

Addendum to SemVer: System-on-Chip Designs

Overview

SoC ([System-on-Chip](#)) designs are similar to software in many ways, e.g. they are written in human-readable computer languages and often developed using version control, but differ in what comprises their public Application Programming Interface ([API](#)). This is an addendum to the [SemVer 2.0.0](#) specification which clarifies how to apply SemVer to SoC designs. It is assumed that you have read and understood:

- [RFC 2119](#)
- [SemVer 2.0.0](#)

In [C](#) software libraries, an API includes paths of header files, values of constants, names of exposed functions, and anything else which a library user might reasonably rely on. In [command-line](#) applications, an API includes the names of command-line options and their default values, precedence of configuration files, and anything else which an application user might reasonably rely on. Those examples of public APIs in software demonstrate that a public API can be described more generally as *anything which a user might reasonably rely on*.

SoC designs are typically written in specialized languages for digital logic such as [Verilog](#) (IEEE Std 1364), [SystemVerilog](#) (IEEE Std 1800), or [VHDL](#) (IEEE Std 1076) which facilitate synthesis to physical digital logic circuits. Different from software, SoC designs have users with fundamentally different requirements related to higher-level designs, high-level software, and physical implementation. These downstream users likely have differing perspectives about what constitutes the most important part of the public API – A software user might depend on the address and reset value of a register, but not depend on the hierarchical path to the corresponding FF ([flip-flop](#)) because that does not affect their software. In contrast, a user working on physical implementation might see the register address and reset value as trivial details, but depend on the hierarchical path of the FF to ensure that it is implemented with the correct type of cell.

The public API is restricted to the reasonable ways that users are expected to use a release. [In-house](#) projects may use this restriction to avoid incrementing **MAJOR** too often, i.e. the distinction between a breaking change and a bugfix can be redefined if you (1) *identify **all** downstream projects/users* and (2) *obtain explicit agreement from **all** users*. This exemption allows large subsystem and chip-level projects to make arbitrary changes under **MINOR** increments while reserving **MAJOR** increments for project-specific milestones. Only in-house projects may use this exemption because publicly available projects cannot identify all downstream projects/users.

Downstream Users and Auxiliary Components

[Downstream](#) projects, i.e. those which depend on your SoC design(s), usually fall into these categories:

1. Documentation: Describe the intention, features, operation, and limitations of your design as required by other users. The extent of overlap with other categories is highly specific to each particular project.
2. Integration: Include your design as a hierarchical component in a larger system. In SystemVerilog, this means declaring an instance of your `module` with suitable connections to parameter and signal ports.
3. Verification: Check that your design meets specifications. Includes both dynamic and static methods, and checks may be written in a different language from your SoC design, e.g. TCL, SystemC, or Python.
4. Physical implementation: Convert your abstract design into a concrete realization on a physical ASIC or FPGA platform. Includes synthesis, layout, and modifications for testing.
5. Software: Most modern SoC designs feature some programmable components which view your system from a memory-mapped perspective. Includes system-level tests (overlapping with verification), validation and characterization (overlapping with implementation), firmware, and possibly end-user applications.

In addition to the main description of digital logic, e.g. a collection of SystemVerilog files, a SoC design will usually include auxiliary components which may (or may not) correspond to additional files.

- Filesystem structure of the release delivery and associated filelists.
- Standards which the source code adheres to. Includes standards of all types from file encoding (e.g. [ASCII](#) vs [UTF-8](#)) and whitespace/formatting rules to the specification language (e.g. Verilog vs SystemVerilog) and naming conventions. Other users may have flows which extract information which depend on these seemingly minor details.
- Hierarchical paths and specific identifiers (names). In verification, specific FFs may be forced to obtain coverage on a difficult-to-reach state. In physical implementation, specific FFs may be selected as requiring special treatment to meet timing.
- Constraints on clocks, timing, pin-mapping, cell placement, routing, etc.
- Scripts for design modification flows such as [DFT](#), instrumentation, optimization, obfuscation, etc.
- Waivers on errors or warnings from particular tools.
- Power intent, normally specified with [UPF](#) (IEEE Std 1801).
- Abstract models and unit tests. Other users (likely excluding implementation) may depend on these to validate their own work.
- Address map and structure of software-visible registers. All types of software may depend on specific addresses, the layout of register fields, and more subtle attributes like reset values and volatility.

When releasing a new version of a SoC design, it is important to consider how changes to all components of the release will affect all users developing downstream projects.

