USAF Developed Generic Model Base Test Equipment: SysML and ATML Standardized Models and Style Guide

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Note: NI is now the Test & Measurement Group of Emerson.

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Agenda

Walk through the USAF project using a hybrid panel / presenter approach

Please ask questions, provide comments, etc. – your interaction is a primary reason we are doing this

- Our Start Point and Target End Point
- Model-Based Test Engineering – motivation, definition
- Brief overviews of SysML & ATML and our vision of how this could be done
- Generic SysML models developed for this Task Order
  - IEEE 1641 TSF Signal and Test Description (AC signal TSF discussed)
  - Five instrument types (generic DMM is discussed)
  - Test Station
- Model Verification
- Initial Style Guide
- Some Key Learnings and Challenges
- Next Steps
- Call for Participation

NDIA Digital Engineering/Digital Test Project

Problem Statement

Driving force behind project was presentation at 2022 ATC Plenary Session

- The DoD and the ATE industry needs faster and less expensive methods to develop, deploy, and sustain automated test solutions.
- The DoD Digital Acquisition mandate is pressuring government acquisition organizations to emplace processes that deliver digitally acquired digital products.
- The industry lacks definition of the digital acquisition process as it relates to ATE and Digital Engineering / Transformation.
- What is the current state of industry to support an ATS Digital Product Model and Acquisition?
- What are the insights Industry may provide to support our DoD ATS partners with their Digital Engineering and Acquisition needs?

Deliver a document for DoD reference that provides insights into the ATS/ATE Defense Industry's capabilities and potential improvements to support Digital Acquisition and the necessary execution of Digital Engineering and Digital Transformation.

2 8/15/

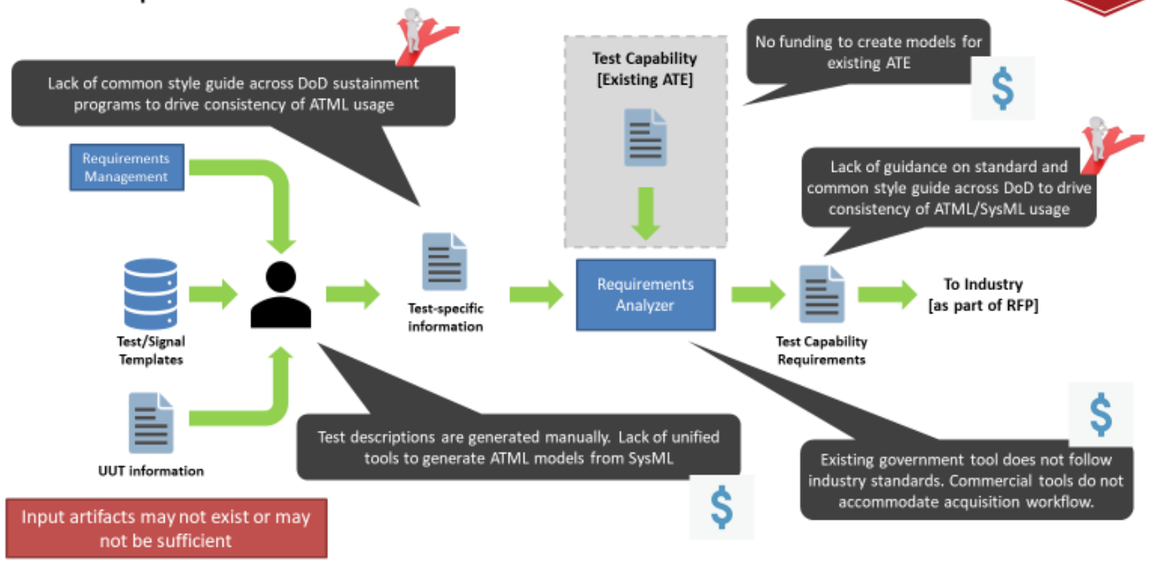
From NDIA Panel at ATC2023

Without standardization, "everyone" doing it differently will not meet the Digital Engineering goals

- Industry:
  - Astronix, Boeing, CACI, Keysight, Lockheed, NI, Teradyne
- DoD:
  - Air Force, Army, Navy, Marines

Digital Acquisition Workflow – Gaps

DoD Pre-acquisition Process



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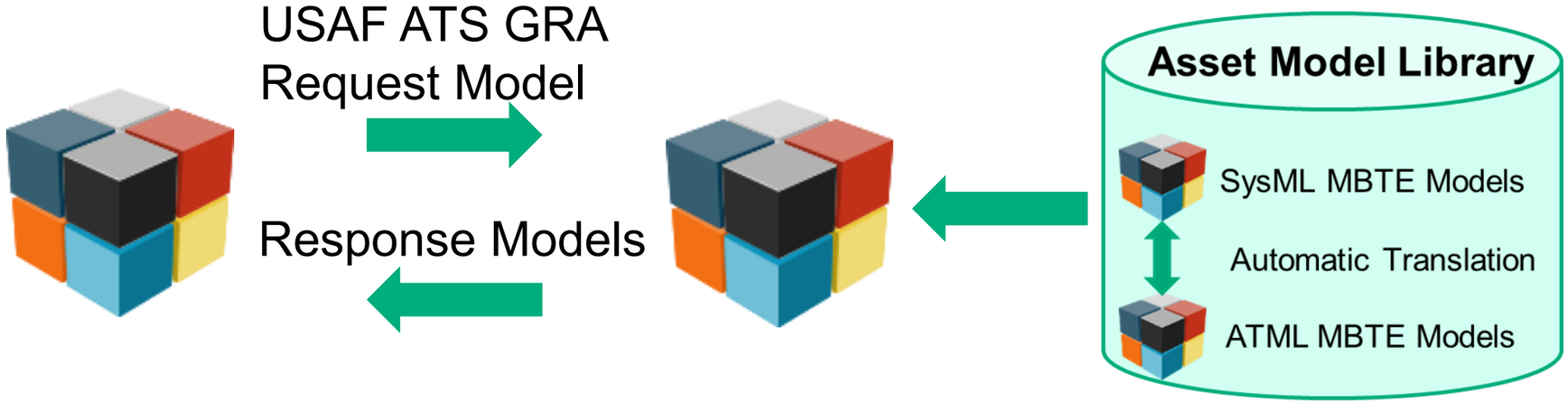
The Beginning of the Journey

- NI and CACI are working with the United States Air Force – ATS (Automated Test Systems) Digital Innovation Team at Warner-Robbins AFB
- Explore Digital Acquisition for Government Reference Architecture (GRA) for ATS'
- Goals of first Task Order:
  - Create generic models for signals, test instruments, and test station that in future could become implementation-specific responses to the GRA for future test solutions
  - Initial (very drafty…) MBTE Style Guide for SysML and ATML models



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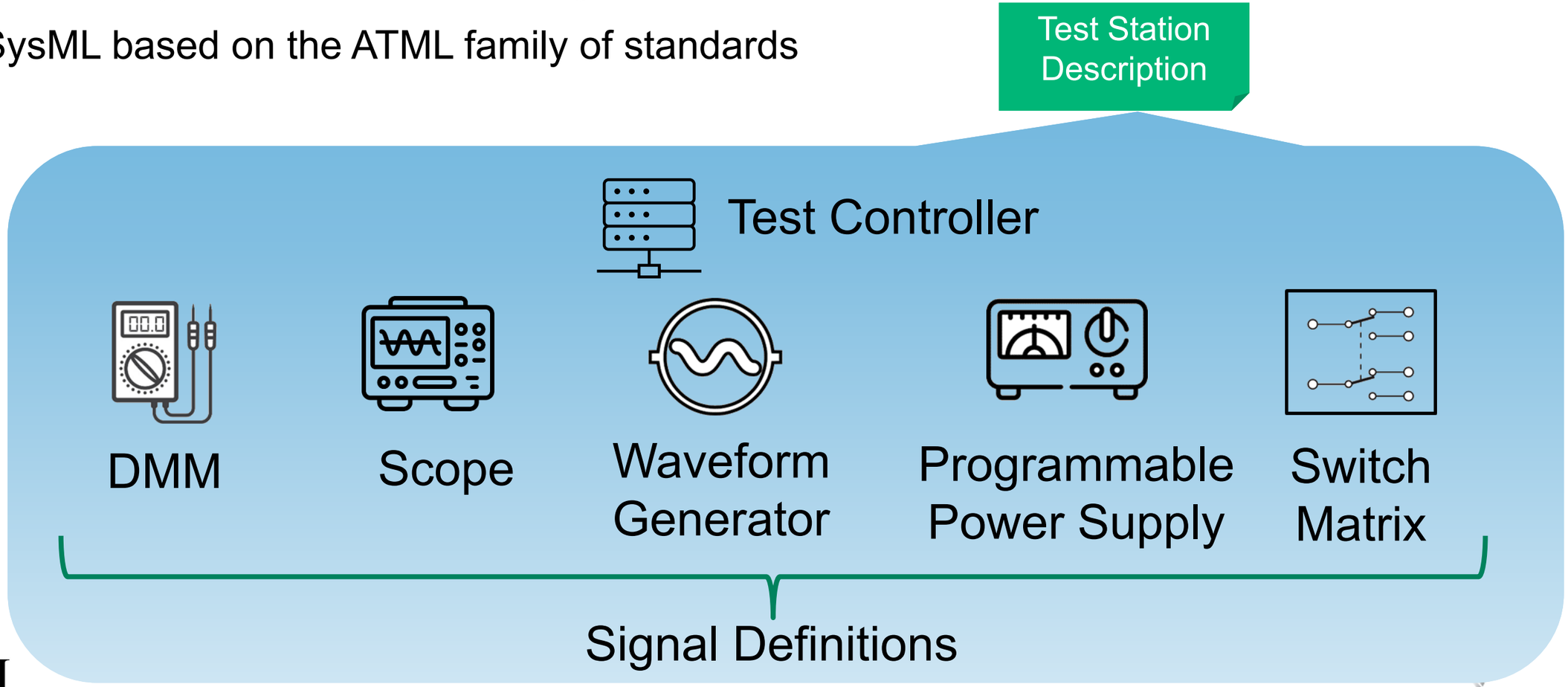
ATSSI II Task Order MBTE ATS Architecture Overview

- Initiated to standardize the way Automated Test Systems are modeled
- Period of Performance 12-Month: 09 August 2023 to 08 August 2024 (Complete)
- Generic SysML models as building blocks
- SysML based on the ATML family of standards



