 01 B) \&\& (C | D)\]

No transition on A, B occurs between 01 A and 01 B, and (C | D) must stay true in-between
01 A and 01 B as well. However, C and D may change their values as long as (C | D) is
satisfied.

### 3.8.4 Referencing multi-dimensional **PINs**

A group of pins of a cell can be logically considered together by declaring a **PIN** with a range.
A pin can be declared with one dimension or two dimensions. For example,

```
PIN A ;  // declares a scalar pin A
PIN [1:8] A1 ;  // declares pin A1 with bits numbered 1 through 8
```

When a pin is declared with one dimension, the left number in the range shall specify the most
significant bit number and the right number shall specify the least significant bit number. If the
pin is declared with two dimensions, the second dimension shall specify the index of the first
and the last rows of the two-dimension pin object.

A **PIN** object can be referenced in one of the four forms:

1. Individual bit - pin name shall be followed by an index of the bit
2. Contiguous group of bits - pin name shall be followed by the contiguous range of bits. The most significant and least significant bit numbers shall follow the same relationship as given in the declaration.

3. Entire PIN object - Only pin name shall be used. It shall be illegal to reference entire two-dimension pin object in any operation.

4. One row of a PIN object - For a two-dimension pin object, name of the pin shall be followed by the row index of that pin. It shall be illegal to reference either individual bit or a group of bits of a two-dimension pin object directly in an operation.

When a PIN object is referenced on the left-hand side of an assignment, the result of the right-hand side expression is copied from the least significant bit towards the most significant bit. If the right-hand side value has lesser number of bits than the referenced PIN object in an assignment, the right-hand side value shall be zero-extended to fill the remaining bits of the referenced PIN object. If the right-hand side value has more bits than the referenced PIN object in an assignment, the right-hand side value shall be truncated to the size of the referenced PIN object.

Example:

    pin [1:8] A1;

    A1[8] = 'b0 ;
    // left most bit is truncated
    A2[18] = 'h5 ; // is equivalent to A2[18] = 'b0000_0101
    // entire row 18 of A2 is assigned a value.

The two-dimension PIN objects shall be referenced with the row index. It shall be illegal to directly reference an individual bit or a contiguous group of bits of a two-dimension PIN object. It shall be illegal to reference the entire PIN object as a two-dimension PIN object.

Example:

    pin [1:8] B1 ;
    pin C ;
    // legal references and assignments

    A2[10] = 'h45 ; // assign 'h45 to row 10 of A2 ('b0100_0101)
    B1   = A2[10] ; // copies whole row A2[10] to B1
    C    = B1[3] ; // c = 'b0

    // Illegal references and assignments
    // A2 = B1 ; illegal reference to entire A2

It shall be legal to use identifiers as index, but expressions shall not be permitted as index.
Example

```plaintext
pin [4:1] ADDR;

ADDR       = 'd 10;
A2[ADDR]   = 'h45 ; // assign 'h45 to row 10 of A2  ('b0100_0101)

// A2[ADDR+1] = 'h45 ; illegal
```

### 3.8.5 Referencing arithmetic models

Input variables, also called *arguments of arithmetic models*, appear in the **HEADER** of the model. In the simplest case, the **HEADER** is just a list of arguments, each being a context-sensitive keyword. The model itself is also defined with a context-sensitive keyword.

The model can be in equation form. All arguments of the equation must be in the **HEADER**. The **ALF parser** should issue an error if the **EQUATION** uses an argument not defined in the **HEADER**. A warning should be issued if the **HEADER** contains arguments not used in the **EQUATION**.

Example:

```plaintext
DELAY {
    ...
    HEADER {
        CAPACITANCE {...}
        SLEWRATE {...}
    }
    EQUATION {
        0.01 + 0.3*SLEWRATE + (0.6 + 0.1*SLEWRATE)*CAPACITANCE
    }
}
```

If the model uses a **TABLE**, then each argument in the **HEADER** also needs a table in order to define the format. The order of arguments decides how the index to each entry is calculated. The first argument is the innermost index, the following arguments are outer indices.

```plaintext
DELAY {
    HEADER {
        CAPACITANCE {
            TABLE {0.03 0.06 0.12 0.24}
        }
        SLEWRATE {
            TABLE {0.1 0.3 0.9}
        }
    }
    TABLE {
        0.07 0.10 0.14 0.22
        0.09 0.13 0.19 0.30
        0.10 0.15 0.25 0.41
    }
}
```
The first argument `load` has 4 entries. The second argument `ramptime` has 3 entries. Hence `DELAY` has 4*3=12 entries. For readability, comments may be inserted in the table.

```
TABLE {
    //capacitance:0.03 0.06 0.12 0.24
    //            -------------------   slewrate:
    0.07 0.10 0.14 0.22 // 0.1
    0.09 0.13 0.19 0.30 // 0.3
    0.10 0.15 0.25 0.41 // 0.9
}
```

Comments have no significance for the ALF parser, nor has the arrangement in rows and columns. Only the order of values is important for index calculation. The table can be made more compact by removing newlines.

```
TABLE { 0.07 0.10 0.14 0.22 0.09 0.13 0.19 0.30 0.10 0.15 0.25 0.41 }
```

For readability, the models and arguments can also have names, i.e. object IDs. For named objects, the name is used for referencing, rather than the keyword.

```
DELAY rise_out{
    ...
    HEADER {
        CAPACITANCE c_out {...}
        SLEWRATE fall_in {...}
    }
    EQUATION {
        0.01 + 0.3 * fall_in + (0.6 + 0.1* fall_in) * c_out
    }
}
```

The arguments of an arithmetic model can be arithmetic models themselves. In this way, combinations of `TABLE-` and `EQUATION-based` models can be used, for instance, in derating. Coherent with `FUNCTION`, both `EQUATION` and `TABLE` representation of an arithmetic model are allowed. The `EQUATION` is intended to be used when the values of the arguments fall out of range, i.e. to avoid extrapolation. This is especially used in wire models.

### 3.9 Functional modeling styles and rules

ALF allows the following functional modeling styles: equation based, table-based, and primitive based. Both equation- and table-based functions are canonical and specify exactly the same functionality. Each primitive must be definable in either of the canonical modeling styles.

Since ALF supports both combinational and sequential functional specification using the 8-value logic system, an exhaustive behavioral description of all scenarios, which is needed for a simulation model, would be very cumbersome and defeat the purpose of a simple, easy-to-use language. Hence the following rules shall apply for compilation of the ALF description into a full simulation model. These rules cover all cases where the functional description is not explicit. All of these rules can be overruled by explicit specification of the behavior.
3.9.1 Rules for combinational functions

If a boolean expression evaluates True, the assigned output value is 1. If a boolean expression evaluates False, the assigned output value is 0. If the value of a boolean expression cannot be determined, the assigned output value is X. Assignment of values other than 1, 0, or X must be specified explicitly.

For evaluation of the boolean expression, input value 'bH shall be treated as 'b1. Input value 'bL shall be treated as 'b0. All other input values shall be treated as 'bX.

Examples:

In equation form, these rules can be expressed as follows.

```
BEHAVIOR {
  Z = A;
}
```

is equivalent to

```
BEHAVIOR {
  Z = A ? 'b1 : 'b0;
}
```

More explicitly, this is also equivalent to

```
BEHAVIOR {
  Z = (A=='b1 || A=='bH)? 'b1 : (A=='b0 || A=='bL)? 'b0 : 'bX;
}
```

In table form, this can be expressed as follows:

```
STATETABLE {
  A : Z;
  ? : (A);
}
```

which is equivalent to

```
STATETABLE {
  A : Z;
  0 : 0;
  1 : 1;
}
```

More explicitly, this is also equivalent to

```
STATETABLE {
  A : Z;
  0 : 0;
  L : 0;
  1 : 1;
  H : 1;
  X : X;
  W : X;
  Z : X;
  U : X;
}
```
3.9.2 Basic rules for sequential functions

A sequential function is described in equation form by a boolean assignment with a condition specified by a boolean expression or a vector expression. If the condition evaluates to 1 (true), the boolean assignment is activated and the assigned output values follows the rules for combinational functions. If the vector expression evaluates to 0 (false), the output variables hold their assigned value from the previous evaluation.

For evaluation of a condition, the value 'bH shall be treated as true, the value 'bL shall be treated as false. All other values shall be treated as the unknown value 'bX.

Example:

The following behavior statement

```
BEHAVIOR {
  @ (E) {Z = A;}
}
```

is equivalent to

```
BEHAVIOR {
  @ (E=='b1 || E=='bH) {Z = A;}
}
```

The following statetable statement, describing the same logic function

```
STATETABLE {
  E A : Z;
  0 ? : (Z);
  1 ? : (A);
}
```

is equivalent to

```
STATETABLE {
  E A : Z;
  0 ? : (Z);
  L ? : (Z);
  1 ? : (A);
  H ? : (A);
}
```

For edge-sensitive and higher-order event sensitive functions, transitions from or to 'bL shall be treated like transitions from or to 'b0, and transitions from or to 'bH shall be treated like transitions from or to 'b1.

Not every transition may trigger the evaluation of a function. The set of vectors triggering the evaluation of a function are called active vectors. From the set of active vectors, a set of inactive vectors can be derived, which will clearly not trigger the evaluation of a function. There are also a set of ambiguous vectors, which may or may not trigger the evaluation of the function.

The set of active vectors is the set of vectors for which both observed states before and after the transition are known to be logically equivalent to the corresponding states defined in the vector expression.
The set of inactive vectors is the set of vectors for which at least one of the observed states before or after the transition is known to be not logically equivalent to the corresponding states defined in the vector expression.

Example:

For the following sequential function

\[
\text{\texttt{@ (01 CP) \{ Z = A; \}}}
\]

the active vectors are

\[
(\text{'b0'b1 CP})
(\text{'b0'bH CP})
(\text{'bL'b1 CP})
(\text{'bL'bH CP})
\]

and the inactive vectors are

\[
(\text{'b1'b0 CP})
(\text{'b1'bL CP})
(\text{'b1'bX CP})
(\text{'b1'bW CP})
(\text{'b1'bZ CP})
(\text{'bH'b0 CP})
(\text{'bH'bL CP})
(\text{'bH'bX CP})
(\text{'bH'bW CP})
(\text{'bH'bZ CP})
(\text{'bX'b0 CP})
(\text{'bX'bL CP})
(\text{'bX'bW CP})
(\text{'bX'bZ CP})
(\text{'bW'b0 CP})
(\text{'bW'bL CP})
(\text{'bW'bZ CP})
(\text{'bZ'b0 CP})
(\text{'bZ'bL CP})
(\text{'bU'b0 CP})
(\text{'bU'bL CP})
\]

and the ambiguous vectors are

\[
(\text{'b0'bX CP})
(\text{'b0'bW CP})
(\text{'b0'bZ CP})
(\text{'bL'bX CP})
(\text{'bL'bW CP})
(\text{'bL'bZ CP})
(\text{'bX'b1 CP})
(\text{'bW'b1 CP})
(\text{'bZ'b1 CP})
(\text{'bX'bH CP})
(\text{'bW'bH CP})
(\text{'bZ'bH CP})
(\text{'bX'bW CP})
(\text{'bX'bZ CP})
(\text{'bW'bX CP})
\]
For vectors using exclusively based literals, the set of active vectors is the vector itself, the set of inactive vectors is any vector with at least one different literal, the set of ambiguous vectors is empty.

Therefore ALF does not provide a default behavior for ambiguous vectors, since the behavior for each vector may be explicitly defined in vectors using based literals.

### 3.9.3 Concurrency in combinational and sequential functions

Multiple boolean assignments in combinational functions are understood to be concurrent. The order in the functional description does not matter, as each boolean assignment describes a piece of a logic circuit. This is illustrated below.

```plaintext
BEHAVIOR {
    Q1 = <1st_boolean_expression(D1..Di)> ;
    ...
    Qn = <nth_boolean_expression(D1..Di)> ;
}
```

![Diagram](image)

**Figure 3-20: Concurrency for combinational logic**

In level-sensitive sequential logic, one condition may trigger more than one boolean assignment, which are also understood to be concurrent. This is illustrated below.
The principle of concurrency applies also for edge-sensitive sequential functions, where the triggering condition is described by a vector expression rather than a boolean expression. In edge-sensitive logic, the target logic variable for the boolean assignment (LHS) may also be an operand of the boolean expression defining the assigned value (RHS). Concurrency implies that the RHS expressions are evaluated immediately before the triggering edge, and the values are assigned to the LHS variables immediately after the triggering edge. This is illustrated below.

**Figure 3-21: Concurrency for level-sensitive sequential logic**
Statements with multiple concurrent conditions for boolean assignments may also be used in sequential logic. In that case conflicting values may be assigned to the same logic variable. A default conflict resolution is not provided for the following reasons:

- Conflict resolution may not be necessary, since the conflicting situation is prohibited by specification.
- For different types of analysis (e.g. logic simulation), a different conflict resolution behavior may be desirable, while the physical behavior of the circuit will not change. For instance, pessimistic conflict resolution would always assign "X", more accurate conflict resolution would first check whether the values are conflicting. Different choices may be motivated by a tradeoff in analysis accuracy and runtime.
- If complete library control over analysis is desired, conflict resolution can be specified explicitly.

Example:

```
BEHAVIOR {
  @ ( <condition_1> ) { Q = <value_1>; }
  @ ( <condition_2> ) { Q = <value_2>; }
}
```

Explicit pessimistic conflict resolution can be described as follows:

```
BEHAVIOR {
  @ ( <condition_1> && <condition_2> ) { Q = 'bX; }
  @ ( <condition_1> && ! <condition_2>) { Q = <value_1>; }
  @ ( <condition_2> && ! <condition_1>) { Q = <value_2>; }
}
```
Explicit accurate conflict resolution can be described as follows:

```
BEHAVIOR {
    @ ( <condition_1> && <condition_2>  ) { 
        Q = ((value_1)==(value_2))? <value_1> : 'bX;
    }
    @ ( <condition_1> && ! <condition_2> ) { Q = <value_1> ; }
    @ ( <condition_2> && ! <condition_1> ) { Q = <value_2> ; }
}
```

Since the conditions are now rendered mutually exclusive, equivalent descriptions with priority statements can be used. They are more elegant than descriptions with concurrent statements.

```
BEHAVIOR {
    @ ( <condition_1> && <condition_2>  ) {
        Q = <conflict_resolution_value> ;
    }
    : ( <condition_1> ) { Q = <value_1> ; }
    : ( <condition_2> ) { Q = <value_2> ; }
}
```

Given the various explicit description possibilities, the standard does not prescribe a default behavior. The model developer has the freedom of incomplete specification.

### 3.9.4 Initial values for logic variables

Per definition, all logic variables in a behavioral description have the initial value "U" which means "uninitialized". This value cannot be assigned to a logic variable, yet it can be used in a behavioral description in order to assign initial values different from "U", if desired.

Example:

```
BEHAVIOR {
    @ ( Q1 == 'bU ) { Q1 = 'b1 ; }
    @ ( Q2 == 'bU ) { Q2 = 'b0 ; }
    // followed by the rest of the behavioral description
}
```

A template can be used to make the intent more obvious, for example:

```
TEMPLATE INITIAL_VALUE {
    @ ( <logic_variable> == 'bU ) {
        <logic_variable> = <initial_value> ;
    }
}
```

```
BEHAVIOR {
    INITIAL_VALUE ( Q1 'b1' )
    INITIAL_VALUE ( Q2 'b0' )
    // followed by the rest of the behavioral description
}
```
3.10 Primitives

3.10.1 Concept of user-defined and predefined primitives

Primitives are described in ALF syntax. Primitives are generic cells containing PIN and FUNCTION objects only, i.e. no characterization data. The primitives are used for structural functional modeling.

Example:

```
PRIMITIVE MY_PRIMITIVE {
    PIN x { ... }
    PIN y { ... }
    PIN z { ... }
    FUNCTION { ... }
}
CELL MY_CELL {
    PIN a { ... }
    PIN b { ... }
    PIN c { ... }
    FUNCTION {
        BEHAVIOR { MY_PRIMITIVE { x=a; y=b; z=c; } }
    }
    ...
}
```

Extensible primitives, i.e. primitives with variable number of pins can be modeled with TEMPLATE.

Example:

```
TEMPLATE EXTENSIBLE_PRIMITIVE{
    PRIMITIVE <primitive_name> {
        PIN [0:<max_index>] pin_name { ... }
        ...
    }
}

// instantiation of the template creates a primitive
EXTENSIBLE_PRIMITIVE {
    primitive_name = MY_EXTENSIBLE_PRIMITIVE;
    max_index = 2;
}
```

The set of statements above is equivalent to the following statement:

```
PRIMITIVE MY_EXTENSIBLE_PRIMITIVE {
    PIN [0:2] pin_name { ... }
    ...
}
```
The primitive can be used as shown in the following example:

```plaintext
CELL MY_MEGACELL {
    PIN a { ... }
    PIN b { ... }
    PIN c { ... }
    FUNCTION {
        BEHAVIOR {
            // reference to the primitive
            MY_EXTENSIBLE_PRIMITIVE {
                pin_name[0] = a;
                pin_name[1] = b;
                pin_name[2] = c;
            }
        }
    }
    ...
}
```

Primitives can be freely defined by the user. For convenience, ALF provides a set of predefined primitives with the reserved prefix `ALF_` in their name, which cannot be used by user-defined primitives.

