34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

MBSE Methodology, Digital Engineering Ecosystem & System Architecture Modelling using SysML v2

Presenter

Pranjal Sharma, Ansys

- Pranjal is working as a Senior Application Engineer in Ansys
- As a part of APAC MBE Team, he looks after MBSE activities and has gained experience in Aerospace & Defense (A&D), Automobiles, Electronics, Hi-Tech & advanced technology domains.
- His current role focuses to facilitate implementation of MBSE, enablement of Virtual Product Development, Process Integration & Design Optimization workflow for the customers.
- Pranjal have graduated from National Institute of Technology, Nagpur
- Pranjal has six years of System Engineering experience, where:

  - In Ansys: Have cross product knowledge & experience of Ansys's MBSE Ecosystem with expertise in ModelCenter and Ansys SAM.

  - Prior to Ansys: Have worked on diverse set of powerplant systems including Fuel Gas & Oil Systems, Cooling Systems, HVAC Systems, and Compressed Air & Gas Systems, and engineered equipment like Gas & Steam Turbines, IC Engines, Compressors, Pumps & Heat Exchangers.

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Co-Author

Bernard Dion (Ph.D.), Ansys

Over 40 years in Systems and Embedded Software Engineering

- B.Sc. In Electrical Engineering (Ecole Centrale de Lyon)
- M.Sc. and Ph.D. in Computer Sciences (UW Madison)
- 10+ years as a Professor in Systems and Software Engineering
- Co-founder and CTO Esterel Technologies (SCADE)
- Model-Based Systems and Software Engineering
- Expert in Certification of Critical Systems (Secretary, Tools Qualification / DO-178C)
- SAE G34 Working Group for Certification of AI/ML in Aviation
- Model-Based Methodology Creation and Handbook Creation (20 years)

Supported all corners of the Aerospace, Railways, Nuclear Industries

- Government: FAA | EASA | US Army | CEA | …
- OEMs: Northrop Grumman | Boeing | Airbus | Embraer | COMAC | Alstom | Dassault Aviation | …
- Suppliers: GE | Rolls-Royce | Safran | Thales | Honeywell |

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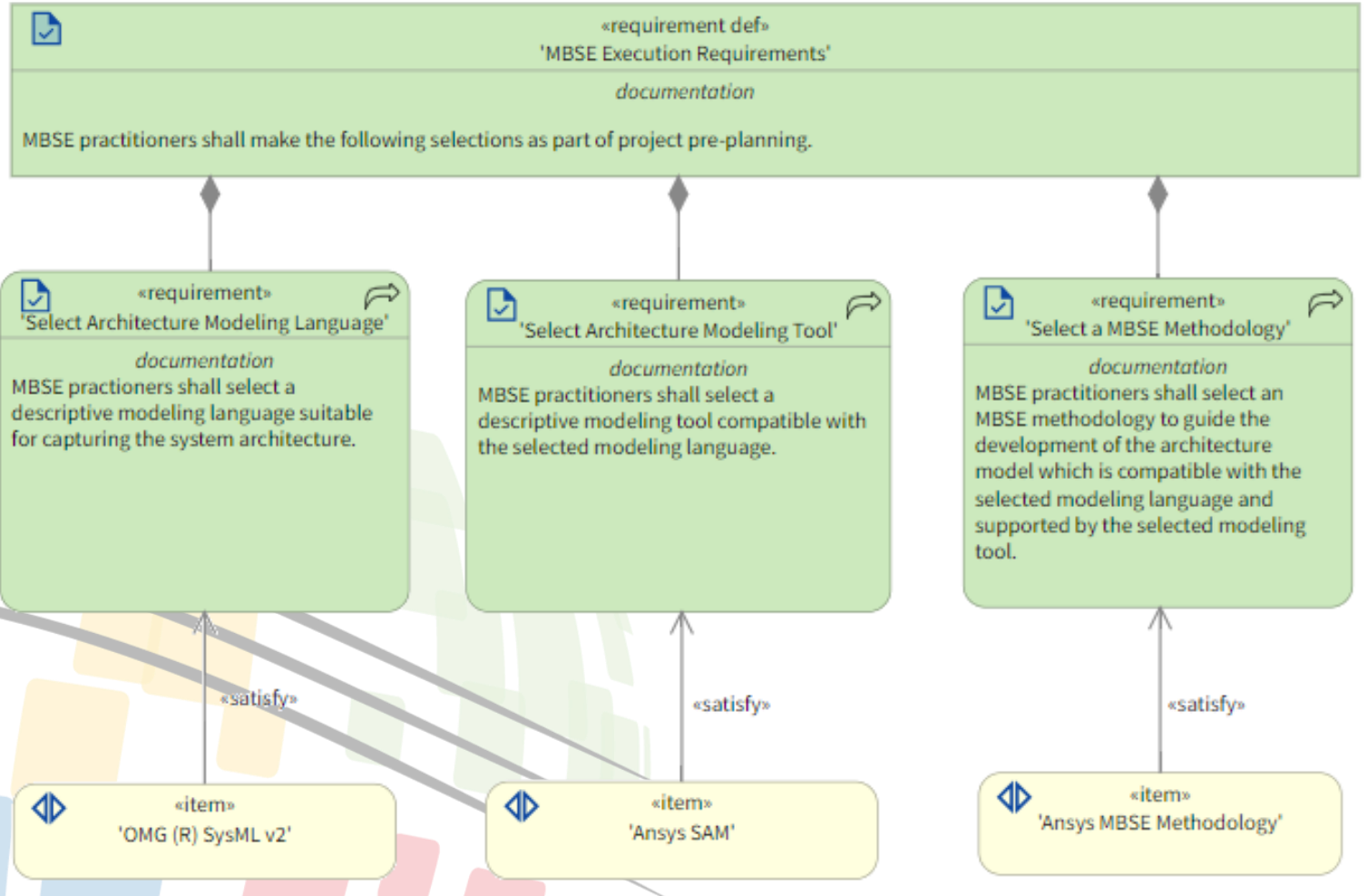
Content

- Overview of the devised MBSE Methodolgy
- Digital Engineering Environnement supporting MBSE Workflow
- MBSE Workflow Implemented
- Defining Design Reference Mission
- System Architecture Modeling using SysML v2
- Capturing System Requirements & System Structure
- Building-up Analytical Workflow
- Connecting Analytical Workflow to System Architecture Model
- Performing Trade Study and Requirements Verification

