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TLM Power 3.0 (CBG) User Manual
Version: CBG 3.0 Alpha
VERY DRAFT VERSION OF THIS MANUAL - BEING UPDATED DURING 1Q2012

MY Yasin, C Koch-Hofer, Pascal Vivet, DJ Greaves

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Contents

1 Introduction

The TLM Power 3.0 library [1] is a framework for logging power consumption of SystemC [3] models with emphasis on TLM (transaction level modelling). It can also help with area and component utilisation modelling. This library defines a set of classes and functions for evaluating the power consumption of the modules of a timed or loosely-timed SystemC platform. A further set of functions can also be used for generating power various reports of the simulation of an instrumented platform.

The library works by asking users to re-code their monitored SystemC modules such that they also inherit a base class from our library or else set a SystemC attribute for a monitored module to point to an instance of that (or a similar ?) base class.

The Cambridge version (release 3 onwards) implements energy-based logging for transactions and also adds physical dimensions and place-and-route operations for wire length estimation.

Energy and power are accumulated in accounts. A single account can model both energy and power consumption, with energy being the primary representation and power being periodically converted to energy debits. Energy figures are converted back to average power in some forms of report.

1.1 Accounts

The default use of accounts is to use account zero for static power/energy and account one for dynamic power/energy and two for wiring power, but other accounts can be freely defined. For instance for leakage power and for short circuit energy.

To control account creation, please call the `start_acct` method. If no accounts have been created before the first logging event, the library will create its own default accounts using the following code:

```
void pw_accounting_base::start_default_accounts(int n)
{
  if (global_n_accounts_in_use() > 0) return;
  start_acct("STATIC0");
  start_acct("DYNAMIC1");
  if (n > 2) start_acct("WIRING2");
  if (n > 3) start_acct("AUX3");
}
```

A set of accounts is stored in an observer. Multiple observers are instantiated for two different reasons: it is desired to accumulate data on different modules or collections of modules and different reporting formats of data are wanted.

An observer may be standalone or may include totals for the part of the design heirarchy it is the parent to. This is controlled by a parameter of trace type `sc_pwr::trace_t` passed to the observer when it is constructed. According to the value of this variable, children can be disregarded or else included in the observer's accounts.

```
typedef enum { no_children, sum_children, also_trace_children } trace_t;
```

The third setting of the trace parameter creates multiple observers, these being a standalone (no_children) observer for the named module and independent standalone observers for all the children.

There is at most one observer of type summing and at most one observer of type standalone for each power module for each trace type. The system itself also creates a top-level, grand total observer that totals the whole design, whether or not such an observer is manually created. The grand total obsever is a `sum_children` observer that includes all power modules found at the top level.

We use the terms *power module* and *component* interchangably to denote a (SC_MODULE) that inherits PW_MODULE.

Currently, the two following kinds of reports can be generated:

1. the power profile with respect to time of the consumption of the monitored modules,
2. total statistics of the power and energy consumption at the end.

There is also a C++ API so that user code can read accounting information for generating custom reports (§5).

There will soon be a set of options for trading off accuracy for simulation performance and associated assistance mechanism to help select a good operating point in this respect.

Given a high-level simulation platform, power consumption can be computed by instrumenting the platform. The library does not to estimate power from an instrumented model. It works as a calculator supplied with external power data, instrumenting the platform (Figure 1).

Power data can come from IP datasheets, from last generation IP power profile (?), can be inferred from estimation of the design size or the functional complexity (top-down approach), or can be extracted from lower-level simulations (bottom-up approach).

In the phase/mode approach the consumption of an IP block is determined from its current state. The state of the block is characterized by both its phase and its mode. A phase, basically a functional phase, is characterized by its power and time duration (e.g. wait, read, compute). A mode is a particular DPM (Dynamic Power Management) mode (e.g. on, sleep, off).

As static power is no longer negligible compared to dynamic power, both forms are included in models and reported separately in outputs. Static power consumption is always modelled using phase/mode. Dynamic power for a component can either also be according to phase/mode or it can be by energy per transaction.

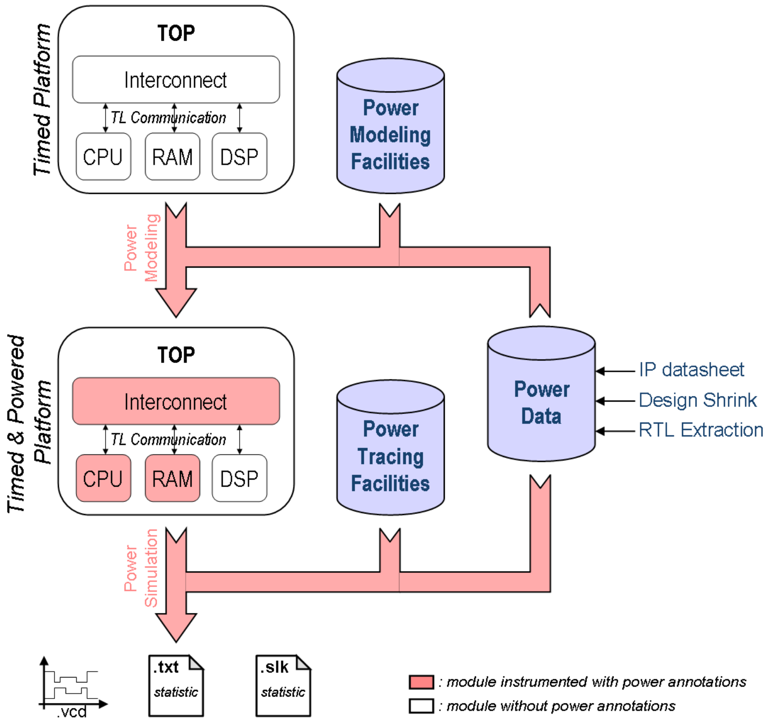


Figure 1: Power Estimation Framework

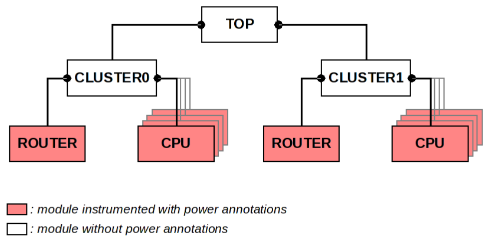


Figure 2: Example of an Instrumented Platform

To support monitoring the power consumption of any SystemC module, the tracing facilities take advantage of the hierarchy of a SystemC model. Indeed the energy consumed by a module is equal to that of the specified processeses of that module plus that of its sub-modules. For example, in Figure 2 the energy consumed by the module CLUSTER0 is equal to the total of expended by its CPUs and its ROUTER.

The remainder of this document is organized as follows. Section 2 presents how to model and instrument a TLM platform with power information. Section 6 presents how to monitor and generate traces from an instrumented TLM platform. Section 3 describes the options relating to physical layout modelling and bit transition counting. Finally, §8 gives some implementation information about this library.