Changes in SystemVerilog

An illustrative example, shown in SystemVerilog, is useful to demonstrate API components of a typical SoC peripheral where sequential logic is implemented with D-type FFs. Let's say that our module `Alu` performs arithmetic operations on its inputs, drives known values on its outputs, and provides register access via the AMBA APB protocol. In the most recently released version, there is one configuration register called `CFG` at the address `12'h444`, with a reset value of `32'd5`, arranged as two fields `CFG[2:1]=OPERATION` and `CFG[0]=ENABLE`.

```
module Alu
  #(parameter int RESULT_W = 16
  )
  ( input  var logic [1:0][7:0]    i_operands
    , output var logic [RESULT_W-1:0] o_resultant
    , APB.slave                    ifc_APB
  );

  localparam bit MYCONSTANT = 1'b1;

  // To be combinatorially assigned via `always_comb`, `assign`,
  // or connection to sub-module.
  logic foo_d;

  // To be sequentially assigned via `always_ff`.
  logic foo_q;

  // ... snip ...

  ArithmeticPipe u_pipeA1
  ( .i_opA  (i_operands[3:0])
    , .i_opB  (i_operands[7:4])
    , .o_taps (foo_d)
  );

  always_ff @(posedge ifc_APB.clk, posedge ifc_APB.arst)
    if (ifc_APB.arst)
      foo_q <= '0;
    else if (updateFoo)
      foo_q <= foo_d;

  // ... snip ...

endmodule
```

The public API of this example module consists of the module declaration, APB registers, hierarchical paths to sequential elements, and other packaged components like helper scripts and design constraints.

MAJOR Versions

Given a version number **MAJOR**.**MINOR**.**PATCH**, increment the:

1. **MAJOR** version when you make incompatible API changes

Referencing the example, the **MAJOR** version must be incremented with any of the following changes:

1. Modified module name which integrators use to declare an instance of the peripheral, e.g. `Alu` → `MyArithmetic`. Existing code using the name `Alu` will not elaborate unchanged.
2. Removed parameter port, e.g. `RESULT_W`. Existing code overriding the parameter value will not elaborate unchanged.
3. Modified parameter port kind, e.g. `parameter` → `localparam`, i.e. overridable to non-overridable. Existing code overriding the parameter value will not elaborate unchanged.
4. Modified parameter port name, e.g. `RESULT_W` → `OUT_WIDTH`. Existing code using the name `RESULT_W` will not elaborate unchanged.
5. Modified parameter port default value, e.g. `16` → `5`, including addition or removal of the explicit default value. Existing code may depend on the default value for critical functionality.
6. Removed signal port, e.g. `o_resultant`. Existing code using that port will not elaborate unchanged.
7. Modified signal port datatype, e.g. `logic [1:0][7:0]` → `logic [15:0]`. Existing code may depend on the size and structure of the port datatype, and input expressions may be cast to an unexpected width or datatype.
8. Modified signal port name, e.g. `i_operands` → `i_numbers`. Existing code using the name `i_operands` will not elaborate unchanged.
9. Removed interface port, e.g. `ifc_APB`. Existing code using the APB interface will not elaborate unchanged.
10. Modified interface port type, e.g. `APB.slave` → `AXI.slave`. Existing code using the APB interface will not elaborate unchanged.
11. Modified interface port name, e.g. `ifc_APB` → `myApb`. Existing code using the name `ifc_APB` will not elaborate unchanged.
12. Removed or modified sequential signal name, e.g. `foo_q` → `bar_q`. Existing code referencing `foo_q` will not find the inferred FF(s). You may not notice the breakage until your colleagues in physical implementation notify you that their scripts don't work. In the worst cases, FFs requiring special treatment can be silently missed.
13. Any added, removed, or renamed hierarchical middle layer, e.g. `Alu.u_pipe` → `Alu.u_wrapperA.u_pipe`. Existing code, particularly for physical implementation, may depend on the hierarchical names including generate blocks.
14. Removed, or renamed hierarchical bottom layer, e.g. `Alu.u_pipe1` → `Alu.u_pipe[1]`. Existing code, particularly for physical implementation, may depend on the hierarchical names including generate loops.
15. Removed or functionally modified package function. Higher-level designs may depend on any aspect of a function in a supplied package at elaboration time, simulation time, and in synthesis.
16. Added, removed, or modified any machine-readable comment, e.g. tool-

- specific directives like `// synopsys parallel_case`. Existing flows are likely to depend on these for critical functionality.
17. Removed software-accessible register, e.g. `CFG`. Existing system software accessing the `CFG` address will not operate equivalently.
 18. Modified software-accessible register address, e.g. `12'h444` → `12'h888`. Existing system software accessing the address `0x444` will not operate equivalently.
 19. Modified software-accessible register field layout, e.g. `CFG[0]=ENABLE` → `CFG[31]=ENABLE`. Existing system software accessing the register will not operate equivalently.
 20. Modified software-accessible register reset value, e.g. `32'd5` → `32'd0`. Existing system software accessing the register will not operate equivalently, particularly software performing non-atomic read-modify-write operations on startup like `cfg->operation++`.

To summarize, the **MAJOR** version must be incremented with any changes which *require* updates to any projects that fetch the newly released version. Note, changes to match the documentation of a previous release should be considered bug fixes, so may only warrant a **MINOR** increment.