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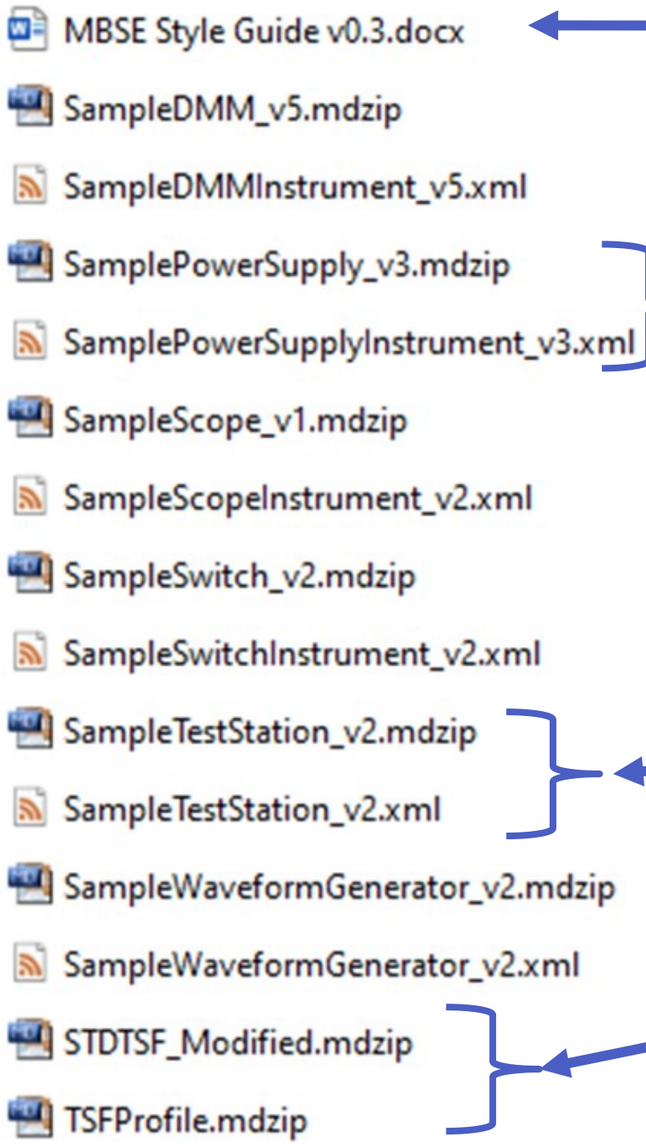
Delivered Dataset



An overarching style guides describes the models and how they are used to construct a test station

Each SysML model is accompanied by an ATML model

Automatic, bi-directional, lossless translation between SysML and ATML was demonstrated

Instrument models are referenced by the system model

Everything is built up from signals based on IEEE 1641.1

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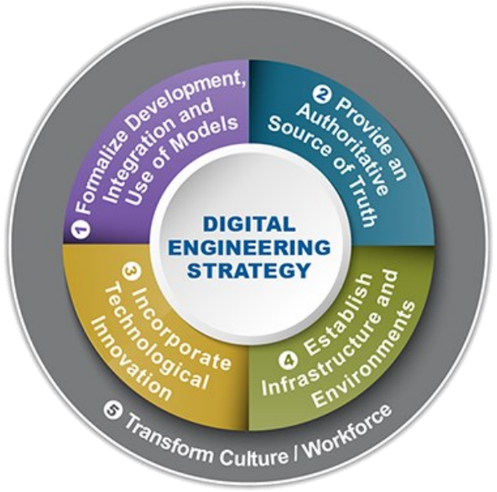
What is Model-Based Test Engineering?

- DoD and MoD have visions of how they want “everything” to work together and leverage standards in “Digital Engineering”
  - **But test contributions are not well understood**
- Different groups and different parts of the product life cycle (within the branches, primes, and suppliers) have “different/similar” challenges and desire “different/similar” outcomes
  - **But test contributions are not well understood**
- Many companies have internal Digital Transformation initiatives with their own desired outcomes
  - **But test contributions are not well understood**
- However, a set of common core of required capabilities required can be leveraged to create linked workflows that address:
  - The vision of the DoD/MoD AND
  - The different groups and parts of the life cycle AND
  - Test aspects of Digital Transformation initiatives
- Model-Based Test Engineering is a Digital Engineering initiative to address all the above



DoD Instruction 5000.97

Digital Engineering

Originating Component:	Office of the Under Secretary of Defense for Research and Engineering
Effective:	December 21, 2023
Releasability:	Cleared for public release. Available on the Directives Division Website at https://www.esd.whs.mil/DD/.
Incorporates and Cancels:	Department of Defense Directive 5000.59, “DoD Modeling and Simulation (M&S) Management,” August 8, 2007, as amended
Approved by:	Heidi Shyu, Under Secretary of Defense for Research and Engineering

Purpose: In accordance with the authority in DoD Directive 5137.02, this issuance establishes policy, assigns responsibilities, and provides procedures for implementing and using digital engineering in the development and sustainment of defense systems.

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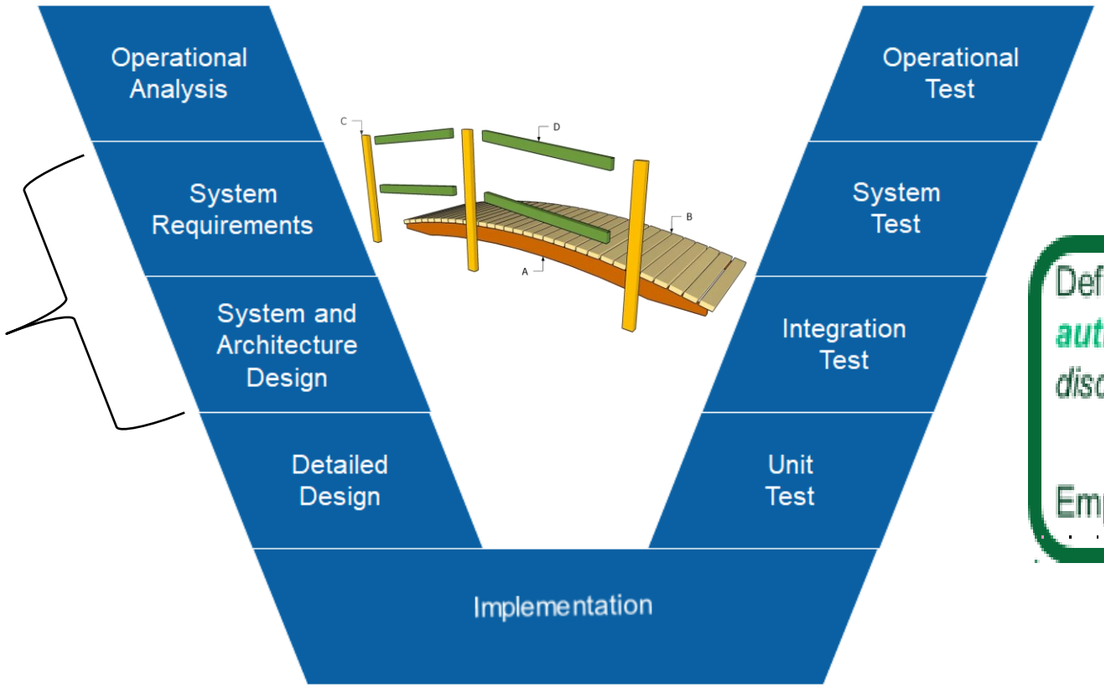
Can We go Across the "V" with MBSE in Test?

MBSE Today



US DoD

Defines Digital Engineering as an *"integrated digital approach that uses **authoritative sources of system data and models** as a continuum across disciplines to support **lifecycle activities from concept through disposal.**"*

Emphasizes **continuity of models** across program lifecycle

MBSE is a set of workflows that well support Systems Engineering & has many capabilities / concepts that can be leveraged for test

By adopting MBSE to a subset of Test AND adopting a subset of Test to MBSE, we can create and leverage bi-directional value across the "V" **= Model-Based Test Engineering (MBTE)**

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Vision of Model-Based Test Engineering

Defines Digital Engineering as an *"integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal."*

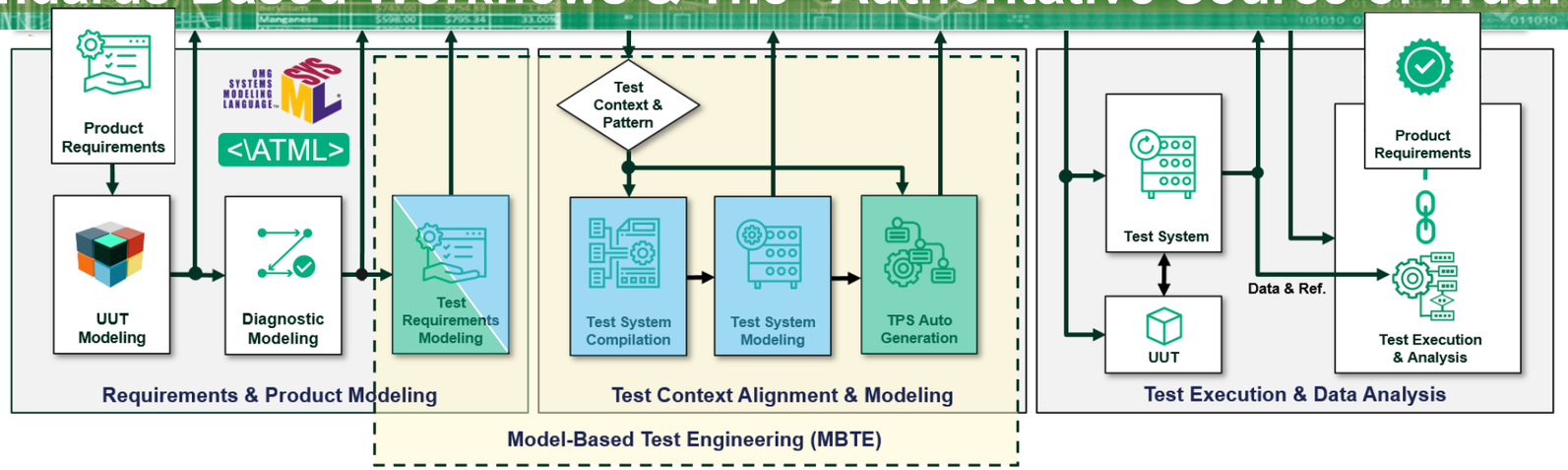
Emphasizes continuity of models across program lifecycle

Product Lifecycle: Design | Validation (Box, SIL, etc.) | Production | Depot | Field

Digital Threads

Standards-Based Workflows & The "Authoritative Source of Truth"

Requirements -
Equipment Models -
Plant Models -
Scripts -
Results -
etc. -



- Requirements flow down through automated tooling and workflow
- Industry standard formats
  - SysML
  - ATML (IEEE 1641/1671)

- Lowers direct personnel interaction
- Product design iterations trigger automated workflows
- Personnel bandwidth has a low impact on workflow efficiency
- Critical information, such as requirements, preserved through digital threads

- Efficiencies scale across the Program/Product Lifecycle
- Reduces loss of information across lifecycle and through time
- Enables new modes of monetization of critical information

What is SysML?