2 Power Modelling

Versions 1 and 2 of the library were based on power mode/phases for components (sleep, standby, active, etc.) whereas version 3 adds support for energy-per-transaction logging.

Mode/phase-based approach: The power consumption of a SystemC module is defined for each operation mode and modules switch between modes and phases throughout the simulation.

Energy-per-transaction approach: SystemC modules log an energy quanta for each transaction they process, based on computations of how much energy is used. For instance, for a bus the energy per transaction may include a component proportional to the burst length field in the generic payload.

2.1 Physical Units

As in the SystemC SC_TIME class, the TLM Power library implements classes that define units for manipulating power, energy voltage, length and area values (§2.2). It also defines some base classes for defining the power consumption and the running mode of a module during a simulation (§??). As a running example, these different facilities were used for modelling the power consumption of a simple platform based on the TLM TAC router (§??).

2.2 Physical Data Types

Class PW_POWER is used to represent electrical power value (internal representation is internally a double and a PW_POWER_UNIT). A `pw_power_unit` is an enumerate type representing power physical unit: `pw_fW` for femto-watt, `pw_pW` for pico-watt, ..., `pw_WATT` for watt.

The default power resolution is 1 pico-watt. The power resolution can only be changed by calling the function `pw_set_power_resolution(double)`. This function can only be called during elaboration, cannot be called more than once and cannot be called after constructing an object of type `pw_power` with a non-zero power value. The value of the double argument shall be positive and shall be a power of 10. A report of severity SC_ERROR is thrown if these rules are not respected. The value of the power resolution is given by the `pw_get_power_resolution()` function.

The constant `pw_ZERO_POWER` represents a power value of zero. The static method `max()` returns the maximal power value according to the power resolution.

All the traditional arithmetic, relational, equality and assignment operators are supported. A report of severity SC_WARNING or SC_ERROR is thrown when the result of an arithmetic is not coherent:

When an overflow is detected the resulting value is equal to the maximal power value, when an underflow is detected the resulting value is equal to zero, when a division by zero is detected the resulting value is equal to the maximal power value.

Much like the `pw_power` class, the class `pw_energy` is used to represent electrical energy values and has the same functions. The default energy resolution is 1 pico-joule and the physical unit is also represented by an enumerated type `pw_energy_unit` (i.e. `pw_fJ` for femto-joule, `pw_pJ` for pico-joule, ..., `pw_JOULE` for Joule).

Much like the `pw_energy` class, the class `pw_length` is used to represent physical length and has the same functions. The default energy resolution is 1 pico-metre (SHOULD BE micron by default) and the physical unit is also represented by an enumerated type `pw_energy_unit` (i.e. `pw_fm` for femto-metre, `pw_pm` for pico-metre, ..., `pw_METRE` for metre).

Much like the pw_length class, the class pw_area is used to represent layout area and has the same functions. The default area resolution is the square micron and the physical unit is also represented by an enumerated type pw_area_unit (i.e. pw_squm for square microns, pw_sqcm for square centimeters, pw_sqmm for square millimetres and pw_sqm for square metres.

Much like the pw_energy class, the class pw_voltage is used to represent potential difference values and has the same functions. The default energy resolution is 1 pico-volt (should be VOLTs) and the physical unit is also represented by an enumerated type pw_energy_unit (i.e. pw_fV for femto-volt, pw_pV for pico-volt, ..., pw_VOLT for volt).

THESE UNITS SHOULD ALL BE FULLY DOCUMENTED IN TABLES.

Finally, some arithmetic operators using these various classes plus the SC_TIME class are provided for performing multiplication and division with different physical quantity parameters.

2.3 Instrumenting a SystemC module

Class pw_module_base should be listed as a base class of a SystemC module that is instrumented for power monitoring. The SystemC module should also inherit sc_module as usual.

The constructor for a module, such as a RAM or CPU, is typically provided with physical size parameters (bit width, number of words, and so on) and it should can use these in setting its placement and power profile. These instantantiations parameters can be combined with values read from a technology/instance file and supply voltage settings to determine standing powers and transaction energies.

2.4 Technology/Instance configuration file.

Components that inherit pw_module must import a technology/instance configuration file to assist with setting their physical size, allocating power consumption to transactions and naming different power modes and phases.

Normally the name of the file to be read is given by the SystemC 'kind' of the component. This approach is suitable where all of the per-instance variations are controlled by the constructor of the SC_MODULE and nothing needs reading from the configuration file on a per-instance basis.

When the pw_module constructor is called with no arguments, the module should implement the 'kind' method (i.e. module type name) that returns a constant string whose name is used as the basis for the file to be consulted.

The name of the file to read can alternatively be specified as an argument to the constructor and this again may be based on the SystemC kind() or on the SystemC instance name name(). Generally the latter is not needed since each instance should be identically parameterised in terms of technology constants, even if different in per-instance parameters, such as size.

The syntax of a configuration file respects the following pseudo-EBNF grammar. OUT OF DATE: There are more forms now.

line	::=	MODE [PHASE] DYNAMIC STATIC | # comment
MODE	::=	string
PHASE	::=	string
DYNAMIC	::=	power
STATIC	::=	power
string	::=	[a-zA-Z_.]+
power	::=	floating-literal unit
unit	::=	fW | pW | nW | uW | mW | W

A limitation of the parser, currently used, is to not support spaces between the floating-literal and the unit token of the power rule.

2.5 Logging Power Consumption: Mode/Phase Approach

The mode/phase-based power consumption approach deals separately with static and dynamic power.

The mode/phase-based power consumption is used always for static power dissipation. It can also be used for dynamic power when per-transaction energy is not being used. But when dynamic power is being modelled on a per-transaction basis, it is appropriate to set the dynamic power of the mode/phase to zero.

The mode/phase-based power consumption of a module is defined by the following four parameters which determine the current standing powers (static and dynamic):

1. the dynamic power consumption which can be set with the SET_DYNAMIC_POWER() method,
2. the static power consumption which can be set with the SET_STATIC_POWER() method,
3. the mode of power consumption which can set with the SET_POWER_MODE() method,
4. the phase of the power mode consumption which can set with the SET_POWER_PHASE() method.

The power mode and phase are strings used for associating a power consumption to any computation mode and phase of a module. Some frequently used power modes and phases are pre-defined: `pw_MODE_ON`, `pw_MODE_OFF`, `pw_PHASE_WAIT`, ...

The example in Figure reffig:figure3 presents how to associate different power information to the different computation modes and phases of the FOO module.

When the power behavior of a model just needs to know the current mode and phase, it is possible to use the class `pw_module`. This class is an extension of the class `pw_module_base`.

As illustrated by the example of Figure 3 the same behavior as the one of Figure reffig:three can be written more shortly using the class `pw_module`. Indeed, the associations defined in the configuration file can be used with the method UPDATE_POWER for setting the power information.

