Models Exchange through ISIS and SMP2: From Prototype to Reality

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ABSTRACT

From several years now, the CNES with AIRBUS France (ADS-F), THALES ALENIA SPACE France (TAS-F) and SPACEBEL have started exchanging models in order to promote reuse among the different phases of a project and to reduce costs. This would have not been possible without ISIS and SMP2 standards. Everything started with a prototype around ISIS and right now this approach is effective in all CNES satellite platform simulators. This paper describes the main milestones, the overcome challenges, but also those still to be overthrown.

When one speaks about models exchange, it means that the models are developed using one specific simulation framework but then they are used in distinct contexts (for the SVF, the TOMS …), by different stakeholders and employing multiple simulation infrastructures (BASILES, SIMTG or K2). For this purpose, the advent of the SMP2 standard has been an important breakthrough towards a global solution as it allows specifying a common model definition. Nevertheless, that is not sufficient because SMP2 standard focuses on the model syntax point of view but does not deal with the modelling semantics aspects specific to space simulation.

This need has therefore been addressed by the ISIS initiative which aims at defining a common, fully SMP2 compliant, specification to cover the System Interfaces between the OBC/SMU Model and the Equipment Models (or between the Equipment Models), the Space Ground Interfaces (a.k.a. External Interfaces), the Physical Models, the Central Solver and the Model Data exchanges. Such standardisation allows communication between models developed by different stakeholders as well as favouring the creation of a Space Interfaces library for reuse in each new mission. Furthermore, the ISIS Space Interfaces have been developed with the aim to map directly to the ECSS spacecraft on board communication standard interfaces to facilitate the understanding by Space System Engineers.

Following CNES and non CNES simulation projects use the ISIS interfaces:

- A French National Program for Earth observation (CNES and AIRBUS)
- Another French national program (CNES, THALES ALENIA SPACE and AIRBUS)

- Myriade Evolutions product line (CNES, AIRBUS and THALES ALENIA SPACE)
- EUCLID SVF & EGSE (SPACEBEL and TERMA)
- MTG SVF (OHB, SPACEBEL and TERMA)
- PROBA 3 (SPACEBEL)

INTRODUCTION

This article starts by a complete introduction to ISIS system interfaces, its history, rationale and specification context.

From a Reflection on Model Exchange to the ISIS Interfaces

Since years, model exchange has been an important concern for the CNES during the activities performed with its partners, AIRBUS and THALES ALENIA SPACE, in model development, validation and integration. The need to exchange models is of primary importance. First of all, CNES has the needs to reuse SVF/AIT models (for Software Validation Facility and for Assembly Integration Testing testbeds), that are developed by Industrials in TOMS (Training Operation and Maintenance Simulators), which were developed in different simulation infrastructures. Secondly, in most of the CNES simulation projects are involved more than one single model providers, which work with heterogeneous simulation environment. It was urgently required to agree on a common framework that enables effective model exchange between partners and between projects.

The issue was partially addressed with the advent of SMP2 standard. The SMP2 standard allows defining a common formalism in simulation and modelling on the syntax level, that specifies the model interfaces, the inter-model communication mechanisms (Field Links, Event Links and Interface Links) and services provided by a simulation infrastructure. However, system aspects, i.e. semantics aspects specific to the space simulation domain, are not covered by SMP2. A SMP2 space equipment model developed by industrial A can generally not be connected to a SMP2 model developed by industrial B if they use totally different interfaces (although these are SMP2 interfaces).

Therefore, within the global Initiative for Innovative Space Standard (ISIS), CNES invited AIRBUS and TAS, with the SPACEBEL support to cooperate in order to specify a set of simple but representative SMP2 simulation interfaces between Equipment Models, specifically targeting the system interfaces between the OBC Model and Equipment Models of a spacecraft. The ISIS system interface specifications were born! Today, they prove to be efficient and productive in various simulator projects which are presented further in this paper.

The ISIS specifications are not limited to the inter-equipment system interfaces, which are by far the most used interfaces. Efforts were also deployed to increase model exchange for the following data and interfaces:

- External TM/TC interfaces (to Space-Ground interface models).
- Physical Models interfaces (Orbit, Environment and Dynamics).
- Central Solver interfaces (for continuous simulations).
- Model configuration data exchange (promoting the use of the SMP Configuration files).
- Calibration functions.