- **Definition**: SysML, the **Systems Modeling Language**, is a graphical modeling language developed by the **Object Management Group (OMG)**
- **V1 is an extension of UML**: It extends the **Unified Modeling Language (UML)** to address the specific needs of **systems engineering**
- **Modeling Complex Systems**: SysML is designed for modeling **complex systems**, especially those consisting of multiple interconnected systems (often referred to as “systems of systems”)
- **Graphical Representation**: It provides a graphical notation for expressing system architecture, requirements, behavior, and other aspects
- **Model-Based Systems Engineering (MBSE)**: SysML supports **model-based systems engineering**, enabling engineers to capture system requirements, design, and analysis in a standardized way
- **Key Diagrams**: Common SysML diagrams include **Block Definition Diagrams (BDDs)**, **Internal Block Diagrams (IBDs)**, **Parametric Diagrams, Sequence Diagrams, Activity Diagrams**
- **Tool Support**: Various modeling tools, such as **Cameo Systems Modeler**, support SysML for system design and analysis
- **SysML v2** is in final approval stages and is **a different language** in many aspects **than v1**
- **Related: UML Testing Profile v2.1, RAAML (Risk Analysis and Assessment Modeling Language)**

What is ATML?

- **Purpose**: The IEEE 1671 standard defines a framework for the family of ATML standards. It serves as a standard exchange medium for sharing information between components of **Automatic Test Systems (ATSs)**
- **Information Exchange**: ATML allows automatic test system and test information to be exchanged in a common format adhering to the **extensible markup language (XML)** standard
- **Test Description**: It provides an exchange format for specifying test performance, test conditions, diagnostic requirements, and support equipment to locate, align, and verify the proper operation of a **Unit Under Test (UUT)**
- **Instrumentation Identification**: The standard also specifies an exchange format for identifying instrumentation that may be integrated into an ATS for testing and diagnosing a UUT
- **Hardware, Software, and Documentation**: Additionally, it defines an exchange format for identifying all the hardware, software, and documentation associated with a UUT
- **Test Configuration**: The standard covers the exchange format for identifying the test configuration used to test for and diagnose faults of a UUT on an automatic test system
- **Companion Standards:** IEEE 1641 – Signal and Test Definition, IEEE 1636 Software Interface for Maintenance Information Collection and Analysis (SIMICA) (includes test results data)

ATML & Related Components

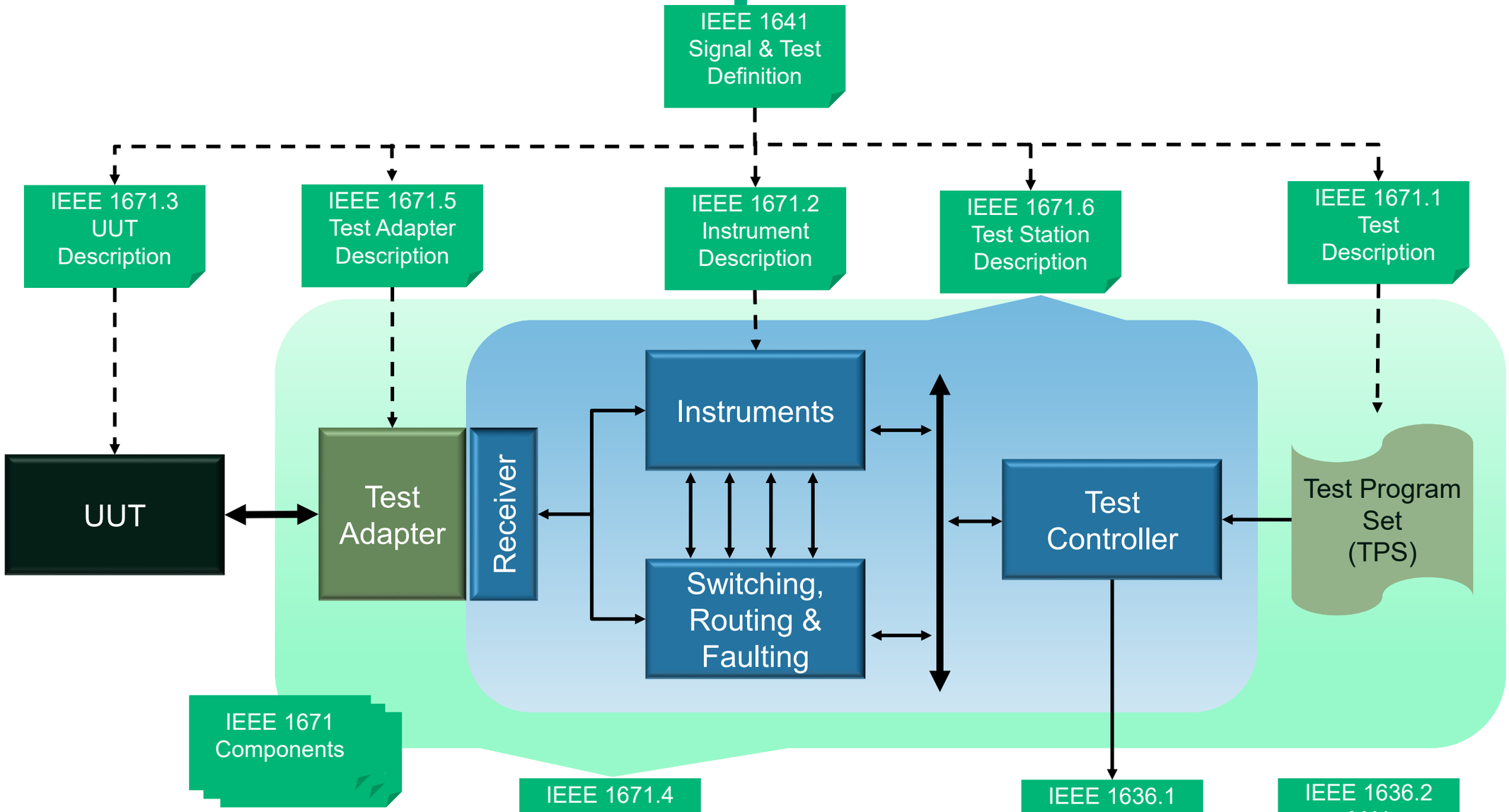


Figure based on presentation given by Mike Malesich (2022, August 30). *DoD ATS Framework IPT Relation to Digital Thread* [Conference panel presentation]. AUTOESTCON 2022, National Harbor, Maryland, United States.

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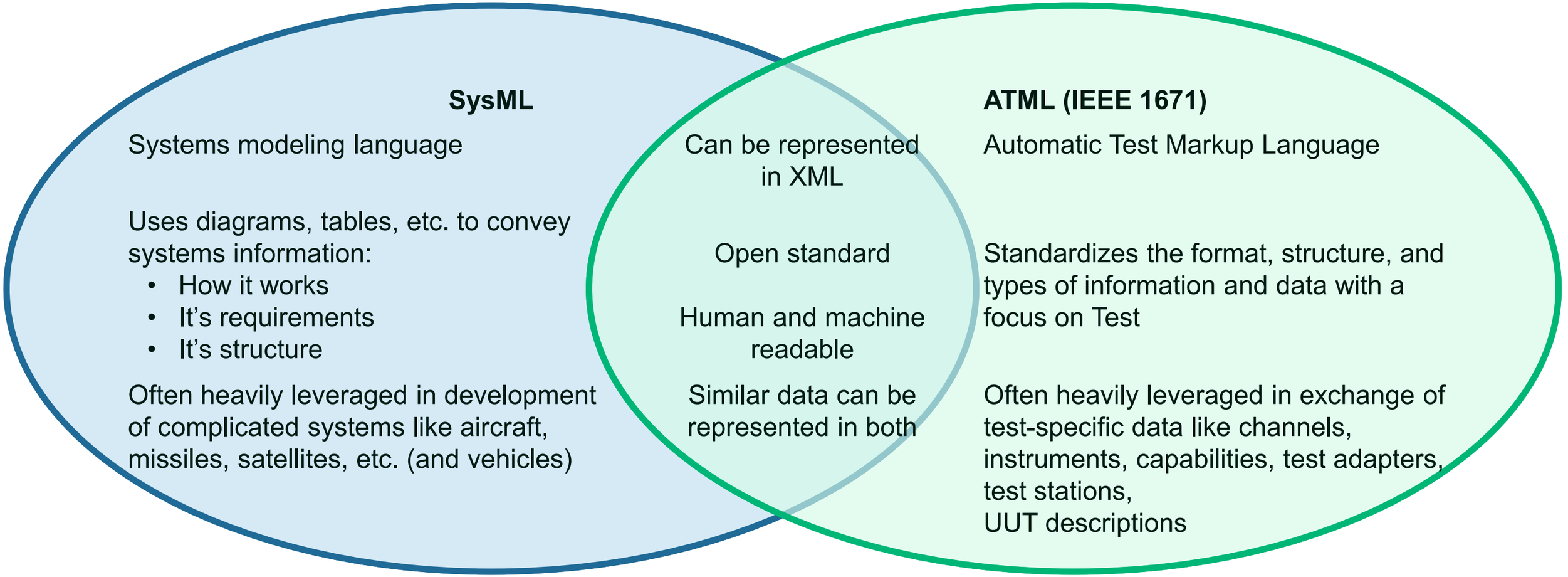
SysML & Automatic Test Markup Language (ATML)



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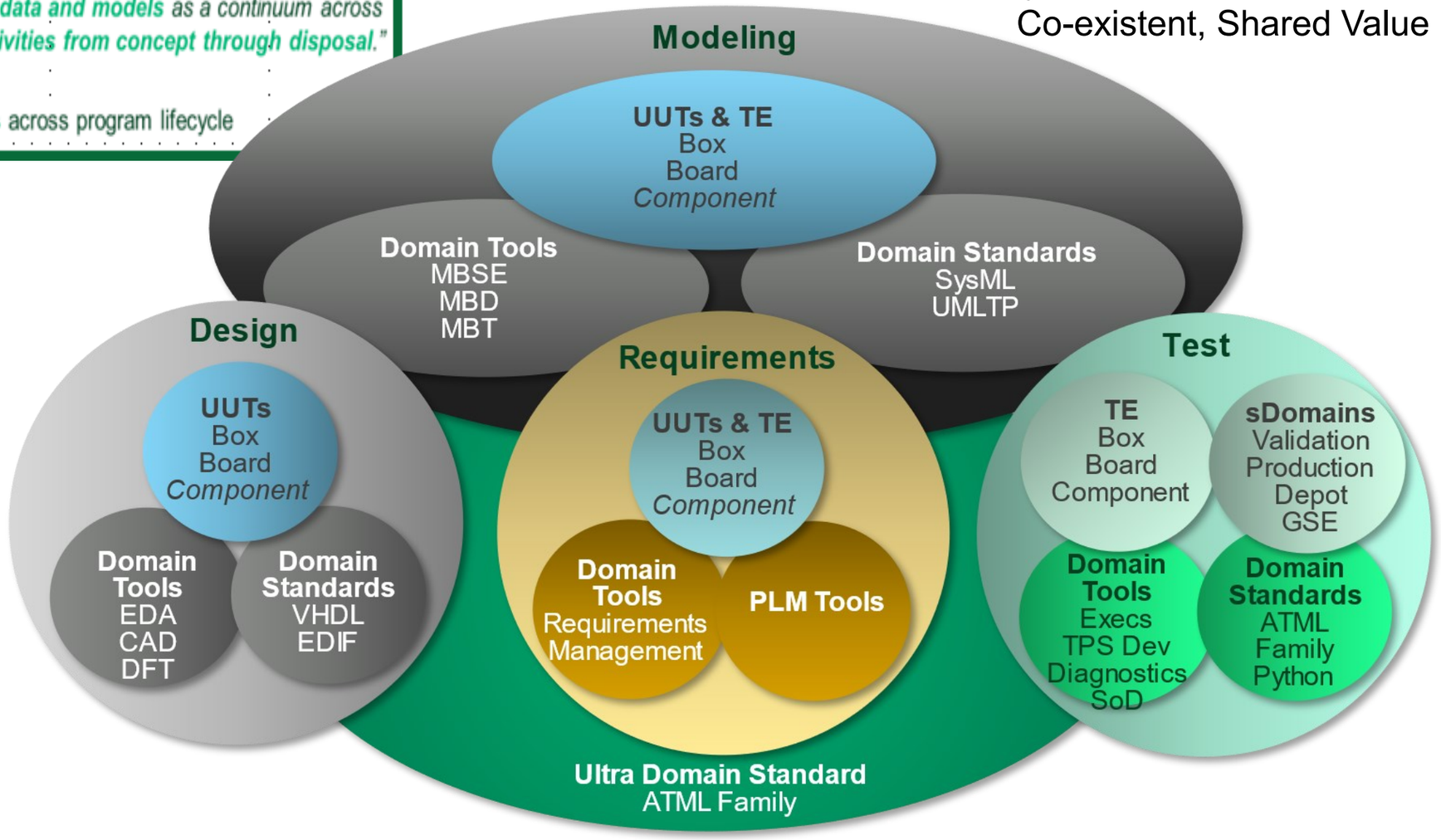
NI's Aerospace, Defense & Government Proposed Future