The power values associated to a power mode can also be accessed through the GET_DYNAMIC_POWER and the GET_STATIC_POWER methods. For example, these methods can be used with the basic

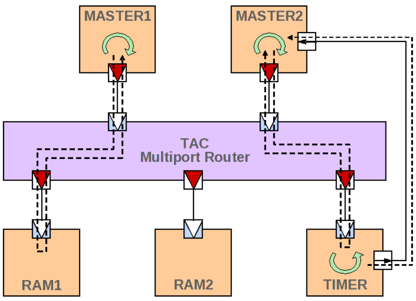


Figure 3: Simple TAC Platform.

```
tac_response tac_multiport_router::b_transport(tlm_generic_payload &trans, sc_time &delay)
{
  unsigned int len = trans.get_data_length();

   ... // Main body of the behavioural model

  sc_time activity_time = ...;

  delay += lt_activity_time; // Or use qk_inc to perform this addition

#ifdef TLM_POWER3
  // bit_width has been set in the constructor... etc
  sc_energy energy_cost = pw_energy((double) (5 * bit_width), pw_energy_unit::PW_pJ * len);
  pw_module_base::update_energy(energy_cost, lt_activity_time);
#endif
}
```

Figure 4: Energy-based instrumentation of TLM call (intra-module component).

```
  trans.pw_set_origin(this, PW_TGP_ADDRESS | PW_TGP_ACCT_SRC, &frontside_bus);
  initiator_socket->b_transport(trans, delay);
  trans.pw_terminus(this);
}
```

Figure 5: Energy-based instrumentation of TLM call (inter-module component).

methods of the class `pw_module` for describing the complex part of a power behavior and still using the method UPDATE_POWER for the simple part.

2.6 Logging Power Consumption: Transaction Energy Approach

Power consumption associated with a transaction consists of two components:

1. Inter-module power (proportional to wiring length and number of bits in transistion)
2. Intra-module power (associated with internal operation inside the component.

Figure 4 is a simple illustration of the the approach where transactional energy consumption internal to a module is logged for each transaction. For each transaction, the transport method logs both the intra-module energy consumed and the activity time for which is has been busy.

The cost-per-bit is multiplied by the transaction length to model its dynamic energy use. This energy is is passed to `update_energy` as the first argument where it is logged.

The second argument is either SC_TIME_ZERO if utilisation logging is not required or appropriate or else the time for which the component has been active since the last call to `update_energy`. Using loosely-timed models the activity time is either the time accumulated in the current component or the time accumulated between call and return from the transport method according to whatever definition of utilisation is required.

The observers, currently, add the energy part to the dynamic energy aggregate and time part to utilization aggregate. Thus, at any instant, (utilization/simulated time) gives the percentage of time that a module has been busy. In the future one could record utilization per quantum

```
class FOO:
  public sc_module,
  public pw_module
{
  public:
   SC_HAS_PROCESS(FOO);
   FOO(const sc_module_name& p_name, int width):
     sc_module(p_name),
     pw_module("config.txt")
   {
     set_excess_area(pw_length(50.0 * width, PW_um), pw_length(5.0 * width, PW_um)); // or from tech file

   }
};
```

Figure 6: Length and area annotations `pw_module`.

to observe busy periods for a module so as to spread its work load over time or over number of modules if needed.

In the TLM_POWER3 library, the energy is scaled by the standing supply voltage squared unless the optional `noscale=true` parameter is passed to `update_energy`.

Figure 5 illustrates a basic form of the companion approach where transactional energy consumption consumed in wiring is logged. This is the inter-module energy. See § refsec:tlmwiringenergy for full details.

2.7 Logging Length and Area

A component can describe its physical size in its constructor using one of the following TLM_POWER3 calls:

```
//Set actual dimensions of current component
void set_fixed_dimensions(pw_length x, pw_length y);

// Set additional area of current component
void set_excess_area(pw_length x, pw_length y, float max_aspect_ratio=2.5);
void set_excess_area(pw_area a, float max_aspect_ratio=2.5);
```

The former sets the actual dimensions of the current component, leading to a TARDIS warning if this is smaller than the sum of its components.

The excess_area calls describe the additional area of the current component beyond that of the sum of its child components. The component is assumed to be flexible in shape from square up to an oblong of maximum aspect ratio specified.

Figure 6 illustrates the basic approach to logging a components area.

Although X/Y dimensions are used to log area, TLM_POWER3 assumes that a component can freely change its aspect ratio from 1:1 to 2:1 to obtain a good layout unless ...

```
class FOO:
  public sc_module,
  public pw_module
{
  public:
   SC_HAS_PROCESS(FOO);
   FOO(const sc_module_name& p_name):
     sc_module(p_name),
     pw_module("config.txt")
   {
     SC_THREAD(process);
   }

   void process(void)
   {
     update_power (PW_MODE_ON, PW_PHASE_IDLE);
     wait(10, SC_NS);

     // Perform some computation
     update_power(PW_MODE_ON, PW_PHASE_COMPUTE);
     wait(20, SC_NS);

     update_power(PW_MODE_OFF);      // Turn off module
   }
};
```

Figure 7: Phase/mode style annotation example based on `pw_module`.

2.8 Modelling Example: TAC Simple Basic Platform

The presented modelling facilities were used to model the power behavior of a simple TAC platform (Figure 3). This platform is composed of a first traffic generator MASTER1 which perform memory accesses to the RAM1. The second traffic generator MASTER2 periodically initializes a TIMER and waits for its interrupt. All these components (except the interrupt signal) communicate via a TAC_MULTIPORT_ROUTER.

All the components of this platform were instrumented with timing and power annotations. For instance, the transport method of the TAC_MULTIPORT_ROUTER was instrumented for modelling the power cost of routing a transaction (cf. **??**). This example also illustrates how to use the methods of the classes `pw_module_base` and `pw_module` for modelling a complex behavior using a configuration file.

The code of this platform is delivered with the library (cf. §**??**) and can be compiled as is (i.e. no external dependency other than SystemC).

3 Layout, Distance and Bit Transition Modelling

Both net-level interconnects and TLM transactions model data moving some distance with associated charge and discharge of the nets.

It is important not to model both the charge and discharge of a given net, otherwise energy costs will be double counted. We adopt the approach of only counting the zero to one transition of a net as energy consuming.

```
tac_response tac_multiport_router::transport(...)
{
#ifdef TLM_POWER3
   static unsigned l_nb_transaction = 0;
   ++l_nb_transaction;
   pw_power l_dynamic_pwr = request.get_number() * get_dynamic_power(ON, ROUTE);
   pw_power l_static_pwr = get_static_power(ON, ROUTE);
   set_power_mode(PW_MODE_ON);
   set_power_phase(PW_PHASE_ROUTE);
   set_dynamic_power(get_dynamic_power() + l_dynamic_pwr);
   set_static_power(l_static_pwr);
#endif
   ... existing TAC code ...
#ifdef TLM_POWER
   if(l_nb_transaction == 1) this->update_power(ON, IDLE);
   else set_dynamic_power(get_dynamic_power() - l_dynamic_pwr);
   --l_nb_transaction;
#endif

   ... // Remainder of behavioural model
   output_port.do_transport(router_request, response); // TLM CALL
   ...
}
```

Figure 8: Phase/Mode (TLM Power 2 Style) instrumentation of the TAC Multiport Router.

```
  pw_excess_area(PR_MICRON(40),PR_MICRON(40), 0.25);
```

Figure 9: Size Annotation.

