NDIA

26th Annual Systems & Mission Engineering Conference
October 16-19, 2023

Model Based Functional Development & Verification

Digital Beam Forming Antenna for a UAV application

Oct. 19, 2023

Prem Andrade, MS ME, Distinguished Engineer,
Nijas Kunju, PhD EE, Technical Leader, Electronics,
P. Len Orlando III, MS EE, Senior Business Development Executive,
Anirudh Mukhopadhyay, PhD ME, Fellow & Chief Technologist

Ansys

Ansys: Digital Engineering for National Security

The strategic, technical, and financial advantage for program capture and execution

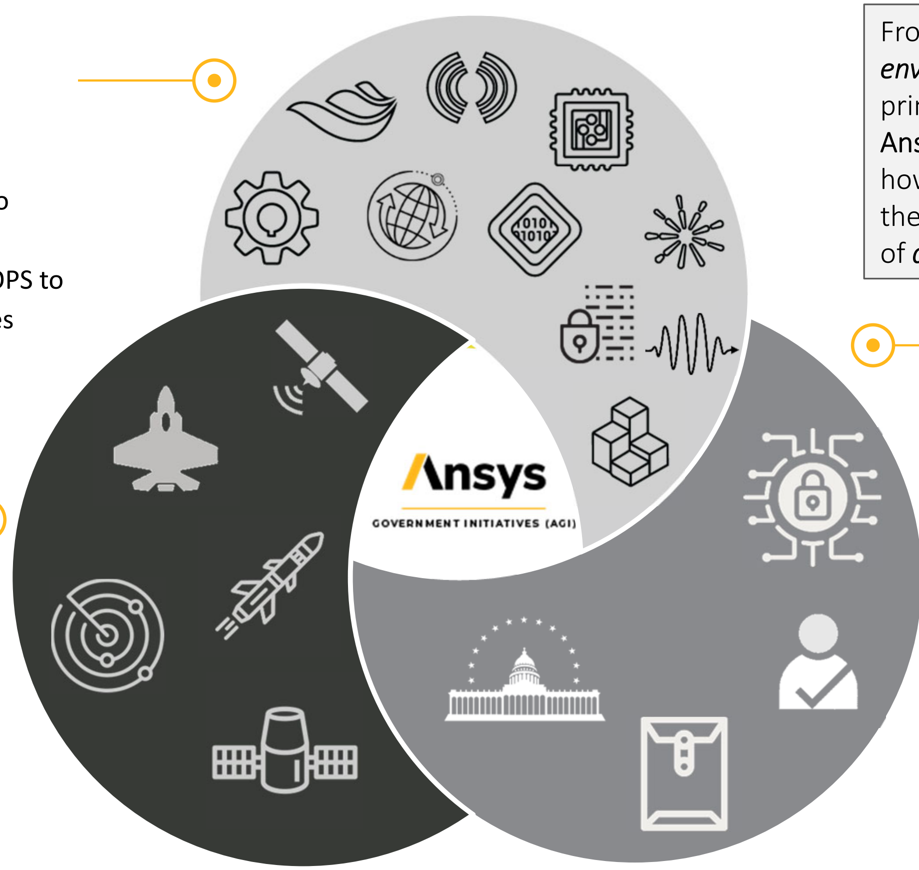
50+ Years of Innovation

Industry leading solutions across physics, systems, safety, materials, and missions

- Intelligent, open, and agile platform to evaluate overall system performance
- Only company that can support CONOPS to detailed engineering for RFP responses
- 375+ technology partners

Domain and Mission Expertise

- Space systems
- Aircraft and UAV systems
- Communications and radar analysis
- Missile defense
- Intelligence, surveillance, and reconnaissance



From the crucial role of *open environments* to the essential principles of *implementation,* Ansys invites you to explore how organizations can unlock the transformative potential of *digital engineering*.