Defines Digital Engineering as an *"integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal."*

Emphasizes continuity of models across program lifecycle

Model-Based Systems & Model-Based Test Engineering
Co-existent, Shared Value



Domain Tools have proprietary formats, but import/export using standards is common

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Guiding Principles

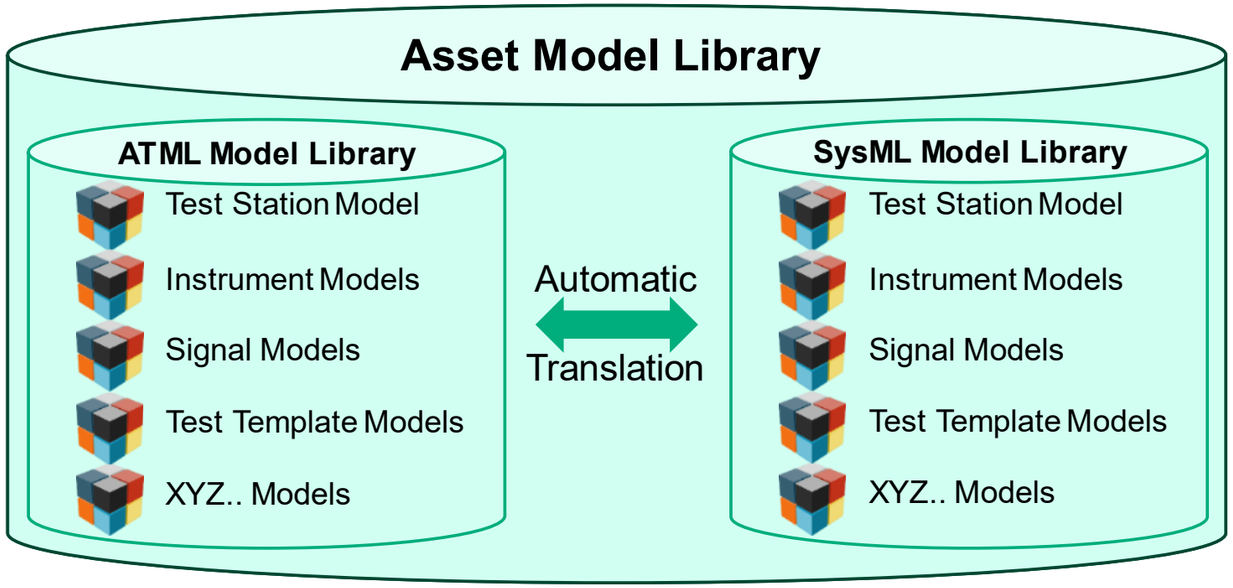
- Approach model development from a workflow-centric view
- Connectivity between ATML and SysML
- Models are used for information exchange and enable workflow automation
- Reasonable and straight-forward to modify in SysML
- Follow recommended practices for SysML v1 in Cameo
- Follow recommended practices for IEEE 1671 (ATML) and IEEE 1641
- Minimize test engineer’s use of SysML

Model Contents Driven by Needs of Specific Workflows

- Goal is to have only required information in SysML (Cameo v21) and not to replicate IEEE 1671/1641 in their entirety
  - Use references when possible, etc.
  - Ease of correlation and create/translate bi-directionally between SysML and ATML
- Each workflow will have its own requirements for model contents
- Models enrichen over time with required contents for all target workflows
- Some workflows of consideration:
  - Digital Acquisition
  - Test Requirements vs Capabilities Analysis
  - TPS Auto Generation
  - Test Equipment Definition and Design

Asset Model Library

- Base library is done in ATML and translated into SysML (Cameo today)
- Base library elements are complete ATML representations that can be used in multiple workflows and are SysML agnostic
- ATML models can be translated into SysML models based on the SysML Style Guide (or future profile / domain overlay v2)
  - Only necessary information for the specific workflow should be translated
- The libraries can become part of the digital thread for standardized usage, versioning, management, etc.
- Interoperable models of test equipment, instruments, test procedure sets, etc. can be provided by industry and others IF standardization is achieved



Standardization, Define Once, Interoperate, Reuse & Modify, etc.

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Model-Based Test Engineering Workflow Concept Demonstration: TPS Auto Generation from Authoritative Source of Truth (ASOT)

ASOT Models in SysML

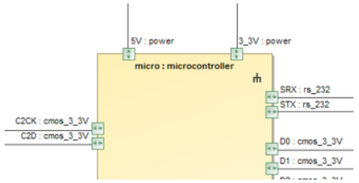
SPHEREA TECHNOLOGY

UUT

Test Requirements

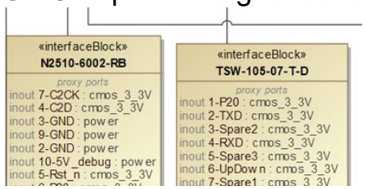
CAMEO SYSTEMS MODELER

UUT I/F & Components Level



UUT Pin Names
IEEE 1641 Signal Descriptions

UUT Component Signal Level

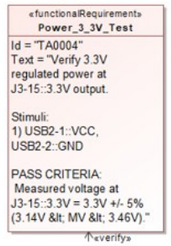


UUT Component Pin Names
IEEE 1641 Signal Descriptions

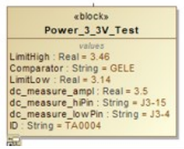
UUT Test Context

Traceable Test Requirements IDs

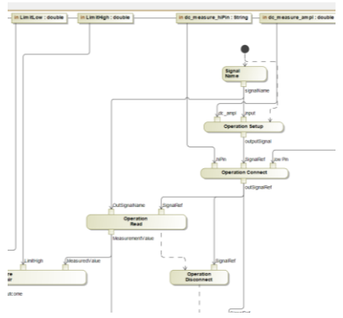
Test Requirements (Context)



Parameterized Test Templates Based on IEEE 1671.1 & 1641

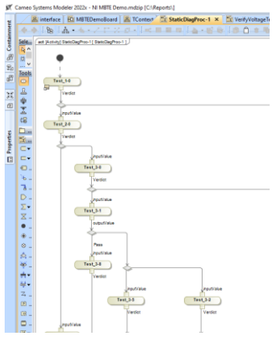


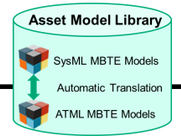
Parameterized Test Templates



1671.1 Test operations are used

UUT Fault Tree





Automated Test System (ATE) Generation

Automated Conversion to ATML Test (1671.1) and UUT (1671.3) Description Documents

ATML File Editors (ATMLPad)

NI ATMLToolkit (executable code generation)

Existing ATE HAL/MAL

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TestStand

TPS Running on ATE (Existing HAL/MAL)