3.1 Place and Route

Every component may compute and register its excess physical size in two dimensions. The excess size is how much more area the component has that the sum of its sub components. A component may also register its absolute size, in which case the sum of its components is ignored, but a warning is issued if it behaves like a TARDIS, having more internal size (on the same chip) than outside size.

Commonly, some models will include components that do not physically exist inside them. For instance, a DRAM controller might instantiate the DRAM chips inside the controller rather than bothering to route the connections up through the top level of the SoC. TLM_POWER3 supports this style of modelling using the concept of chip names. Any component (`sc_module`) can be specified as having a separate chip name. Its area and power are not included in that of its parent component. Moreover, the inter-chip wiring model is applied to transactions and nets that cross between chips.

Placement (and hence wiring distance) can be determined in two ways:

- **Geometric Placement**. With geometric placement, every component is allocated 2-D co-ordinates inside the perimeter of its parent. Geometric placement is based on heuristic algorithms based on random numbers. It can give unpredictable results and users should interpret results only after making several runs with different random seeds.
- **Rentian Placement**. With Rentian placement, no actual placement co-ordinates are determined and no random number generation is required. Instead, wiring distances are given according to Rent's Rule based on component area. The lowest-common module that contains the two-ends of an interconnect is found by walking up the module hierarchy until a common SC_MODULE is encountered. The wiring distance is then predicted from the area of that module.

Placement. Every component is allocated 2-D co-ordinates inside the perimeter of its parent. Rather than performing an accurate placement based on geometric tessellations each component is assumed to be a square. This is a simplistic approach which is correct in terms of area but not suitable for physical manufacture. A png plot file is created for the placement to help visualisation.

Wiring area. An additional wiring swell is added to the area of each component based on the number of internal connections it has. Internal connections may be sc_signals or TLM sockets or user-defined.

Geometric Wiring distance. Using geometric modelling, the wiring length between two components is computed as the Manhattan distance between their centres.

Rentian Wiring Distance. Using rentian wiring, ...

3.2 TLM Wiring Energy Modelling

Given that a transaction takes place between two components that are part of a layout, the distance information can be combined with the number of transitioning bits in an envisaged, underlying bus implementation, to compute the wiring energy associated with the transaction. However, there are a number of general considerations to including in a wiring energy model for TLM:

1. Although a single transaction (generic) payload may typically be transferred on a round trip basis from originator, through the bus, NoC and server components back to the originator, not all fields will be active in the underlying bus implementation at each hop.
2. Some hops may be off-chip PCB traces with associated pads that have different energy cost per unit length compared with on-chip interconnects. On-chip connections are typically unidirectional but off-chip connections are sometimes bi-directional using tri-state drivers.
3. The wiring energy can be charged to the source or destination component or be separately accounted.
4. The cost of bit-transition counting is high on most host workstations, so detailed bit toggle counting should be replaced with estimated average values as an user option.

In a simple example, the originator will complete the address field of the payload and, for writes, also the data and byte-enabled fields. The intermediate components will forward these fields, perhaps with minor changes (e.g. adddress space manipulations at bus bridges or VM units) to the destination. The destination will reply with a low-cost acknowledgment for a write and with the data for a read.

The PW_TLM_PAYLOAD sub-library is provided with the TLM_POWER3 library as an extra component for estimating wiring energy when using the OSCI TLM2.0 TLM library. It has several modes of operation that are controlled by the preprocessor variable PW_TLM_PAYLOAD.

To use the PW_TLM_PAYLOAD LIBRARY, the sockets provided by TLM2.0 must be defined with an additional type parameter that extends the generic payload and the socket use sites must be augmented with additional library calls, as described below. However, the user might typically define their own CPP macros that integrate the TLM 2.0 socket operations with the PW_TLM_PAYLOAD library calls.

The third generic argument to socket definitions must be provided and defined as PW_TLM_TYPES. The signatures to the transaction methods also need to be defined to use PW_TLM_PAYTYPE instead of the standard generic payload.

These two changes have no effect when PW_TLM_PAYLOAD is set to zero since the macros are then defined as their defaults, but for other values the extended generic payload is used.

```
//Providing the third template argument to a socket:
tlm_utils::simple_initiator_socket<tracedriven_core_btlm, 64, PW_TLM_TYPES> initiator_socket;

//Using the extended generic payload in the transaction methods:
void b_access(PW_TLM_PAYTYPE &trans, sc_time &delay)
```

The three primitives used for bus energy modelling are `pw_set_origin`, `pw_terminus` and `pw_log_hop` calls. These mark the beginning, intermediate steps and end of a TLM payload trajectory.

```
void pw_set_origin(sc_module *where, uint flags=0, bit_transition_tracker *transition_reference=0);
void pw_log_hop(sc_module *where, uint flags=0, bit_transition_tracker *transition_reference=0);
void pw_terminus(sc_module *where);
```

The first argument `where` is the `this` pointer for the current component. This is used to track the path through the system.

The second argument is the flags. Most flags are sticky and apply to subsequent hops that do not change that flag. In particular, if the flags argument is zero for the next hop then nothing has changed and the next hop has the same properties as the previous hop.

The third argument is a bus reference. Every transaction is considered to take place over a bus and a bus is a generic set of wires modelled with a `bit_transition_tracker`. Wires present that are not used consume no energy, so it is not important to customise the instance of a bus to its use (e.g. the bus from CPU to memory has address and write data whereas the return bus has just read data). The bus reference is needed so as to check which physical nets are transitioning with respect to their previous value.

3.3 TLM Wiring Energy Modelling Computation

The formula used for energy consumption is a straightforward product of three numbers:

1. the length of the current hop (in millimetres) (from Rentian or other wiring estimator: §3.1)
2. the number of bits that have transitioned (measured or estimated: §3.5)
3. the energy per millimetre per transition for the wiring style being used (taken from technology file)

Name	Description	Notes
PW_TGP_ADDRESS	The address field contains live data.	Sticky. &
PW_TGP_DATA	The data field contains live data.	Sticky. &
PW_TGP_LANES	The byte lanes contain live data.	Sticky. &
PW_TGP_MUXD_AD	The address and data fields contain live data which are sent over a common bus.	Sticky. &
PW_TGP_NOFIELDS	No fields contain live data (apart from command + response)	Sticky. &

Table 1: Active payload field PW_TGP_XXX

Name	Description	Notes
PW_TGP_ONCHIP	The next hop uses the on-chip wiring costs.	Sticky. &
PW_TGP_OFFCHIP	The next hop uses the off-chip wiring costs.	Sticky. &

Table 2: Bus energy model PW_TGP_XXX

3.4 TLM Wiring Energy Modelling Flags

The `flags` field is a bitwise OR of one or more of the PW_TGP_XXX flags. Certain flags are mutually exclusive, with only one from each group being allowed.