The (SysML v2 ®) MBSE Methodology

The Three Requirements for Doing MBSE Effectively



Our MBSE Methodology

Technical Management

Support & Oversee System Engineering Process

Plan
- *Technical Activities*

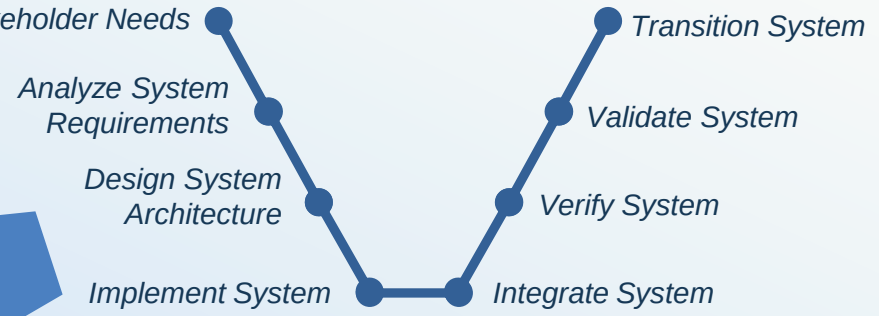
Manage
- *Requirements*
- *Interfaces*
- *Data*
- *Risks*

Support
- *Technical Assessments*
- *Decision Analysis*

Ensure
- *Configuration Management Compliance*

System Development

Virtually develop the system from requirements to validation



Digital Engineering

Implement processes to build digital thread

- *Formalize Development, Integration and use of Model*
- *Provide an ASoT*
- *Establish Infrastructure & Environment*
- *Incorporate Technical Innovation*
- *Transform Culture and Workforce*

System Architecture Analysis

Perform all-round system analysis

- *Analyze System Performance through Simulation*
  - *Perform Static Simulation*
  - *Perform Time-Based Simulation*
- *Ensure System Compliance*
  - *Analyze Requirements*
  - *Analyze Safety*
  - *Analyze Cybersecurity*
- Analyze System Software
  - Verify System Software Design
  - Generate System Software Code

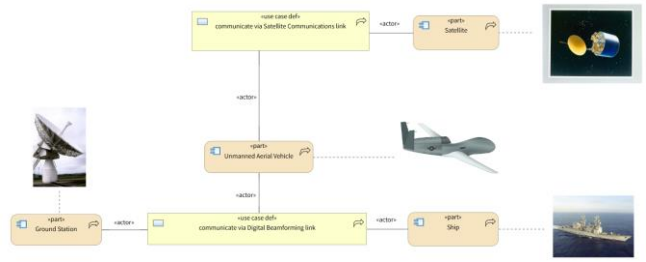
Supporting

Digital Engineering Environment

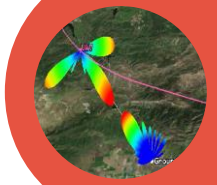
Digital Engineering Environment

Use Case

- ❑ A UAV is deployed for surveillance purpose and communicates with a satellite, a ground station & a ship.
- ❑ Select the best UAV phased array antenna that will ensure adequate link margin during the communication between the UAV & the ground station.
- ❑ Develop MBSE workflow to verify System requirements through trade study on antenna design configurations & selecting best concept Antenna design using DRM.



1. Mission Analysis Tool
   Ansys STK
2. System Architecture Modeler using SysML v2
   Ansys SAM
3. MBSE Orchestrator
   Ansys ModelCenter



Setting-up Design Reference Mission

- Scenario Creation
- Antenna Signal Characteristics computation

Creating System Architecture Model

- Capturing System requirements from DRM
- Modeling System Structure

Analyzing System Architecture Model

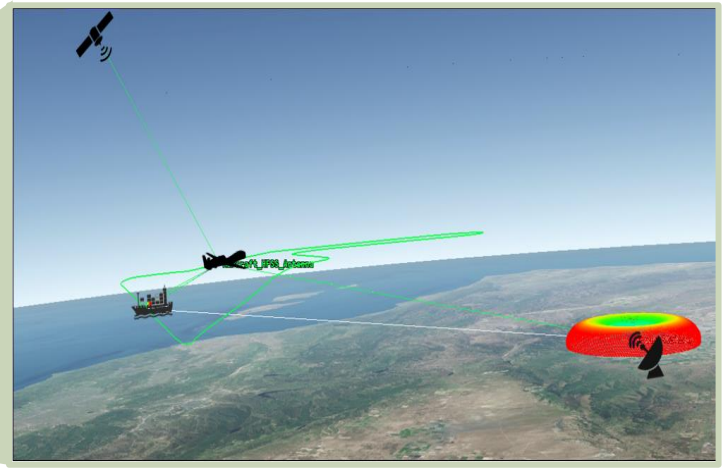
- Integrating SAM with Analytical Workflow
- Performing Trade Study
- Verifying Requirements