For all PINs of predefined primitives, the following annotations are defined per default:

```plaintext
VIEW = functional;
SCOPE = behavioral;
```

For predefined extensible primitives a placeholder may be directly in the PRIMITIVE definition:

```plaintext
PRIMITIVE ALF_EXTENSIBLE_PRIMITIVE {
    PIN [0:<max_index>] pin_name {  ... }
    ...
}
```

This is equivalent to the following more verbose set of statements:

```plaintext
TEMPLATE EXTENSIBLE_PRIMITIVE{
    PRIMITIVE <primitive_name> {
        PIN [0:<max_index>] pin_name {  ... }
        ...
    }
}
```

```plaintext
EXTENSIBLE_PRIMITIVE {
    primitive_name = ALF_EXTENSIBLE_PRIMITIVE;
    max_index = <max_index>;
}
```

### 3.10.2 Predefined combinational primitives

#### 3.10.2.1 One input, multiple output primitives

There are two combinational primitives with one input pin and multiple output pins:

- ALF_BUF
- ALF_NOT
A GROUP statement is used to define the behavior of all output pins in one statement. The output pins are indexed starting with 0. If 0 is the only index used, the index can be omitted when referencing the output pin, e.g. `out` refers to `out[0]`.

```
PRIMITIVE ALF_BUF {
    GROUP index {0:<max_index>}
    PIN[0:<max_index>] out {
        DIRECTION = output ;
    }
    PIN in {
        DIRECTION = input ;
    }
    FUNCTION {
        BEHAVIOR {
            out[index] = in;
        }
    }
}
```

Figure 3-23: Primitive model of ALF_BUF

```
PRIMITIVE ALF_NOT {
    GROUP index {0:<max_index>}
    PIN[0:<max_index>] out {
        DIRECTION = output ;
    }
    PIN in {
        DIRECTION = input ;
    }
    FUNCTION {
        BEHAVIOR {
            out[index] = !in;
        }
    }
}
```

Figure 3-24: Primitive model of ALF_NOT

3.10.2.2 One output, multiple input primitives

There are six combinational primitives with one output pin and multiple input pins:

- ALF_AND, ALF_NAND, ALF_OR, ALF_NOR, ALF_XOR, ALF_XNOR
The input pins are indexed starting with 0. If 0 is the only index used, the index can be omitted when referencing the input pin, e.g. `in` refers to `in[0].`

```
PRIMITIVE ALF_AND {
    PIN out {
        DIRECTION = output;
    }
    PIN[0:<max_index>] in {
        DIRECTION = input;
    }
    FUNCTION {
        BEHAVIOR {
            out = & in;
        }
    }
}
```

Figure 3-25: Primitive model of ALF_AND

```
PRIMITIVE ALF_NAND {
    PIN out {
        DIRECTION = output;
    }
    PIN[0:<max_index>] in {
        DIRECTION = input;
    }
    FUNCTION {
        BEHAVIOR {
            out = ~& in;
        }
    }
}
```

Figure 3-26: Primitive model of ALF_NAND

```
PRIMITIVE ALF_OR {
    PIN out {
        DIRECTION = output;
    }
    PIN[0:<max_index>] in {
        DIRECTION = input;
    }
    FUNCTION {
        BEHAVIOR {
            out = | in;
        }
    }
}
```

Figure 3-27: Primitive model of ALF_OR
Figure 3-28: Primitive model of ALF_NOR

```plaintext
PRIMITIVE ALF_NOR {
    PIN out {
        DIRECTION = output;
    }
    PIN[0:<max_index>] in {
        DIRECTION = input;
    }
    FUNCTION {
        BEHAVIOR {
            out = ~| in;
        }
    }
}
```

Figure 3-29: Primitive model of ALF_XOR

```plaintext
PRIMITIVE ALF_XOR {
    PIN out {
        DIRECTION = output;
    }
    PIN[0:<max_index>] in {
        DIRECTION = input;
    }
    FUNCTION {
        BEHAVIOR {
            out = ^in;
        }
    }
}
```

Figure 3-30: Primitive model of ALF_XNOR

```plaintext
PRIMITIVE ALF_XNOR {
    PIN out {
        DIRECTION = output;
    }
    PIN[0:<max_index>] in {
        DIRECTION = input;
    }
    FUNCTION {
        BEHAVIOR {
            out = ~^in;
        }
    }
}
```
3.10.3 Predefined tristate Primitives

There are four tristate primitives:

ALF_BUFIF1, ALF_BUFIF0, ALF_NOTIF1, ALF_NOTIF0

PRIMITIVE ALF_BUFIF1 {
  PIN out {
    DIRECTION = output;
    ENABLE_PIN = enable;
    ATTRIBUTE {TRISTATE}
  }
  PIN in {
    DIRECTION = input;
  }
  PIN enable {
    DIRECTION = input;
    SIGNALTYPE = out_enable;
  }
  FUNCTION {
    BEHAVIOR {
      out = (enable)? in : 'bZ;
    }
    STATETABLE {
      enable in : out;
      0 ? : Z;
      1 ? : (in);
    }
  }
}

Figure 3-31: Primitive model of ALF_BUFIF1

PRIMITIVE ALF_BUFIF0 {
  PIN out {
    DIRECTION = output;
    ENABLE_PIN = enable;
    ATTRIBUTE {TRISTATE}
  }
  PIN in {
    DIRECTION = input;
  }
  PIN enable {
    DIRECTION = input;
    SIGNALTYPE = out_enable;
  }
  FUNCTION {
    BEHAVIOR {
      out = (!enable)? in : 'bZ;
    }
  }
}
Figure 3-32: Primitive model of ALF_BUFIF0

```
PRIMITIVE ALF_NOTIF1 {
    PIN out {
        DIRECTION = output;
        ENABLE_PIN = enable;
        ATTRIBUTE [TRISTATE]
    }
    PIN in {
        DIRECTION = input;
    }
    PIN enable {
        DIRECTION = input;
        SIGNALTYPE = out_enable;
    }
    FUNCTION {
        BEHAVIOR {
            out = (enable)? !in : 'bZ;
        }
        STATETABLE {
            enable in : out;
            1 ? : Z;
            0 ? : (in);
        }
    }
}
```

Figure 3-33: Primitive model of ALF_NOTIF1

```
PRIMITIVE ALF_NOTIF0 {
    PIN out {
        DIRECTION = output;
        ENABLE_PIN = enable;
        ATTRIBUTE [TRISTATE]
    }
    PIN in {
        DIRECTION = input;
    }
    PIN enable {
        DIRECTION = input;
        SIGNALTYPE = out_enable;
    }
    FUNCTION {
```
3.10.4 Predefined multiplexor

The predefined multiplexor has a known output value if either the select signal and the selected data inputs are known or both data inputs have the same known value while the select signal is unknown.

```
PRIMITIVE ALF_MUX {
    PIN Q {
        DIRECTION = output;
        SIGNALTYPE = data;
    }
    PIN[1:0] D {
        DIRECTION = input;
        SIGNALTYPE = data;
    }
    PIN S {
        DIRECTION = input;
        SIGNALTYPE = select;
    }
    FUNCTION {
        BEHAVIOR {
            Q = (S || (d[0] ^ d[1]) )? d[1] : d[0];
        }
        STATETABLE {
            D[0] D[1] S : Q ;
            ? ? ? 0 : (D[0]);
            ? ? 1 : (D[1]);
            0 0 ? : 0;
            1 1 ? : 1;
        }
    }
}
```

Figure 3-35: Primitive model of ALF_MUX
3.10.5 Predefined flipflop

A dual-rail output D-flipflop with asynchronous set and clear pins is a generic edge-sensitive sequential device. Simpler flipflops can be modeled using this primitive by setting input pins to appropriate constant values. More complex flipflops can be modeled by adding combinational logic around the primitive.

A particularity of this model is the use of the last two pins Q_CONFLICT and QN_CONFLICT, which are virtual pins. They specify the state of Q and QN in the event CLEAR and SET become active simultaneously.

```alp
PRIMITIVE ALF_FLIPFLOP {
  PIN Q {
    DIRECTION = output;
    SIGNALTYPE = data;
    POLARITY = non_inverted;
  }
  PIN QN {
    DIRECTION = output;
    SIGNALTYPE = data;
    POLARITY = inverted;
  }
  PIN D {
    DIRECTION = input;
    SIGNALTYPE = data;
  }
  PIN CLOCK {
    DIRECTION = input;
    SIGNALTYPE = clock;
    POLARITY = rising_edge;
  }
  PIN CLEAR {
    DIRECTION = input;
    SIGNALTYPE = clear;
    POLARITY = high;
    ACTION = asynchronous;
  }
  PIN SET {
    DIRECTION = input;
    SIGNALTYPE = set;
    POLARITY = high;
    ACTION = asynchronous;
  }
  PIN Q_CONFLICT {
    DIRECTION = input;
    VIEW = none;
  }
  PIN QN_CONFLICT {
    DIRECTION = input;
    VIEW = none;
  }
  FUNCTION {
    ALIAS QX = Q_CONFLICT;
    ALIAS QNX = QN_CONFLICT;
  }
}```
BEHAVIOR {
  @ (CLEAR && SET) {
    Q  = QX;
    QN = QNX;
  }
  : (CLEAR) {
    Q  = 0;
    QN = 1;
  }
  : (SET) {
    Q  = 1;
    QN = 0;
  }
  : (01 CLOCK) { // edge-sensitive behavior
    Q  = D;
    QN = !D;
  }
}

STATETABLE {
  D CLOCK CLEAR SET QX QNX : Q QN ;
  ? ?? 1 1 ? ? : (QX) (QNX);
  ? ?? 0 1 ? ? : 1 0 ;
  ? ?? 1 0 ? ? : 0 1 ;
  ? 1? 0 0 ? ? : (Q) (QN) ;
  ? ?0 0 0 ? ? : (Q) (QN) ;
  ? 01 0 0 ? ? : (D) (!D) ;
}
}

Figure 3-36: Primitive model of ALF_FLIPFLOP

3.10.6 Predefined latch

The dual-rail D-latch with set and clear pins has the same functionality as the flipflop, except the level-sensitive clock (ENABLE pin) instead of the edge-sensitive clock.

PRIMITIVE ALF_LATCH {
  PIN Q {
    DIRECTION = output;
    SIGNALTYPE = data;
    POLARITY  = non_inverted;
  }
  PIN QN {
    DIRECTION = output;
    SIGNALTYPE = data;
    POLARITY  = inverted;
  }
  PIN D {
    DIRECTION = input;
    SIGNALTYPE = data;
  }
  PIN ENABLE {
DIRECTION  = input;
SIGNALTYPE = clock;
POLARITY   = high;
}
PIN CLEAR {
  DIRECTION  = input;
  SIGNALTYPE = clear;
  POLARITY   = high;
  ACTION     = asynchronous;
}
PIN SET {
  DIRECTION  = input;
  SIGNALTYPE = set;
  POLARITY   = high;
  ACTION     = asynchronous;
}
PIN Q_CONFLICT {
  DIRECTION = input;
  VIEW      = none;
}
PIN QN_CONFLICT {
  DIRECTION = input;
  VIEW      = none;
}
FUNCTION {
  ALIAS QX  = Q_CONFLICT;
  ALIAS QNX = QN_CONFLICT;
  BEHAVIOR {
    @ (CLEAR && SET) {
      Q  = QX;
      QN = QNX;
    }
    : (CLEAR) {
      Q  = 0;
      QN = 1;
    }
    : (SET) {
      Q  = 1;
      QN = 0;
    }
    : (ENABLE) { // level-sensitive behavior
      Q  = D;
      QN = !D;
    }
  }
}
STATETABLE {
  D  ENABLE CLEAR SET QX  QNX : Q  QN ;
  ?  ?  1  1  ?  ?  : (QX) (QNX);
3.11 Parametrizable Cells

The concept of describing primitives with variable bus size shall be extended to parametrizable cells. Dynamic template instantiations are introduced for that purpose.

Template definitions may incorporate any type of object. Placeholders in the template definition are the equivalent of parameters. Hence the definition of parametrizable cells is already supported within the support of general template definitions.

In a static template instantiation, which is identified by the name of the template and by the optional value assignment static, placeholders are replaced by fixed values or by complex objects containing fixed values. Non-referenced placeholders will stay in place and eventually result in semantically unrecognizable objects, which cannot be processed by downstream applications. Such unrecognizable objects shall be disregarded.

In a dynamic template instantiation, which is identified by the name of the template and by the mandatory value assignment dynamic, some placeholders may not be replaced. Those placeholders are application parameters. The template definition may already contain certain relationships between parameters (e.g. arithmetic model and its arguments in the header). Therefore the template instantiation determines, which parameters need application values in order to calculate values for other parameters.

Going one step further, even the relationship between parameters may be defined in the dynamic template instantiation rather than in the template definition. In this case, the identifiers inside the placeholders become variables for arithmetic assignments. This definition of variables shall only be recognized within the context of the dynamic template instantiation.

Arithmetic assignments provide a shorter syntax for equation-based arithmetic models where only placeholder-parameters are involved.

```
   param1 = 1.5 + 0.4 * param2 ** 3 - 2.7 / param3
```

is equivalent to

```
   param1 {
      HEADER { param2 param3 }
      EQUATION { 1.5 + 0.4 * param2 ** 3 - 2.7 / param3 }
   }
```
For table-based models or for models where the arguments have children objects attached to them, the verbose syntax with HEADER must be used.

**Example:**

```plaintext
TEMPLATE adder {
    CELL <cellname> {
        PIN [ <bitwidth> : 1 ] A { DIRECTION = input; }
        PIN [ <bitwidth> : 1 ] B { DIRECTION = input; }
        PIN Cin { DIRECTION = input; }
        PIN [ <bitwidth> : 1 ] S { DIRECTION = output; }
        PIN Cout { DIRECTION = output; }

        FUNCTION {
            BEHAVIOR {
                S = A + B + Cin;
                Cout = (A + B + Cin >= ('b1 << (<bitwidth> - 1)));
            }
        }

        AREA = <areavalue>;
        VECTOR (?! Cin -> ?! Cout) {
            DELAY {
                HEADER {
                    CAPACITANCE {PIN = Cout; }
                    SLEWRATE {PIN = Cin; }
                }
                EQUATION { <D0> + <D1>*CAPACITANCE + <D2>*SLEWRATE }
            }
        }
    }
}
```

The template is used for instantiation of a hardmacro:

```plaintext
adder { /* a hardmacro */
    cellname = ripple_carry_adder_16_bit;
    bitwidth = 16;
    areavalue = 500;
    // D0, D1, D2 are undefined. DELAY cannot be calculated.
}
```

The static instantiation of the hardmacro is equivalent to the following static object:

```plaintext
CELL ripple_carry_adder_16_bit {
    PIN [ 16 : 1 ] A { DIRECTION = input; }
    PIN [ 16 : 1 ] B { DIRECTION = input; }
    PIN Cin { DIRECTION = input; }
    PIN [ 16 : 1 ] S { DIRECTION = output; }
    PIN Cout { DIRECTION = output; }

    FUNCTION {
        BEHAVIOR {
            S = A + B + Cin;
            Cout = (A + B + Cin >= 'b1000000000000000);
        }
    }
}
```
Library Format Specification

Parametrizable Cells

Now the template is used for instantiation of a softmacro:

```d
adder = dynamic { /* a softmacro */
  cellname = ripple_carry_adder_N_bit;
  areavalue = 20 + 30 * bitwidth;
}
D0 {
  HEADER { AREA { TABLE { 10 20 30 } } }
  TABLE { 15.6 34.3 50.7 }
}
D1 = 0.29;
D2 = 0.08;
}
```

The dynamic instantiation of the softmacro results in an object for which certain data depend on the runtime-values of the placeholder-parameters, as indicated in italic below. The calculation method for such data, however, can be compiled statically (e.g. the equation for AREA as a function of bitwidth, the lookup table for D0 as a function of AREA).

```d
CELL ripple_carry_adder_N_bit {
  PIN [ bitwidth : 1 ] A { DIRECTION = input; }
  PIN [ bitwidth : 1 ] B { DIRECTION = input; }
  PIN Cin { DIRECTION = input; }
  PIN [ bitwidth : 1 ] S { DIRECTION = output; }
  PIN Cout { DIRECTION = output; }
  FUNCTION {
    BEHAVIOR {
      S = A + B + Cin;
      Cout = (A + B + Cin >= ('b1 << (bitwidth - 1)));
    }
  }
  AREA = 20 + 30 * bitwidth ;
  VECTOR (?! Cin -> ?! Cout) {
    DELAY {
      HEADER {
    }
  }
```
CAPACITANCE {PIN = Cout; }
SLEWRATE {PIN = Cin; }
D0 {
    HEADER { AREA { TABLE { 10 20 30 } } }
    TABLE { 15.6 34.3 50.7 }
}
}
EQUATION { D0 + 0.29*CAPACITANCE + 0.08*SLEWRATE }
}
}
This section shows various examples of library cells modeled using ALF.

## 4.1 Truth Table vs Boolean Equation

A combinational logic cell and a sequential logic cell are shown below using two different constructs - truth table and boolean equation.

### 4.1.1 NAND gate

A 2-input NAND gate library cell can be modeled as shown below. The **FUNCTION** of the cell can be modeled either as a **STATETABLE** or as **BEHAVIOR** using a boolean equation.

Modeling a NAND gate using truth table:

```alp
CELL ND2 { /* 2 input NAND gate */
    PIN a {DIRECTION=input;}
    PIN b {DIRECTION=input;}
    PIN z {DIRECTION=output;}

    FUNCTION {
        STATETABLE {
            a b : z ;
            0 ? : 1 ;
            1 ? : (!b);
        }
    }
}
```

Modeling a NAND gate using boolean expression:

```alp
CELL ND2 { /* 2 input NAND gate */
    PIN a {DIRECTION=input;}
    PIN b {DIRECTION=input;}
    PIN z {DIRECTION=output;}

    FUNCTION {
        BEHAVIOR {
            z = !(a && b);
        }
    }
}
```
4.1.2 Flipflop

A flipflop with asynchronous set and clear signals is shown below using truth table.

```plaintext
CELL FLIPFLOP {
    PIN CLEAR {DIRECTION=input; SIGNALTYPE=clear; POLARITY=low;}
    PIN SET {DIRECTION=input; SIGNALTYPE=set; POLARITY=low;}
    PIN CLOCK {DIRECTION=input; SIGNALTYPE=clock; POLARITY=rising_edge;}
    PIN D {DIRECTION=input;}
    PIN Q {DIRECTION=output;}
    FUNCTION {
        .../* One of the descriptions below go here */
    }
}

STATETABLE {
    CLEAR SET CLOCK D Q : Q;
    0 ? ?? ? ? : 0;
    1 0 ?? ?? : 1;
    1 1 01 ?? : (d);
    1 1 1? ?? : (q);
    1 1 ?0 ? ? : (q);
}
```

Modeling a flipflop with asynchronous set and clear using boolean expression:

```plaintext
BEHAVIOR {
    @(!CLEAR) {Q = 0;} : (!SET) {Q = 1;} : (01 CLOCK) {Q = D;}
}
```

4.2 Use of primitives

The functionality of a cell can be described using instances of other cells.

4.2.1 D-Flipflop with asynchronous clear

```plaintext
CELL d_flipflop_clr {
    PIN cd {DIRECTION=input; SIGNALTYPE=clear; POLARITY=low;}
    PIN cp {DIRECTION=input; SIGNALTYPE=clock; POLARITY=rising_edge;}
    PIN d {DIRECTION=input;}
    PIN q {DIRECTION=output;}
    FUNCTION {
        .../* One of the descriptions below go here */
    }
}
```

Explicit description does not use instances of other cells defined in the library:

```plaintext
BEHAVIOR {
    @(01 cp && cd) {q = d;}
    @(!cd) {q = 0;}
}
```
Use of primitives permit derivation of new cells from other cells. Below, a D-Flipflop with asynchronous clear is derived from a predefined ALF_FLIPFLOP with asynchronous set and clear (see Section 4.1.2):

```plaintext
BEHAVIOR {
    ALF_FLIPFLOP {CLOCK=cp; D=d; Q=q; SET='b0; CLEAR=!cd;}
}
```

### 4.2.2 JK-flipflop

This example shows three ways of modeling a JK-Flipflop.