3.5 Transition Density Estimations

Rather than ...

Name	Description	Notes
PW_TGP_SRC_ACCT	The energy for the next hop(s) should be debited to the current component.	Sticky.
PW_TGP_DEST_ACCT	The unaccounted wiring energy so far should be passed on to a subsequent component.	Sticky.
PW_TGP_CKP_ACCT	The unaccounted wiring energy so far should consolidated to the current or originating component depending on the pertaining sticky in methods.	Non-sticky.

Table 3: Bus energy accounting methods PW_TGP_XXX

3.6 TLM Wiring Energy Modelling Example (Blocking Style)

We will first explain its use with the blocking TLM coding style assuming that the TLM is forwarded through one or more `passthough` sockets in the NoC or bus model to an endpoint (e.g. a RAM) and returned the same route.

Here is the basic code for an annotated initiator. Note that different fields in the bus are active depending on whether it is a read or a write transaction.

```
// Example code for a blocking TLM initiator:
if (R) trans.set_read(); else trans.set_write();
trans.pw_set_origin(this, PW_TGP_ADDRESS |
                          PW_TGP_ACCT_SRC |
                          ((R)?0:PW_TGP_DATA|PW_TGP_LANES)),
                    &forward_bus);
initiator_socket->b_transport(trans, delay);
trans.pw_terminus(this);
```

The `forward_bus` should be defined in the initiator class using

```
sc_pwr::tlm_bit_transition_tracker forward_bus;
```

and initialised in the constructor by passing it the `this` pointer of the initiating component.

Two calls to `pw_log_hop` are required in a passthrough component to register the forward and backward operations, but flags and bus arguments are not normally needed (see below):

```
// Example code for a passthough TLM bus or NoC component:
void :b_transport(int id, PW_TLM_PAYTYPE &trans, sc_time &delay)
{
   trans.pw_log_hop(this); // First call - on entry to the component

   ... other code
   // No special decorations are neede around the passthough operation
   passthrough_init_socket->b_transport(trans, delay);
   ... other code
   trans.pw_log_hop(this); //Second call, at return operation.
}
```

The endpoint is much like a hop, but this hop will generally change the active fields. Also, unless using tri-states on a PCB, a different bus should be provided to model separate read and write data busses in a SoC.

```
// Example code for a blocking TLM end point that is to return a payload
// with different fields active and on a separate read bus.
tlm::tlm_command cmd = trans.get_command();
trans.pw_log_hop(this,
                (cmd==tlm::TLM_READ_COMMAND ? PW_TGP_DATA: PW_TGP_NOFIELDS) | PW_TGP_ACCT_CKP,
                &read_return_bus);
```

3.7 TLM Wiring Energy Modelling Example (Non-Blocking Style)

This text is missing. TODO.

3.8 Non-TLM Wiring Energy Modelling Example

Energy use in individual net transitions that are not part of a TLM payload or which use non-standard TLM interfaces can be logged as follows.

This text is missing. TODO.

4 Physical Reports

Physical report files may be written by the library, including area and layout ... these are not traces ...

5 C++ API

Each annotated component (type `sc_module`) has a power module of type `pw_module_base` as a base. The basic form of C++ API is provided through the methods of this base class. This contains static information about component size and varying information such as the current phase/mode power for each account.

However, each component has a summing or standalone (or both) observers, which provide cummulative data for that component (and also its children for the summing variant). The observer API should be used for reading energy use.

```
// How to get a handle on an observer for the current SC_MODULE:
  sc_pwr::pw_stat_observer_base *it = pw_get_observer(this, sc_pwr::no_children);

// How to get a handle on an observer for the current SC_MODULE and its children:
  sc_pwr::pw_stat_observer_base *it = pw_get_observer(this, sc_pwr::sum_children);

// How to get a handle on a global summing observer for the complete system:
  sc_pwr::pw_stat_observer_base *it = pw_get_observer(0, sc_pwr::sum_children);

  sc_start();

  ...

  // At any point then we can print as follows:"


  std::cout << "Energy in account " << it->get_global_name(0)
            << " is  " <<  it->get_energy(0) << "\n";
  std::cout << "Energy in all accounts " << it->get_energy() << "\n";
```

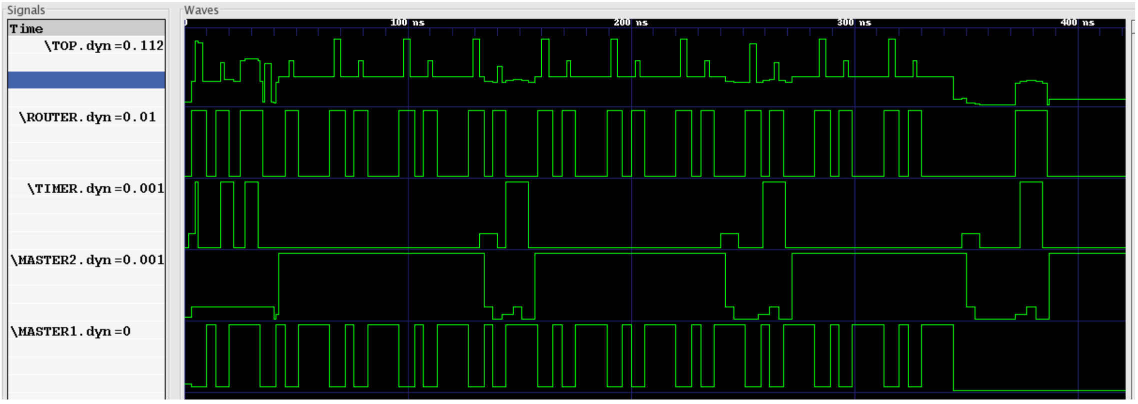


Figure 10: TAC Power Consumption Waveform.

6 Tracing Facilities

Three different forms of trace report can be generated with the TLM_POWER3 library. These include SyLK, VCD, and TEXT. All three include power and energy consumption, utilisation.

Transaction tracing is now being added ...

The library will automatically add up the power and energy used globally but the top module must be traced using one of the trace methods to see this global total in the associated trace file.

Individual sub-systems may also be traced by selecting other points in the hierarchy to trace and passing the associated component as an argument to the power trace function. Each item traced generates a fresh set of totals that include that item and all of its children. So the consumption of a component can be included in more than one trace total of a similar form by tracing it and one or more of its parents or by tracing two or more of its parents.

Firstly, a VCD 6.1 trace file recording the power variations along a simulation. Secondly, a textual file or a SYLK (SYmbolic Link) file gathering different statistics about the power and energy consumptions.