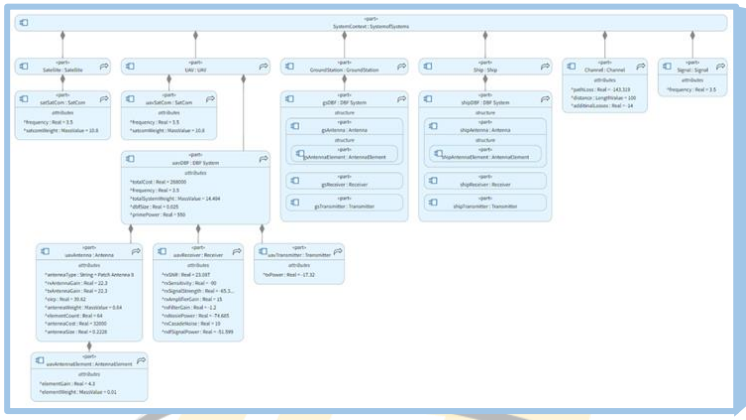
Implemented

MBSE Workflow

MBSE Workflow

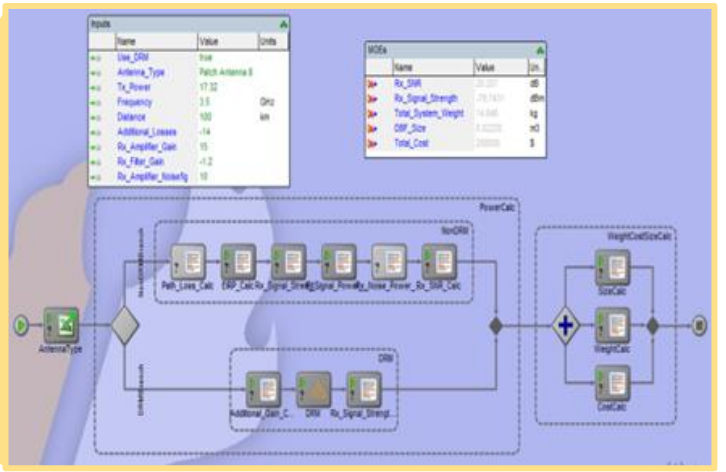
Design Reference Mission

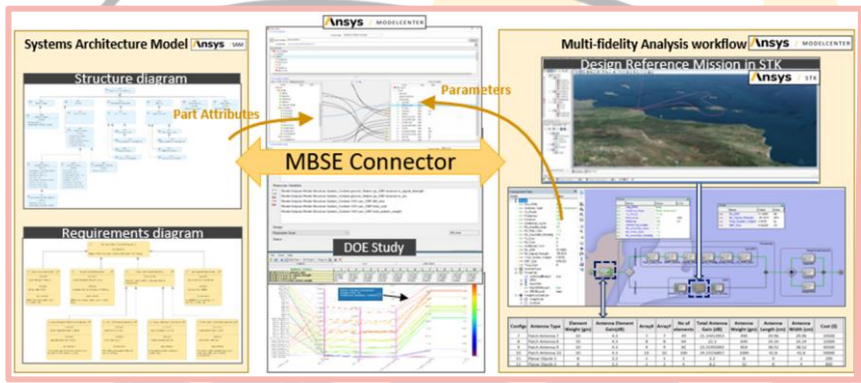




System Architecture Model

Analytical Workflow





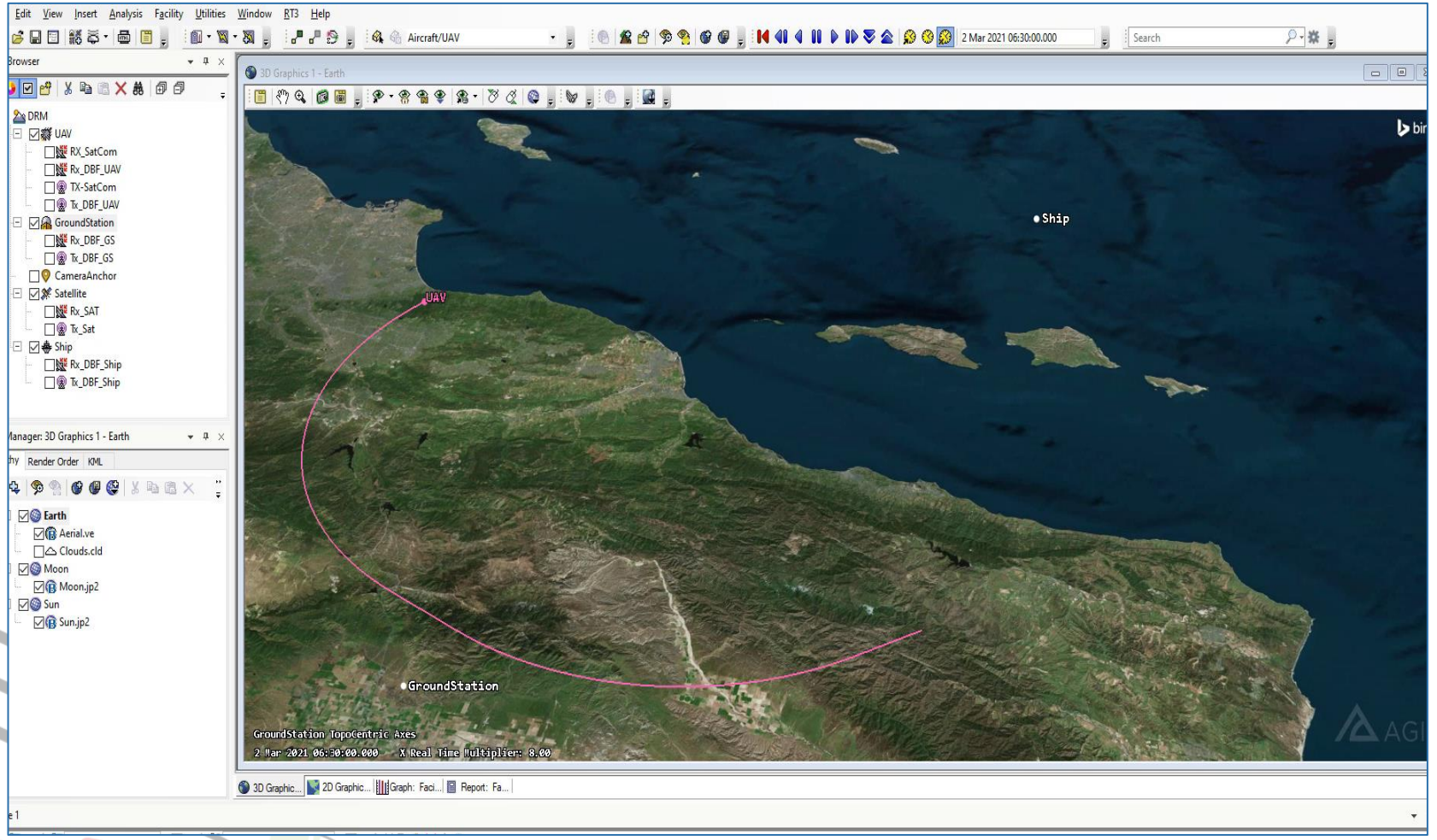
Trade Study & Req. Verification

Defining

Design Reference Mission

Defining Design Reference Mission

- A UAV is deployed for surveillance purpose and communicates with a satellite, a ground station & a ship
- Developed System of system scenario with UAV, Ground Station, Ship & Satellite
- A phased array antenna at the UAV communicate with the Ground station and the Ship
- Separate Satcom communicates with the satellite
- Project Scope: DBF transmitter and its interaction with the Ship & the Ground station DBF receivers



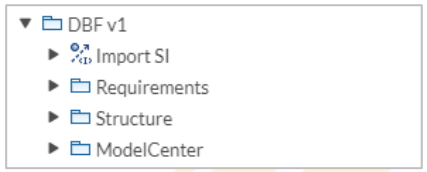
System Architecture Modeling

Using SysML V2

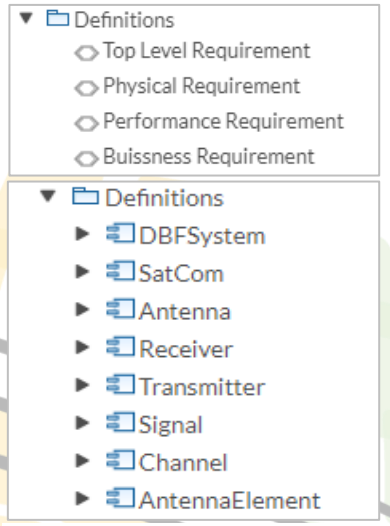
System Architecture Model using SysML v2