```plaintext
CELL jk_flipflop {
    PIN cp {DIRECTION=input; SIGNALTYPE=clock; POLARITY=rising_edge;}
    PIN j {DIRECTION=input;}
    PIN k {DIRECTION=input;}
    PIN q {DIRECTION=output;}
    FUNCTION {
        .../* One of the descriptions below go here */
    }
}
```

**Explicit description:**

```plaintext
BEHAVIOR {
    d =
        (!j && k) ? 0 :
        ( j && !k) ? 1 :
        ( j && k) ? !(q) :
        (!j && !k) ? (q) :
        'bx ;
    @(01 cp) {q = d;}
}
```

**Use of primitives (using predefined ALF_MUX and ALF_FLIPFLOP):**

```plaintext
BEHAVIOR {
    ALF_MUX {Q=d D0=j D1=!k SELECT=q}
    ALF_FLIPFLOP {CLOCK=cp D=d Q=q SET='b0 CLEAR='b0}
}
```

**Use of a hybrid form (boolean expressions within primitive instantiation):**

```plaintext
BEHAVIOR {
    ALF_FLIPFLOP {CLOCK=cp; D=q ? !k : j; Q=q; SET='b0; CLEAR='b0;}
}
```

**Use of truth table:**

```plaintext
STATETABLE {
    cp j k q : (q) ;
    01 0 0 ? : (q) ;
    01 0 1 ? : 0 ;
    01 1 0 ? : 1 ;
    01 1 1 ? : (!q);
    1? ? ? ? : (q) ;
    ?0 ? ? ? : (q) ;
}
```
4.2.3  D-Flipflop with synchronous load and clear

This example shows two different models of a synchronous D-Flipflop.

```alfrm
CELL d_flipflop_ld_clr {
    PIN cs {DIRECTION=input; SIGNALTYPE=clear; POLARITY=low; ACTION=synchronous;}
    PIN ls {DIRECTION=input;}
    PIN cp {DIRECTION=input; SIGNALTYPE=clock; POLARITY=rising_edge;}
    PIN d {DIRECTION=input;}
    PIN q {DIRECTION=output;}
    FUNCTION { ... }
}

Explicit description:

```alfrm
BEHAVIOR {
    d1 = (ls)? d : q;
    d2 = d1 && cs;
    @(01 cp) {q = d2;}
}

Use of primitives:

```alfrm
BEHAVIOR {
    ALF_MUX {Q=d1; D0=q; D1=d; SELECT=ls;}/> Connection by pin name */
    ALF_AND {d2 d1 cs} /* Connection by pin order */
    ALF_FLIPFLOP {CLOCK=cp; D=d2; Q=q; SET='b0; CLEAR='b0; }
}
```

4.2.4  D-Flipflop with input multiplexor

This example shows three different modeling styles for a D-flipflop with input multiplexor, asynchronous set and asynchronous clear:

```alfrm
CELL d_flipflop_mux_set_clr {
    PIN sel {DIRECTION=input;}
    PIN sd {DIRECTION=input; SIGNALTYPE=set; POLARITY=low;}
    PIN cd {DIRECTION=input; SIGNALTYPE=clear; POLARITY=low;}
    PIN cp {DIRECTION=input; SIGNALTYPE=clock; POLARITY=rising_edge;}
    PIN d1 {DIRECTION=input;}
    PIN d2 {DIRECTION=input;}
    PIN q {DIRECTION=output;}
    FUNCTION { ... }
}

Explicit description:

```alfrm
BEHAVIOR {
    @(!cd) {q = 0;}
    @(!sd && cd) {q = 1;}
    @(01 cp && cd && sd) {q = (sel)? d1: d2;}
}
More efficient description can be created using if-then-else style:

```plaintext
BEHAVIOR {
    @(!(cd)} {q = 0;}
    :(!(sd)} {q = 1;}
    :(01 cp){q = (sel)? d1: d2;}
}
```

Use of primitive:

```plaintext
BEHAVIOR {
    ALF_FLIPFLOP {CLOCK=cp D=((sel)? d1: d2) Q=q SET=!sd CLEAR=!cd}
}
```

Note that the use of `ALF_MUX` primitive is eliminated by using an assignment expression to D input in `ALF_FLIPFLOP` instance.

### 4.2.5 D-latch

This example shows a level-sensitive cell in two different styles.

```plaintext
CELL d_latch {
    PIN g {DIRECTION=input; SIGNALTYPE=clock; POLARITY=high;}
    PIN d {DIRECTION=input;}
    PIN q {DIRECTION=output;}
    FUNCTION { ... }
}
```

Explicit description:

```plaintext
BEHAVIOR {
    @(g) {q = d;}
}
```

Use of primitive:

```plaintext
BEHAVIOR {
    ALF_LATCH {ENABLE=g; D=d; Q=q; SET='b0; CLEAR='b0;}
}
```

### 4.2.6 SR-latch

The example below shows how some of the input pins can be left unconnected if they represent don’t care situation.

```plaintext
CELL sr_latch {
    PIN sn {DIRECTION=input; SIGNALTYPE=set; POLARITY=low;}
    PIN rn {DIRECTION=input; SIGNALTYPE=clear; POLARITY=low;}
    PIN q {DIRECTION = output;}
    PIN qn {DIRECTION = output;}
    FUNCTION { ... }
}
```

Explicit description:

```plaintext
BEHAVIOR {
    @(sn) {q = 'b1; qn = !rn;}
    @(rn) {qn = 'b1; q = !sn;}
}
```
Use of primitive:

```
BEHAVIOR {
    ALF_LATCH {ENABLE='b0; Q=q; SET=!sn; CLEAR=!rn;}
}
```

Since `ENABLE` pin is always set to 0, the connection of `D` pin is irrelevant. Even if `D` is considered `'bX` or `'bZ`, the behavior will not change.

### 4.2.7 JTAG BSR

The following example shows a JTAG BSR cell with built-in scan chain.

```
CELL F10_18 {
    PIN SysOut {DIRECTION = output;}
    PIN TDO {DIRECTION = output; SIGNALTYPE = scan_data;}
    PIN SysIn {DIRECTION = input;}
    PIN TDI {DIRECTION = input; SIGNALTYPE = scan_data;}
    PIN Shift {DIRECTION = input; SIGNALTYPE = scan_enable;}
    PIN Clk {DIRECTION = input; POLARITY = rising_edge;
             SIGNALTYPE = master_clock;}
    PIN Update {DIRECTION = input; POLARITY = rising_edge;
               SIGNALTYPE = slave_clock;}
    PIN Mode {DIRECTION = input; SIGNALTYPE = select;}
    PIN STATE0 { // This state is on the scan chain
                 SCAN_POSITION = 1; DIRECTION = output; VIEW = none;}
    PIN STATE1 { // NOT on scan chain (just update latch)
                 DIRECTION = output; VIEW = none;}
    FUNCTION {
        BEHAVIOR {
            @(01 Clk) {STATE0 = Shift ? TDI : SysIn;}
            @(01 Update) {STATE1 = STATE0;}
            TDO = STATE0;
            SysOut = Mode ? STATE1 : SysIn;
        }
    }
}
```

### 4.2.8 Combinational Scan Cell

The following example shows a combinational scan cell with a reused primitive.

```
LIBRARY major_ASIC_vendor {
    INFORMATION {
        version = v2.1.0;
        title = "0.35 standard cell";
        product = p35sc;
        author = "Major Asic Vendor, Inc.";
        datetime = "Wed Jul 23 13:50:12 MST 1997";
    }
    CELL ND3A {
        INFORMATION {
            version = v6.0;
            title = "3 input nand";
        }
    }
}
```
product = p35sc_lib;
author = "Joe Cell Designer";
datetime = "Tue Apr 1 01:39:47 PST 1997";

PIN Z {DIRECTION=output;}
PIN A {DIRECTION=input;}
PIN B {DIRECTION=input;}
PIN C {DIRECTION=input;}
FUNCTION {
  BEHAVIOR {
    ALF_NAND {Z A B C}
  }
}

/* fill in timing and power data for ND3A cell */

CELL ND3B {
  PIN Z {DIRECTION=output;}
  PIN A {DIRECTION=input;}
  PIN B {DIRECTION=input;}
  PIN C {DIRECTION=input;}
  FUNCTION {
    BEHAVIOR {
      ALF_NAND {Z A B C}
    }
  }
  /* fill in timing and power data for ND3B cell */
}

CELL SCAN_ND4 {
  PIN Z {DIRECTION=output;}
  PIN A {DIRECTION=input;}
  PIN B {DIRECTION=input;}
  PIN C {DIRECTION=input;}
  PIN D {DIRECTION=input; SIGNALTYPE=scan_enable;}

  SCAN_TYPE = control_0;
  NON_SCAN_CELL = ALF_NAND {Z A B C}
  FUNCTION {
    BEHAVIOR {
      Z = !(A && B && C && D);
    }
  }
  ...
  ..
}
4.2.9 Scan Flipflop

The following example shows a scan flipflop using the generic ALF_FLIPFLOP primitive.

LIBRARY major_ASIC_vendor {
  ...
  CELL F614 {
    PIN H01 {DIRECTION = input; SIGNALTYPE = data;}
    PIN H02 {DIRECTION = input; SIGNALTYPE = clock;}
    PIN H03 {DIRECTION = input; SIGNALTYPE = clear; POLARITY = high;}
    PIN H04 {DIRECTION = input; SIGNALTYPE = set; POLARITY = high;}
    PIN N01 {DIRECTION = output;
           SCAN {SIGNALTYPE = data; POLARITY = non_inverted;}}
    PIN N02 {DIRECTION = output; POLARITY = inverted;}
    FUNCTION {
      BEHAVIOR {
        ALF_FLIPFLOP {
          D=H01; CLOCK=H02; CLEAR=H03; SET=H04;
          Q=N01; QN=N02; Q_CONFLICT='bX; QN_CONFLICT='bX;
        }
      }
    }
  }
  ...
  CELL S000 {
    PIN H01 {DIRECTION = input; SIGNALTYPE = scan_data;}
    PIN H02 {DIRECTION = input; SIGNALTYPE = clock;
           OFFSTATE = non_inverted;}
    PIN H03 {DIRECTION = input; SIGNALTYPE = scan_enable;
           POLARITY = low;}
    PIN H04 {DIRECTION = input; SIGNALTYPE = set; POLARITY = high;}
    PIN H05 {DIRECTION = input; SIGNALTYPE = clear; POLARITY = high;}
    PIN H06 {DIRECTION = input; SIGNALTYPE = data;}
    PIN N01 {DIRECTION = output; SIGNALTYPE = data;
           POLARITY = non_inverted;}
    PIN N02 {DIRECTION = output; POLARITY = inverted;}
    FUNCTION{
      BEHAVIOR { // flipflop_d is an implicitly defined internal pin
        ALF_MUX {Q=flipflop_d; D0=H06; D1=H01; SELECT=H03;}
        ALF_FLIPFLOP {
          D=flipflop_d; CLOCK=H02; CLEAR=H05; SET=H04;
          Q=N01; QN=N02; Q_CONFLICT='bX; QN_CONFLICT='bX;
        }
      }
    }
  }
  SCAN_TYPE = muxscan;
  NON_SCAN_CELL = ALF_FLIPFLOP {D=H06; CLOCK=H02; CLEAR=H05; SET=H04;
    Q=N01; QN=N02; Q_CONFLICT='bX; QN_CONFLICT='bX;
    'b0=H03; 'b0=H01;}
} // H03 and H01 have no corresponding pin in ALF_FLIPFLOP
...
4.2.10 Quad D-Flipflop

The following example shows a quad D-Flipflop with and without built-in scan chain.

```verbatim
LIBRARY major ASIC_vendors {
  PRIMITIVE FFX4 {
    PIN CK { DIRECTION = input; }
    PIN D0 { DIRECTION = input; }
    PIN D1 { DIRECTION = input; }
    PIN D2 { DIRECTION = input; }
    PIN D3 { DIRECTION = input; }
    PIN Q0 { DIRECTION = output; }
    PIN Q1 { DIRECTION = output; }
    PIN Q2 { DIRECTION = output; }
    PIN Q3 { DIRECTION = output; }
    FUNCTION {
      BEHAVIOR {
        ALF_FLIPFLOP {Q=Q0; D=D0; CLOCK=CK; SET='b0; CLEAR='b0;}
        ALF_FLIPFLOP {Q=Q1; D=D1; CLOCK=CK; SET='b0; CLEAR='b0;}
        ALF_FLIPFLOP {Q=Q2; D=D2; CLOCK=CK; SET='b0; CLEAR='b0;}
        ALF_FLIPFLOP {Q=Q3; D=D3; CLOCK=CK; SET='b0; CLEAR='b0;}
      }
    }
  }
  CELL SCAN_FFX4 {
    PIN OUT0 { DIRECTION = output; }
    PIN OUT1 { DIRECTION = output; }
    PIN OUT2 { DIRECTION = output; }
    PIN OUT3 { DIRECTION = output; }
    PIN SO { DIRECTION = output; SIGNALTYPE = scan_data; }
    PIN IN0 { DIRECTION = input; SIGNALTYPE = data; }
    PIN IN1 { DIRECTION = input; SIGNALTYPE = data; }
    PIN IN2 { DIRECTION = input; SIGNALTYPE = data; }
    PIN IN3 { DIRECTION = input; SIGNALTYPE = data; }
    PIN CLK { DIRECTION = input; SIGNALTYPE = clock; }
    PIN SI { DIRECTION = input; SIGNALTYPE = scan_enable; }
    PIN SE { DIRECTION = input; SIGNALTYPE = scan_enable; }
    PIN STATE0 { SCAN_POSITION = 1; DIRECTION = output; VIEW = none; }
    PIN STATE1 { SCAN_POSITION = 2; DIRECTION = output; VIEW = none; }
    PIN STATE2 { SCAN_POSITION = 3; DIRECTION = output; VIEW = none; }
    PIN STATE3 { SCAN_POSITION = 4; DIRECTION = output; VIEW = none; }
    FUNCTION {
      BEHAVIOR {
        OUT0 = STATE0; OUT1 = STATE1; OUT2 = STATE2; OUT3 = STATE3;
        SO = !STATE3;
        @(01 CLK) {
          STATE0 = SE ? !SI : IN0;
          STATE1 = SE ? !STATE0 : IN1;
          STATE2 = SE ? !STATE1 : IN2;
          STATE3 = SE ? !STATE2 : IN3;
        }
      }
    }
  }
}
```
4.3 Templates and vector-specific models

4.3.1 Vector specific delay and power Tables

In this example, the use of vector specific models for input-to-output delay, output slewrate, and switching energy is shown.

CELL nand2 {
    PIN a {DIRECTION = input; CAPACITANCE = 0.02 {UNIT = pF;}}
    PIN b {DIRECTION = input; CAPACITANCE = 0.02 {UNIT = pF;}}
    PIN z {DIRECTION = output;}
    FUNCTION {
        BEHAVIOR {z = !(a && b); }
    }
    VECTOR (10 a -> 01 z){ /* Vector specific characterization */
        DELAY {
            UNIT = ns;
            FROM {PIN = a; THRESHOLD = 0.4;}
            TO {PIN = z; THRESHOLD = 0.6;}
            HEADER {
                CAPACITANCE {
                    PIN = z; UNIT = pF;
                    TABLE {0.01 0.02 0.04 0.08 0.16}
                }
                SLEWRATE {
                    PIN = a; UNIT = ns;
                    FROM {THRESHOLD = 0.5;}
                    TO {THRESHOLD = 0.3;}
                    TABLE {0.1 0.3 0.9}
                }
            }
            TABLE {
                0.1 0.2 0.4 0.8 1.6
                0.2 0.3 0.5 0.9 1.7
                0.4 0.5 0.7 1.1 1.9
            }
        }
        SLEWRATE {
            PIN = z; UNIT = ns;
            FROM {THRESHOLD = 0.3;}
            TO {THRESHOLD = 0.5;}
            HEADER {
                CAPACITANCE {
                    PIN = z; UNIT = pF;
                    TABLE {0.01 0.02 0.04 0.08 0.16}
                }
                SLEWRATE {
                    PIN = a; UNIT = ns;
                    FROM {THRESHOLD = 0.5;}
                    TO {THRESHOLD = 0.3;}
                    TABLE {0.1 0.3 0.9}
                }
            }
            TABLE {
                0.1 0.2 0.4 0.8 1.6
                0.2 0.3 0.5 0.9 1.7
                0.4 0.5 0.7 1.1 1.9
            }
        }
    }
}
}  

SLEWRATE {  
  PIN = a; UNIT = ns;  
  FROM {THRESHOLD = 0.5;}  
  TO {THRESHOLD = 0.3;}  
  TABLE {0.1 0.3 0.9}  
}  

TABLE {  
  0.1 0.2 0.4 0.8 1.6  
  0.2 0.4 0.6 1.0 1.8  
}  

ENERGY {  
  UNIT = pJ;  
  HEADER {  
    CAPACITANCE {  
      PIN = z; UNIT = pF;  
      TABLE {0.01 0.02 0.04 0.08 0.16}  
    }  
    SLEWRATE {  
      PIN = a; UNIT = ns;  
      FROM {THRESHOLD = 0.5;}  
      TO {THRESHOLD = 0.3;}  
      TABLE {0.1 0.3 0.9}  
    }  
  }  
  TABLE {  
    0.21 0.32 0.64 0.98 1.96  
    0.22 0.33 0.65 0.99 1.97  
    0.31 0.42 0.74 1.08 2.06  
  }  
}  

VECTOR (01 a -> 10 z){  
  DELAY { ... }  
  SLEWRATE { ... }  
  ENERGY { ... }  
}  

VECTOR (10 b -> 01 z){  
  DELAY { ... }  
  SLEWRATE { ... }  
  ENERGY { ... }  
}  

VECTOR (01 b -> 10 z){  
  DELAY { ... }  
  SLEWRATE { ... }  
  ENERGY { ... }  
}  

}
4.3.2 Use of TEMPLATE

Notice that the header for the delay, ramptime, and energy models was the same in the example above. Therefore creating a template definition can eliminate duplicate information, reduce the possibility of inadvertent errors, and make the models compact. For example, a header template can be created as shown below:

```plaintext
TEMPLATE std_header_2d {
    HEADER {
        CAPACITANCE {
            PIN = <out_pin>; UNIT = pF;
            TABLE {0.01 0.02 0.04 0.08 0.16}
        }
        SLEWRATE {
            PIN = <in_pin>; UNIT = ns;
            FROM {THRESHOLD {RISE = 0.3; FALL = 0.5;}}
            TO {THRESHOLD {RISE = 0.5; FALL = 0.3;}}
            TABLE {0.1 0.3 0.9}
        }
    }
}
```

The use of `TEMPLATE` eliminates the repetition of header information by rewriting the previous example (only the first vector) as shown below.