From Requirements to Specifications & Implementations

The requirements which have governed the ISIS system interfaces specification are:

- The ISIS system interfaces shall be SMP2 compliant. This guarantees that all users adhere to the same formalism and the model portability from one simulation infrastructure to another. Models developed in SimTG (AIRBUS simulation infrastructure) or K2 (TAS simulation infrastructure) can be executed unchanged in BASILES (CNES simulation infrastructure).
- The ISIS system interfaces shall be representative of most simulation use cases (Functional, SVF Operational simulators), shall be simple to use and to be understood to simulation engineers. The interfaces go “straight to the point” of the simulation needs.
- The ISIS system interfaces shall be mapped on standard I/O interface, i.e ASM, TSM, BSM, BDM, ISD, OSD, OBDH, M1553, UART, Serial, Spacewire, Power, HPC, … A specific or non standard I/O interface can be simulated by choosing the closest existing interface in behaviour.

The following table shows the currently supported electrical I/O interfaces.

Electrical I/F	***Comments***	***ISIS interface***
ASM1 (Analog)	Analogue signal monitor (0/5V)	Analog acquisition
ASM2 (Analog)	Analogue signal monitor (-5/+5V)	Analog acquisition
ASM3 (Analog)	Analogue signal monitor (-10/+10V)	Analog acquisition
TSM1 (Thermistor)	Temperature sensor monitoring	Analog acquisition
TSM2 (Thermistor)	Temperature sensor monitoring Positive thermal coefficient	Analog acquisition
BDM (Digital bi-level)	Bi-level discrete monitor	Digital acquisition
BSM (Digital relay)	Bi-level switch monitor OPEN / CLOSED	Digital acquisition
HV-HPC	High Voltage HPC	HPC
LV-HPC	Low Voltage HPC	HPC
HC-HPC	High Current HPC	HPC
LPC-P (N/A ISIS)	Low Power Command (pulse)	Not supported
LPC-S (N/A ISIS)	Low Power Command (static)	Not supported
SBDLC	Signal Balanced Differential Line Command	Synchronisation / TC
SBDLA	Signal Balanced Differential Line Acquisition	Synchronisation / TM
PPS	PPS pulse	Synchronisation
H8	Synchronisation pulse (clock 8Hz)	Synchronisation
MIL 1553 data bus	3 models : BC, Bus, RT	M1553
Serial UART	Serial line	Serial
Spacewire link	SpaceWire link	Spacewire
LCL	Standard power line (Latching Current Limiter)	Power line
OP-LCL	ON protected power line	Power line
HL	Heater Line	Power line
HPL (ISIS option)	High Power Line	Power line
ACL pulse	Actuator Command Line (pulse)	Power pulse
Permanent ACL	Actuator Command line (permanent)	Power line
TM	Telemetries	TM (exchange of CADU)
TC	Telecommands	TC (exchange of CLTU)
OSD	16-bit output serial digital	Serial digital 16bits
ISD	16-bit input serial digital	Serial digital 16bits
BSD	16-bit bi-directional serial digital	Serial digital 16bits
Alarm activation	SBDLA (True: ACTIVATED, False: DEACTIVATED)	Digital alarm acquisition
Separation strap	SBDLA (True: SEPARATED, False: NOT SEPARATED)	Digital alarm acquisition
Umbilical presence	SBDLA (True: PRESENT, False: ABSENT)	Digital alarm acquisition
Watch dog inhibition	SBDLA (True: INHIBITION, False: UNINHIBITION)	Digital alarm acquisition

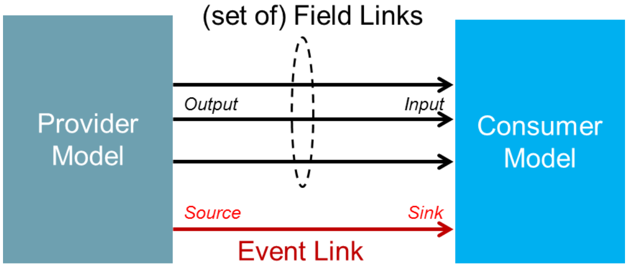
The implementation of these specifications results in a set of SMP2 Catalogues and C++ headers which can be easily used by simulation models. All interfaces are specified under requirements form in a document accessible to all [1].