"Back Annotate" Downstream Changes to ASOT

Shown at AutoTestCon 2023 in the NI Booth

- Proof of Concept Today
- Future Proof of Concept
- Existing Capabilities

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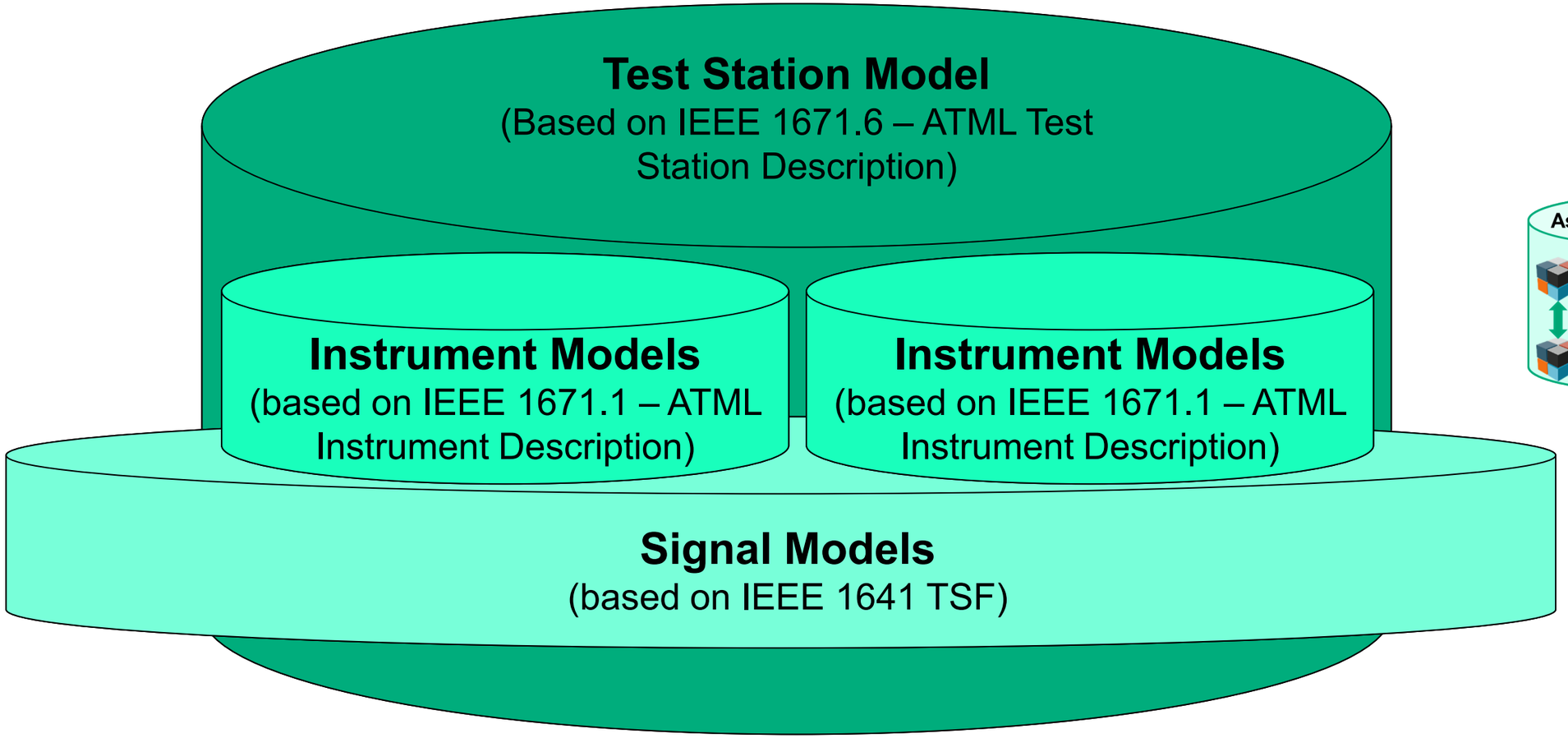
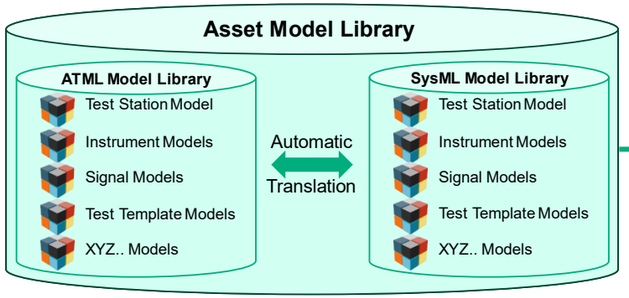
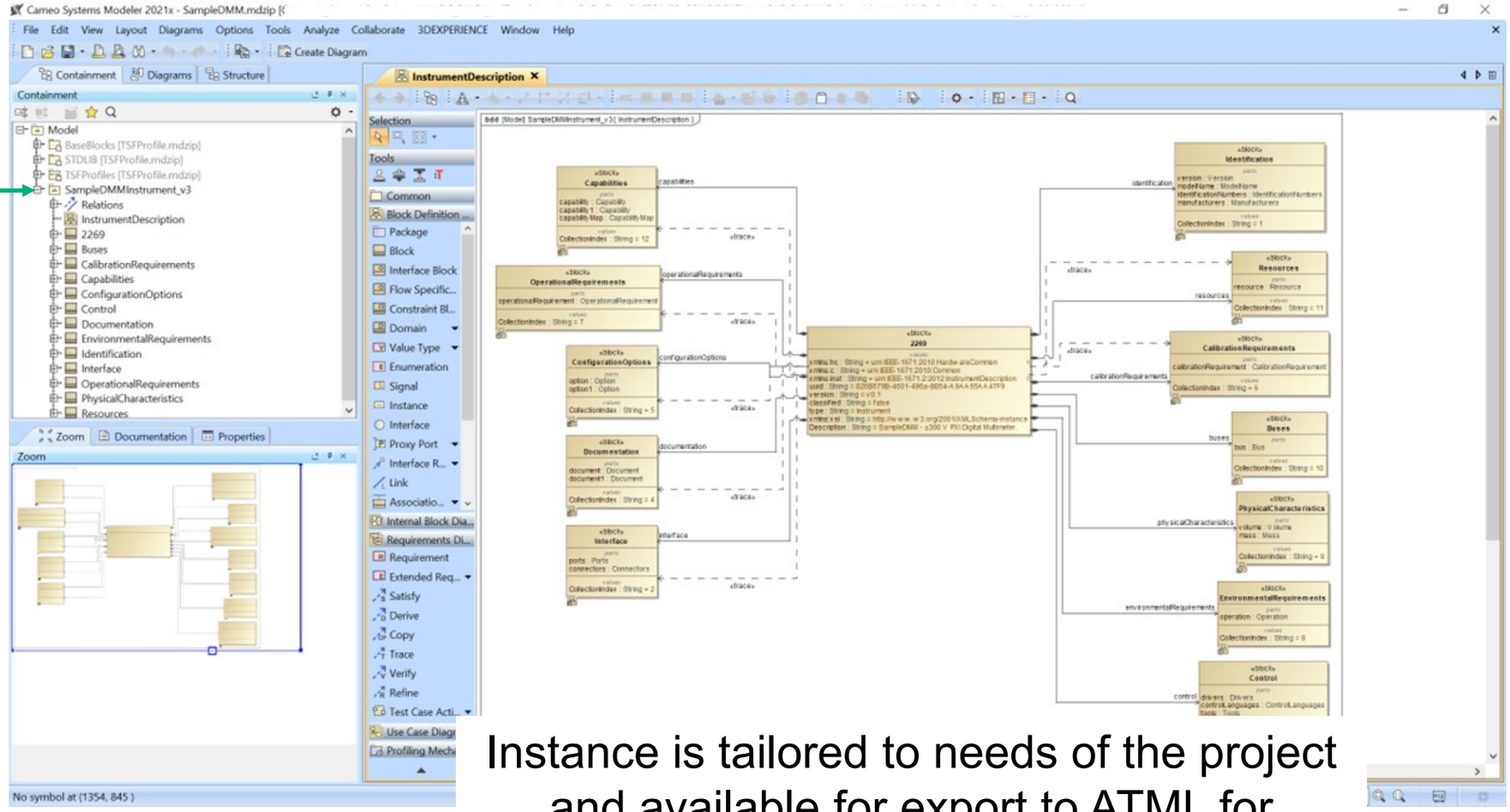
SysML Model Hierarchy



Using an ATML Model in Cameo v21

ATML Model Imported from Library





Instance is tailored to needs of the project and available for export to ATML for downstream usage

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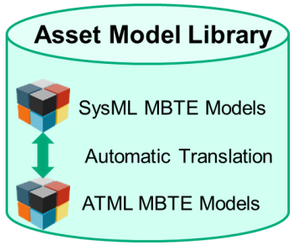
Connecting ATML to SysML v1

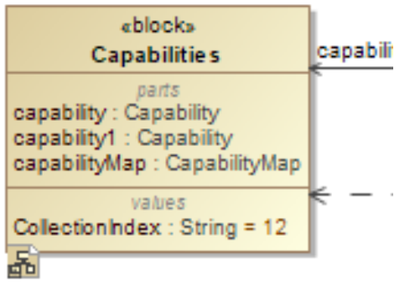
IEEE 1671.2
Instrument
Description

IEEE 1641
Signal & Test
Definition



Maps to The Part >
Block > Part > Block
v1 hierarchy

Instrument Capabilities Block



Part Properties
Value Properties hold the meta data

Instruments refer to signals using reference property

Instruments use Part > Block >…

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Standardization, Define Once and Reuse

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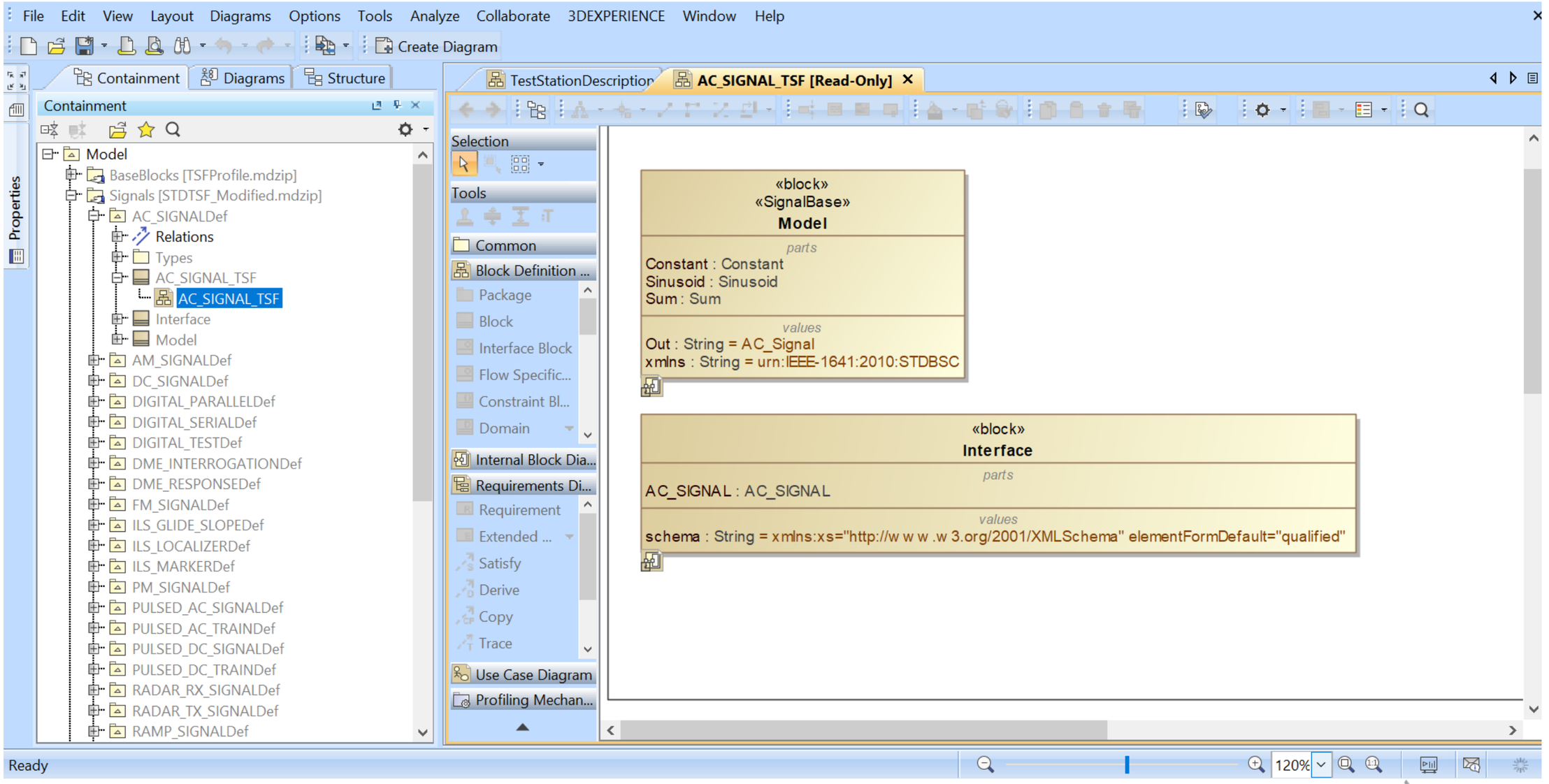
1641 Signal Models in Cameo v21

- **Uses IEEE 1641** - Signal and Test Definition standard
- **Signal Definitions:** Allows for the creation of signal definitions that can be used across various test platforms. These definitions are built upon formal mathematical specifications
- **Basic Signal Components (BSC):** These are the fundamental building blocks used to create more complex signals. They include elements like loads, impedances, and other signal properties
- **Test Signal Framework (TSF):** TSF is a library of signal components (BSCs) that can be combined to form complex signals.