30+ Years of National Security Expertise

- Deploying modeling and simulation in the national security environment
- Classified business and technical support
- Program capture and program execution
- Able to support you within your environments
- FEDRamped

Model Based Functional Development & Verification

Digital Beam Forming Antenna for a UAV application

- This session presents the Model Based Functional Development and Verification of a Digital Beam Forming (DBF) Antenna for a UAV application. The use case considered is to study a UAV that communicates with a ground station and a ship using a phased array antenna. Based on the stakeholder needs the design reference mission is defined using a mission software to capture the dynamic use case of how the system interacts with the other systems and the environment around it. Also, for the system Measures of Effectiveness (MoEs) such as Signal to Noise Ratio (SNR), Link budget and so on as well as the constraints like size, weight, power, cost (SWaP-C) and cooling constraints are established. The descriptive model of the system and the system of systems is assumed to have been already captured using sysML and some initial trade studies have been done to get the overall specification for the digital beam forming antenna. This study then looks at optimizing the DBF through the paradigm of model-based design to establish the best specifications for the sub system and components which will also determine whether to build, modify or buy these sub systems or components. This is done by exploring the design space by considering different off the shelf specifications available for components like filters, amplifiers, mixers and so on using libraries available in commercial model-based design software. These functional models are then integrated together to capture the DBF's full receiver and transmit system in conjunction with the other assets. The RF channel between the antennas is modelled in a mission software as the design reference mission executes. This study thus not only captures the model-based design of the system but also verifies the system in the context of the design reference mission.

Digital Engineering (DE)

Layer 1:

Initial Requirements | Security Posture | Notional Architecture | Software Algorithm

Model Based Systems Engineering
Quick Analysis of Alternatives
Preliminary Cost Target

Layer 2:

Refined Constraints | Operational Environment | Architecture Improvements | Physical Floorplan

Model Based Engineering
Realizable Hardware Implementation
Supply Chain and Assurance Assessment

Layer 3:

Final Constraints | Final Architecture | Physical Implementation

Modeling, Simulation and Analysis
Final Hardware Implementation
Detailed Hardware Analysis

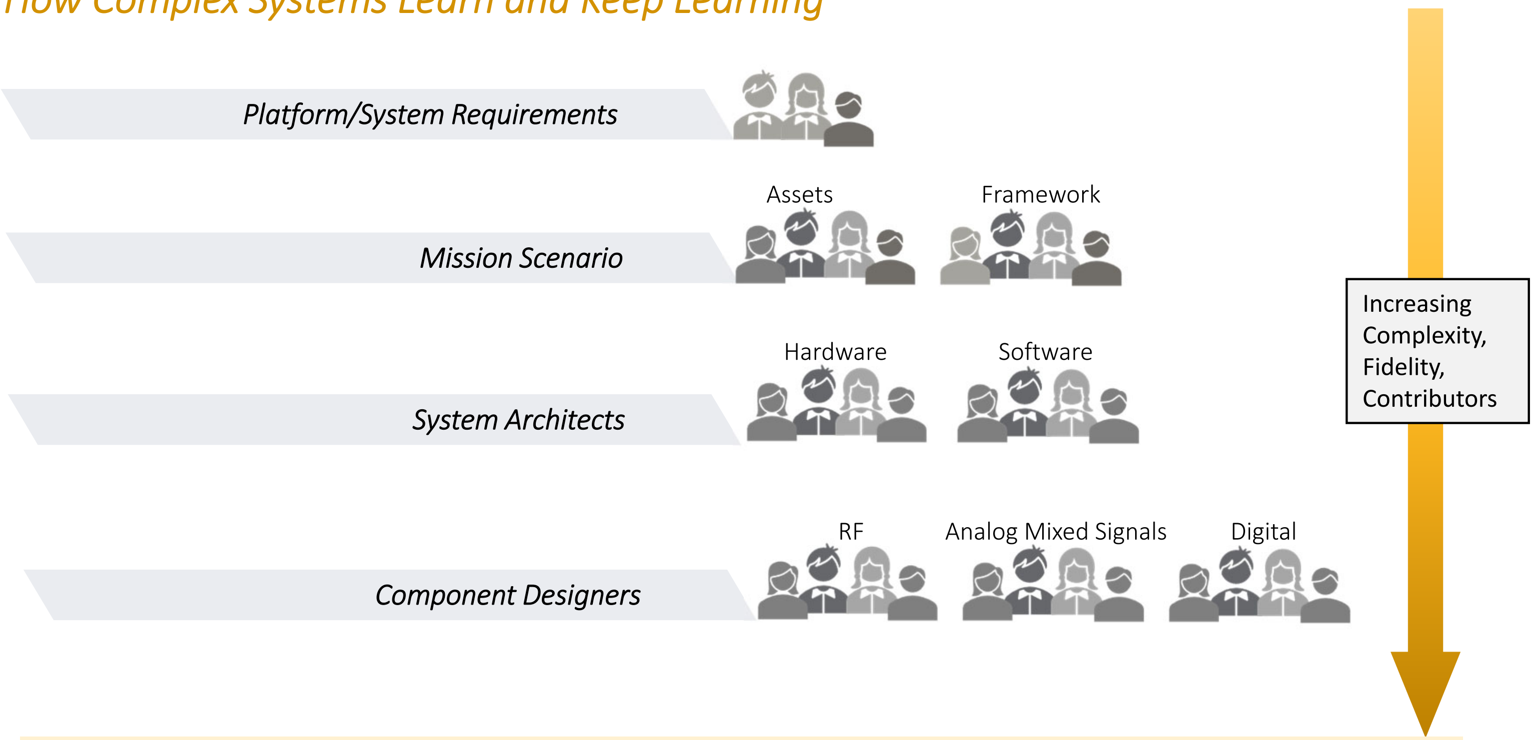
Layer 4:

Authoritative Source of Truth

DE approach allows evaluation and re-evaluation at all levels of abstraction enabling informed decisions. Ultimately resulting in mature digital twins capable of serving as the authoritative source.

Technology Integration

How Complex Systems Learn and Keep Learning

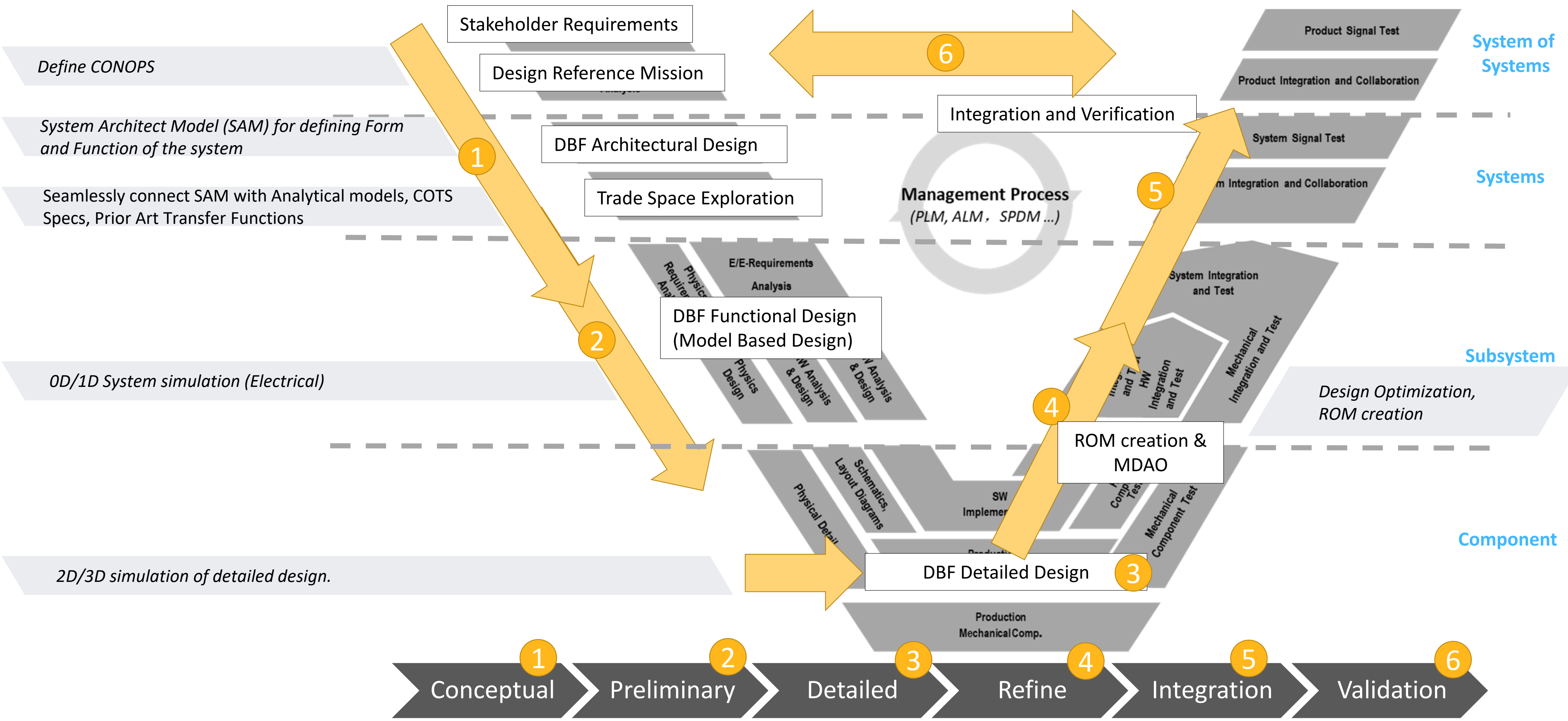


For Microelectronics Systems:

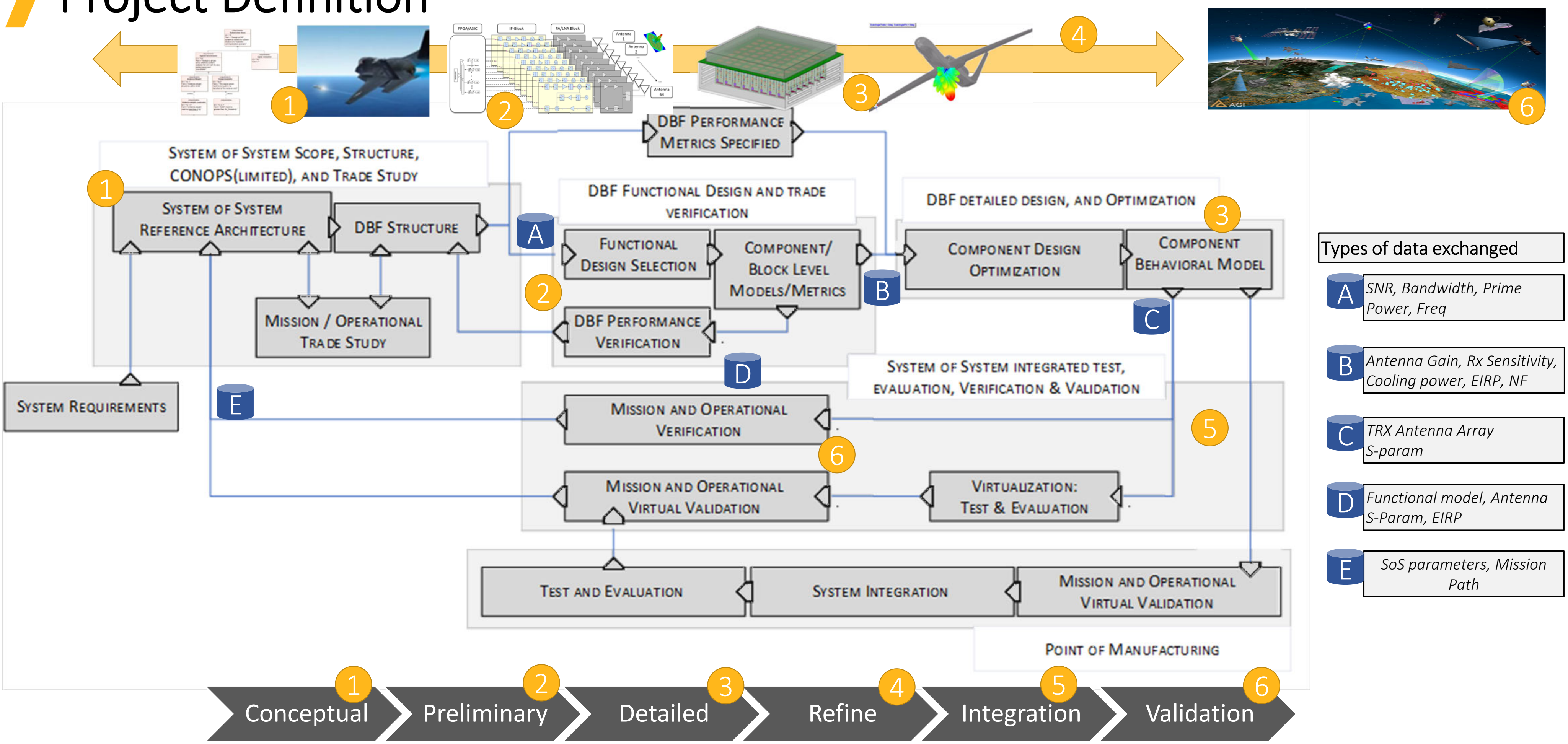
- *Requirements serve to Stabilize the Design process;*
- *Innovation occurs across the team*
- *Scales from the few (System Engineers) to the many (disciplined team of teams)*