Design approaches

Model design approaches can vary among the model developers. For this reason, we came to the conclusion that it is required to specify the ISIS system interfaces for two design approaches, both being supported by SMP2: *Event & Field Links* approach and *Interface Links* approach.

The two design approaches are illustrated and explained here after.

Event & Field Links



In this approach, a communication from the data Provider model and a data Consumer model is realized by a set of Field Links (dataflow, from an Output variable to an Input variable) and one Event Link (optional as it could be absent in some interfaces).

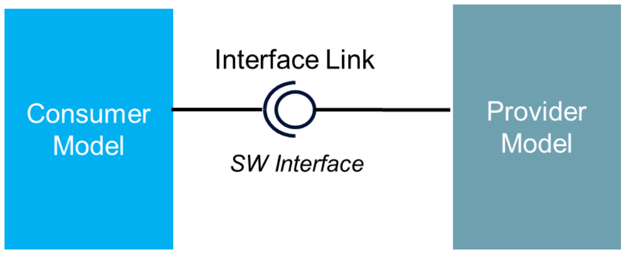
As the communication is totally asynchronous, assumption is that the Field Links propagation is automatic. The caveat is that this communication scheme was not yet supported in SMP2. Nevertheless, this need has been met as the automatic dataflow propagation is a new feature of the upcoming SMP standard.

The Provider changes its Output data, which get propagated to the Consumer, and then notifies the Consumer via the associated Event Link.

Pro:
Natural design from the simulation engineers perspective.
Easy errors & failure injection, controlled by the infrastructure

Cons:
Complexity due to the numerous connections to be established between models.

Interface Links



In this approach, the data Consumer model and the Provider model communicate through the same (SMP2) software interface(s). It is realized by one Interface Link between the two parties. The Consumer model calls the software interface implemented by the Provider model.

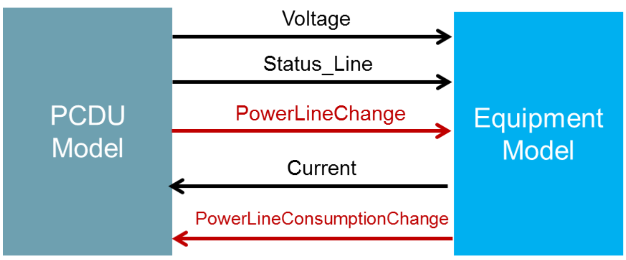
Communication is totally asynchronous.

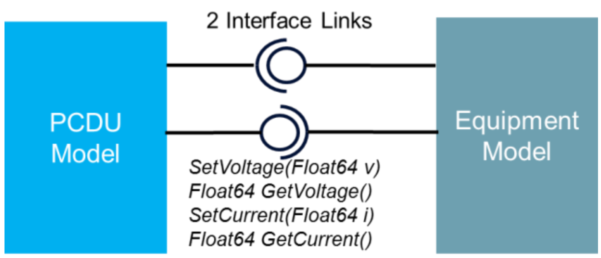
The interface Consumer calls the methods exposed by the interface Provider.

Pro:
Software oriented interface.
Very performing as an exchange is one single software call.
No limit in the functionalities (it is software!) and simple model connectivity.

Cons:
Errors & failure injection has to be controlled by the models.
Connection is bound to the corresponding software interface.

Example of a Power Line interface between a power supplier model and a power consumer model





ISIS PROTOTYPE

A proof of concept prototype was realised with the initial ISIS specifications. Focus was put on the most representative system interfaces, i.e. power line, HPC line, M1553 and analog acquisitions. In this prototyping activity, the roles were distributed as follows:

- AIRBUS developed the OBC model in its SimTG infrastructure, following the Interface Links approach
- TAS developed the OBC model in its K2 infrastructure, following the Event & Field Links approach
- SPACEBEL developed a Payload model, supporting both Interface and Event & Field Links approach

The prototype concluded with success when SPACEBEL could connect and integrate all the models into the final simulator, running on top of BASILES.

ISIS USE IN ACTUAL SATELLITE PROJECTS

Since its inception, the ISIS interfaces have been used in numerous, CNES and non CNES, satellite simulation projects, The following sections describe the feedback from the ISIS users in these projects.