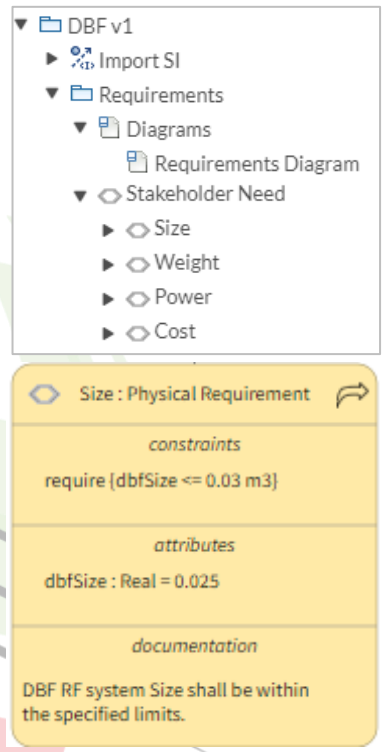
Approach followed

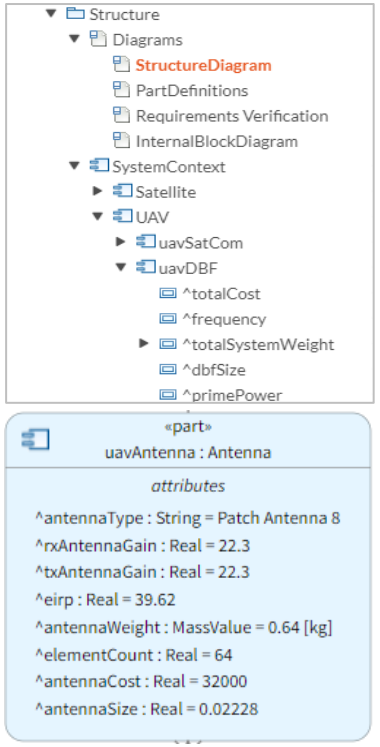
Defined Packages & Imported Libraries → *Created Element Definitions* → *Created Requirements Diagram* → *Created System Structure* → *Created Internal Block Diagram*

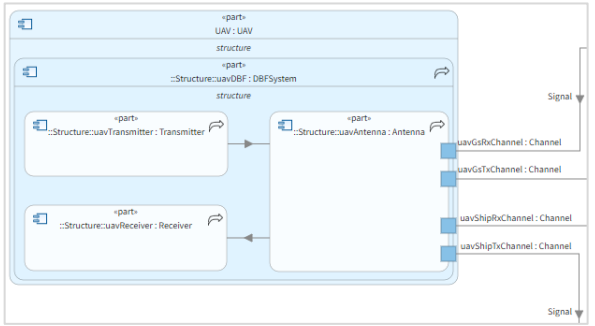


Standard Library for SI Units available within the tool is imported









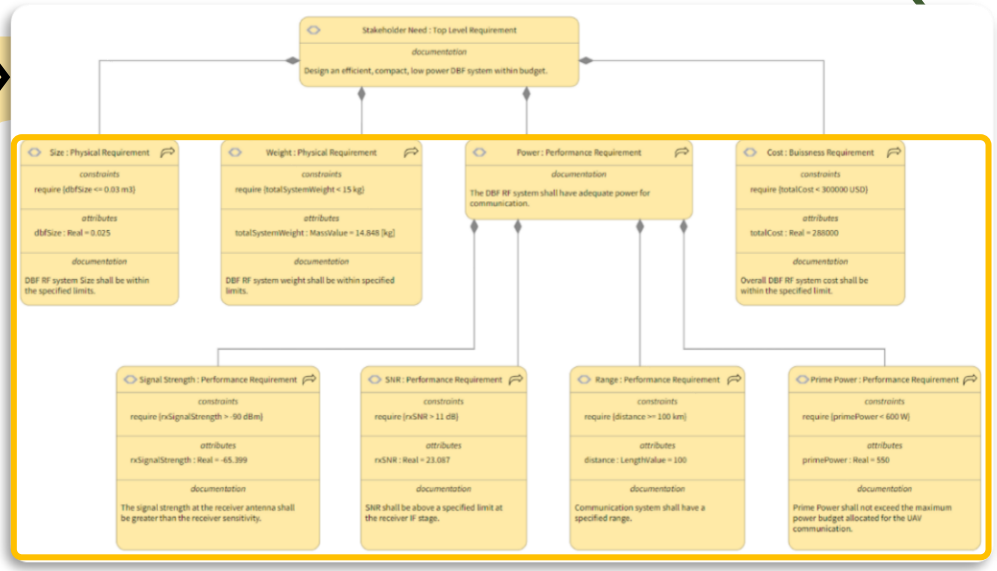
Capturing

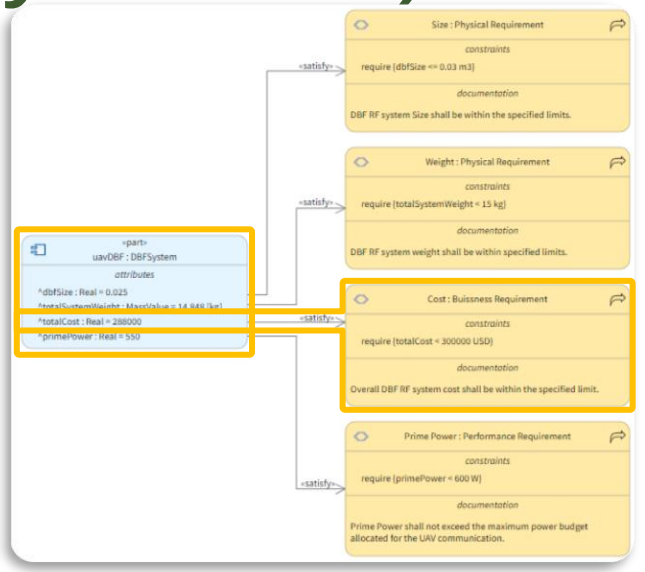
System Requirements & Structure

System Requirements & Structure (SysML v2)