- NI imported and exported the current IEEE 1641 TSF with Cameo v21
- IEEE 1641 signal models
  - Each Signal uses a TSF Signal block that has a BDD
  - Each Signal block describes the Model and the Interface to the Signal
- All TSF Signal blocks use a stereotype, “TSFBase”, as the block
- The Model block of the Signal uses a stereotype, “SignalBase”, as the block
- The Model block contains an Out Value property that identifies the Signal being generated

AC Signal TSF



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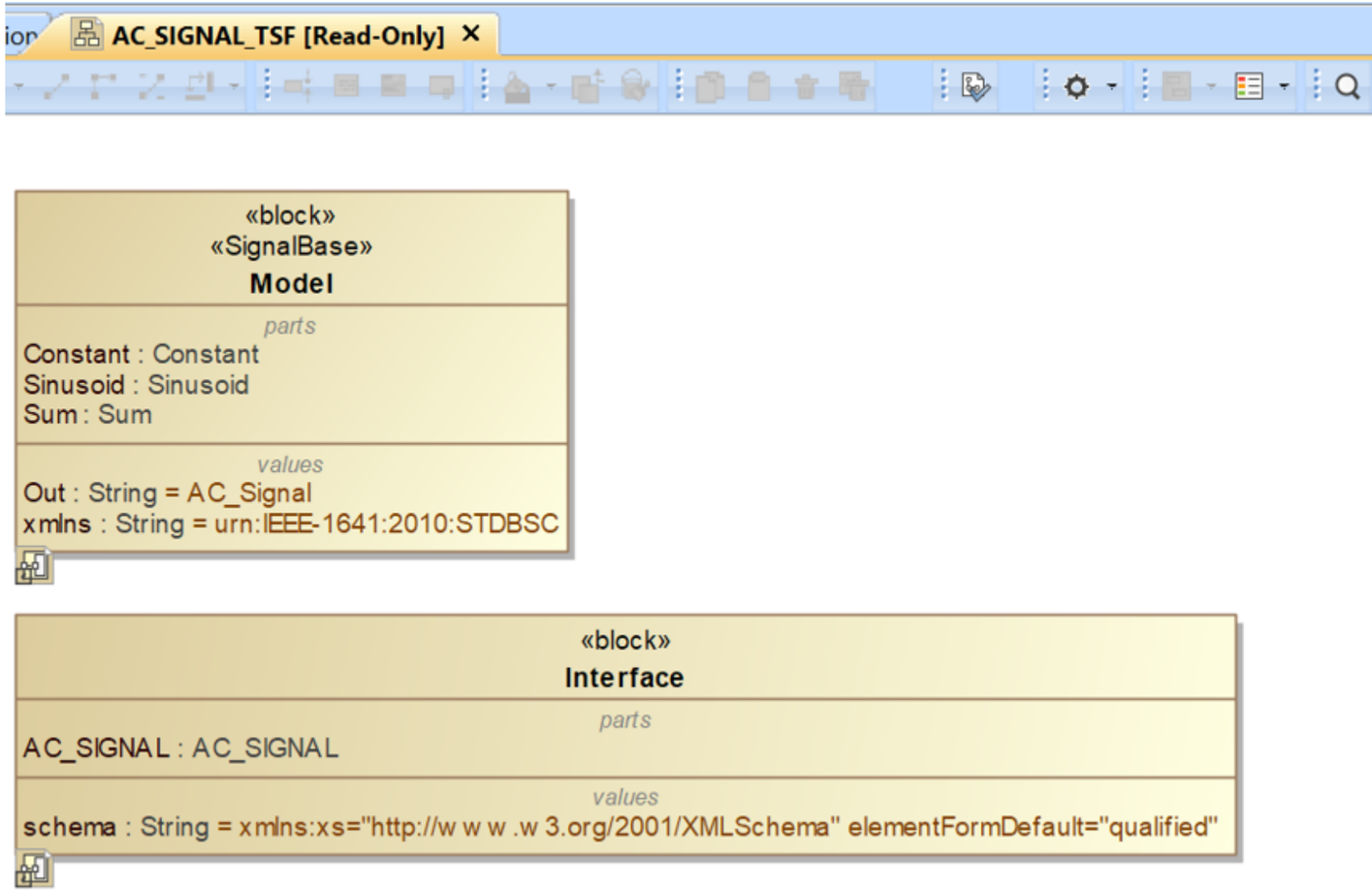
AC Signal TSF

- The Model block uses an IBD to describe the model
  - Blocks for each Part property of the Model
  - Each Part property Block uses Value properties to describe the various attributes of the Signal model
- The Interface block
  - Contains schema tag of the Interface block and the namespace of the signal
- The Interface block uses an IBD to describe the signal's interface
  - Part property Block in the IBD uses Value properties to describe attribute types and default values of the signal's interface
- All Signals contain a Package called Types that contains the definition of various Blocks used in the Model and Interface



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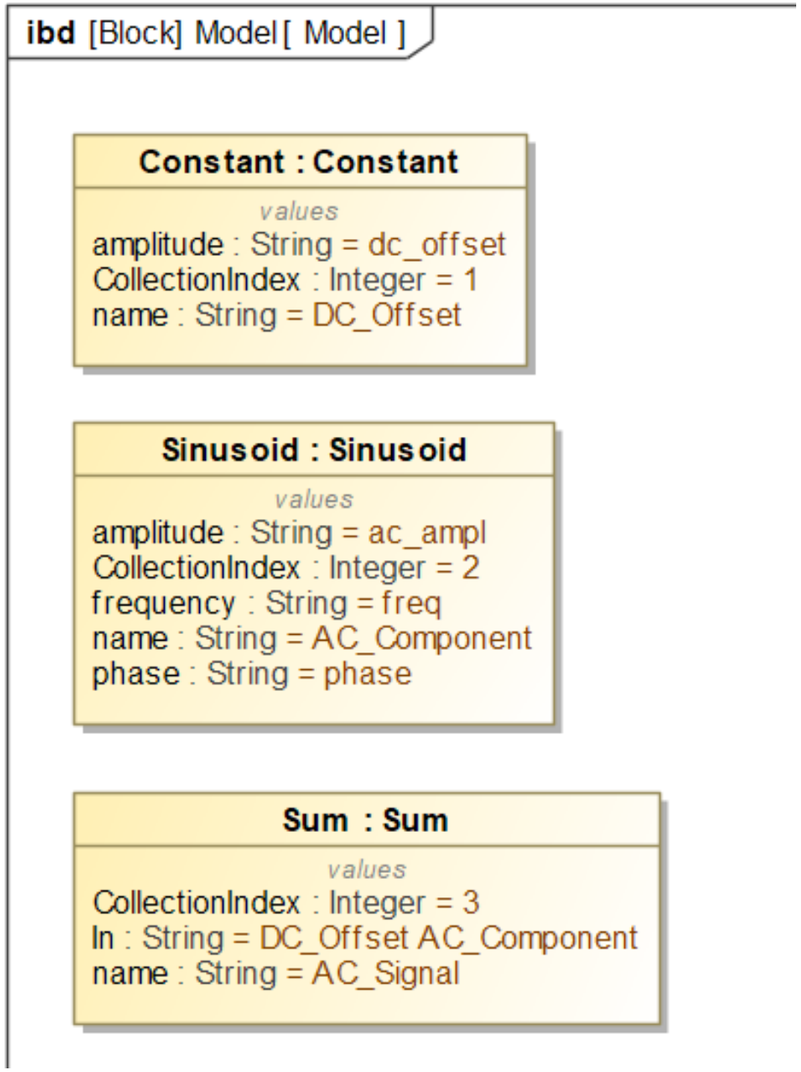
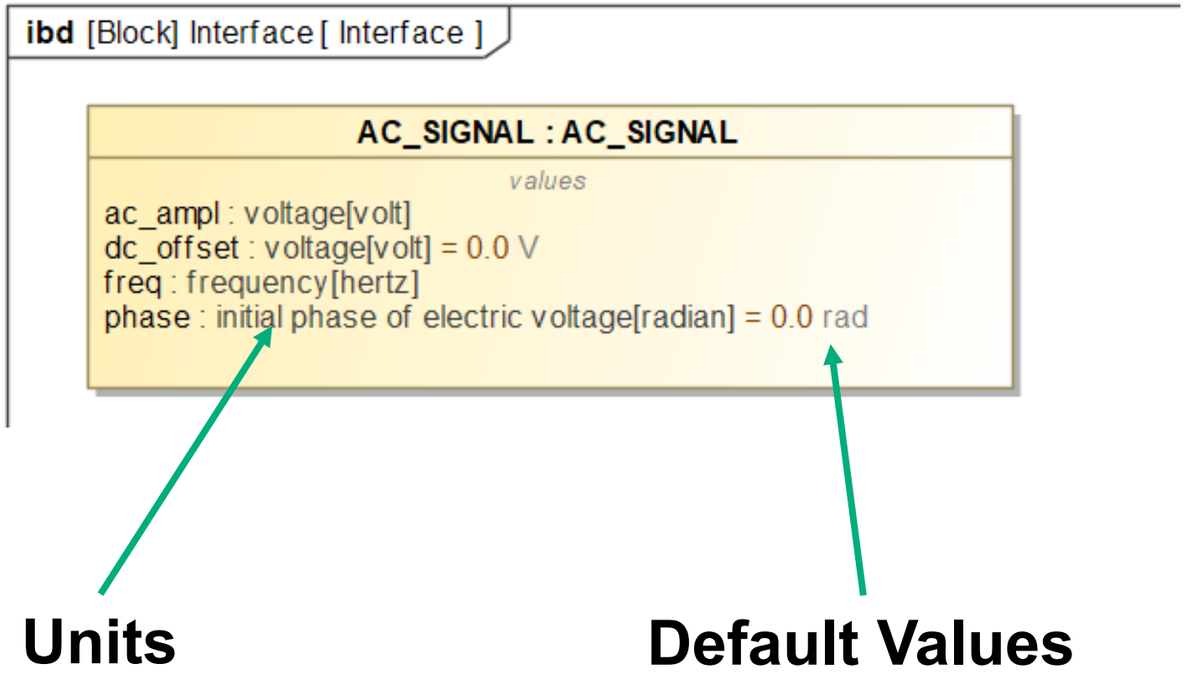
AC Signal TSF

Model Block



Interface Block



Units

Default Values

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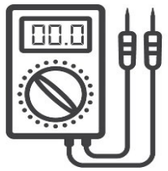
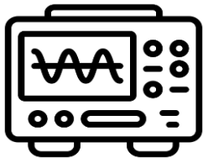
Generic Instrument Models