6.1 VCD Traces

A VCD trace file records a time-ordered sequence of power and energy values during simulation. A VCD trace file can be created and opened by calling function `pw_create_vcd_trace_file`. A trace file may be opened during elaboration or at any time during simulation. Values can be traced by calling function `pw_trace`. A trace file shall be opened before values can be traced to that file and values shall not be traced to a given trace file if one or more delta cycles have elapsed since opening the file. A VCD trace file shall be closed by calling function `pw_close_vcd_trace_file` at the end of the simulation.

Figure 10 shows the waveform diagram of the VCD trace file generating by the simulation of a modified simple TAC platform. As illustrated by the code of Figure 7, the `main()` method was modified to create the trace file and indicate the modules to monitor. TODO: Can't we capture them all by default?

The first call to the function `pw_trace` generates the first waveform of the Figure 10. This waveform shows that the power of the module TOP is equal to the sum of the power consumed by all its sub-components (router, timer, ...). Finally, the second call to the function `pw_trace` generates the second waveform of the Figure 10 which is equal to the power consumed by a TAC multiport router.

6.2 Textual Statistics File

A text file gathering different statistics about power consumption can be created and opened by calling function `pw_create_txt_trace_file`. It may be opened during elaboration or at any time during simulation. The modules to monitor are defined by calling function `pw_trace`. A textual file shall be opened before the power changes of the monitored modules and shall be closed by calling function `pw_close_txt_trace_file` at the end of the simulation.

As for the VCD trace file, the code of the `main()` method was modified for generating a textual file and indicating the modules to monitor. The first part of this file (Figure **??**) contains the elapsed simulation time used for computing the different power statistics and the three following arrays:

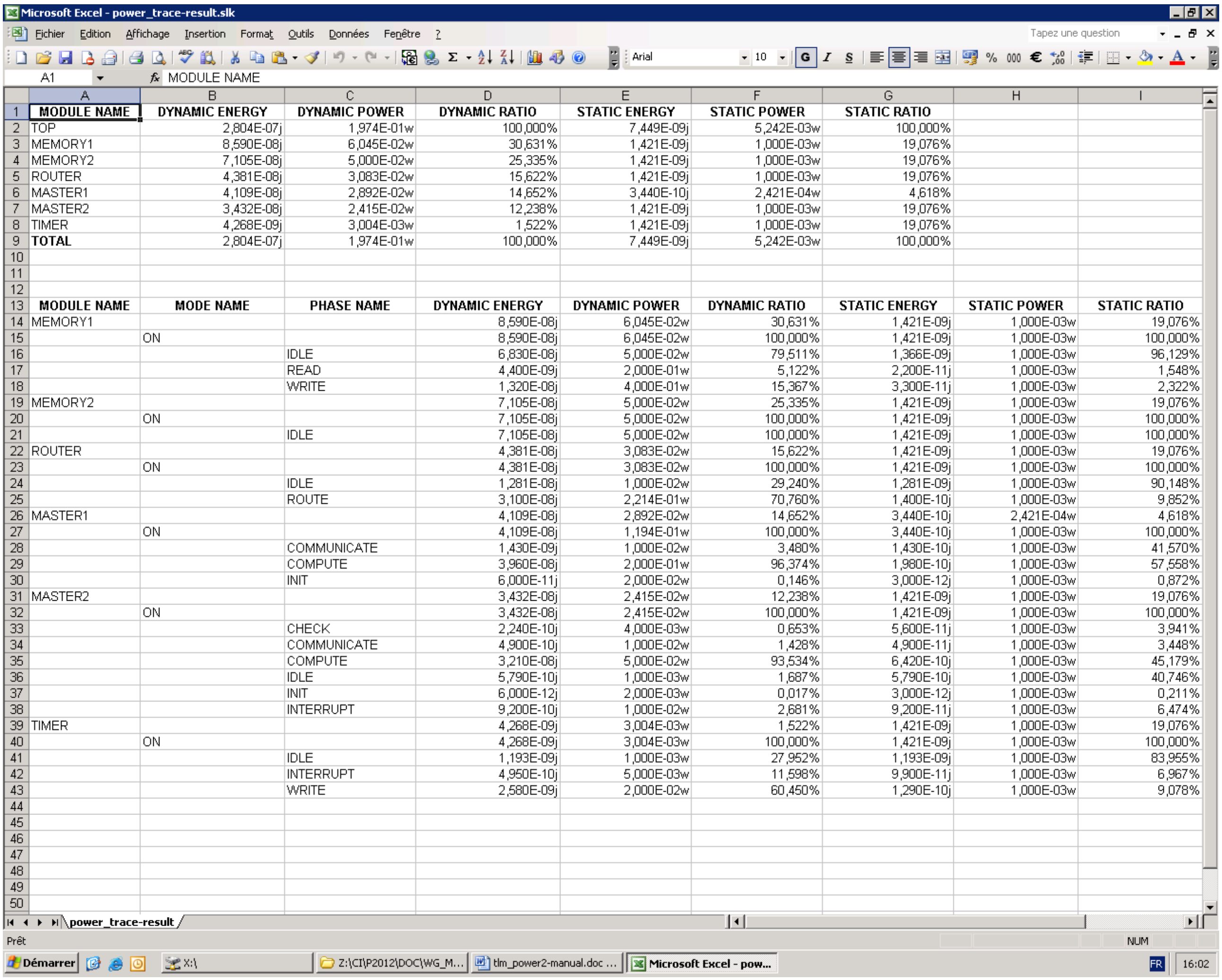
- The first array contains the dynamic and static energy (in Joules) consumed by the monitored modules. The percentage values indicate the dynamic or static energy consumed of a module compared to its global consumption.
- The second array contains the same information as the one before but for power consumption (in Watts).
- The third array gives the power contribution (in percentage) of the monitored modules.

The second part of the generated textual file details the power consumption of each module. For example, Figure **??** illustrates the power information given of the first memory bank. As before, this section is composed of three arrays where the column module is replaced by the power modes (e.g. ...'ON') and phases (e.g. 'IDLE', 'READ' ...) used by this memory during the simulation.

6.3 SYLK Statistic File

As for the textual trace file, the SYLK (Symbolic LinK) trace file gathers different statistics about power consumption. The functions for managing this format of trace file is the same as the ones for the textual trace file, except their suffix names TXT_TRACE_FILE is replaced by SLK_TRACE_FILE. The main advantage of this trace file format is to be supported by most of the spreadsheet applications like ExcelB

As presented in Figure 11, the statistics generated are the same as the one gathered in a textual trace file. The first array gives the power consumption, the energy consumption and the power contribution of each monitored modules. The second array gives details about the power consumption of each module.