```plaintext
DELAY {
    UNIT = ns;
    THRESHOLD {RISE=0.4; FALL=0.6;}
    FROM {PIN = a;}
    TO {PIN = z;}
    std_header_2d { /* Template is used */
        in_pin = a;
        out_pin = z;
    }
    TABLE {
        0.1 0.2 0.4 0.8 1.6
        0.2 0.3 0.5 0.9 1.7
        0.4 0.5 0.7 1.1 1.9
    }
}
```

```plaintext
SLEWRATE {
    PIN = z; UNIT = ns;
    FROM {THRESHOLD {RISE = 0.3; FALL = 0.5;}}
    TO {THRESHOLD {RISE = 0.5; FALL = 0.3;}}
    std_header_2d { /* Template is used */
        in_pin = a;
        out_pin = z;
    }
    TABLE {
        0.1 0.2 0.4 0.8 1.6
        0.2 0.4 0.6 1.0 1.8
    }
}
```

```plaintext
ENERGY {
    UNIT = pJ;
}
```
std_header_2d { /* Template is used */
    in_pin = a;
    out_pin = z;
}
TABLE {
    0.21 0.32 0.64 0.98 1.96
    0.22 0.33 0.65 0.99 1.97
    0.31 0.42 0.74 1.08 2.06
}
}

Note that the entire characterization model for CELL nand2 is the same for each vector (i.e. pair of input and output pins), so further efficiency can be achieved by defining the characterization model itself as a template. This template definition uses the instantiation of the previously defined header template.

TEMPLATE std_char_2d {
    DELAY {
        UNIT = ns;
        THRESHOLD {RISE=0.4; FALL=0.6;}
        FROM {PIN = <in_pin>; }
        TO {PIN = <out_pin>; }
        std_header_2d {
            in_pin = <input_pin>;
            out_pin = <output_pin>;
        }
        TABLE <delay_data>
    }
    SLEWRATE {
        PIN = <out_pin>; UNIT = ns;
        FROM {THRESHOLD {RISE = 0.3; FALL = 0.5;}}
        TO {THRESHOLD {RISE = 0.5; FALL = 0.3;}}
        std_header_2d {
            in_pin = <input_pin>;
            out_pin = <output_pin>;
        }
        TABLE <slewrate_data>
    }
    ENERGY {
        UNIT = pJ;
        std_header_2d {
            in_pin = <input_pin>;
            out_pin = <output_pin>;
        }
        TABLE <energy_data>
    }
}
Now only the delay, slewrate and energy models contain specific data that is different for each vector. All repetitive information is in the template definition. The characterization model can be rewritten compactly as shown below:

```plaintext
std_char_2d {
  in_pin = a;
  out_pin = z;
  delay_data {
    0.1 0.2 0.4 0.8 1.6
    0.2 0.3 0.5 0.9 1.7
    0.4 0.5 0.7 1.1 1.9
  }
  slewrate_data {
    0.1 0.2 0.4 0.8 1.6
    0.1 0.2 0.4 0.8 1.6
    0.2 0.4 0.6 1.0 1.8
  }
  energy_data {
    0.21 0.32 0.64 0.98 1.96
    0.22 0.33 0.65 0.99 1.97
    0.31 0.42 0.74 1.08 2.06
  }
}
```

### 4.3.3 Vector description styles for timing arcs

In previous examples, the vectors were specified as timing arcs. This is not ambiguous, since the sequence of transitions can only happen under one test condition.

```plaintext
VECTOR (10 a -> 01 z){
  std_char_2d { ... }
}
VECTOR (01 a -> 10 z){
  std_char_2d { ... }
}
VECTOR (10 b -> 01 z){
  std_char_2d { ... }
}
VECTOR (01 b -> 10 z){
  std_char_2d { ... }
}
```
An alternate way of describing the above vectors is to specify the input transition and the state of the other input(s) which control the output transition.

```c
VECTOR (10 a && b){
    std_char_2d { ... }
}
VECTOR (01 a && b){
    std_char_2d { ... }
}
VECTOR (10 b && a){
    std_char_2d { ... }
}
VECTOR (01 b && a){
    std_char_2d { ... }
}
```

A redundant yet safe way of vector description is to specify both output transition and input state(s) together with the input transition.

```c
VECTOR (10 a -> 01 z && b){
    std_char_2d { ... }
}
VECTOR (01 a -> 10 z && b){
    std_char_2d { ... }
}
VECTOR (10 b -> 01 z && a){
    std_char_2d { ... }
}
VECTOR (01 b -> 10 z && a){
    std_char_2d { ... }
}
```

In the non-redundant specification, either the input state or the output transition can be derived from the functional description.

### 4.3.4 Vectors for delay, power and timing constraints

A D-Flipflop model without the set and clear signals is shown below. This model has vectors for specific purpose - some for delay and power, some for power only (output is not switching), and some for timing constraints. However, each vector has the same structure, although the input variables change. The vectors for delay and power model require 2-dimensional tables with load capacitance and input ramptime as variables, the vectors for power model require 1-dimensional tables with input ramptime as variable, and the vectors for time constraints require 2-dimensional tables with ramptime on two inputs as variables.

```c
CELL d_flipflop {
    PIN cp {DIRECTION = input;}
    PIN d {DIRECTION = input;}
    PIN q {DIRECTION = output;}
    FUNCTION {
        BEHAVIOR { @(01 cp) {q = d; } }
    }
    VECTOR (01 cp -> 01 q) {
        /* fill in arithmetic models for delay and power */
```
VECTOR (01 cp -> 10 q) {
   /* fill in arithmetic models for delay and power */
}
VECTOR (01 cp && d == q) {
   /* fill in arithmetic model for power */
}
VECTOR (10 cp && d == q) {
   /* fill in arithmetic model for power */
}
VECTOR (10 cp && d != q) {
   /* fill in arithmetic model for power */
}
VECTOR (01 d && !cp) {
   /* fill in arithmetic model for power */
}
VECTOR (10 d && !cp) {
   /* fill in arithmetic model for power */
}
VECTOR (01 d && cp) {
   /* fill in arithmetic model for power */
}
VECTOR (10 d && cp) {
   /* fill in arithmetic model for power */
}
VECTOR (01 d <&> 01 cp)
   SETUP {
      /* fill in arithmetic model for setup time constraint */
      VIOLATION {
         BEHAVIOR (q = 'bx;)
         MESSAGE_TYPE = error;
         MESSAGE = "setup violation 01 d <-> 01 cp";
      }
   }
   HOLD {
      /* fill in arithmetic model for hold time constraint */
      VIOLATION {
         BEHAVIOR (q = 'bx;)
         MESSAGE_TYPE = error;
         MESSAGE = "hold violation 01 d <-> 01 cp";
      }
   }
VECTOR (10 d <&> 01 cp)
   SETUP {
      /* fill in arithmetic model for setup time constraint */
      VIOLATION {
         BEHAVIOR (q = 'bx;)
         MESSAGE_TYPE = error;
         MESSAGE = "setup violation 10 d <-> 01 cp";
      }
   }
   HOLD {
      /* fill in arithmetic model for hold time constraint */
      VIOLATION {

4.4 Combining tables and equations

4.4.1 Table vs equation

The following examples show the usage of `TABLE` and `EQUATION` in the model.

Example with table:

```plaintext
CURRENT {
  PIN = VDD;
  UNIT = mA;
  TIME = 30  {UNIT = ns;}
  MEASUREMENT = average;
  HEADER {
    CAPACITANCE {
      PIN = z; UNIT = pF;
      TABLE {0.02 0.04 0.08 0.16}
    }
    SLEWRATE {
      PIN = a; UNIT = ns;
      TABLE {0.1 0.3 0.9}
    }
  }
  TABLE {
    0.0011 0.0021 0.0041 0.0081
    0.0013 0.0023 0.0043 0.0083
    0.0019 0.0029 0.0049 0.0089
  }
}
```

Equivalent example with equation:

```plaintext
CURRENT {
  PIN = VDD;  UNIT = mA;
  TIME = 30  {UNIT = ns;}
  MEASUREMENT = average;
  HEADER {
    CAPACITANCE {PIN = z; UNIT = pF;}
    SLEWRATE {PIN = a; UNIT = ns;}
  }
  EQUATION { 0.05*CAPACITANCE + 0.001*SLEWRATE }
}
```

If the model uses an `EQUATION`, then each argument must appear in the `HEADER`. If the model uses a `TABLE`, then the `HEADER` must contain a `TABLE` for each argument. The number of values
in the main table and the indexing scheme is defined by the order and the number of values in each table inside the header.

4.4.2 Cell with Multiple Output Pins

The following example shows how to use combinations of tables and equations for efficient modeling of energy consumption of a cell with two (buffered) outputs. When two outputs are switching, triggered by the same input, the dynamic energy consumption depends on ramptime of the input signal and load capacitance on each output.

Instead of creating a 3-dimensional table, two 2-dimensional tables are used, varying the load capacitance at one output and keeping zero load at the other output. The equation calculates the energy for both outputs switching by adding the values from each table together for the applicable load capacitance and by subtracting a corresponding correction term. The result is exact for cells with buffered outputs.

As shown in the example below, an arithmetic model must be a named object, if several objects of the same type occur within the same scope (e.g. \texttt{ENERGY}). For named objects, the equation uses the object name instead of the object type.

```plaintext
VECTOR (01 ci -> (01 co <-> 10 s) & a) { 
  ENERGY { 
    UNIT = pJ; 
    HEADER { 
      ENERGY energy_co { // named object 
        UNIT = pJ; 
        HEADER { 
          CAPACITANCE { 
            PIN = co; UNIT = pF; 
            TABLE { ... } 
          }
          SLEWRATE { 
            PIN = ci; UNIT = ns; 
            TABLE { ... } 
          }
        } 
        TABLE { ... } 
      }
      TABLE { ... } 
    }
    ENERGY energy_s { // named object 
      UNIT = pJ; 
      HEADER { 
        CAPACITANCE { 
          PIN = s; UNIT = pF; 
          TABLE { ... } 
        }
        SLEWRATE { 
          PIN = ci; UNIT = ns; 
          TABLE { ... } 
        }
      } 
      TABLE { ... } 
    }
    ENERGY energy_noload { // named object 
      UNIT = pJ; 
      HEADER { 
        TABLE { ... } 
      }
    }
  }
```
Combining tables and equations

Applications

UNIT = pJ;
HEADER {
    SLEWRATE {
        PIN = ci; UNIT = ns;
    TABLE { ... }
    }
}
TABLE { ... }
} 

EQUATION { energy_co + energy_s - energy_noload }
}

4.4.3 PVT Derating

Combinations of tables and equations can also be used for derating with respect to voltage and temperature, since those variables would add more dimensions to a purely table-based model.

In this example, the DELAY objects must be named, since there is both a nominal and a derated DELAY.

DELAY rise_out{
    HEADER {
        PROCESS {
            HEADER {nom snsp snwp wnsp wnwp}
        TABLE {0.0 -0.1 -0.2 +0.3 +0.2}
        }
        VOLTAGE {//fill in any annotations
        }
        TEMPERATURE {//fill in any annotations
        }
        DELAY nom_rise_out { 
            HEADER {
                CAPACITANCE {
                    TABLE {0.03 0.06 0.12 0.24}
                }
                SLEWRATE {
                    TABLE {0.1 0.3 0.9}
                }
            }
        TABLE {
            0.07 0.10 0.14 0.22
            0.09 0.13 0.19 0.30
            0.10 0.15 0.25 0.41
        }
    }
}
EQUATION {
  nom_rise_out
  * (1 + PROCESS)
  * (1 + (TEMPERATURE - 25)*0.001)
  * (1 + (VOLTAGE - 3.3)*(-0.3))
}

The HEADER in the process object contains exclusively named variables (nom, snsp...), similar to the truth table of a FUNCTION that contains only pin names. Therefore the TABLE is expected to have as many entries as the HEADER. The TABLE inside nom_rise_out must follow the format defined by each TABLE inside the declarations of load and ramptime. Other declared object in the HEADER would be ignored for the TABLE format, if they do not have a TABLE inside themselves.

For convenience, the derating equation can be defined as a template for future reuse.

TEMPLATE std_derating {
  EQUATION {
    <variable>
    * (1 + <Kp>)
    * (1 + (TEMPERATURE - 25)*<Kt>)
    * (1 + (VOLTAGE - 3.3)*<Kv>)
  }
}

Instantiation of the template in the model:

DELAY rise_out{
  HEADER {
    PROCESS {
      HEADER {nom snsp snwp wnsp wnwp}
      TABLE {0.0 -0.1 -0.2 +0.3 +0.2}
    }
    VOLTAGE { ... }
    TEMPERATURE { ... }
    DELAY nom_rise_out {
      HEADER {
        CAPACITANCE {TABLE { ... }}
        SLEWRATE {TABLE { ... }}
      }
      TABLE { ... }
    }
    std_derating {
      variable = nom_rise_out ;
      Kp = PROCESS ;
      Kt = 0.001 ;
      Kv = -0.3 ;
    }
  }
}

It is possible to assign explicit values to the predefined process and derating case identifiers.
Example:

```plaintext
PROCESS snsp = 0.9;
PROCESS wnwp = 1.1;
TEMPERATURE nom = 25;
VOLTAGE nom = 3.3;
TEMPERATURE bccom = 0;
VOLTAGE bccom = 3.5;
TEMPERATURE wcmil = 125;
VOLTAGE wcmil = 2.8;
```

It is also possible to express voltage, temperature and delay with the derating case as an independent variable:

```plaintext
VOLTAGE {
    HEADER {nom bccom wcmil}
    TABLE {3.3 3.5 2.8}
}
TEMPERATURE {
    HEADER {nom bccom wcmil}
    TABLE {25 0 125}
}
DELAY {
    HEADER {
        DERATE_CASE {
            HEADER {nom bccom wcmil}
            TABLE {0 -0.0835 0.265}
        }
        PROCESS {
            HEADER {nom snsp snwp wnsp wnwp}
            TABLE {0.0 -0.1 -0.2 +0.3 +0.2}
        }
        DELAY nom_rise_out { ... }
    }
    EQUATION {
        nom_rise_out
        * (1 + PROCESS)
        * (1 + DERATE_CASE)
    }
}
```

Yet another possibility is a completely tabulated model, where the process and derating identifiers can be directly used as table items.

```plaintext
DELAY {
    HEADER {
        DERATE_CASE {
            TABLE {nom bccom wcmil}
        }
        PROCESS {
            TABLE {nom snsp snwp wnsp wnwp}
        }
        TABLE {
            // 3*5 = 15 values
        }
    }
```
4.5 Use of Annotations

4.5.1 Annotations for a PIN

Direct annotation:

```plaintext
PIN data_in {DIRECTION = input; THRESHOLD = 0.35; CAPACITANCE = 0.010;}
```

Using annotation containers:

```plaintext
PIN data_in {
   DIRECTION = input;
   THRESHOLD = 0.35;
   CAPACITANCE = 0.010;
   {
      UNIT = pF; MEASUREMENT = average;
      MIN = 0.009; TYP = 0.010; MAX = 0.012;
   }
   LIMIT {
      SLEWRATE {MAX=3.0; UNIT=ns;}
      VOLTAGE {MAX=3.5; MIN=-0.2;}
   }
}
```

The input pin `data_in` has a non-linear capacitance which was characterized using an average measurement (as opposed to RMS or peak measurements). Different measurements yield average capacitances between 0.009 pF and 0.012 pF, typical average capacitance is 0.010 pF. The slewrate applied to the pin must not exceed 3.0 ns. The voltage swing must not exceed the lower bound of -0.2 V and the upper bound of 3.5 volt.