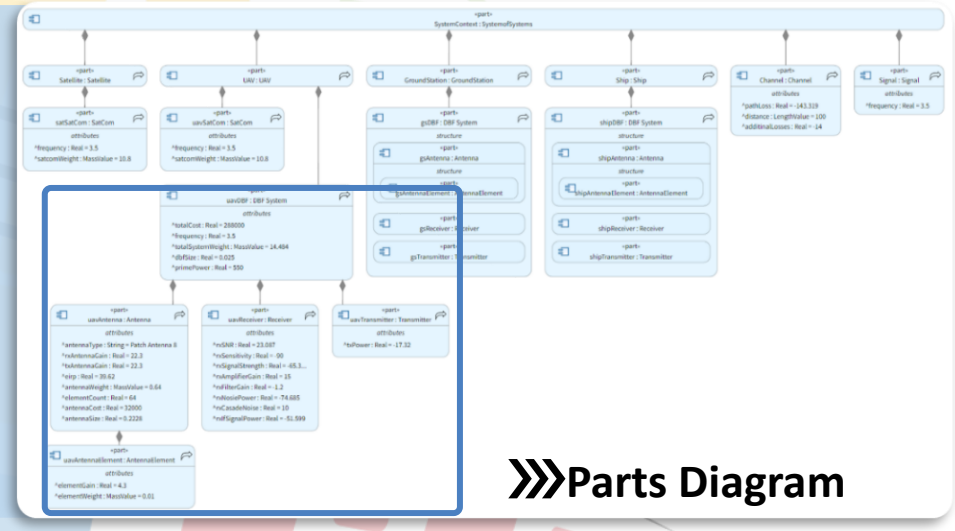
Requirements Diagram »»

- DBF system requirements are derived based on Design Reference Mission (DRM)
- System Requirements are decomposed to Size, Weight, Power and Cost Constraints
- System Parts responsible for fulfilling the requirements are identified
- Part Attributes satisfying the requirement constraints are marked through 'satisfy' relationship



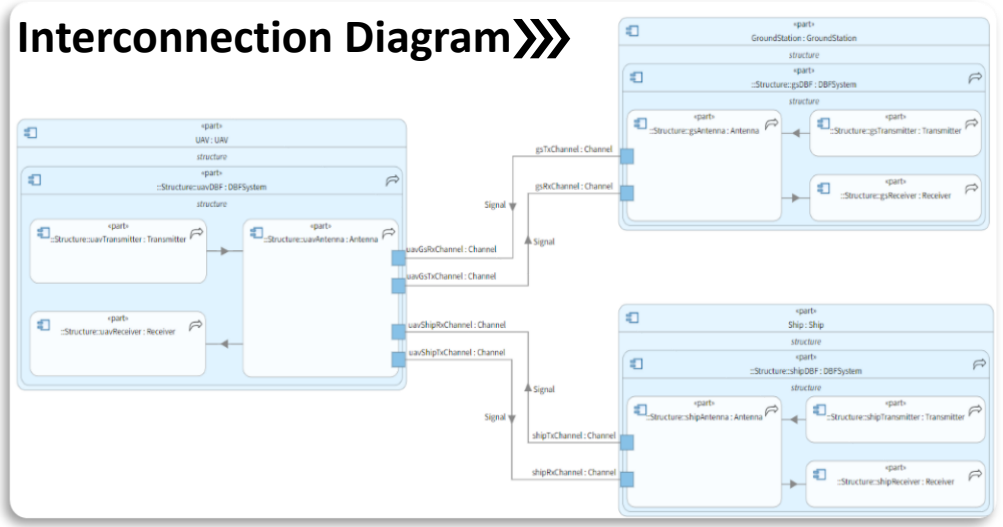


- Structure (Parts) diagram represents a detailed hierarchical structure of the DBF system
- Key attributes were defined for each part
- Interconnection Diagram represents the connection & item flow between the system parts



»»Parts Diagram

Interconnection Diagram»»



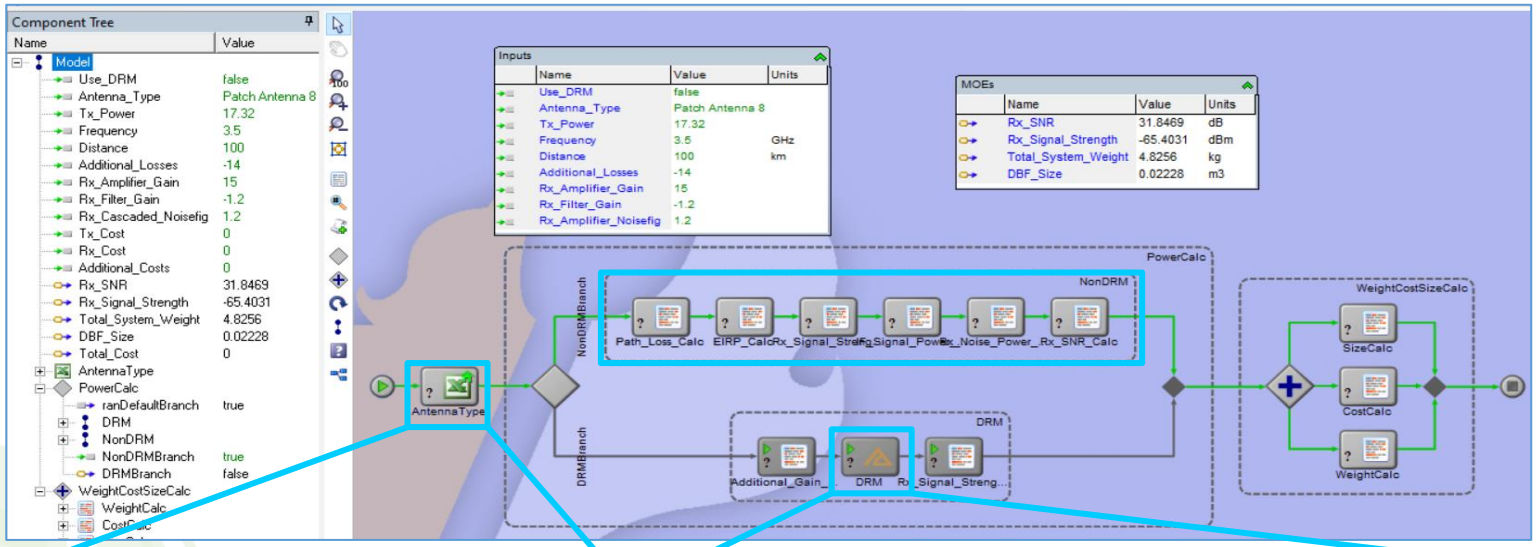
Building-up

Analytical Workflow

Analytical Workflow

➢ A multi-fidelity analysis workflow is developed to calculate the Measure of Effectiveness (MOEs) like Receiver's signal strength, SNR, Weight, Size & Cost.