MODULE NAME	DYNAMIC ENERGY	DYNAMIC POWER	DYNAMIC RATIO	STATIC ENERGY	STATIC POWER	STATIC RATIO
TOP	2,804E-07j	1,974E-01w	100,000%	7,449E-09j	5,242E-03w	100,000%
MEMORY1	8,590E-08j	6,045E-02w	30,631%	1,421E-09j	1,000E-03w	19,076%
MEMORY2	7,105E-08j	5,000E-02w	25,335%	1,421E-09j	1,000E-03w	19,076%
ROUTER	4,381E-08j	3,083E-02w	15,622%	1,421E-09j	1,000E-03w	19,076%
MASTER1	4,109E-08j	2,892E-02w	14,652%	3,440E-10j	2,421E-04w	4,618%
MASTER2	3,432E-08j	2,415E-02w	12,238%	1,421E-09j	1,000E-03w	19,076%
TIMER	4,268E-09j	3,004E-03w	1,522%	1,421E-09j	1,000E-03w	19,076%
TOTAL	2,804E-07j	1,974E-01w	100,000%	7,449E-09j	5,242E-03w	100,000%

MODULE NAME	MODE NAME	PHASE NAME	DYNAMIC ENERGY	DYNAMIC POWER	DYNAMIC RATIO	STATIC ENERGY	STATIC POWER	STATIC RATIO
MEMORY1			8,590E-08j	6,045E-02w	30,631%	1,421E-09j	1,000E-03w	19,076%
	ON		8,590E-08j	6,045E-02w	100,000%	1,421E-09j	1,000E-03w	100,000%
		IDLE	6,830E-08j	5,000E-02w	79,511%	1,366E-09j	1,000E-03w	96,129%
		READ	4,400E-09j	2,000E-01w	5,122%	2,200E-11j	1,000E-03w	1,548%
		WRITE	1,320E-08j	4,000E-01w	15,367%	3,300E-11j	1,000E-03w	2,322%
MEMORY2			7,105E-08j	5,000E-02w	25,335%	1,421E-09j	1,000E-03w	19,076%
	ON		7,105E-08j	5,000E-02w	100,000%	1,421E-09j	1,000E-03w	100,000%
		IDLE	7,105E-08j	5,000E-02w	100,000%	1,421E-09j	1,000E-03w	100,000%
ROUTER			4,381E-08j	3,083E-02w	15,622%	1,421E-09j	1,000E-03w	19,076%
	ON		4,381E-08j	3,083E-02w	100,000%	1,421E-09j	1,000E-03w	100,000%
		IDLE	1,281E-08j	1,000E-02w	29,240%	1,281E-09j	1,000E-03w	90,148%
		ROUTE	3,100E-08j	2,214E-01w	70,760%	1,400E-10j	1,000E-03w	9,852%
MASTER1			4,109E-08j	2,892E-02w	14,652%	3,440E-10j	2,421E-04w	4,618%
	ON		4,109E-08j	1,194E-01w	100,000%	3,440E-10j	1,000E-03w	100,000%
		COMMUNICATE	1,430E-09j	1,000E-02w	3,480%	1,430E-10j	1,000E-03w	41,570%
		COMPUTE	3,960E-08j	2,000E-01w	96,374%	1,980E-10j	1,000E-03w	57,558%
		INIT	6,000E-11j	2,000E-02w	0,146%	3,000E-12j	1,000E-03w	0,872%
MASTER2			3,432E-08j	2,415E-02w	12,238%	1,421E-09j	1,000E-03w	19,076%
	ON		3,432E-08j	2,415E-02w	100,000%	1,421E-09j	1,000E-03w	100,000%
		CHECK	2,240E-10j	4,000E-03w	0,653%	5,600E-11j	1,000E-03w	3,941%
		COMMUNICATE	4,900E-10j	1,000E-02w	1,428%	4,900E-11j	1,000E-03w	3,448%
		COMPUTE	3,210E-08j	5,000E-02w	93,534%	6,420E-10j	1,000E-03w	45,179%
		IDLE	5,790E-10j	1,000E-03w	1,687%	5,790E-10j	1,000E-03w	40,746%
		INIT	6,000E-12j	2,000E-03w	0,017%	3,000E-12j	1,000E-03w	0,211%
		INTERRUPT	9,200E-10j	1,000E-02w	2,681%	9,200E-11j	1,000E-03w	6,474%
TIMER			4,268E-09j	3,004E-03w	1,522%	1,421E-09j	1,000E-03w	19,076%
	ON		4,268E-09j	3,004E-03w	100,000%	1,421E-09j	1,000E-03w	100,000%
		IDLE	1,193E-09j	1,000E-03w	27,952%	1,193E-09j	1,000E-03w	83,955%
		INTERRUPT	4,950E-10j	5,000E-03w	11,598%	9,900E-11j	1,000E-03w	6,967%
		WRITE	2,580E-09j	2,000E-02w	60,450%	1,290E-10j	1,000E-03w	9,078%

Figure 11: SYLK Statistics.

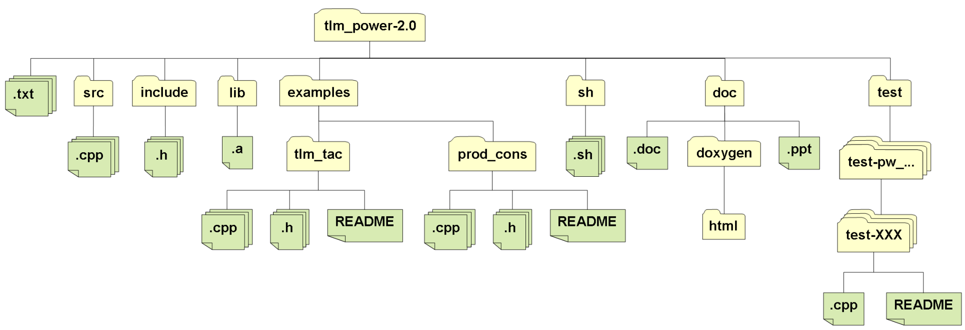


Figure 12: File Tree.

7 Options

7.1 Net Transitions

The net-transition monitor may be enabled to compute the number of wires that change value in a transaction. This behaviour typically follows well-known patterns, and so energy useage based on net-transitions is not often required to be modelled. However, this facility helps calibrate and confirm such models.

7.2 DMI Callbacks

Power consumption is not accurately modelled when DMI is in use. The library has an invalidate hook that can be used to si

8 Implementation Notes

The TLM Power library is fully compliant with the IEEE 1666 standard and has no dependencies other than the SystemC library itself. It can be used as a static standalone library or as an ST INFRA development kit. To use it, an application shall include either of the following C++ headers:

1. `tlm_power`: this header adds the names `sc_pwr` to the declarative region in which it is declared. It also adds in this namespace all the components requested for using the TLM Power library.
2. `tlm_power.h`: this header adds all of the names from the namespace `sc_pwr` to the declarative region in which it is declared.