```plaintext
CAPACITANCE {UNIT = pF;}
PIN data_out {
   DIRECTION = output; CAPACITANCE = 0.002;
   LIMIT {CAPACITANCE {MAX = 0.96;}}
}
```

The output pin `data_out` has a capacitance of 0.002 pF. The maximum load capacitance that may be applied to the pin is 0.96 pF.

4.5.2 Annotations for a timing arc

Specifications for a particular timing arc references specific pins:

```plaintext
DELAY {
   UNIT = ns;
   FROM {PIN = data_in; THRESHOLD = 0.4;}
   TO {PIN = data_out; THRESHOLD = 0.6;}
}
```

```plaintext
SLEWRATE {
   PIN = data_out; UNIT = ns;
   FROM {THRESHOLD = 0.3;}
   TO {THRESHOLD = 0.5;}
}
```
Specifications for a generic timing arc does not reference specific pins, but values for both switching directions must be defined):

```
DELAY {
  UNIT = ns;
  THRESHOLD {RISE=0.4; FALL=0.6;}
}
SLEWRATE {
  UNIT = ns;
  FROM {THRESHOLD {RISE=0.3; FALL=0.5;}}
  TO {THRESHOLD {RISE=0.5; FALL=0.3;}}
}
```

### 4.5.3 Creating Self-explaining Annotations

The self-explaining annotations can be created using `TEMPLATE`. Example: number of connections allowed for each pin

```
TEMPLATE must_connect {
  LIMIT {CONNECTION {MIN = 1;}}
}
TEMPLATE can_float {
  LIMIT {CONNECTION {MIN = 0;}}
}
TEMPLATE no_connection {
  LIMIT {CONNECTION {MAX = 0;}}
}
CELL a_flipflop {
  PIN q {must_connect DIRECTION=output;}
  PINqn {can_float DIRECTION=output;}
  PIN qi {no_connection DIRECTION=output;}
  ...
}
```

### 4.6 Providing fallback position for applications

#### 4.6.1 Use of DEFAULT

ALF’s modeling capabilities address the needs for all types of applications. However, ALF should also work for applications that use only a subset of information. In order to make the subset of information controllable, modeling capability with `DEFAULT` is provided. The information provided by `DEFAULT` can be strictly ignored by applications that understand the full information.

A particular application may not be able to use 3-dimensional tables, or it may not understand certain models. `DEFAULT` values can be provided for each model.
Example:

```
DELAY {
    HEADER {
        SLEWRATE {
            PIN = a; UNIT = 1e-9;
            TABLE (0.5 1.0 1.5)
            DEFAULT = 1.0;
        }
        CAPACITANCE {
            PIN = z; UNIT = 1e-12;
            TABLE (0.1 0.2 0.3 0.4)
            DEFAULT = 0.1;
        }
        VOLTAGE {
            PIN = vdd; UNIT = 1;
            TABLE (3.0 3.3 3.6)
            DEFAULT = 3.3;
        }
    }
    TABLE {
        // arrangement of whitespaces and comments
        // is only for readability
        // parser sees just a sequence of 3x4x3=36 numbers
        //slewrate 0.5 1.0 1.5 capacitance voltage
        // ------------------------------+---------
        0.2 0.8 1.1 // 0.1 3.0
        0.4 1.0 1.2 // 0.2
        0.7 1.2 1.4 // 0.3
        0.9 1.5 1.8 // 0.4
        0.1 0.7 1.2 // 0.1 3.3
        0.3 0.9 1.3 // 0.2
        0.6 1.1 1.5 // 0.3
        0.8 1.3 1.7 // 0.4
        0.1 0.6 1.0 // 0.1 3.6
        0.2 0.8 1.1 // 0.2
        0.4 1.0 1.3 // 0.3
        0.7 1.2 1.6 // 0.4
    }
}
```

An application that does not understand `VOLTAGE`, will extract the following information from this example:

```
DELAY {
    HEADER {
        SLEWRATE {
            PIN = a; UNIT = 1e-9;
            TABLE (0.5 1.0 1.5)
        }
    CAPACITANCE {
        PIN = z; UNIT = 1e-12;
```
TABLE {0.1 0.2 0.3 0.4}

TABLE {
//slewrate 0.5 1.0 1.5 capacitance voltage
// --------------------------+--------------+-------
0.1 0.7 1.2 // 0.1 3.3
0.3 0.9 1.3 // 0.2
0.6 1.1 1.5 // 0.3
0.8 1.3 1.7 // 0.4
}

An application that does not understand SLEWRATE, will extract only the following information:

DELAY {
HEADER {
CAPACITANCE {
UNIT = 1e-12;
PIN = z;
TABLE {0.1 0.2 0.3 0.4}
}
}
TABLE {
//slewrate 1.0 capacitance voltage
// --------------------------+--------------+-------
0.7 // 0.1 3.3
0.9 // 0.2
1.1 // 0.3
1.3 // 0.4
}
}

4.7 Bus Modeling

4.7.1 Tristate Driver

Bus drivers are usually tristate buffers, which have straightforward functional models. If both input signal and enable signal have well-defined logic states, the output is driven to 'b1, 'b0, or 'bz, otherwise it is driven to 'bx.

CELL tristate_buffer {
PIN a {DIRECTION = input; SIGNALTYPE = data;}
PIN e {DIRECTION = input; SIGNALTYPE = out_enable;}
PIN z {DIRECTION = output; SIGNALTYPE = data;
SIGNALDRIVE = tristate; ENABLE_PIN = e;}
FUNCTION {
BEHAVIOR {
z =
A different model can be used for transmission-gate type of buffers, which also passes the high impedance state from input to output.

```
(state ? 'b1: state ? 'b0: !state ? 'bz: 'bx;
```

In order to model bus contention, the drive strength information of tristate buffers is needed. This is easily achieved by annotation of a pin property, using a context-sensitive keyword.

```
CELL tristate_buffer {
  ...
  PIN z {DIRECTION = output; DRIVE_STRENGTH = 4;}
  ...
}
```

The pin-property `DRIVE_STRENGTH` can take an arbitrary positive integer or a real number. In general, greater values override smaller values, and that `DRIVE_STRENGTH=0` is equivalent to

```
BEHAVIOR {z='bz;}
```

ALF does not assume a particular set of legal drive strengths. The scale and granularity is left to the discretion of the ASIC vendor (user).

Modeling of state-dependent drive strength is achieved by annotating drive strength within a vector rather than within a pin. The following example shows a buffer with strong-0 and weak-1 drive.

```
CELL tristate_buffer {
  ...
  PIN z {DIRECTION = output;}
  ...
  VECTOR (z==0) {
    DRIVE_STRENGTH = 4; {PIN = z;}
  }
  VECTOR (z==1) {
    DRIVE_STRENGTH = 2; {PIN = z;}
  }
}
```

The bus itself is not described by an ALF model, since the bus is a design construct rather than a library cell. A simulation model (Verilog or VHDL) would handle the bus contention. However, since buses can also be embedded within a core cell, the functional model of the core would need a functional model of that bus as well.
4.7.2  Bus with multiple drivers

The following example shows a bus with 3 drivers of equal strength. The output is the resolved value of the bus.

CELL bus3 {
    PIN z1 {DIRECTION = input;}
    PIN z2 {DIRECTION = input;}
    PIN z3 {DIRECTION = input;}
    PIN z {DIRECTION = output;}
    FUNCTION {
        BEHAVIOR {
            z =
            ((z2=='bz || z2==z1) && z3=='bz)? z1:
            ((z3=='bz || z3==z2) && z1=='bz)? z2:
            ((z1=='bz || z1==z3) && z2=='bz)? z3:
            (z1=='b1 && z2=='b1 && z3=='b1)? 'b1:
            (z1=='b0 && z2=='b0 && z3=='b0)? 'b0:
            'bx;
        }
    }
}

The following example shows a bus with two drivers of equal strength and one driver with weaker strength (e.g. a busholder).

CELL bus2s1w {
    PIN z_strong1 {DIRECTION = input;}
    PIN z_strong2 {DIRECTION = input;}
    PIN z_weak  {DIRECTION = input;}
    PIN z  {DIRECTION = output;}
    FUNCTION {
        BEHAVIOR {
            z =
            (z_strong1=='b1 && z_strong2=='b1)? 'b1:
            (z_strong1=='b0 && z_strong2=='b0)? 'b0:
            (z_strong1=='bz && z_strong2=='bz)? z_weak:
            'bx;
        }
    }
}
4.7.3 Busholder

A busholder is a cell that retains the previous value of a tristate bus, when all drivers go to high impedance. This device has only one external pin, which is bidirectional. The input to this bidirectional pin is the resolved value of the bus.

```plaintext
CELL busholder {
    PIN a {DIRECTION = both;}
    PIN z {DIRECTION = output; VIEW = none;}
    FUNCTION {
        BEHAVIOR {
            a = !z;
            @(a==0) {z = 1;}
            @(a==1) {z = 0;}
            @(a=='bx) {z = 'bx;}
        }
    }
}
```

In order to understand the functionality of a bidirectional pin, we split the pin conceptually into an input pin and an output pin as shown below.

```plaintext
CELL busholder_explicit {
    PIN a_in {DIRECTION = input;}
    PIN a_out {DIRECTION = output;}
    PIN z {DIRECTION = output; VIEW = none;}
    FUNCTION {
        BEHAVIOR {
            a_out = !z;
            @(a_in==0) {z = 1;}
            @(a_in==1) {z = 0;}
            @(a_in=='bx) {z = 'bx;}
        }
    }
}
```

The function of this device is well defined, if a_out==a_in for all cases where a_in!='bz. In the case of a_in=='bz, a_out can take any value. This is a general modeling rule for functions with bidirectional pins.

4.8 Wire models

4.8.1 Basic Wire Model

This example shows two wire models, using tables and equations. The equation is used outside the defined table range. If no equation was defined, the table would be extrapolated.

```plaintext
WIRE small_wire {
    CAPACITANCE {
        UNIT = pF;
        HEADER {
            CONNECTIONS {
                TABLE (2 3 4 5)
            }
        }
    }
}
```
4.8.2 Wire select model

Since a library may contain multiple wire models, it is necessary to specify which model should be selected for an application. The annotations inside each wire model can be used for this purpose.

WIRE small_wire {
    LIMIT {AREA {UNIT=1e-6; MAX=25;}}
    ...
}

WIRE large_wire {
    LIMIT {AREA {UNIT=1e-6; MIN=25; MAX=100;}}
    ...
}
If the area covering the routing space is smaller than 25mm², the small_wire model will be chosen. If the area covering the routing space is between 25mm² and 100mm², the large_wire model is chosen. The unit for area is 1mm².

More annotations using the USAGE keyword can be introduced in order to enable customized wire model selection.

### 4.9 Megacell Modeling

#### 4.9.1 Expansion of Timing Arcs

GROUP can be used for sets of numbers or for a continuous range of numbers. This can be useful for defining timing arcs between all bits of two vectors. For example,

```
GROUP adr_bits {1 2 3}
GROUP data_bits {1 2}
VECTOR (01 adr[adr_bits] -> 01 dout[data_bits]) { ... }
```

replaces the following statements:

```
VECTOR (01 adr[1] -> 01 dout[1]) { ... }
VECTOR (01 adr[2] -> 01 dout[1]) { ... }
VECTOR (01 adr[3] -> 01 dout[1]) { ... }
VECTOR (01 adr[1] -> 01 dout[2]) { ... }
VECTOR (01 adr[2] -> 01 dout[2]) { ... }
VECTOR (01 adr[3] -> 01 dout[2]) { ... }
```

The following example shows bit-wise expansion of two vectors:

```
GROUP data_bits {1 2}
VECTOR (01 din[data_bits] -> 01 dout[data_bits]) { ... }
```

This replaces the following statements:

```
VECTOR (01 din[1] -> 01 dout[1]) { ... }
VECTOR (01 din[2] -> 01 dout[2]) { ... }
```

Example for bytewise (or sub-word wise) expansion:

```
GROUP low_byte {1 2}
GROUP high_byte {3 4}
VECTOR (01 we[0] -> 01 din[low_byte]) { ... }
VECTOR (01 we[1] -> 01 din[high_byte]) { ... }
```

This replaces the following statements:

```
VECTOR (01 we[0] -> 01 din[1]) { ... }
VECTOR (01 we[0] -> 01 din[2]) { ... }
VECTOR (01 we[1] -> 01 din[3]) { ... }
VECTOR (01 we[1] -> 01 din[4]) { ... }
```
4.9.2 Two-port memory

The memory model example below shows the use of abstract transition operators on words in various vectors. Note the simplicity of the functional description of this two-port asynchronous memory. This example also contains some vectors with distinction between events on row and column address lines.

```plaintext
CELL async_1write_1read_ram {
  GROUP col {1:0}
  GROUP row {4:2}
  GROUP all {row col}
  GROUP byte{7:0}
  GROUP \* {0:31}
  PIN enable_write {DIRECTION = input}
  PIN [4:0] adr_write {DIRECTION = input}
  PIN [4:0] adr_read {DIRECTION = input}
  PIN [7:0] data_write {DIRECTION = input}
  PIN [7:0] data_read {DIRECTION = output}
  PIN [7:0] data_store [0:31] {DIRECTION = output VIEW = none}
  FUNCTION {
    BEHAVIOR {
      data_read = data_store[adr_read];
      @(enable_write) {data_store[adr_write] = data_write;}
    }
  }
  VECTOR
  (?! adr_read[col] -> ?? data_read[byte]) {
    /* fill in arithmetic models for delay and power */
  }
  VECTOR
  (?! adr_read[row] -> ?? data_read[byte]) {
    /* fill in arithmetic models for delay and power */
  }
  VECTOR
  ((?!adr_read[col] && ?!adr_read[row]) -> ??data_read[byte]){
    /* fill in arithmetic models for delay and power */
  }
  VECTOR (01 enable_write -> ?? data_read[byte]) {
    /* fill in arithmetic models for delay and power */
  }
  VECTOR (?! data_write[byte] -> ?? data_read[byte]) {
    /* fill in arithmetic models for delay and power */
  }
  VECTOR (?! adr_write[col]) {
    /* fill in arithmetic models for power */
  }
  VECTOR (?! adr_write[row]) {
    /* fill in arithmetic models for power */
  }
  VECTOR (?! adr_write[row] && ?! adr_write[col]) {
    /* fill in arithmetic models for power */
  }
  VECTOR (01 enable_write) {
    /* fill in arithmetic models for power */
  }
}
```
VECTOR (10 enable_write) {
    /* fill in arithmetic models for power */
}

VECTOR (!data_write[byte] && !enable_write) {
    /* fill in arithmetic models for power */
}

VECTOR (!data_write[byte] && enable_write) {
    /* fill in arithmetic models for power */
}

VECTOR (!adr_write[all] <-> 01 enable_write) {
    SETUP {
        VIOLATION {
            BEHAVIOR { data_store[*] = 'bxxxxxxxxx; }
            MESSAGE_TYPE = error;
            MESSAGE =
            "setup violation: changing 'adr_write' -> rising 'enable_write', memory -> 'X';"
        }
        FROM { pin = adr_write; }
        TO { pin = enable_write; }
        /* fill in header, table or equation */
    }
}

VECTOR (10 enable_write <-> ?! adr_write[all]) {
    HOLD {
        VIOLATION {
            BEHAVIOR { data_store[*] = 'bxxxxxxxxx; }
            MESSAGE_TYPE = error;
            MESSAGE =
            "hold violation: falling 'enable_write' -> changing 'adr_write', memory -> 'X';"
        }
        FROM { pin = enable_write; }
        TO { pin = adr_write; }
        /* fill in header, table or equation */
    }
}

VECTOR (!data_write[byte] <-> 10 enable_write) {
    SETUP {
        VIOLATION {
            BEHAVIOR { data_store[adr_write] = 'bxxxxxxxxx; }
            MESSAGE_TYPE = error;
            MESSAGE =
            "setup violation: changing 'data_write' -> falling 'enable_write',
             memory[adr_write] -> 'X';"
        }
        FROM { pin = data_write; }
        TO { pin = enable_write; }
        /* fill in header, table or equation */
    }
    HOLD {
        VIOLATION {

}
BEHAVIOR { data_store[adr_write] = 'bxxxxxxxx; }
MESSAGE_TYPE = error;
MESSAGE = 
"hold violation: falling 'enable_write' -> changing 'data_write',
memory[adr_write] -> 'X'";
)
FROM { pin = enable_write; }
TO { pin = data_write; }
/* fill in header, table or equation */
)
VECTOR (01 enable_write -> 10 enable_write) {
PULSEWIDTH {
VIOLATION {
MESSAGE_TYPE = error;
MESSAGE = "pulsewidth violation: high 'enable_write'";
)
PIN = enable_write;
/* fill in header, table or equation */
)
}
VECTOR (10 enable_write -> 01 enable_write) {
PULSEWIDTH {
VIOLATION {
MESSAGE_TYPE = error;
MESSAGE = "pulsewidth violation: low 'enable_write'";
)
PIN = enable_write;
/* fill in header, table or equation */
)
}
}

The energy consumption for each operation depends on the number of switching bits of the bus. Therefore, the model for power inside a particular vector may look like this:
VECTOR (!? data_write && enable_write) {
ENERGY {
UNIT = pJ;
HEADER {switching_bits {PIN = data_write;}}
EQUATION {1.3 * switching_bits}
}
}

The rule that the address on a write port must not change during write enable high can be incorporated easily in the functional model. A pessimistic model assumes that the whole memory content will become unknown, if such an illegal address change occurs.

BEHAVIOR {
data_read = data_store[adr_read];
@end {enable_write} {data_store[adr_write] = data_write;}
@(!?adr_write && enable_write) {
data_store[*] = 'bxxxxxxxx;
}
4.9.3 Three-port memory

Functional models of more complex memories are also straightforward. The conflicts of writing to one memory location simultaneously from different ports can be modeled in a pessimistic way as follows:

```plaintext
CELL async_2write_1read_ram {
    PIN enb_write1 {DIRECTION = input;}
    PIN enb_write2 {DIRECTION = input;}
    PIN [4:0] adr_write1 {DIRECTION = input;}
    PIN [4:0] adr_write2 {DIRECTION = input;}
    PIN [4:0] adr_read {DIRECTION = input;}
    PIN [7:0] data_write1 {DIRECTION = input;}
    PIN [7:0] data_write2 {DIRECTION = input;}
    PIN [7:0] data_read {DIRECTION = output;}
    PIN [7:0] data_store [0:31] {DIRECTION = output; VIEW = none;}
    FUNCTION {
        BEHAVIOR {
            data_read = data_store[adr_read];
            @(enb_write1 && !enb_write2)
                {data_store[adr_write1] = data_write1;}
            @(enb_write2 && !enb_write1)
                {data_store[adr_write2] = data_write2;}
            @(enb_write1 && enb_write2 && adr_write1!=adr_write2) {
                data_store[adr_write1] = data_write1;
                data_store[adr_write2] = data_write2;
            }
            @(enb_write1 && enb_write2 && adr_write1==adr_write2) {
                data_store[adr_write1] =
                    (data_write1==data_write2)? data_write1:8'bx;
                data_store[adr_write2] =
                    (data_write2==data_write1)? data_write2:8'bx;
            }
        }
    }
}
```

4.9.4 Annotation for pins of a bus

Annotations of numeric values to a bus apply to the total bus, not to each individual pin.

Example:

```plaintext
PIN [1:4] my_bus_pin {
    CAPACITANCE = 0.04 ;
}
```

The total bus pin capacitance is 0.4, the capacitance values on each individual pin are not defined.
The individual pin capacitance can be defined as follows:

```
PIN [1:4] my_bus_pin {
   CAPACITANCE c1 = 0.01 { PIN = my_bus_pin[1]; }
   CAPACITANCE c2 = 0.01 { PIN = my_bus_pin[2]; }
   CAPACITANCE c3 = 0.01 { PIN = my_bus_pin[3]; }
   CAPACITANCE c4 = 0.01 { PIN = my_bus_pin[4]; }
}
```

### 4.9.5 Skew for simultaneously switching signals on a bus

Vectors with simultaneously switching bits on a bus may contain a specification of the allowed skew in order to be still considered as simultaneously switching bits.

Example:

```
PIN [1:3] address;
VECTOR (?! address )
   SKEW {
      PIN = address;
      /* fill in data */
   }
```

SKEW applied to a bus pin is the maximal allowed time window between the earliest and latest edge within simultaneously switching signals of a bus.

The multiple value annotation feature allows the definition of a group of pins equivalent to a bus for SKEW modeling in the following way:

```
PIN A;
PIN [1:4] B;
VECTOR (?! A && ?! B)
   SKEW { PIN { A B[2:3] } }
```

SKEW applies to the group of pins A, B[2], B[3]. Note that the following is semantically different, since this would result in expansion of each object where the group is instantiated:

```
PIN A;
PIN [1:4] B;
VECTOR (?! my_group)
   SKEW { PIN = my_group; }
```
The expansion yields the following:

```plaintext
PIN A;
PIN [1:4] B;
VECTOR (! A)
  SKEW { PIN = A ; }
}
VECTOR (! B[2])
  SKEW { PIN = B[2] ; }
}
VECTOR (! B[3])
  SKEW { PIN = B[3] ; }
}
```

See Section 4.15.2.7 for definition of SKEW for scalar pins.

## 4.10 Special cells

### 4.10.1 Pulse generator

The following cell generates a one-shot pulse of 1 ns duration when enable goes high.