A French National Program Feedback

For a French national program, AIRBUS has developed Satellites Simulators for the purpose of Software Validation, System Test and AIT support; all based on a set of independent Physical and Equipments models running on the SimTG infrastructure. Those models, which natively embed SMP2 layers, are integrated unmodified in the CNES BASILES infrastructure to build an Operation Simulator (TOMS) thanks to SMP2 artefacts and standardized SMP2/ISIS communication interfaces, thus latter allowing straight forward replacement of some models by CNES ones.

The AIRBUS models are complemented with other models developed by CNES-SPACEBEL joint team to cope with specific TOMS needs (e.g. Physical Models and Station Model). This first experience has contributed to consolidate the ISIS interfaces as well as different mechanisms around SMP2.

The experience feedback shows that the model exchange is really efficient thanks to ISIS and SMP2. However there are some limitations/differences concerning the services at infrastructure level in order to interact with the models. Another difficulty is the cross validation of models between different infrastructures due to the different test languages used (e.g. Java for SimTG and Tcl for BASILES). The last point to be highlighted is that the configuration of assembly and schedules files remains really laborious.

Another French National Program Feedback

In this project, most of the satellite platform models are developed by TAS-F through K2. There are also some models developed by ADS-F. This is the first operational experience at CNES using SMP2 models developed by TAS, which is mainly a Event & Field Link based design. In order to accommodate this, the BASILES infrastructure has been updated to provide a MDK that supports automatic propagation dataflow.

Following is the feedback from TAS:

- ISIS allows solving most compatibility issues of recurrent interfaces (1553, clock, etc.) between model, at the early stage of model development.
- The ISIS standard does not specify which ISIS interface should be used for a given electrical interface. This allows the simulation team to cover cases not foreseen by ISIS. For instance, the dual use of ASM and BDM acquisitions on the RTU.
- The units of Analog acquisitions are not covered by the standard, which may lead to incompatibilities discovered during integration.
- The ISIS standard describes a ConnectionService to allow connecting Isis InterfaceLinks together. Implementation in K2 showed that it should be specified more precisely (procurement of the class definitions in the Isis namespace). Though the function (model connection) of such a service is already provided by any SMP2 infrastructure, the ConnectionService adds an intermediary object «ILink», that could be used as a mean of error injection controlled by the infrastructure.

Myriade Evolutions Feedback

Myriade Evolutions program aims at developing and qualifying a platform for the 2015-2025 period for satellites in the range of 400 kg. The project is carried out in partnership between CNES, AIRBUS, and THALES ALENIA SPACE. It is the next generation of the Myriade product line (platform for microsatellites). This new platform will be used for CNES missions like MERLIN as well as for AIRBUS and THALES ALENIA SPACE export missions (if not the whole platform at least some of the equipments).

This new platform includes the components that have been considered common to all next missions (structure, S-Band, X-Band, Reaction Wheel, Propulsion, GNSS, Mass Memory, PCDU, Battery and Solar Arrays). The rest of the equipments will be specific to the mission's satellite contractor. Each new component means a new simulation model. In order to reduce costs and favour model reuse, it has been decided to use the same models for the SVF/AIT and the TOMS (Training Operations and Maintenance Simulator). This approach is applied in most of CNES projects. It is important to highlight that the simulation environments are different between the SVF/AIT (satellite contractor responsibility) and the TOMS (CNES responsibility).

In this context, ISIS has proven to be useful from the very beginning within the specification phase. All electrical interfaces were already defined by ISIS, therefore, from interfaces point of view, it has only been necessary to list the kind of ISIS interface to be used. Next, models have been developed by SPACEBEL using ESA tools and delivered to CNES for validation in BASILES for future TOMS. Thanks to the standardisation, SPACEBEL has implemented a library containing all the system lines defined by ISIS in order to reuse them in other projects. After that, models have been provided to AIRBUS and THALES ALENIA SPACE for integration in their simulation infrastructure with the rest of the simulator for the SVF. All these exchanges and integration with other models developed by different partners would not have been possible without ISIS and SMP2.