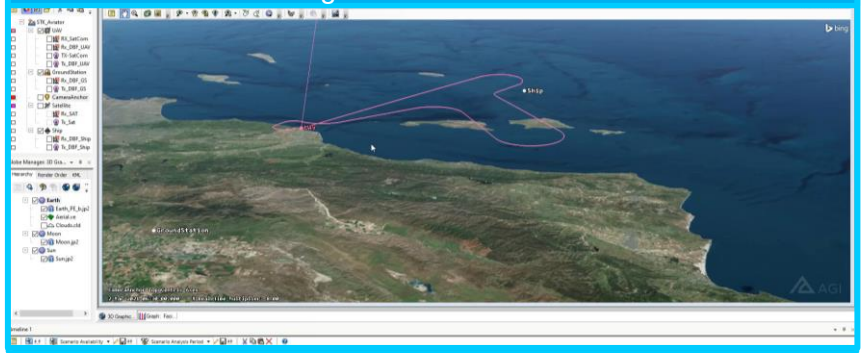
- Low fidelity workflow is developed based on set of canonical equations
- High fidelity workflow is developed using Mission Analysis Tool
- Varied different antenna configurations using in-built Excel Plugin
- Non-DRM workflow:
  - Canonical equations are used to develop Non-DRM analysis workflow
- DRM workflow:
  - Mission Scenario is utilized in DRM analysis workflow
- Outputs calculation done for Receiver's signal strength, SNR, Weight, Size & Cost.



Antenna Configurations in Excel

Configs	Antenna Type	Element Weight (gm)	Antenna Element Gain(dB)	ArrayX	ArrayY	No of elements	Total Antenna Gain (dB)	Antenna Weight (gm)	Antenna Length (cm)	Antenna Width (cm)	Cost
1	Patch Antenna 1	10	4.3	1	1	1	4.3	10	4.28	4.28	500
2	Patch Antenna 2	10	4.3	2	2	4	10.3	40	8.56	8.56	2000
3	Patch Antenna 3	10	4.3	3	3	9	13.809775	90	12.84	12.84	4500
4	Patch Antenna 4	10	4.3	4	4	16	16.3	160	17.12	17.12	8000
5	Patch Antenna 5	10	4.3	5	5	25	18.23156857	250	21.4	21.4	12500
6	Patch Antenna 6	10	4.3	6	6	36	19.809775	360	25.68	25.68	18000
7	Patch Antenna 7	10	4.3	7	7	49	21.14412953	490	29.96	29.96	24500
8	Patch Antenna 8	10	4.3	8	8	64	22.3	640	34.24	34.24	32000
9	Patch Antenna 9	10	4.3	9	9	81	23.31955001	810	38.52	38.52	40500
10	Patch Antenna 10	10	4.3	10	10	100	24.23156857	1000	42.8	42.8	50000
11	Planar Dipole 1	8	2.2	1	1	1	2.2	8	4	2	200
12	Planar Dipole 2	8	2.2	2	2	4	8.2	32	8	4	800
13	Planar Dipole 3	8	2.2	3	3	9	11.709775	72	12	6	1800
14	Planar Dipole 4	8	2.2	4	4	16	14.2	128	16	8	3200
15	Planar Dipole 5	8	2.2	5	5	25	16.13156857	200	20	10	5000
16	Planar Dipole 6	8	2.2	6	6	36	17.709775	288	24	12	7200
17	Planar Dipole 7	8	2.2	7	7	49	19.04412953	392	28	14	9800
18	Planar Dipole 8	8	2.2	8	8	64	20.2	512	32	16	12800
19	Planar Dipole 9	8	2.2	9	9	81	21.21955001	648	36	18	16200
20	Planar Dipole 10	8	2.2	10	10	100	22.13156857	800	40	20	20000
21	PIFA 1	12.5	3.93	1	1	1	3.93	12.5	3.3	5.16	300
22	PIFA 2	12.5	3.93	2	2	4	9.93	50	6.6	10.32	1200
23	PIFA 3	12.5	3.93	3	3	9	13.439775	112.5	9.9	15.48	2700
24	PIFA 4	12.5	3.93	4	4	16	15.93	200	13.2	20.64	4800
25	PIFA 5	12.5	3.93	5	5	25	17.86156857	312.5	16.5	25.8	7500
26	PIFA 6	12.5	3.93	6	6	36	19.439775	450	19.8	30.96	10800
27	PIFA 7	12.5	3.93	7	7	49	20.77412953	612.5	23.1	36.12	14700
28	PIFA 8	12.5	3.93	8	8	64	21.93	800	26.4	41.28	19200
29	PIFA 9	12.5	3.93	9	9	81	22.94955001	1012.5	29.7	46.44	24300
30	PIFA 10	12.5	3.93	10	10	100	23.86156857	1250	33	51.6	30000
31	Bow tie 1	9	2.32	1	1	1	2.32	9	3.95	3.95	700
32	Bow tie 2	9	2.32	2	2	4	8.32	36	7.9	7.9	2800