```plaintext
CELL one_shot {
    PIN enable {DIRECTION = input;}
    PIN q {DIRECTION = output;}
    FUNCTION {
        BEHAVIOR {
            @(01 enable) {q = 1;}
            @(q) {q = 0;}
        }
    }
    VECTOR (01 q -> 10 q) {
        DELAY = 1.0 {UNIT = ns;}
    }
}
```

### 4.10.2 VCO

The following cell is a voltage controlled oscillator with 50% duty cycle and enable.

```plaintext
CELL vco {
    PIN enable {DIRECTION = input; PINTYPE = digital;}
    PIN v_in {DIRECTION = input; PINTYPE = analog;}
    PIN q {DIRECTION = output; PINTYPE = digital;}
    FUNCTION {
        BEHAVIOR {
            @(!enable) {q = 0;}
            @(!q && enable) {q = 1;}
            @( q && enable) {q = 0;}
        }
    }
    TEMPLATE voltage_controlled_delay {
        DELAY {
```
UNIT = ns;
HEADER {
    voltage {
        PIN = v_in;
        TABLE {0.5 1.0 1.5 2.0 2.5 3.0}
    }
}
TABLE {10.00 5.00 3.33 2.50 2.00 1.67}
}
VECTOR (01 q -> 10 q)
    voltage_controlled_delay
} VECTOR (10 q -> 01 q)
    voltage_controlled_delay
}

The template shown above can also be written as an equation to map voltage to frequency:

```
TEMPLATE voltage_controlled_delay {
    DELAY {
        UNIT = ns;
        HEADER {voltage {PIN = v_in;}}
        EQUATION {5.0 / voltage}
    }
}
```

4.11 Core Modeling

4.11.1 Digital Filter

This example illustrates the potential of ALF for modeling complex blocks. It shows a digital filter performing the following operation

\[
\begin{align*}
    dout(t) &= state(t) + b1 \times state(t-1) + b2 \times state(t-2) \\
    state(t) &= din(t) - a1 \times state(t-1) - a2 \times state(t-2)
\end{align*}
\]

This second order infinite impulse response (IIR) filter is implemented with a single multiplier and a single adder/subtractor in a way that a new \(dout\) is produced every 4 clock cycles. The variable coefficients \(a1, a2, b1,\) and \(b2\) are stored in a dual port RAM.

The model uses templates for the functional blocks of a 2-bit counter used as controller for memory access and I/O operation, a RAM for coefficient storage, and the filter itself. In the top module they are instantiated as a structural netlist.
The use of templates is more general than the use of primitives, since not all basic blocks of the core may be supported as primitives.

```alfr
LIBRARY core_lib {

TEMPLATE CNT2 {
    BEHAVIOR {
        @ (!<cd>) {<cnt> = 2'b0;}
        : (01 <cp>) {<cnt> = <start> ? 2'b0 : <cnt> + 1;}
    }
}

TEMPLATE RAM16X4 {
    BEHAVIOR {
        <dout> = <dmem>[<r_adr>];
        @ (<we>) {<dmem>[<w_adr>] = <din>;
    }
}

TEMPLATE IIR2 {
    BEHAVIOR {
        sum =
        (<cntrl>=='d0)? <din> - product :
        (<cntrl>=='d1)? accu - product :
        (<cntrl>=='d2)? accu + product :
        (<cntrl>=='d3)? accu + product;
        @ (!<cd>) {
            product = 16'b0;
            accu = 16'b0;
        }
        : (01 <cp>){
            product =
            (<cntrl>=='d0)? coeff * state2 :
            (<cntrl>=='d1)? coeff * state1 :
            (<cntrl>=='d2)? coeff * state2 :
            (<cntrl>=='d3)? coeff * state1 :
            16'bX;
            accu = sum;
        }
        @ (!<cd>) {
            <dout> = 16'b0;
            state1 = 16'b0;
            state2 = 16'b0;
        }
        : (01 <cp> && <cntrl>=='d0){
            state2 = state1;
            state1 = accu;
            <dout> = accu;
        }
    }
}

CELL digital_filter {
    PIN [15:0] data_out (DIRECTION = output)
}
```
Connectivity

Connectivity information may be specified within the definition of the ALF language format as described below. A connectivity object always contains a rule specifying the type of connections (e.g. must short, can short, cannot short) and a table. If no header is given, then the table contains the pins or pin classes subject to the connectivity rule. If a header is given, then the table contains the values of the connectivity function between arguments in the header. There must be a table inside each connectivity argument, containing the pins or pin classes subject to the connectivity rule. Valid arguments are DRIVER and/or RECEIVER. Valid values are the boolean digits 0, 1, and ?. The value 1 implies the connection rule is true, the value 0 implies the connection rule is false, the value ? implies don’t care situation with the connection rule.

4.12.1 External connections between pins of a cell

The following example shows how to specify required and disallowed interconnections external to a cell.

CELL pll 
  PIN vdd_ana {PINTYPE=supply;}
  PIN vdd_dig {PINTYPE=supply;}
  PIN vss_ana {PINTYPE=supply;}
  PIN vss_dig {PINTYPE=supply;}
  CONNECTIVITY common_ground 
    CONNECT_RULE = must_short;
    TABLE {vss_ana vss_dig}
  CONNECTIVITY separate_supply 
    CONNECT_RULE = cannot_short;
    TABLE {vdd_ana vdd_dig}
}
4.12.2 Allowed connections for classes of pins

The following example defines allowable pin interconnections. The constants for the desired connectivity classes, the grouping of these classes, and the allowable class connectivity table are first defined at the library level. The non-zero values within the matrix specify allowable connectivity of indexed classes. The connectivity classes for pins are then specified with the pin annotation sections.

```
LIBRARY example_library {
    ...
    CLASS default_class;
    CLASS clock_class;
    CLASS enable_class;
    CLASS reset_class;
    CLASS tristate_class;
    ...
    TEMPLATE drivers {
        default_class
        clock_class
        enable_class
        reset_class
        tristate_class
    }
    TEMPLATE receivers {
        default_class
        clock_class
        enable_class
        reset_class
    }
    CONNECTIVITY driver_to_driver {
        CONNECT_RULE = can_short;
        HEADER {
            DRIVER {TABLE {drivers}}
        }
        TABLE {// def clk enb rst tri
            0 0 0 0 1
        }
    }
    CONNECTIVITY receiver_to_receiver {
        CONNECT_RULE = can_short;
        HEADER {
            RECEIVER {TABLE {receivers}}
        }
        TABLE {// def clk enb rst
            1 1 1 1
        }
    }
    CONNECTIVITY driver_to_receiver {
        CONNECT_RULE = can_short;
        HEADER {
            DRIVER {TABLE {drivers}}
            RECEIVER {TABLE {receivers}}
        }
    }
}
```
TABLE {// def clk enb rst tri // driver/receiver
  1 1 1 1 0  // def
  0 1 0 0 0  // clk
  0 0 1 0 0  // enb
  0 0 0 1 0  // rst
}

The above table specifies allowed connectivity from each class to itself, as well as from each class to default_class except for the tristate_class class which may only connect to itself. Note also that while any class may connect to default_class, the default_class may only connect to itself.

Once the library level connectivity is defined, connection class specifications are defined for each pin within cells. The default integer value for the CLASS annotation is 0, which corresponds to the constant declaration value for default_class.

CELL d_flipflop_clr {
  PIN cd {PINTYPE = input; SIGNALTYPE = clear; POLARITY = low; CONNECT_CLASS = reset_class;}
  PIN cp {PINTYPE = input; SIGNALTYPE = clock; POLARITY = rising_edge; CONNECT_CLASS = clock_class;}
  PIN d {PINTYPE = input;}
  PIN q {PINTYPE = output; CONNECT_CLASS = default_class;}
}

CELL d_latch {
  PIN g {PINTYPE = input; SIGNALTYPE = enable; POLARITY = high; CONNECT_CLASS = enable_class;}
  PIN d {PINTYPE = input; CONNECT_CLASS = default_class;}
  PIN q {PINTYPE = output; CONNECT_CLASS = default_class;}
}

CELL tristate_buffer {
  PIN a {PINTYPE = input;}
  PIN enable {PINTYPE = input; CONNECT_CLASS = enable_class;}
  PIN z {PINTYPE = output; CONNECT_CLASS = tristate_class;}
  ...
}

Net-specific connectivity, as opposed to the pin-specific connectivity as shown above, is also possible within the syntax of the language, since a CLASS is not restricted to pins. Specific applications may assign all pins of a specific type as well as nets like power and ground rails to a defined class. This class may be used within the connectivity tables to allow or disallow certain connectivity.
For example, if `vddrail_class` was defined as a net-specific connectivity class, then a specific pin may be disallowed from connecting to any net in the `vddrail_class` connectivity class.

```al)
CLASS vddrail_class
...
CELL inverter {
    PIN in_pin {PINTYPE = input; SIGNALTYPE = clear;
        POLARITY = low; CONNECT_CLASS = reset_class; }
    CONNECTIVITY dont_tie {
        CONNECT_RULE = cannot_short;
        TABLE {in_pin vddrail_class}
    }
}...
```

### 4.13 Signal Integrity

#### 4.13.1 I/V curves

I/V curves describe the driven or drawn current at a pin as a function of the voltage at one or several pins. The following example describes the output current of a buffer as a function of the input and output voltage with a 2-dimensional lookup table.

```al)
CELL simple_buffer {
    PIN z { DIRECTION = output; }
    PIN a { DIRECTION = input; }
    // current @ z dependent on voltage @ z and @ a
    CURRENT {
        PIN = z;
        UNIT = ma;
        HEADER {
            VOLTAGE vout {
                PIN = z;
                TABLE { 0.0 0.5 1.0 1.5 2.0 2.5 3.0 }
            }
            VOLTAGE vin {
                PIN = a;
                TABLE { 0.0 1.0 2.0 3.0 }
            }
        }
        TABLE {
            5.0 5.0 4.8 4.2 3.2 1.6 0.0
            2.5 1.5 0.2 -0.4 -1.8 -2.7 -3.5
            1.2 0.1 -1.3 -1.9 -2.5 -3.8 -4.6
            0.0 -2.0 -3.8 -4.7 -5.5 -6.2 -6.3
        }
    }
    // fill in function, vector and other stuff
}
```
An equation can also be used instead of a lookup table, for example:

```plaintext
CURRENT {
    PIN = z;
    UNIT = ma;
    HEADER {
        VOLTAGE vout {
            PIN = z;
        }
        VOLTAGE vin {
            PIN = a;
        }
    }
    EQUATION {
        (1 - exp(6.3 - 2.4*vout))*exp(0.9 - 0.3*vin) - (1 - exp(3.2*vout))*exp(0.3*vin)
    }
}
```

A buffer may have programmable drive strength controlled by the state of additional input pins. State-dependent I/V curves can be described by vector-specific CURRENT models.

```plaintext
CELL programmable_drive_strength_buffer {
    PIN z { DIRECTION = output; }
    PIN a { DIRECTION = input; }
    // control pins for drive strength
    PIN p1 { DIRECTION = input; }
    PIN p2 { DIRECTION = input; }
    VECTOR (!p1 && !p2) {
        CURRENT {
            // fill in the model
        }
    }
    VECTOR (!p1 && p2) {
        CURRENT {
            // fill in the model
        }
    }
    VECTOR ( p1 && !p2) {
        CURRENT {
            // fill in the model
        }
    }
    VECTOR ( p1 && !p2) {
        CURRENT {
            // fill in the model
        }
    }
}
```

Note that it is also possible to describe other analog cell characteristics, state-dependent or state-independent, for instance voltage versus voltage, frequency versus voltage, current versus temperature etc. in the same way.
4.13.2 Driver resistance

Driver resistance is used to model the transient behavior of signals especially for crosstalk. The drivers are modeled by voltage sources and driver resistances, as illustrated below:

![Figure 4-1: Modeling driver resistance](image)

The purpose is to use linear circuit theory for the analysis of multiple drivers interacting with coupled RC-interconnect networks. In reality, the drivers have non-linear resistance. The linear resistance is a model of the non-linear resistance with the best-fitting linear resistance. Therefore the driver resistance is state-dependent and eventually also load-and slewrate dependent, since for different states and different ranges of load and slewrates the best-fitting value for driver resistance is different.

The following example shows a buffer featuring different driver resistance values for static low and high states, and tables of slewrate and load-dependent transient driver resistance values for rise and fall transitions.

```plaintext
cell simple_buffer {
  PIN z { DIRECTION = output; }
  PIN a { DIRECTION = input; }
  // state-dependent static driver resistance
  VECTOR (!z) {
    RESISTANCE = 0.7k { PIN = z; }
  }
  VECTOR (z) {
    RESISTANCE = 1.2k { PIN = z; }
  }
  // slew & load dependent transient driver resistance
  VECTOR (01 a -> 01 z) {
    RESISTANCE {
      PIN = z;
      UNIT = kohm;
      HEADER {
        CAPACITANCE {
          PIN = z;
          UNIT = pfarad;
          TABLE ( 0.1  0.4  1.6 )
        }
      }
    }
  }
}
```
The transient driver resistance can also be state-dependent, for example in the case of a buffer with programmable drive-strength.

CELL programmable_drive_strength_buffer {
    PIN z { DIRECTION = output; } 
    PIN a { DIRECTION = input; } 
    // control pins for drive strength 
    PIN p1 { DIRECTION = input; } 
    PIN p2 { DIRECTION = input; } 
    // state-dependent static driver resistance 
    VECTOR (!z && !p1 && !p2) {
        RESISTANCE = 0.7k { PIN = z; }
    }
    VECTOR (!z && !p1 &&  p2) {
        RESISTANCE = 0.6k { PIN = z; }
    }
    VECTOR (!z &&  p1 && !p2) {
        RESISTANCE = 0.5k { PIN = z; }
    }
    VECTOR (!z &&  p1 &&  p2) {
        RESISTANCE = 0.4k { PIN = z; }
    }
    VECTOR (z && !p1 && !p2) {
        RESISTANCE = 1.2k { PIN = z; }
    }
    VECTOR (z && !p1 &&  p2) {
    }
}
RESISTANCE = 1.0k { PIN = z; }
}
VECTOR (z && pl && p2) {
    RESISTANCE = 0.8k { PIN = z; }
}
VECTOR (z && pl && p2) {
    RESISTANCE = 0.6k { PIN = z; }
}
// slew & load and state dependent transient driver resistance
VECTOR (01 a -> 01 z && !pl && !p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (01 a -> 01 z && !pl && p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (01 a -> 01 z && pl && !p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (01 a -> 01 z && pl && p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (10 a -> 10 z && !pl && !p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (10 a -> 10 z && !pl && p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (10 a -> 10 z && pl && !p2) {
    RESISTANCE {
        // fill in the model
    }
}
VECTOR (10 a -> 10 z && pl && p2) {
    RESISTANCE {
        // fill in the model
    }
}
)

The model for transient driver resistance has the same form as a slewrate and load dependent model for delay. Voltage, process, and temperature dependent driver resistance can also be modeled in the same way as voltage, process, and temperature-dependent delay.
4.14 Resistance and Capacitance on a Pin

4.14.1 Self-Resistance and Capacitance on Input Pin

A pin resistance is a resistance inside a PIN object.

```plaintext
PIN <pin_identifier> {
    DIRECTION = input;
    RESISTANCE = <resistance_number>;
    CAPACITANCE = <capacitance_number>;
}
```

The pin resistance is in series with the pin capacitance, as shown in figure 4-2:

![Figure 4-2: Resistance and capacitance on a pin](image)

4.14.2 Pullup and Pulldown Resistance on Input Pin

A pullup or pulldown resistance or a combination of both on an input pin can be described as follows:

```plaintext
PIN <pin_identifier> {
    DIRECTION = input;
    PULL = < up | down | both > {
        VOLTAGE = <voltage_number>;
        RESISTANCE = <resistance_number>;
    }
}
```

The pullup/pulldown resistance is in series with a clamp voltage, as shown in figure 4-3:

![Figure 4-3: Pullup or pulldown resistance](image)
In the case of a pullup/pulldown combination, the resistance and voltage represent the Thevenin equivalent resistance and voltage, respectively, as shown in figure 4-4:

\[
R = \frac{R_1 \cdot R_0}{R_1 + R_0}
\]

\[
V = \frac{V_1 \cdot R_0 + V_0 \cdot R_1}{R_1 + R_0}
\]

**Figure 4-4: Thevenin equivalent resistance**

### 4.14.3 Pin and Load Resistance and Capacitance on Output Pin

The driver resistance (see 4.13.2) can also be represented as pin capacitance of an output pin, in case there is no state dependency.

```plaintext
PIN <pin_identifier> {
    DIRECTION = output;
    CAPACITANCE = <capacitance_number>;
    RESISTANCE {
        RISE = <rise_resistance_number>;
        FALL = <rise_resistance_number>;
    }
}
```

Please note the distinction of capacitance and resistance of the pin itself and capacitance and resistance applied as load to the pin in the following schematic. The load capacitance and resistance would be specified in a characterization vector (see Section 4.3).

See the following schematic for driver signal, pin and load resistance and capacitance:

**Figure 4-5: Resistance and capacitance on output pin**
4.15 ALF/SDF cross reference

This section provides a cross reference between the representation of timing data in ALF and SDF. In general, ALF is used as a characterization library, which is the input to a delay calculator, whereas SDF is the output from a delay calculator. Therefore ALF typically contains tables or equations (i.e. arithmetic models) for timing data whereas SDF contains a discrete set of data in fixed format. However, in an ALF representation of timing shells for cores, which are typically represented in SDF today, the ALF library would contain the same data as the SDF.

The specification of the stimulus for a particular timing measurement (i.e. the timing diagram) is pertinent to both ALF and SDF. In ALF, timing diagrams are directly described in the vector expression language, and the timing measurements are always specified in relation to a particular timing vector. In SDF, timing diagrams are partly described in the language and partly implied by the keyword for timing measurements. Therefore SDF needs a larger set of keywords than ALF for the same description capability.

4.15.1 SDF delays

4.15.1.1 SDF DELAY for IOPATH and INTERCONNECT

DELAY is a measurement of the time needed for a signal to travel from one port to another port. In ALF, delay measurements are described in a uniform language, independent of whether A and Z are the input and output port of the same cell, respectively, or A and Z are the driver and receiver connected to the same net, or A and Z are both outputs of a cell. Therefore the SDF keywords IOPATH and INTERCONNECT have no counterpart in ALF.

VECTOR (01 A -> 01 Z) {
    DELAY {
        FROM {PIN = A;}
        TO {PIN = Z;}
        /* fill in data */
    }
}

Figure 4-6: Measurement of SDF IOPATH or INTERCONNECT delay

The ALF VECTOR describes the sequence of events shown in figure 4-6

rising edge at A followed by rising edge at Z.
The FROM and TO pin annotations define the sense of measurement for DELAY. As opposed to SDF where input ports of an IOPATH may have an edge specification and output ports may not, the vector expression language in ALF always contains the specification of the edge:

\[ \text{rising edge} = "01", \text{falling edge} = "10", \text{any edge} = "?!". \]

### 4.15.1.2 SDF PATHPULSE

PATHPULSE in SDF defines the smallest pulse that may appear at a port in form of

1. a full-swing pulse
2. a pulse to X.

The equivalent model in ALF uses two vectors in conjunction with the keyword PULSEWIDTH.  

The ALF keywords are of more general use than the SDF PATHPULSE keyword, which is just for one specific use.