- Five models were developed

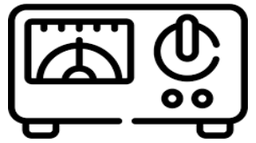


DMM

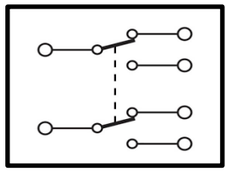


Scope

Waveform Generator



Programmable Power Supply



Switch Matrix

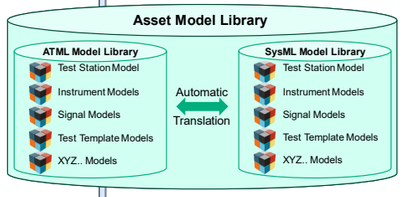
- Uses the Signal TSF by reference
- Models were developed as ATML XML files and imported into Cameo v21

ATML Instrument Model

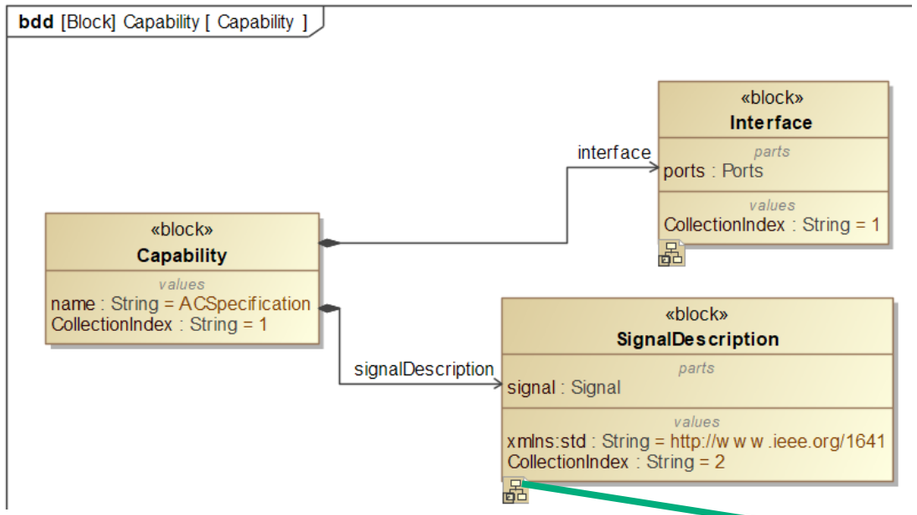
- Identification
- Interface (electrical)
- Components
  - Identification of the subassemblies
- Control
  - Control languages, drivers, extension, firmware, and tools
- Configuration Options
  - Options are values the user can modify, which will persist after a power cycle of the hardware item
- Factory Defaults
- Calibration Requirements
- Operational Requirements
- Environmental Requirements
- Power Requirement
- Physical Characteristics
  - Identification of the mass, volume, and measurements for the instrument
- Errors
- NetworkList
  - Ports on the hardware item are connected
- Buses
- Power On Defaults
- Paths
  - Identify the characteristics of the signal paths through the Instrument and interface hardware
- Specifications
- Resources
  - Physical entities within the instrument that provide source, sensor, or load capabilities.
- Switching
- Capabilities
  - Types of signals that an instrument can produce (or measure) and the uncertainties involved in either generating or producing the signals

Generic DMM Instrument – Cameo v21

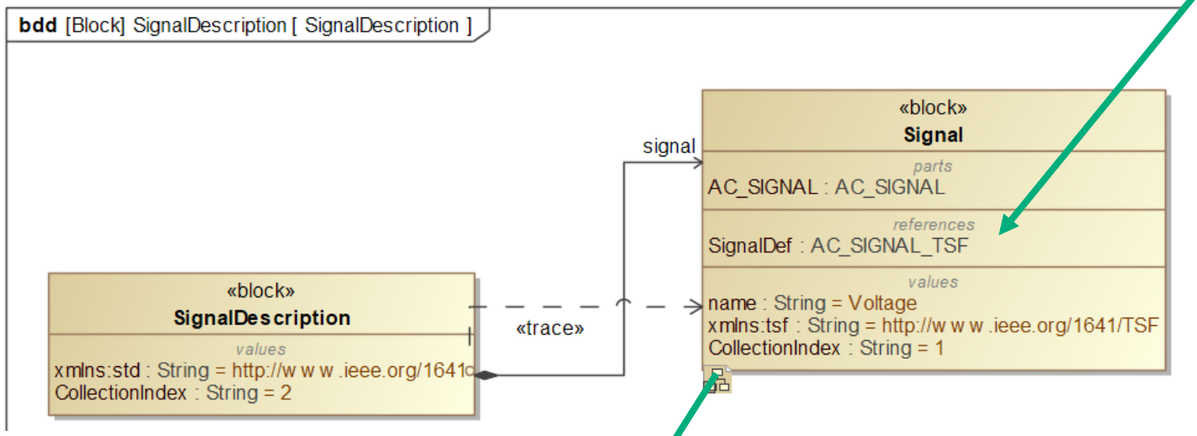
Instrument Model
Imported from Library



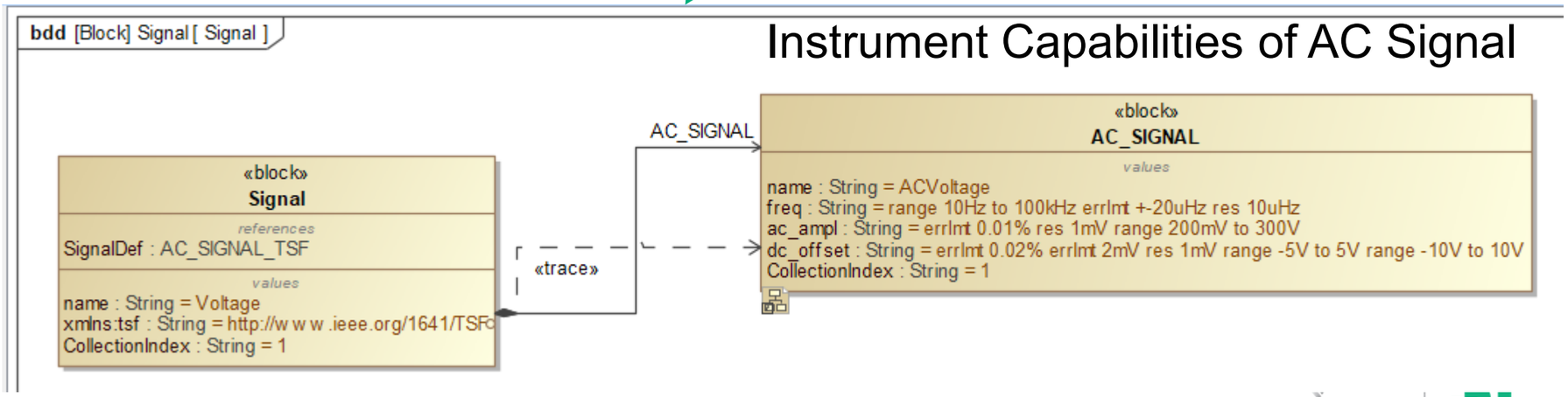
Instrument and Signal Connectivity



Reference to AC Signal TSF



Instrument Capabilities of AC Signal



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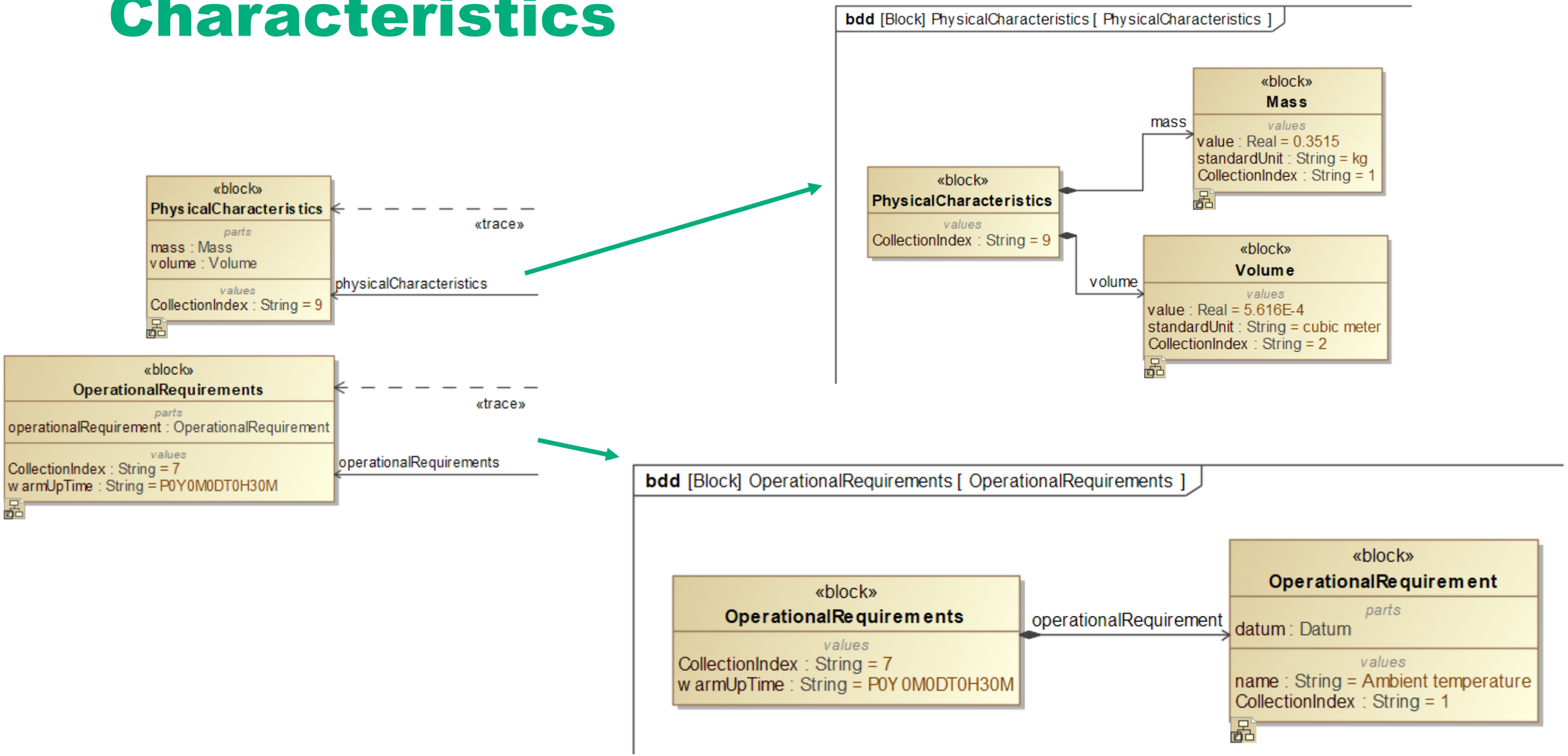
Operational Requirements and Physical Characteristics



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Generic Test Station Model – Cameo v21

- Test Station model contains a Block called “TestStationDescription” that contains all the information associated with a Test Station model