[8] Pace Layering: How Complex Systems Learn and Keep Learning, https://jods.mitpress.mit.edu/pub/issue3-brand/release/2

Generalized Process for Microelectronics Digital Engineering



Project Definition



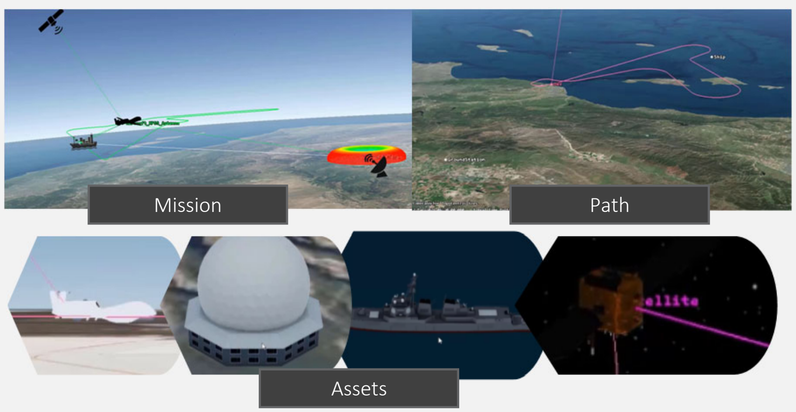
Conceptual Phase

Analysis Initial Conditions

System Specifications

Requirement	Value	Constraints	Value
Distance	0-100Km	Size	<0.03m^3
Frequency	3.5GHz	Weight	<15Kg
RF sensitivity	-90dBm	Power	<1KW
Multiuser	Yes	Cost	<$300K

Mission Scenario



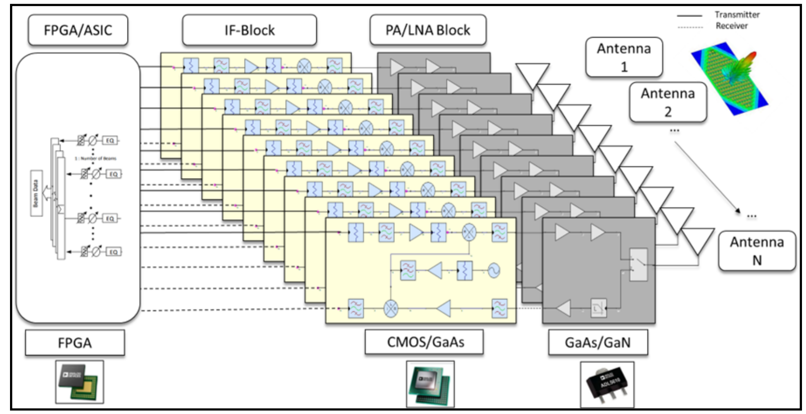
Architectural Trades

- Zero-IF
- Homodyne
- Heterodyne

Frequency Plan

Feasibility Analysis

Architectural Implementation



Digital Signal Processing	Data Converter	RF Down/Up Frequency Conversion	RF RX/TX Front-End	Antenna Element