```alfetch
VECTOR (01 Z -> 10 Z) {
    PULSEWIDTH {
        PIN = Z;
        /* fill in data */
    }
}
```

![Figure 4-7: Measurement of SDF PATHPULSE full-swing](image)

The ALF VECTOR above describes the sequence of events

\[ \text{rising edge at Z followed by falling edge at Z}. \]

The smallest possible full-swing pulse applies at pin Z.

```alfetch
VECTOR ('b0''bX Z -> 'bX''b0 Z) {
    PULSEWIDTH {
        PIN = Z;
        /* fill in data */
    }
}
```

1. The same keyword PULSEWIDTH is also used for a timing constraint in ALF. The semantic meaning in both usage cases is consistent: PULSEWIDTH = smallest possible pulse at output or smallest allowed pulse at input. Therefore the usage of the same keyword is justified.
This ALF VECTOR describes the sequence of events

rising edge at Z from 0 to X followed by falling edge at Z from X to 0.

The smallest possible pulse to “X” applies at pin Z.

VECTOR (01 A -> 10 B -> 01 Z -> 10 Z) {
  PULSEWIDTH {
    PIN = Z;
    /* fill in data */
  }
}

This ALF VECTOR describes the sequence of events as shown in figure 4-9

rising edge at A followed by falling edge at B followed by rising edge at Z followed by falling edge at Z.

This is a detailed specification of the pulse itself at pin Z as well as of the triggering input signals A and B.

4.15.1.3 SDF RETAIN delays

RETAIN delay in SDF is a measurement for the time for which an output signal will retain its value after a change at a related input signal occurs. It appears always in conjunction with a IOPATH delay, which is the time for which an output will stabilize after changing its value.
RETAIN is mainly used for asynchronous memories, where decoder glitches may appear at the data output port.

```
VECTOR (01 A -> ?! Z) {
  RETAIN {
    FROM {PIN = A;}
    TO {PIN = Z;}
    /* fill in data */
  }
  DELAY {
    FROM {PIN = A;}
    TO {PIN = Z;}
    /* fill in data */
  }
}
```

![Diagram of RETAIN and IOPATH delay]

**Figure 4-10: RETAIN and IOPATH delay**

The ALF VECTOR describes the sequence of events shown in figure 4-10

*rising edge at A followed by any edge at Z.*

The intermediate events at Z, occurring eventually between retain and delay time, are not specified.

4.15.1.4 SDF PORT delays

PORT delay in SDF is a delay measurement with unspecified start point, since the start point is going to be established by a connection to a driver in the design and not in the library.

```
VECTOR (01 A) {
  DELAY {
    TO {PIN = A;}
    /* fill in data */
  }
}
```
This ALF VECTOR describes the event figure 4-11

\textit{rising edge at A.}

The absence of a FROM pin defines the absence of a start point, which corresponds to the exact meaning of PORT in SDF.

ALF also has the capability of describing a delay measurement with unspecified end point.

\begin{verbatim}
VECTOR (01 Z) {
    DELAY {
        FROM {PIN = Z;}
        /* fill in data */
    }
}
\end{verbatim}

Hence ALF provides the description capability for both a delay from unspecified driver to specified receiver and a delay from specified driver to unspecified receiver.

\textbf{4.15.1.5 SDF DEVICE delays}

DEVICE delay in SDF is a delay that applies from all input ports of a device to one specific output port or to all output ports by default.

The ALF vector expression language has no notion of “all input ports of a device”. ALF has a more general capability of declaring groups of pins and define delays from group to group or from group to pin or from pin to group.

\begin{verbatim}
GROUP any_input { A B }
GROUP any_output { Y Z }
VECTOR (01 any_input -> 01 any_output) {
    DELAY {
        FROM {PIN = any_input;}
        TO {PIN = any_output;}
        /* fill in data */
    }
}
\end{verbatim}

The ALF VECTOR above describes the event

\textit{rising edge at any_input (i.e. A or B) followed by rising edge at any_output (i.e. Y or Z).}
This construct is equivalent to the following four vectors:

```
VECTOR (01 A -> 01 Y) {
  DELAY {
    FROM {PIN = A;}
    TO {PIN = Y;}
    /* fill in data */
  }
}
VECTOR (01 B -> 01 Y) {
  DELAY {
    FROM {PIN = B;}
    TO {PIN = Y;}
    /* same data */
  }
}
VECTOR (01 A -> 01 Z) {
  DELAY {
    FROM {PIN = A;}
    TO {PIN = Z;}
    /* same data */
  }
}
VECTOR (01 B -> 01 Z) {
  DELAY {
    FROM {PIN = B;}
    TO {PIN = Z;}
    /* same data */
  }
}
```

4.15.2 SDF timing constraints

4.15.2.1 SDF SETUP

SETUP in SDF is the minimal time required for a data signal to arrive before the sampling edge of a clock signal in order to be sampled correctly.

```
VECTOR (!? din -> 01 clk) {
  SETUP {
    FROM {PIN = din;}
    TO {PIN = clk;}
    /* fill in data */
  }
}
```
The ALF VECTOR describes the sequence of events as shown in figure 4-12

\textit{any edge at din followed by rising edge at clk.}

The FROM and TO pin annotations define the sense of measurement for SETUP. Since setup time is measured in positive sense from data to clock, din is the data pin, and clk is the clock pin.

\subsection*{4.15.2.2 SDF HOLD}
HOLD in SDF is the minimal non-negative time required for a data signal to stay at its value after the sampling edge of a clock signal in order to be sampled correctly.

VECTOR (01 clk \rightarrow \text{?! din}) { 
    HOLD { 
        FROM (PIN = clk;)
        TO (PIN = din;)
        /* fill in data */
    }
}

The ALF VECTOR describes the sequence of events as shown in figure 4-13

\textit{rising edge at clk followed by any edge at din.}

The FROM and TO pin annotations define the sense of measurement for HOLD. Since hold time is measured in positive sense from clock to data, clk is the clock pin, and din is the data pin.
4.15.2.3 SDF SETUPHOLD

SETUPHOLD in SDF is a combination of SETUP and HOLD. In this combination, either SETUP or HOLD may be a negative value, but the sum of both values, which represents the minimal pulsewidth of the data in order to be sampled correctly, must be non-negative. The time from the leading data edge to the sampling clock edge is SETUP. The time from the sampling clock edge to the trailing data edge is HOLD.

VECTOR // for SETUPHOLD
{
  ?! din -> 01 clk -> ?! din //setup & hold both positive
  01 clk -> ?! din -> ?! din //negative setup, positive hold
  ?! din -> ?! din -> 01 clk //positive setup, negative hold
}

SETUP {
  FROM {PIN = din;}
  TO {PIN = clk;}
  /* fill in data */
}

HOLD {
  FROM {PIN = clk;}
  TO {PIN = din;}
  /* fill in data */
}

Figure 4-14: Measurement of SDF SETUPHOLD

The ALF VECTOR describes the alternative sequences of events as shown in figure 4-14:

- any edge at din followed by rising edge at clk followed by any edge at din
- or rising edge at clk followed by any edge at din followed by any edge at din
- or any edge at din followed by any edge at din followed by rising edge at clk.

The FROM and TO pin annotations define the sense of measurement for SETUP and HOLD, respectively, in the same way as if they were specified in separate vectors.
4.15.2.4 SDF RECOVERY

RECOVERY in SDF is the minimal time required for a higher priority asynchronous control signal to be released before a lower priority clock signal in order to allow the clock to be in control.

VECTOR (01 clearbar -> 01 clk) {
    RECOVERY {
        FROM {PIN = clearbar;}
        TO {PIN = clk;}
    }
}

Figure 4-15: Measurement of SDF RECOVERY

The ALF VECTOR describes the sequence of events as shown in figure 4-15

*rising edge at clearbar followed by rising edge at clk.*

The FROM and TO pin annotations define the sense of measurement for RECOVERY. Since recovery time is measured in positive sense from the higher priority asynchronous control signal to the lower priority clock, clearbar is the asynchronous control pin, and clk is the clock pin.

4.15.2.5 SDF REMOVAL

REMOVAL in SDF is the minimal time required for a higher priority asynchronous control signal to stay active after a lower priority clock signal in order to keep overriding the clock.

VECTOR (01 clk -> 01 clearbar) {
    REMOVAL {
        FROM {PIN = clk;}
        TO {PIN = clearbar;}
    }
}
The ALF VECTOR describes the sequence of events as shown in figure 4-16

- rising edge at clk followed by rising edge at clearbar.

The FROM and TO pin annotations define the sense of measurement for REMOVAL. Since removal time is measured in positive sense from the lower priority clock to the higher priority asynchronous control signal, clk is the clock pin, and clearbar is the asynchronous control pin.

4.15.2.6 SDF RECREM

RECREM in SDF is a combination of RECOVERY and REMOVAL. In this combination either RECOVERY or REMOVAL may be negative, but the sum of both must be non-negative. The sum of RECOVERY and REMOVAL represents the width of the “forbidden zone” for the phase between the higher priority and the lower priority signal. The boundary to the left is RECOVERY, the boundary to the right is REMOVAL.

In a characterization vector for RECREM, either the RECOVERY or the REMOVAL effect can be observed, depending on the phase relationship between the signals. This is different from SETUPHOLD where the effects of both SETUP and HOLD can be observed in the same characterization vector.

VECTOR // for RECREM

```plaintext
( 01 clearbar -> 01 clk // pos. recovery or neg. removal
 | 01 clk -> 01 clearbar // neg. recovery or pos. removal
)

RECOVERY{
    FROM {PIN = clearbar;}
    TO {PIN = clk;}
    /* fill in data */
}

REMOVAL{
    FROM {PIN = clk;}
    TO {PIN = clearbar;}
    /* fill in data */
}
```
The ALF VECTOR describes the alternative sequences of events as shown in figure 4-17:

- rising edge at clearbar followed by rising edge at clk
- or rising edge at clk followed by rising edge at clearbar

The FROM and TO pin annotations define the sense of measurement for RECOVERY and REMOVAL, respectively, in the same way as if they were specified in separate vectors.

### 4.15.2.7 SDF SKEW

SKEW in SDF is maximum allowed difference in arrival time between signals. The allowed region for the phase between signals is bound by zero to the left and SKEW to the right for positive SKEW or by SKEW to the left and zero to the right for negative SKEW.

```
VECTOR (01 clk1 <&> 01 clk2) {// pos. or neg. or zero skew
SKEW {
    FROM {PIN = clk1;}
    TO {PIN = clk2;}
    /* fill in data */
}
}
```

![Figure 4-18: Measurement of SDF SKEW](image)
The ALF VECTOR describes the alternative sequences of events as shown in figure 4-18:

- rising edge at clk\textsubscript{1} followed by rising edge at clk\textsubscript{2}
- or rising edge at clk\textsubscript{2} followed by rising edge at clk\textsubscript{1}
- or rising edge at clk\textsubscript{2} simultaneously with rising edge at clk\textsubscript{1}

This is the most general case, where the skew may be positive, negative or zero across the characterization space. The FROM and TO pin annotations define the sense of measurement for SKEW.

### 4.15.2.8 SDF WIDTH

VECTOR (01 clk -> 10 clk) {// high pulse
  PULSEWIDTH {
    PIN = clk;
    /* fill in data */
  }
}

This ALF vector describe the sequence of events as shown in figure 4-19:

- rising edge at clk followed by falling edge at clk.

The pulsewidth applies to the positive phase of the signal clk.

VECTOR (10 clk -> 01 clk) {// low pulse
  PULSEWIDTH {
    PIN = clk;
    /* fill in data */
  }
}

This ALF vector describe the sequence of events

- falling edge at clk followed by rising edge at clk.

The pulsewidth applies to the negative phase of the signal clk.

\[ \text{Figure 4-19: Measurement of SDF WIDTH} \]

VECTOR (01 clk -> 10 clk | 10 clk -> 01 clk) {// high or low pulse
  PULSEWIDTH {
    PIN = clk;
    /* fill in data */
  }
}

This ALF vectors describes the alternative sequences of events as shown in figure 4-20.
rising edge at clk followed by falling edge at clk
or falling edge at clk followed by rising edge at clk.

The pulsewidth applies to both phases of the signal clk.

4.15.2.9  SDF PERIOD

VECTOR (01 clk -> 10 clk -> 01 clk) {
  PERIOD {
    PIN = clk;
    /* fill in data */
  }
}

![Figure 4-20: Measurement of SDF PERIOD](Image)

This ALF vectors describes the sequence of events as shown in figure 4-21
rising edge at clk followed by falling edge at clk followed by rising edge at clk.
Thus the period is measured between two consecutive rising edges at the signal clk.

4.15.2.10  SDF NOCHANGE

VECTOR (?! addr -> 10 write -> 01 write -> ?! addr) {
  SETUP {
    FROM {PIN = addr;}
    TO {PIN = write;}
    /* fill in data */
    HOLD {
      FROM {PIN = write;}
      TO {PIN = addr;}
      /* fill in data */
    }
    NOCHANGE {
      PIN = addr;
      /* fill in optional data */
      }
      }
      }
This ALF vector describes the sequence of events as shown in figure 4-21

\[
\text{any edge at addr followed by falling edge at write followed by rising edge at write followed by any edge at addr.}
\]

The SETUP time is measured from the first edge at addr to the first edge at write. The HOLD time is measured from the second edge at write to the second edge at addr. The signal addr may not change between the start time of the setup measurement until the end time of the hold measurement. ALF allows to specify an additional measurement between the first and second edge of the signal subject to NOCHANGE. However, this additional measurement could not be directly translated into SDF and would be for characterization and future purpose only.

### 4.15.3 SDF conditions and labels for delays and timing constraints

Conditions for IOPATH timing arcs in SDF apply to the entire timing arc. The condition is evaluated during the event on the “from” port (i.e. an input pin), and the event on the “to” port (i.e. an output pin) is scheduled consequently.

Conditions for timing constraints in SDF can be defined individually for each port. The condition associated with the start point of the timing constraint (i.e. data for SETUP, clock for HOLD etc.) is called stamp condition. The condition associated with the end point of the timing constraint (i.e. clock for SETUP, data for HOLD) is called check condition.

The use of SETUPHOLD instead of individual SETUP and HOLD or RECREM instead of individual RECOVERY and REMOVAL in SDF imposes restrictions in the definition of conditions. Whereas the use of 2 individual timing constraints allows the definition of 4 conditions (2 stamp, 2 check), the use of 1 combined timing constraint allows only the definition of 2 conditions (1 stamp, 1 check).

The ALF vector expression language allows to specify conditions during the sequence of events in a more general way than SDF.

Some more examples in ALF:
VECTOR ( C & ( 01 A -> 01 B) )

alternative specification options:
VECTOR ( ?1 C -> 01 A -> 01 B -> 1? C ) // verbose
VECTOR ( ?1 C -> 01 A -> 01 B ) // C must be true before start
VECTOR ( 01 A -> 01 B -> 1? C ) // C must be true until the end

This ALF vector describes the sequence of events as shown in figure 4-22

rising edge at A is followed by rising edge at B, C is true before rising edge of A until after rising edge of B.

Either of the pseudo-events (?1 C, 1? C) at the boundary can be omitted, since either one of them is sufficient to specify that the condition C must be true during the entire event sequence.

VECTOR ( ( C & 01 A ) -> 01 B )

alternative specification options:
VECTOR ( ?1 C -> 01 A -> 1? C -> 01 B )
VECTOR ( 01 A -> 1? C -> 01 B )

This ALF vector describes the sequence of events as shown in figure 4-23
rising edge at A is followed by rising edge at B, C is true before rising edge of A until after rising edge of A.

\[ \text{VECTOR ( 01 A \rightarrow (C \& 01 B) )} \]

alternative syntax:
\[ \text{VECTOR ( 01 A \rightarrow ?1 C \rightarrow 01 B \rightarrow 1? C )} \]

This ALF vector describes the sequence of events as shown in figure 4-24

\[ \text{rising edge at A is followed by rising edge at B, C is true before rising edge of B until after rising edge of B.} \]

SETUPHOLD with SCOND (stamp condition) and CCOND (check condition) in SDF can be described in ALF in the following way:
A more verbose specification of the vector looks as follows:

```
VECTOR ( ?! din -> ?1 ccond -> 01 clk -> 1? scond -> ?! din ) {
    SETUP {
        FROM {PIN = din;}
        TO {PIN = clk;}
        /* fill in data */
    }
    HOLD {
        FROM {PIN = clk;}
        TO {PIN = din;}
        /* fill in data */
    }
}
```

The optional condition label in SDF has its counterpart in ALF (see 3.6.4.1). As in SDF, the use and interpretation of this label is defined by the application tool and not by the standard.
Index

Symbols
(N+1) order sequential logic 11
-> operator 11
?! 29
?? 29
?</29
@ 9

Numerics
2-dimensional tables 137
3-dimensional table 140, 145
A
ABS 48
abs 36
abstract transition operators 153
active vectors 101
ALF_AND 109, 110, 126
ALF_BUF 108, 109
ALF_BUFIF0 112
ALF_BUFIF1 112
ALF_FLIPFLOP 115, 124
ALF_LATCH 116
ALF_MUX 114, 125
ALF_NAND 109, 110
ALF_NAND2 123
ALF_NOR 109, 111
ALF_NOT 108, 109
ALF_NOTIF0 112, 113
ALF_NOTIF1 112, 113
ALF_OR 109, 110
ALF_XNOR 109, 111
ALF_XOR 109, 111
ALIAS 19
alias 38
all_purpose_items 38
alphabetic_bit_literal 27
annotated properties 15
annotation 38
arithmetic model tables
AREA 78
CAPACITANCE 77
CONNECTIONS 79
CONNECTIVITY 79
CURRENT 77
DELAY 76
DERATE_CASE 80
DISTANCE 78
DRIVE_STRENGTH 78, 79
DRIVER 79
ENERGY 77
FANIN 79
FANOUT 79
FREQUENCY 77
HEIGHT 78
HOLD 76
JITTER 77
LENGTH 78
NOCHANGE 76
PERIOD 76
POWER 77
PROCESS 80
PULSEWIDTH 76
RECEIVER 79
RECOVERY 76
REMOVAL 76
RESISTANCE 77
SETUP 76
SKEW 76
SLEWRATE 76
SWITCHING_BITS 79
TEMPERATURE 77
THRESHOLD 79
TIME 77
VOLTAGE 77
WIDTH 78
average 74
can_short 74
cannot_short 74
CONNECT_RULE 74
DEFAULT 72
FALL 75
MAX 75
MEASUREMENT 74
MIN 75
must_short 74
peak 74
RISE 75
rms 74
static 74
transient 74
TYP 75
UNIT 73
CELL 67
BUFFERTYPE 68
CELLTYPE 67
DRIVERTYPE 68
NON_SCAN_CELL 69
PARALLEL_DRIVE 68
SCAN_TYPE 68
SCAN_USAGE 69
cell buffertype
inout 68
input 68
internal 68
output 68
cell celltype
block 68
buffer 67
combinational 67
core 68
flipflop 67
latch 67
memory 67
multiplexor 67
pad 68
special 68
cell drivertype
both 68
predriver 68
slotdriver 68
cell scan_type
clocked 69
control_0 69
control_1 69
lssd 69
muxscan 69
cell scan_usage
hold 69
input 69
output 69
default 72
from 56
information 57
AUTHOR 59
DATETIME 59
PRODUCT 59
TITLE 59
VERSION 59
limit 57
object reference
cell 60
pin 60
primitive 60
PIN
ACTION 63
CONNECT_CLASS 64
DATATYPE 64
DIRECTION 62
DRIVERTYPE 61
ENABLE_PIN 63
OFF_STATE 65
ORIENTATION 64
POLARITY 63
PULL 63
SCAN_POSITION 64
SCOPE 62
SIGNALTYPE 61
STUCK 64
VIEW 60
pin
PINTYPE 60
pin action
asynchronous 63
synchronous 63
pin datatype
signed 64
unsigned 64
pin direction
both 62
input 62
none 62
output 62
pin drivertype
ccmos 62
cmos_pass 62
nmos 62
nmos_pass 62
open_drain 62
open_source 62
pmos 62
pmos_pass 62
ttl 62
pin off_state
    inverted 65
    non_inverted 65
pin orientation
    bottom 64
    left 64
    right 64
    top 64
pin pintype
    analog 61
    digital 61
    supply 61
pin polarity
    both 63
    double_edge 63
    falling_edge 63
    high 63
    inverted 63
    low 63
    non_inverted 63
    none 63
    rising_edge 63
pin pull
    both 64
    down 64
    none 64
    up 64
pin scope
    behavior 62
    both 62
    measure 62
    none 62
pin signaltype
    clear 61
    clock 61
    control 61
    data 61
    enable 61
    master_clock 61
    out_enable 61
    read 61
    scan_clock 61
    scan_data 61
    scan_enable 61
    scan_out_enable 61
    select 61
    set 61
    slave_clock 61
    write 61
    pin stuck
        both 65
        none 65
        stuck_at_0 65
        stuck_at_1 65
    pin view
        both 60
        functional 60
        none 60
        physical 60
        scan 56
        to 57
        unnamed 56
        VECTOR 65
        LABEL 65, 66, 67
        violation 57
        MESSAGE 59
        MESSAGE_TYPE 59
annotation container 21, 56
annotation_container 38
annotations 144
    PIN 144
    pin 162
    self-explaining 145
    timing arc 144
    any_character 26
    arithmetic models 18
    arithmetic operations 13
    arithmetic operators
        binary 48
        function 48
        unary 48
        arithmetic_binary_operator 36
### arithmetic_expression 34
- arithmetic_function_operator 36
- arithmetic_model 42
- arithmetic_model_template_instantiation 42
- arithmetic_unary_operator 37
- assignment_base 33
- async_2write_1read_ram 156
- atomic_megacell 7
- atomic_object 17
- ATTRIBUTE 20, 71
- attribute 38
  - CELL 72
    - cell
      - asynchronous 72
      - CAM 72
      - dynamic 72
      - RAM 72
      - ROM 72
      - static 72
      - synchronous 72
- LIBRARY 72
- PIN 71
- pin
  - PAD 71
  - SCHMITT 71
  - TRISTATE 71
  - XTAL 71
- pin polarity
  - READ 72
  - TIE 72
  - WRITE 72
- attribute_items 39
- average 139

### B
- based literal 28
- based_literal 28
- BEHAVIOR 123
- behavior 43
- behavior_body 43
- bidirectional pin 150
- binary 28
- Binary operators
  - arithmetic 48
  - bitwise 50
  - boolean, scalars 49
- reduction 49
- vector 52, 53
- binary_base 28
- binary_digit 28
- bit 27
- bit_edge_literal 29
- bit_literal 27
- Bitwise operators
  - binary 50
  - unary 50
- block comment 26
- bodies 43
- Boolean Equation 123
- boolean functions 7
- boolean operators
  - binary 49
  - unary 48
  - boolean_and_operator 37
  - boolean_arithmetic_operator 37
  - boolean_binary_operator 37
  - boolean_case_compare_operator 37
  - boolean_condition_operator 37
  - boolean_else_operator 37
  - boolean_expression 34, 41
  - boolean_logic_compare_operator 37
  - boolean_or_operator 37
  - boolean_unary_operator 37
- both 150
- bus contention 148
- bus modeling 147
- bus with multiple drivers 149
- busholder 149

### C
- can_float 145
- CAPACITANCE 132, 150
- case-insensitive language 26
- cell 40
- cell modeling 15
- cell_identifier 35, 40
- cell_instantiation 35
- cell_items 40
- cell_template_instantiation 40
- characterization 5, 7
  - power 7, 14
  - timing 7
characterization model 136
Characterization Modeling 12
coloration variables 7
children object 17
CLASS 19, 162
class 39
    connectivity 162
combinational logic 8
combinational primitives 108
combinational scan cell 128
combinational_assignments 44
comment 25
    block 26
    long 26
    short 26
    single-line 26
comments
    nested 26
compound operators 26
CONNECT_RULE 162
CONNECTION 145
connections
    allowed 162
    disallowed 161
    external 161
CONNECTIVITY 162
connectivity 161
    class 162
    net-specific 163
    pin-specific 163
connectivity class 162
CONSTANT 19
constant 39
constant numbers 26
constraints
    delay 137
    power 137
    timing 137
context_sensitive_keyword 35
context-sensitive keyword 32, 148
context-sensitive keywords 13
core 7
core cell 148
core modeling 159

D
d_flipflopClr 124
d_flipflopld_clr 126
d_flipflop_mux_set_clr 126
dLatch 127
decimal 28
decimal_base 28
deep submicron 5
DEFAULT 145, 146
default annotation 72
delay mode
    inertial 14
    invalid-value-detection 14
    transport 14
delay models 12
delay predictor 13
delimiter 25, 26
derating 141
derating equation 142
digit 28
digital filter 159
digital_filter 160
DRIVE_STRENGTH 148
DRIVER 162

E
edge literal 29
edge rate 12
edge_literal 29
edge_literals 35
edge-sensitive sequential logic 8
elapsed time 12
ENERGY 140
energy 14
equation 43
equation_template_instantiation 43
escape codes 29
escape_character 25
escaped identifier 30
escaped_identifier 30
event sequence detection 11
EXP 48
exp 37
expansion
    bit-wise 152
    bytewise 152
expansion of vectors 152
exponentiation 13
extensible primitives 107
external connections 161

F
fanout 16
Flipflop 115
flipflop 124
forward referencing 17
fringe capacitance 16
FUNCTION 123
function 43
exponentiation 13
logarithm 13
Function operators
arithmetic 48
function_template_instantiation 43
functional model 4
functional modeling 8
functional models 7
functions 18

G
generic objects 18
generic_object 38
glitch 14
GROUP 21, 152
group 39
group_identifier 39

H
hard keyword 32
hardware description language 7
HDL 7
header 42
header_template_instantiation 42
hex_base 28
hex_digit 28
hexadecimal 28
hierarchical object 17

I
identifier 17, 25
Identifiers 30
identifiers 35
inactive vectors 101
INCLUDE 19, 92
include 39
index 35
inertial delay mode 14
infinite impulse response filter 159
INFORMATION 128
integer 26, 27
internal load 13
intrinsic delay 12

J
JK-flipflop 125
JTAG BSR cell 128

K
keyword 17
Keywords
context-sensitive 33
generic objects 32
operators 33
keywords
context-sensitive 13

L
Latch 116
layout parasitics 13
level-sensitive cell 127
level-sensitive sequential logic 8
libraries 40
LIBRARY 128
library 17
Library creation 1
library_identifier 41
library_items 40
library_specific_object 38
library_template_instantiation 40
library-specific objects 18
LIMIT 145
literal 17, 25
load characterization model 13
LOG 48
log 37
logarithm 13
logic_literals 36
logic_values 36
logic_variables 36

M
  macrocells 7
  MAX 48
  max 37
  MEASUREMENT 139
  megacell modeling 152
  megacells 7
  metal layer 16
  MIN 48
  min 37
  mode of operation 5
  modeling
    bus 147
    cell 15
    characterization 12
    cores 159
    functional 8
    megacell 152
    physical 15
    power 13
    synthesis 15
    test 15
    timing 12
    wire 16
    wireload 150
  multiplexor 114
  must_connect 145
  muxscan 130

N
  named_assignment 33
  named_assignment_base 33
  NAND gate 123
  nested comments 26
  no_connection 145
  non_negative_number 27
  NON_SCAN_CELL 129
  non-escaped identifier 30
  noneescaped_identifier 30
  nonreserved_character 25
  non-scan cells 15
  Number 26
  number 27
  numbers 36
  numeric_bit_literal 27

O
  objects 17, 39
  octal 28
  octal_base 28
  octal_digit 28
  one_shot 158
  one-pass parser 17
  operation mode 5
  operator
    -> 11
    followed by 11
  operators
    arithmetic 48
    boolean, scalars 48
    boolean, words 49
    signed 50
    unsigned 50
  output ramptime 132

P
  parasitic capacitance 16
  parasitic resistance 16
  physical modeling 15
  pin_assignments 34
  pin_identifier 40
  pin_items 41
  pin_template_instantiation 40
  pins 40
  placeholder identifier 30
  placeholder_identifier 30
  placeholders 20
  POLARITY 130
  power 14
  Power characterization 7
  power characterization 14
  power constraint 5
  power dissipation 14
  Power model 5
  power modeling 13
  predefined derating cases 81, 88, 89
    bccom 81
    bcind 81
    bcmil 81
    wccom 81
wcind 81
wcnil 81
predefined process names 81
  snsp 81
  snwp 81
  wns 81
  wnwp 81
primitive 124
primitive_identifier 35, 41
primitive_instantiation 35
primitive_items 41
primitive_template_instantiation 41
primitives 41
private keywords 33
PROCESS 141
PROPERTY 21
property 39
public keywords 33
pulse generator 158
PVT Derating 141
Q
  Q_CONFLICT 115
  QN_CONFLICT 115
  quad D-Flipflop 131
  quoted string 25, 29
  quoted_string 29
R
  RAM16X4 161
  real 26
  Reduction operators
    binary 49
    unary 49
  reserved keyword 32
  reserved_character 25
  RESISTANCE 151
  RTL 4
S
  scaled average current 14
  scaled average power 14
  scan cell
    combinational 128
  scan chai 128
  Scan Flipflop 130
  Scan insertion 15
  scan test 15
  scan_data 130
  scan_enable 130
  SCAN_FFX4 131
  SCAN_ND4 129
  SCAN_TYPE 129
  self capacitanc 16
  self-explaining annotations 145
  sequential logic
    edge-sensitive 8
    level-sensitive 8
    N+1 order 11
    vector-sensitive 11
  sequential_assignment 44
  sheet resistance 16
  sign 26
  signed operators 50
  simulation model 5
  single-line comment 26
  slew rate 12
  SLEWRATE 132, 147
  soft keyword 32
  source_text 38
  sr_latch 127
  state-dependent drive strength 148
  STATETABLE 123
  statetable 43
  statetable_body 43
  static power 15
  std_derating 142
  std_header_2d 134
  string 36
  sublibraries 41
  sublibrary_template_instantiation 41
  switching energy 132
  symbolic_edge_literal 29
T
  TABLE 132
  table 43
  table_items 43
  table_template_instantiation 43
  TEMPERATURE 141
  TEMPLATE 20, 134
  template 39, 132
<table>
<thead>
<tr>
<th>Keyword</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>template definition</td>
<td>134</td>
</tr>
<tr>
<td>template_identifier</td>
<td>39</td>
</tr>
<tr>
<td>template_instantiation</td>
<td>35</td>
</tr>
<tr>
<td>template-reference scheme</td>
<td>13</td>
</tr>
<tr>
<td>Ternary operator</td>
<td>49</td>
</tr>
<tr>
<td>Three-port Memory</td>
<td>156</td>
</tr>
<tr>
<td>timing arc</td>
<td>144</td>
</tr>
<tr>
<td>timing characterization</td>
<td>7</td>
</tr>
<tr>
<td>timing constraint model</td>
<td>12</td>
</tr>
<tr>
<td>timing constraint models</td>
<td>12</td>
</tr>
<tr>
<td>timing constraints</td>
<td>5, 137</td>
</tr>
<tr>
<td>timing modeling</td>
<td>12</td>
</tr>
<tr>
<td>timing models</td>
<td>5</td>
</tr>
<tr>
<td>transcendent functions</td>
<td>13</td>
</tr>
<tr>
<td>transient power</td>
<td>15</td>
</tr>
<tr>
<td>transition delay</td>
<td>12</td>
</tr>
<tr>
<td>transmission-gate</td>
<td>148</td>
</tr>
<tr>
<td>transport delay</td>
<td>14</td>
</tr>
<tr>
<td>triggering conditions</td>
<td>8</td>
</tr>
<tr>
<td>triggering function</td>
<td>8</td>
</tr>
<tr>
<td>tristate driver</td>
<td>147</td>
</tr>
<tr>
<td>tristate primitives</td>
<td>112</td>
</tr>
<tr>
<td>tristate_buffer</td>
<td>147</td>
</tr>
<tr>
<td>Truth Table</td>
<td>123</td>
</tr>
<tr>
<td>truth table</td>
<td>7</td>
</tr>
<tr>
<td>Two-port memory</td>
<td>153</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td></td>
</tr>
<tr>
<td>Unary operator</td>
<td></td>
</tr>
<tr>
<td>bitwise</td>
<td>50</td>
</tr>
<tr>
<td>Unary operators</td>
<td></td>
</tr>
<tr>
<td>arithmetic</td>
<td>48</td>
</tr>
<tr>
<td>boolean, scalar</td>
<td>48</td>
</tr>
<tr>
<td>reduction</td>
<td>49</td>
</tr>
<tr>
<td>Unary vector operators</td>
<td>51</td>
</tr>
<tr>
<td>unnamed annotation containers</td>
<td>56</td>
</tr>
<tr>
<td>unnamed_assignment</td>
<td>33</td>
</tr>
<tr>
<td>unnamed_assignment_base</td>
<td>33</td>
</tr>
<tr>
<td>unnamed_assignments</td>
<td>33</td>
</tr>
<tr>
<td>unsigned</td>
<td>27</td>
</tr>
<tr>
<td>unsigned operators</td>
<td>50</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td></td>
</tr>
<tr>
<td>VCO</td>
<td>158</td>
</tr>
<tr>
<td>VECTOR</td>
<td>132</td>
</tr>
<tr>
<td>Vector operators</td>
<td></td>
</tr>
<tr>
<td>binary</td>
<td>52, 53</td>
</tr>
<tr>
<td>unary, bits</td>
<td>51</td>
</tr>
<tr>
<td>unary, words</td>
<td>52</td>
</tr>
<tr>
<td>vector_binary_operator</td>
<td>37</td>
</tr>
<tr>
<td>vector_elsif_operator</td>
<td>37</td>
</tr>
<tr>
<td>vector_expression</td>
<td>34, 41</td>
</tr>
<tr>
<td>vector_if_operator</td>
<td>37</td>
</tr>
<tr>
<td>vector_items</td>
<td>41</td>
</tr>
<tr>
<td>vector_template_instantiation</td>
<td>41</td>
</tr>
<tr>
<td>vector_unary_operator</td>
<td>37</td>
</tr>
<tr>
<td>vector-based modeling</td>
<td>5</td>
</tr>
<tr>
<td>Vector-Sensitive Sequential Logic</td>
<td>11</td>
</tr>
<tr>
<td>vector-specific model</td>
<td>132</td>
</tr>
<tr>
<td>Verilog</td>
<td>4, 9</td>
</tr>
<tr>
<td>VHDL</td>
<td>4, 9</td>
</tr>
<tr>
<td>via resistance</td>
<td>16</td>
</tr>
<tr>
<td>VIOLATION</td>
<td>138</td>
</tr>
<tr>
<td>virtual pins</td>
<td>15, 115</td>
</tr>
<tr>
<td>VOLTAGE</td>
<td>141, 146</td>
</tr>
<tr>
<td>voltage_posted_delay</td>
<td>159</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td></td>
</tr>
<tr>
<td>whitespace</td>
<td>26</td>
</tr>
<tr>
<td>whitespace characters</td>
<td>25</td>
</tr>
<tr>
<td>wildcard_literal</td>
<td>27</td>
</tr>
<tr>
<td>wire</td>
<td>42</td>
</tr>
<tr>
<td>wire modeling</td>
<td>16</td>
</tr>
<tr>
<td>wire select model</td>
<td>151</td>
</tr>
<tr>
<td>wire_identifier</td>
<td>42</td>
</tr>
<tr>
<td>wire_items</td>
<td>42</td>
</tr>
<tr>
<td>wire_template_instantiation</td>
<td>42</td>
</tr>
<tr>
<td>word_edge_literal</td>
<td>29</td>
</tr>
</tbody>
</table>