- Root block of the Test Station model models all elements using Part and Value properties
- All namespaces defined in the IEEE 1671 XML definition of the Test Station model are stored using Value properties
  - Used to define “Traced From” properties of all children elements of the model

- Test Station model references imported IEEE 1641 TSF and Instruments

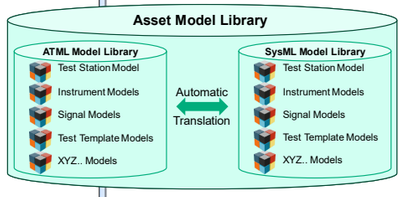
- All other attributes associated with the Test Station model are stored as Value properties of the Root block

- The model refers to other Signal models using Reference property to refer to the imported Signal Model
  - The properties of the Signal Interface can be be modified using the type as defined in the Signal model

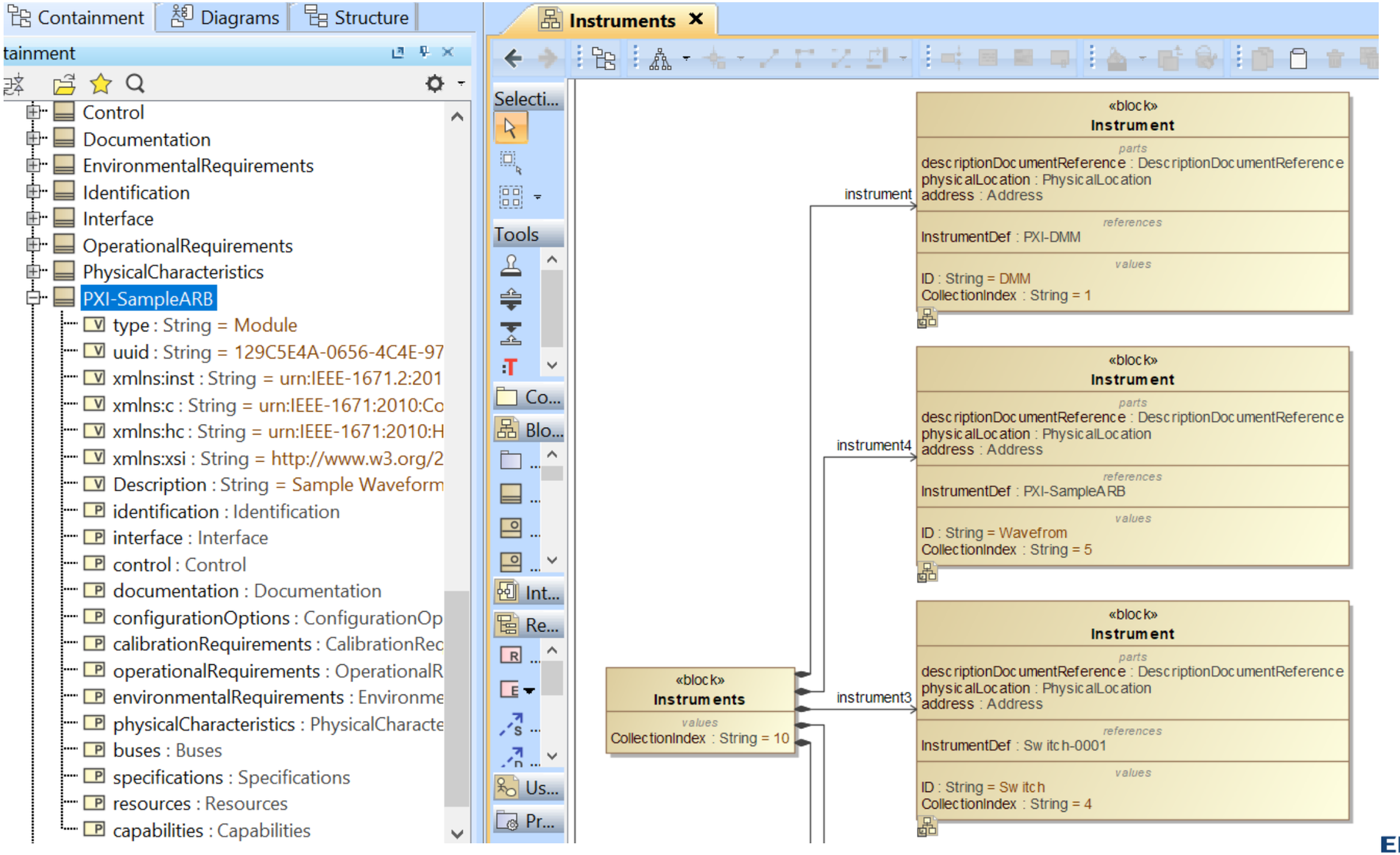
- The model refers to other Instrument models using Reference property to refer to the imported Instrument Model

Generic DMM Instrument – Cameo v21

Instrument Model
Imported from Library



Instrument References



DMM

Waveform Generator

Switch Matrix

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Model Verification

- Requires both ATML and SysML related verification
- Validates the model against
  - SysML style guidelines
  - ATML standard
  - Style Guide
- Can be enhanced to add custom rules

Initial Style Guide Draft

- Describes how various components of an Automatic Test System (ATS) can be modeled using Cameo and SysML profilers provided by National Instruments that adheres IEEE 1671 and IEEE 1641 standards
- Can also be used as a manual guide to validate the model
- Assumes the reader is familiar with concepts related to Cameo, MBSE, SysML, IEEE 1671 (ATML) Standards, IEEE 1641 standard, ATS
- Does not document standard Cameo and MBSE best practices
- Is a guide for modelers and not a step-by-step instruction set to create/validate the model
- It is meant to be a supporting document for Cameo models, IEEE 1671 and 1641 XML documents that were created as part of the Task Order

- Note: This style guide represents an initial release and feedback is welcomed

ATSSI II Task Order MBTE ATS Architecture Result

- Initial way to standardize how Automated Test Systems are modeled
- Five generic instruments and a generic test station model
- Standardized generic ATML & SysML models as building blocks

- SysML models based on the ATML family of standards
- Demonstrated bi-directional translation
- Foundation for further work has been established

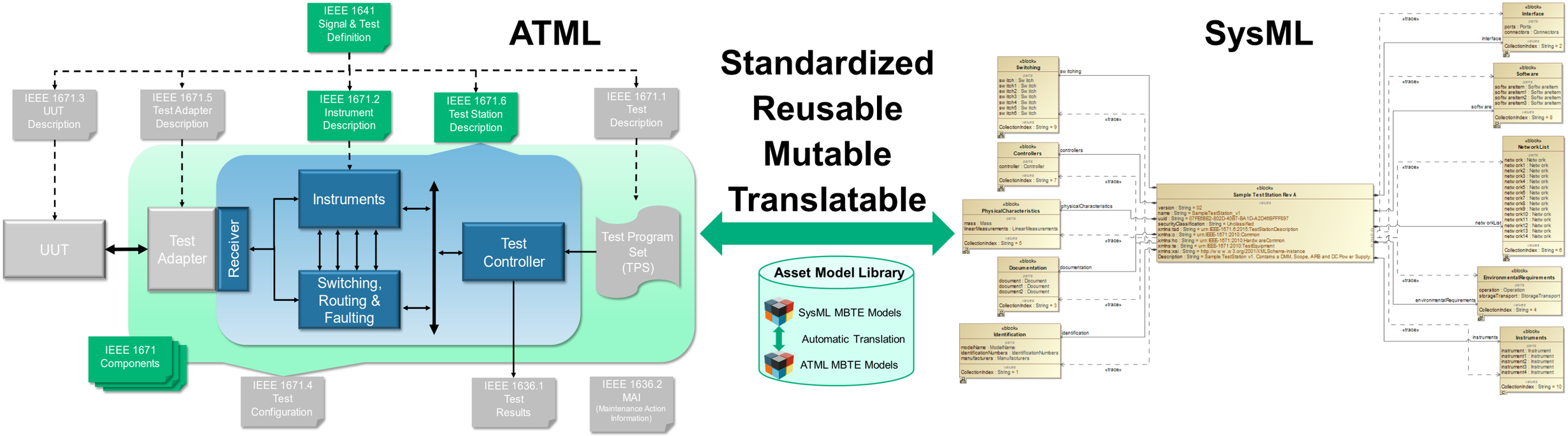

Figure based on presentation given by Mike Malesich (2022, August 30). *DoD ATS Framework IPT Relation to Digital Thread* [Conference panel presentation]. AUTOESTCON 2022, National Harbor, Maryland, United States.

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Some Key Learnings and Challenges

- Use newer versions of Cameo (faster, many quirks addressed)
- Models need to be approached from the target workflow perspective
- Only put as much ATML in the SysML models as needed for the target workflow
- No predefined and limited previous workflow approaches to build from – exploring new territory
- SysML v2 is on the horizon…

Path to Model-Based Test Engineering

Current State

Target State

Manual Test Engineering
- Repetitive
- Time and resource intensive
- Error-prone
- Limited knowledge capture
- High risk over time

Automated Test Engineering
- Repeatability
- Improved time saving
- Resource intensive
- Limited knowledge capture
- High risk over time

Standard Interfaces & Test
- Reduction to standard interfaces
- Hardware and Measurement Abstraction Layers
- Test templates defined
- Increased knowledge capture

Auto-Generation
- Standardized test software
- Standardized test systems
- Improved time saving
- Improved resource utilization
- Based on Style Guide

Model-Based Test Engineering
- Models as Source of truth
- Knowledge capture
- Downstream test is autogenerated and/or derived
- Lowest risk over time
- Decision Support System/ Test Capabilities Analysis

Standards to be used
- IEEE 1671/1641 – ATML
- Standardized UUT signal types
- Standardized test templates
- HAL/MAL implementation
- Standardized Style Guide

Workflow Automation
- Auto test code generation
  - Supports rapid, iterative development
- Auto test system generation
  - Supports UUT requirements change rapid response

Full MBTE Implementation
- Models are Source of Truth
- Test Requirements are negotiated between SE, DE and TE
- Knowledge is immortalized for program life

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Next Steps

A lot of work still to be done

- Wider participation in the standardization efforts by industry and government
- Style Guide…
- More use cases and workflows to explore
- Specific instrument models
- Further definition of the test station model
- Specific test station models
- And the list goes on…

MBTE future is so bright, we gotta wear shades

Let's make test engineering cool for the upcoming generation

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Call for Participation

- To achieve standardization on the models wider DoD & industry participation is needed
- NI is looking into how to make these models (ATML and SysML as Cameo v21 files) and initial draft style guide available
- Potential collaborations
  - Direct engagements
    - Contact tim.stanley@caci.com or greg.brown@ni.com
  - IEEE SSC20 study Group on “ATML compatible representation in SysML of test requirements“
    - Contact ion.neag@restonsoftware.com
  - OMG SysML V2 Digital Acquisition Managed Community
    - Started operation Sept, 2023
  - OMG SysML v2 System Modeling Managed Community for Validation
    - Under definition
  - Contact greg.brown@ni.com if you would like to be kept up to date on the models & style guide availability and/or the OMG SysML managed communities working groups

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