The reuse of Myriade Evolutions models within the AIRBUS SimTG simulation environment has been the second experience of the integration of CNES/SPB SMP2 models using the ISIS system interfaces (the first one has been done within the frame of the ISIS project itself). A Wrapper tool allows from catalogues, assembly, scheduler files to generate automatically the layer to integrate the models without any modification within the AIRBUS SimMF models development tool (graphical environment used to develop & integrate models). The generation of the complete simulator to be executed on the SimTG Kernel is afterward performed in a straight forward manner through SimMF: the communication interface compatibility with the Myriade Evolutions models being possible thanks to standardized SMP2/ISIS communication interfaces (interface-based in our case).

One difference with respect to previous CNES projects is that all the models and sub-models are fully SMP2. This means that all elements are accessible by standard SMP2 functionalities. In addition, for the system interface layer, it has been decided to implement the interface link approach as well as the field and event link approach with automatic data propagation. Each model is provided with these two sets of system interfaces. The automatic data propagation has proven to be essential for asynchronous communication through field links. Without ISIS extension for that, only the interface link approach could have been followed.

While the integration of the models in the different infrastructures has taken place without effort, the validation has shown some difficulties, mainly due to the fact that there is no standardisation in the validation procedures. Each partner uses different script languages for the validation along with different infrastructures. The different scripts languages involve always a conversion of test scenario. On the side of the infrastructures, even if some services are standardised by SMP2 there are topics such as the event priority which are not addressed. In these conditions, it is difficult to get exactly the same results in the different environments. Because of that, most of the time we exchange unit tests at model level instead of tests for the whole simulator.

Another area of improvement is the calibration functions and the configuration files for that. For Myriade Evolutions, a specific solution has been adopted but a standardisation is on-going on ISIS side.

A last issue to be pointed out is, that in the case of interface approach, ISIS defines sometimes in the same software interface methods that should not be implemented by the same model (e.g. PowerLine with set/get voltage and set/get current). For the same software interface, model A can act as provider for some methods (e.g. set voltage) and as consumer for other ones (get current); it means that it includes a partial implementation of the software interface as well as a reference to the same software interface to call methods in another model. This can become confusing; maybe more examples could be available in ISIS documents or maybe the software interface could be split into two different ones to better identify the physical functionalities.

Despite these limitations, SMP2 and ISIS are key elements in our simulation activities in order to promote model reuse among the different project phases and to reduce costs with a really tight time schedule.

The first Myriade Evolutions application is MERLIN. The organisation is close to previous project but with AIRBUS Germany (ADS-G) as a new model provider. In total, there are 4 different models sources: Myriade Evolutions common trunk models, ADS-F specific platform models, ADS-G payload model and MERLIN TOMS specific models.

MTG-SVF Simulation Framework Feedback (OHB)

In the MTG-SVF project, lead by OHB, the MTG SMU model was developed by TERMA while the spacecraft equipment models were developed partly by SPACEBEL and partly by OHB. They are connected to the SMU model through the ISIS interfaces, following the Interface Links approach. Below is the return of experience about ISIS from OHB.

Interfaces like ISIS are a necessary building block of model exchange, because SMP (for good reasons) only concentrates on the lowest layer of interoperability. Without interfaces like ISIS, model exchange is not possible at all.
In the beginning it was confusing that ISIS allows a lot of freedom for the best way to use a certain interface. It allows interface-based or event- and field-based exchange. After deciding for a particular option (interface-based in our case), ISIS was easy to use.

ISIS allowed us to integrate SPACEBEL and TERMA models together in the MTG SVF with little effort. Being able to mate models from different suppliers that have never been used together before was a tremendous cost-saver.
ISIS interfaces satisfy fully the needs, there are no missing functionalities.

With the flexiblity of ISIS, there can come incompatibility (e.g. if it is not clear whether interface-based or field-based flow is used). Also within the interface-based apporach, it needs to be explicitly specified, who needs to implement SetValue and who calls it, or if GetValue is used, or both together.
Another example is SpaceWire, where it is not clear why/if three different methods needs to be implemented/called.
There, a project/company specific tailoring is needed.