MINOR Versions

Given a version number **MAJOR**.**MINOR**.**PATCH**, increment the:

2. **MINOR** version when you add functionality in a backwards compatible manner

Where SemVer specifies adding functionality, SoC designs must update *at least* the **MINOR** version with any of the following modifications:

1. Added parameter port, e.g. `ANOTHER`. Existing code will elaborate unchanged.
2. Modified parameter port datatype, e.g. `int` to `bit [3:0]`, including removal of the explicit datatype. Existing code may elaborate unchanged, but override values may be cast to an unexpected width or datatype. If existing code needs changes to elaborate with the updated version, then increment **MAJOR** instead.
3. Added signal port, e.g. `output o_another`. Existing code may elaborate unchanged and a new signal port implies new functionality.
4. Modified signal port direction, e.g. `inout myport` → `output myport`. Existing code may elaborate unchanged, but simulation semantics may be different. If existing code needs changes to elaborate with the updated version, then increment **MAJOR** instead.
5. Modified signal port nettype, e.g. `input logic` → `input var logic`. Default nettype of `input` and `inout` signal ports with datatype `logic` is `tri`, but for `output` ports it's `var`. Existing code may elaborate unchanged, but simulation semantics may be different. If existing code needs changes to elaborate with the updated version, then increment **MAJOR** instead.
6. Added interface port, e.g. `OCP.slave`. Existing code may elaborate unchanged and a new interface port implies new functionality.

7. Modified sequential signal datatype or expression, e.g. `logic [1:0] foo_q` → `FooEnum_t foo_q`. Backwards-compatible changes only require a **MINOR** increment, but incompatible changes like reducing the *intended* width of a FF vector require a **MAJOR** increment.
8. Added hierarchical bottom layer, e.g. `Alu.u_pipeA2`. New hierarchy implies new functionality, not just a bug fix.
9. Added package function, e.g. `function bit isPrime (int x);`. A new function implies new functionality, not just a bug fix.
10. Added software-accessible register, e.g. `STATUS`. Existing system software will not operate equivalently, and updated software may use the new functionality.

To summarize, the **MINOR** version must be incremented with any changes which add or modify functionality in a manner which *does not require* downstream users to make changes. If downstream users are required to make changes to their project in order to accept the new version, increment **MAJOR** instead.

PATCH Versions

Given a version number **MAJOR.MINOR.PATCH**, increment the:

3. **PATCH** version when you make backwards compatible bug fixes

As with SemVer, only backwards-compatible changes (for all downstream users) are allowed within a **PATCH** increment version.

1. Added, removed, or modified internal constant, e.g. `MYCONSTANT` → `BETTERNAME`. Internal constants should not be relied upon downstream.
2. Added, removed, or modified internal combinational signal, e.g. `foo_d` → `bar_d`. Internal combinational signals should not be relied upon downstream. Exemption: If you change signals which are *intended* to be probed or forced by downstream users, increment **MAJOR** instead, e.g. `disableChecks` → `turnOffChecks`.
3. Added internal sequential signal, e.g. `new_q`. Additional FFs will affect area, power, achievable fmax and cost, but are unlikely to break physical implementation flows outright. Note, removed or renamed internal signals require a **MAJOR** increment.
4. Non-functionally modified package function, e.g. to improve simulation performance without affecting its **domain**, **codomain**, or **image**.
5. Any **tag comment**, e.g. `/* TODO: Something */`. Note, where changes include updates to tag comments, there's a good chance the changes also involve enough to warrant a **MINOR** or **MAJOR** increment.
6. Any human-only comment, e.g. `/* Isn't this nice */`.

SemVer for SystemVerilog Cheatsheet

How	What	Increment (at least)
mod	Top-level module name	MAJOR
add	Parameter port	MINOR
rem	Parameter port	MAJOR
mod	Parameter port kind	MAJOR
mod	Parameter port datatype	MINOR
mod	Parameter port name	MAJOR
mod	Parameter port default value	MAJOR
add	Signal port	MINOR
rem	Signal port	MAJOR
mod	Signal port direction	MINOR
mod	Signal port nettype	MINOR
mod	Signal port datatype	MAJOR
mod	Signal port name	MAJOR
add	Interface port	MINOR
rem	Interface port	MAJOR
mod	Interface port type	MAJOR
mod	Interface port name	MAJOR
any	Internal constant	PATCH
any	Combinatorial signal	PATCH
add	Sequential signal	PATCH
rem	Sequential signal	MAJOR
mod	Sequential signal name	MAJOR
mod	Sequential signal datatype	MINOR
mod	Sequential signal expression	MINOR
any	Hierarchy middle layer	MAJOR
add	Hierarchy bottom layer	MINOR
mod	Hierarchy bottom layer	MAJOR
rem	Hierarchy bottom layer	MAJOR
add	Package function	MINOR
rem	Package function	MAJOR
mod	Package function behavior	PATCH
any	Tool directive comment	MAJOR
any	Tag comment	PATCH
any	Human-only comment	PATCH
add	Software register	MINOR
rem	Software register	MAJOR
mod	Software register address	MAJOR
mod	Software register field layout	MAJOR
mod	Software register reset value	MAJOR