Design Reference Mission



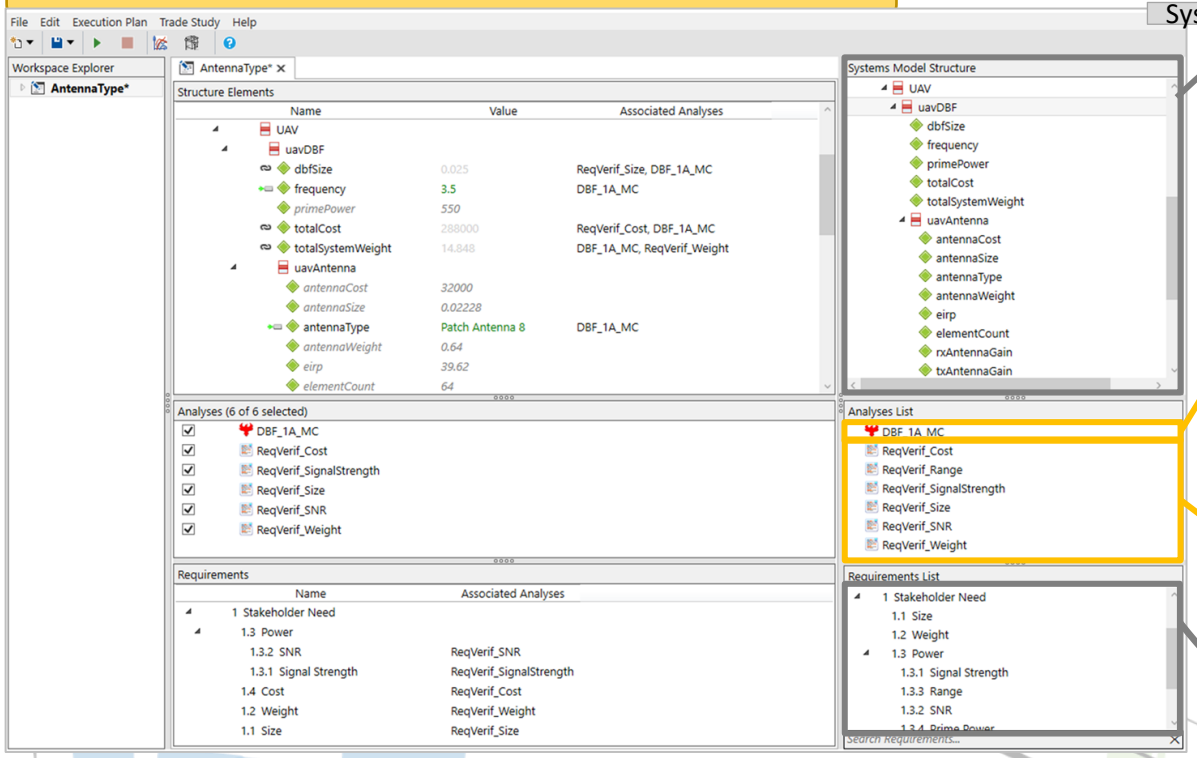
MBSE Workflow

Connecting SAM to Analysis

Connecting SAM to Analysis

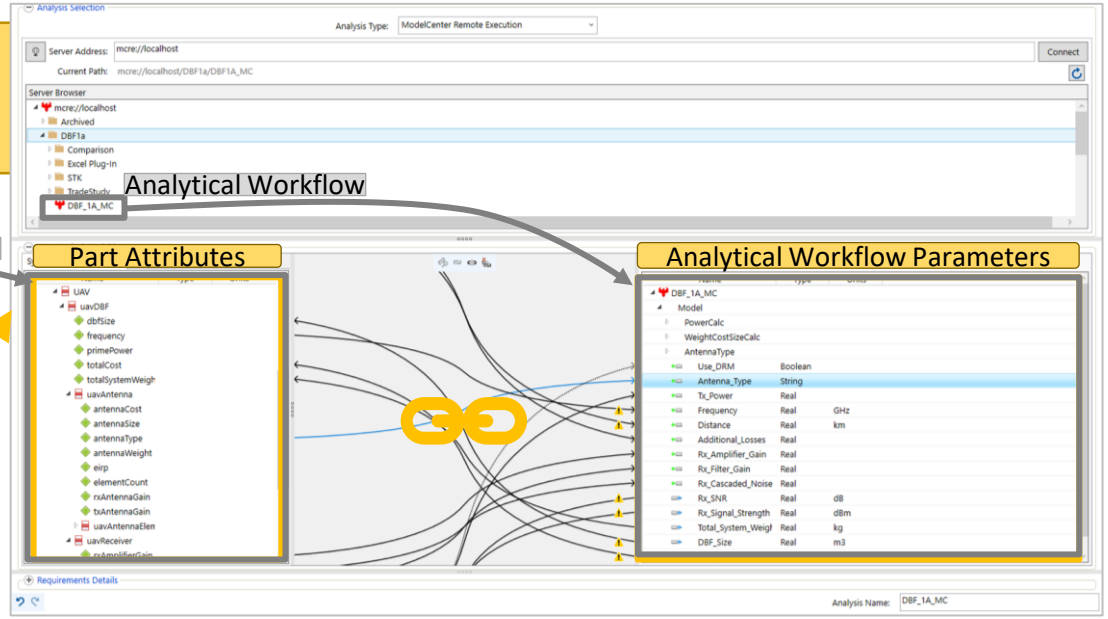
System Architecture Model built using SysMl v2 in SAM tool connected to Analysis through MBSE Connector

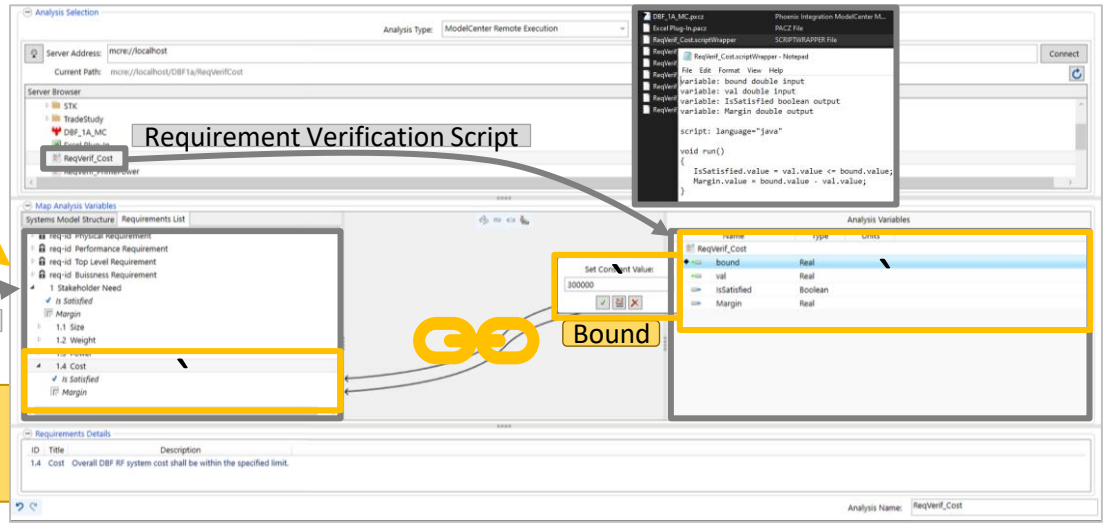
Attributes defined for parts in SAM are seamlessly linked to Analysis Parameters



System Structure

Requirements





Requirement Verification Script parameters is linked to Requirements, with bound set for verification analysis.