The file tree of the complete distribution is presented in Figure 12. At the top a README and a RELEASENOTE file briefly describe this library and how to use it. The LICENSE file describes the licensing and contractual issues of the TLM_POWER library. The 'src' and the 'include' directories contain the source code of the library. The static library version is located in the 'lib' directory. The simple TAC platform presented at §**??** is located in the 'examples' directory. This directory also contains an example of a simple platform composed of a producer and a consumer exchanging messages. This document, an overview presentation, and a 'doxygen' documentation of the source code can be found in the directory 'doc' Finally, the 'test' directory contains a set of non-regression tests.

8.1 Compilation Modes

The library can be compiled in verbose mode. It can also be compiled in debug/developer's mode. This is conrolled by setting the relevant flags in the environment or at the top of the Makefile.def.

9 Messages

9.1 Warning Messages

Message:	Overflow with `pw_power` data.
Meaning:	Arithmetic operation with power value has generated an overflow.
Message:	Underflow with `pw_power` data.
Meaning:	Arithmetic operation with power value has generated an underflow.
Message:	Overflow with `pw_power_unit` data.
Meaning:	Try to use or to perform some operation with invalid unit of power.
Message:	Overflow with `pw_energy` data.
Meaning:	Arithmetic operation with energy value has generated an overflow.
Message:	Underflow with `pw_energy` date
Meaning:	Arithmetic operation with energy value has generated an underflow.
Message:	Overflow with `pw_energy_unit` data.
Meaning:	Try to use or to perform some operation with invalid unit of energy.
Message:	Redefinition of the power couple (XXX, XXX).
Meaning:	The same couple of power mode and power phase was defined more than one time in the same configuration file.
Message:	Reach end of infinite simulation without calling SC_STOP.
Meaning:	For properly generating the textual trace file, the SystemC function SC_STOP shall be called at the end of the simulation.
Message:	Reach end of infinite simulation with non null power value (XXX).
Meaning:	At the end of infinite simulation the module XXX has non-null power value. For preserving coherency, the power consumption of this module will be calculated until the last power modification of the System.

9.2 Error Messages

Message:	Overflow with `pw_power_unit` data.
Meaning:	Try to create a power value with an incorrect unit.
Message:	Division by zero not allowed with `pw_power`.
Meaning:	Try to divide a power value with zero.
Message:	Power resolution can only be set during elaboration phase.
Meaning:	Call the SET_POWER_resolution during the simulation phase.
Message:	Power resolution already fixed.
Meaning:	Call the SET_POWER_resolution function more than one time or after constructing a power object different from zero.
Message:	Power value must be positive.
Meaning:	Try to construct a power object with a negative double parameter.
Message:	Overflow with power resolution value.
Meaning:	The SET_POWER_resolution function was called with an incorrect double parameter (greater than 2^{64}-1 or fewer than 1.0).
Message:	Failed to initialize input stream.
Meaning:	The initialization of an input stream (POWER_UNIT, power, ...) failed.
Message:	Failed to extract power value from input stream.
Meaning:	The token of an input stream was not representing a power value (syntax error).
Message:	Failed to extract power value from input stream
Meaning:	The token of an input stream was not representing a power unit value (syntax error).
Message:	Overflow with `pw_energy_unit` data.
Meaning:	Try to create an energy value with an incorrect unit.
Message:	Division by zero not allowed with `pw_energy`.
Meaning:	Try to divide an energy value with zero.
Message:	Energy resolution can only be set during elaboration phase.
Meaning:	Call the SET_ENERGY_resolution during the simulation phase.
Message:	Energy resolution already fixed.
Meaning:	Call the SET_ENERGY_resolution function more than one time or after constructing a energy object different from zero.
Message:	Energy value must be positive.
Meaning:	Try to construct a energy object with a negative double parameter.
Message:	Overflow with energy resolution value.
Meaning:	The SET_ENERGY_resolution function was called with an incorrect double parameter (greater than 2^{64}-1 or fewer than 1.0).
Message:	Failed to initialize input stream.
Meaning:	The initialization of an input stream (ENERGY_UNIT, energy, ...) failed.
Message:	Failed to extract energy value from input stream.
Meaning:	The token of an input stream was not representing an energy value (syntax error).
Message:	Failed to extract energy value from input stream
Meaning:	The token of an input stream was not representing an energy unit value (syntax error).
Message:	Division by zero not allowed.
Meaning:	Try to divide an energy value with a zero power or time value.
Message:	Overflow with `pw_module_base`::ATTRIBUTE_ID data.
Meaning:	Internal error code which should not happen.
Message:	Power module must be an SC_OBJECT.
Meaning:	Try to use the `pw_module` or the `pw_module_base` class with an object not inheriting of the class SC_OBJECT.
Message:	Unknown power mode: failed to switch from (XXX, XXX) to (XXX, XXX).
Meaning:	Call the UPDATE_POWER method of the class `pw_module` with power and/or phase parameter not defined in the configuration file.
Message:	Failed to initialize output stream.
Meaning:	The initialization of an output stream (ENERGY_UNIT, energy, ...) failed.
Message:	Failed to open configuration file XXX (YYY).
Meaning:	Unable to open the configuration file XXX for the reason YYY.
Message:	No power value associated to the couple (XXX, XXX).
Meaning:	Internal error code which should not happen.
Message:	Syntax error on power value definition in file XXX at line YYY.
Meaning:	A power field of the configuration file was not respecting the syntax for defining a power value.
Message:	VCD observer unavailable.

Revision History

Version 1 this library was developed, by Hugo Lebreton, for evaluating the power management mechanisms designed for the Magali Platform [2]. This first version was suffering from the following limitations:

1. The power and energy value are defined by raw value which can lead to un-debuggable errors: for example mixing raw values using different implicit units (e.g. milli-watt and pico-watt) or types (e.g. power and energy).
2. The designer has to define intermediary classes and enumerated types for accessing and setting the power values of a SystemC module.
3. The statistic module does not take into account the mode and phase. For example, it was the responsibility of the user intermediary classes to compute the global energy consumed by a module for different mode and phase.
4. The power consumption of a module does not care about the consumption of its sub-module. With the example of Figure 1 it was not possible to automatically generate power information on the module CLUSTER0 from its sub-module.

Version 2.0 of this library was developed by C Koch-Hofer, Pascal Vivet at CEA to overcome these problems.

Version 3.0 (CBG) shifted the focus to energy-based modelling of transactions and added physical distances.

References

[1]H. Lebreton and P. Vivet: Power Modeling in SystemC at Transaction Level, Application to a DVFS Architecture. IVLSI'08: International Symposium on VLSI, Montpellier, FR, 2008, pp. 463-466.

[2]H. Lebreton: ModC)lisation de la consommation C)lectrique en SystemC/TLM et rC)duction de la consummation par le contrC4le de mC)canisme DVFS. DiplC4me de recherche technologique, Institut National Polytechnique de Grenoble (INPG), 2009.

[3]IEEE Std. 1666-2005: IEEE: Standard SystemC Language Reference Manual. NY, USA, 2006, ISBN 0-7381-4871-7. http://standards.ieee.org/getieee/1666/index.htmlhttp://standards.ieee.org/getieee/1666/index.html

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