MTG-SVF SF & EUCLID SVF Feedback (TERMA)

In the context of the MTG SMU and EUCLID CDMU Models development, TERMA has used the ISIS interfaces, which serve to connect later to Equipment Models developed by SPACEBEL. TERMA has sent us their reflections on ISIS interfaces:

1. When different companies develop models, it is necessary to agree on common interfaces. ISIS fulfills clearly this purpose.
2. Our issues to understanding and using ISIS:
    a. ISIS interfaces are simple and do not depend on any other products, just SMP2 types, therefore are very simple to use. They define standard model / subsystem communication representing common hardware functionality. ISIS is not a Reference Architecture and therefore does not impose any design restrictions on model development.
    b. It is not always obvious how each ISIS interface should be used or which interface is the most adequate for a specific situation. This problem could be addressed by improving each interface's own documentation (in MagicDraw and source code), which is insufficient. The documentation should be expanded explaining the purpose of each interface and its operations, what it represents, how it should be used, examples, etc.
    c. The deriving of interfaces with no added functionality was not understood and only added confusion when working out what interface a model should inherit from and what interface a model should be using e.g. ISpaceWireLineIFConsumer that derives from ISpaceWireLineIF. ISpaceWireLineIF is sufficient
3. There are no spared development costs due to ISIS directly, only because standard interfaces were defined and fixed before development started

4. ISIS interfaces do not cover all simulator needs. A per project tailoring could be required. For example, ITCReceiver was added for MTG and Euclid to receive TC Segments into the TC Decoder where MAP ID and VC ID were needed. ITMReceiver was added for MTG and Euclid to send TM packets to the RF models where VC ID and data bit rate were needed. ISpaceWireLineIF and ISpaceWireLineConsumer interfaces extended existing ISpaceWire interfaces to set the SPW connection state to allow testing OBSW when SPW connections fail
5. When a model has many ISIS interface references e.g. HPC lines or Digital/Analog connectors days can be spent adding these in the UML design. It would be nice if the IHPCLineIF could take an ID or pulse line number, therefore one single interface could be used for multiple connections. Same applies to the IDigitalLineIF and IAnalogIF interfaces.

EUCLID RTS Simulator (AIRBUS Defence & Space Netherlands)

In the context of the EUCLID SVF the ISIS interfaces are used to connect the ADSN RTS Simulator (AOCS equipment models) to the CDMU Model (TERMA) and Equipment Models (SPACEBEL). This proves once more time the effective model exchange thanks to the ISIS interfaces when a satellite simulation project involves many partners.

PROBA-3 SVF (SPACEBEL)

In the PROBA-3 SVF, SPACEBEL is the only models provider, for the ADPMS and equipment models. There is no model exchange as such but ISIS interfaces are reused as an interfaces library, that allows sparing interface design efforts. From SPACEBEL perspective, the ISIS interfaces functionalities satisfy all our needs, there are no missing functionalities identified.

NEXT STEPS

The ISIS/SMP2 evolutions are or will be centered around following axis:

- Consolidation of the current interfaces (System, Physical, Solver, Calibration Functions, Model Data).
- Major evolution of the Spacewire interfaces
- Support of new interfaces: LVDS, …
- Improved documentation
- Align with the upcoming ECSS SMP standard (where Automatic Dataflow has been integrated)
- Consideration of the feedback from the various projects.

The ISIS system interfaces use is promoted in all current and future CNES/SPACEBEL initiated projects.

CONCLUSIONS

CNES and its main partners, SPACEBEL, AIRBUS, TAS are totally convinced by the ISIS system interfaces initiative. The main challenge was to allow an effective model exchange between the simulation models providers. This goal is reached thanks to the ISIS interfaces.

Since the start, ISIS interfaces have been and are being used by an increasing number of simulation projects. The ISIS initiative has clearly a wide support. General feedback is positive despite some concerns on the lack of documentation and unclarities in the specifications. There is certainly room for improvement and extension of the ISIS interfaces.

The ISIS initiative shows the importance and advantages of the standardisation (SMP2 and system aspects like in ISIS) in simulation modelling activities. It is crucial for all the actors involved in space simulation projects to continue on this line and to address and solve the different limitations found.

ACKNOWLEDGMENTS

We would like to thank CNES, THALES ALENIA SPACE, AIRBUS, OHB, SPACEBEL, TERMA and ADSN for their valuable return of experience in using the ISIS interfaces.

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