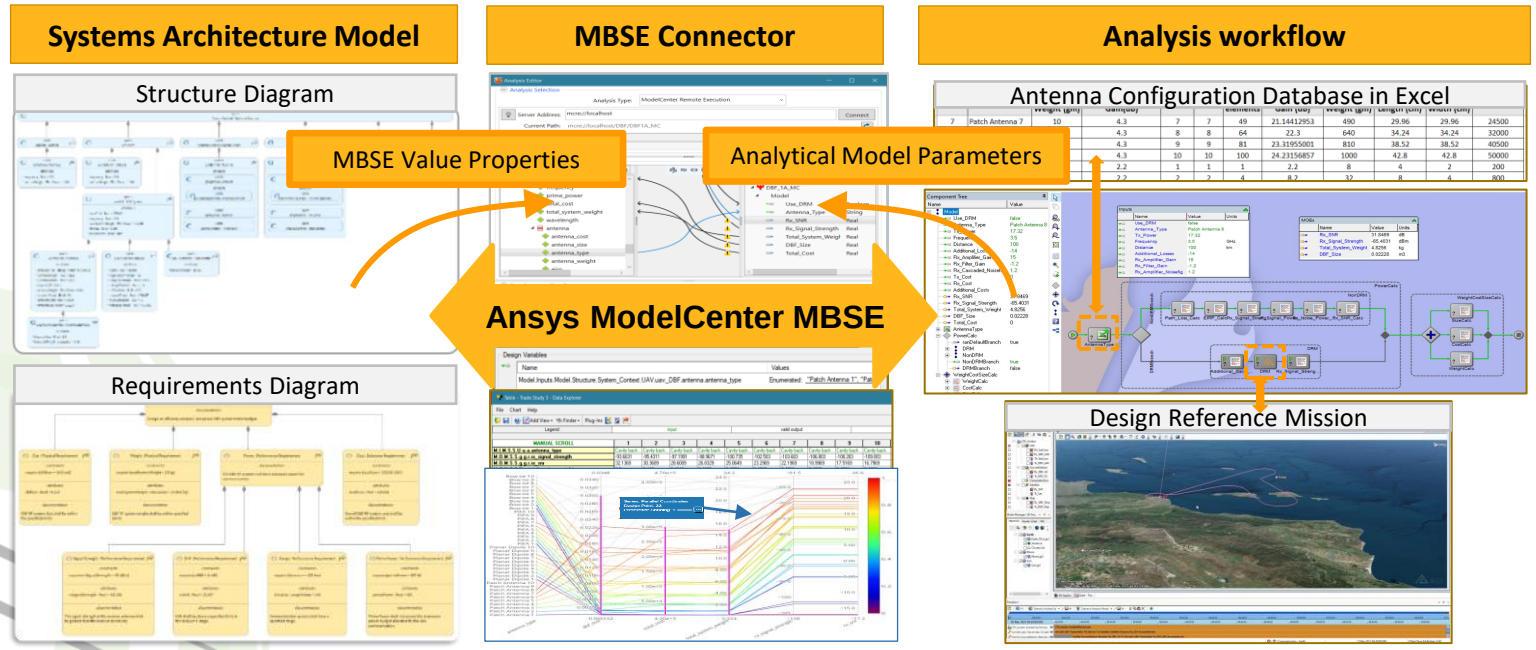
Performing

Trade Study & Requirements Verification

Trade Study & Requirements Verification

- Post linking the system attributes with analysis parameters, A DOE Study can be initiated within MBSE Connector Interface
- Various antenna configurations are verified during trade study to come up with potential concept design

- System requirement verification is performed using MBSE Connector
- Various Antenna configuration are verified using DOE trade study
- DOE runs are visualized against multi-objectives Measure of Effectiveness (MOEs)
- Identify the potential design
- Identified design cases can be individually evaluated in MBSE Connector for requirement verification and can be passed back to SAM



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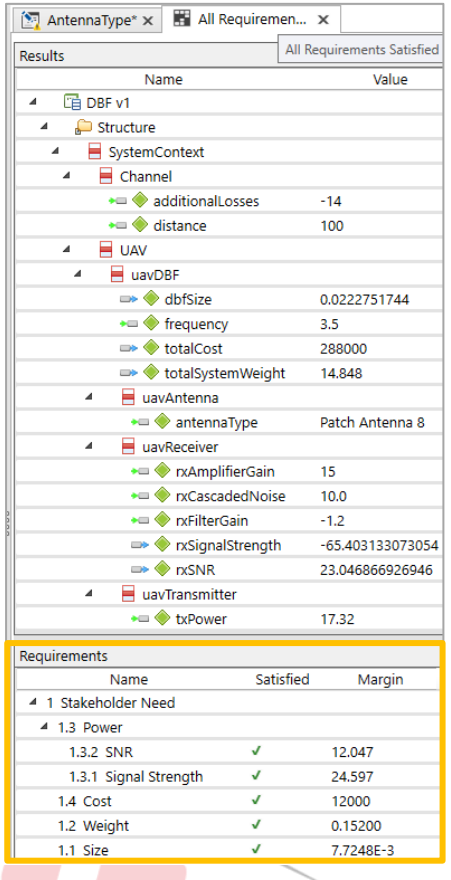

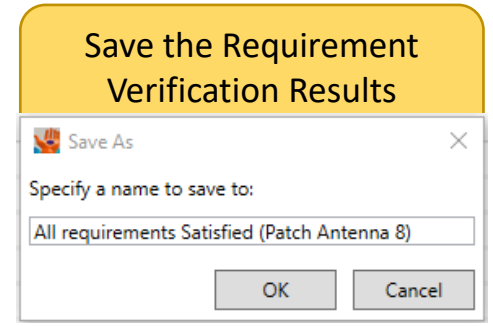

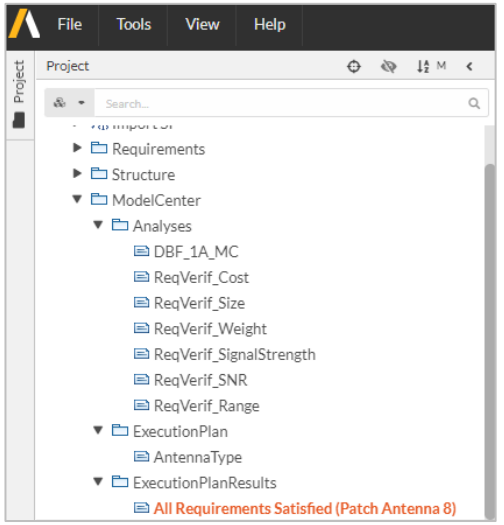

Conclusions and Future Work

Conclusions and Future Work

- Showcased **Implementation** of the DBF Use case by utilizing the Ansys MBSE Methodology
- Highlighted one of the key aspects of MBSE of performing **Requirements Verification in Early-stage Design**
- **MBSE Methodology** and **Digital Engineering** bring together all Disciplines and Stakeholders in a well-defined digital environment that is needed for developing complex systems.
- We will pursue our development of the Ansys MBSE Methodology, enabling **Doman Specific Methodologies** (Eg. A&D, Automotive).

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