Multi-fidelity analysis workflow:

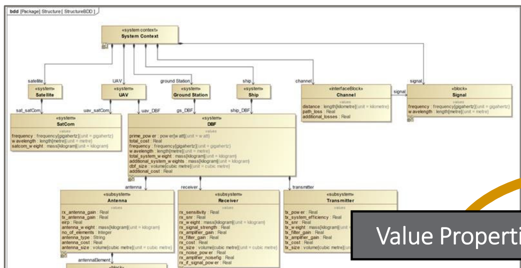
Calculates Measure of Effectiveness (MoE): Rx signal strength, SNR, Weight, Size & Cost

Workflow Mission Scenario: Included physics-based models for signal strength, noise, etc to be included in a dynamic manner as scenario evolves.

- *Enables improved accuracy of MoE combined within the scenario inclusive of the environment, terrain etc.*
- *Hard requirements (Initial Conditions) are used to continuously evaluate fluid-dynamically derived requirements during system development*

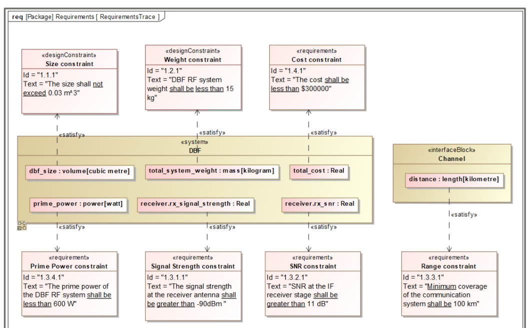
Conceptual Phase: Trade Study Analysis Workflow

Systems Architecture Modeler



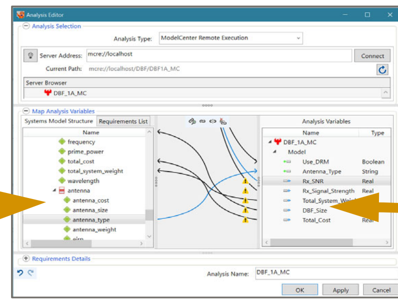
Block definition diagram

Value Properties

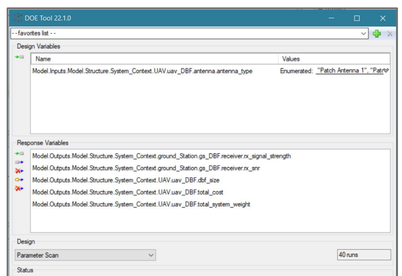


Requirements diagram

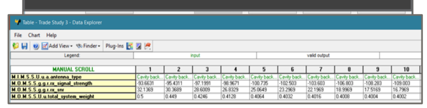
MBSE Connector



ModelCenter MBSE



Design of Experiments Study

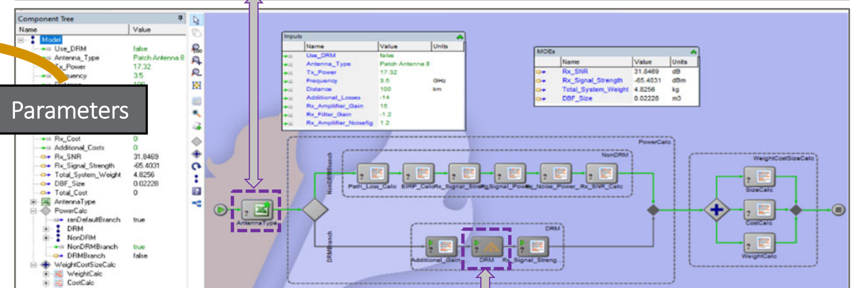


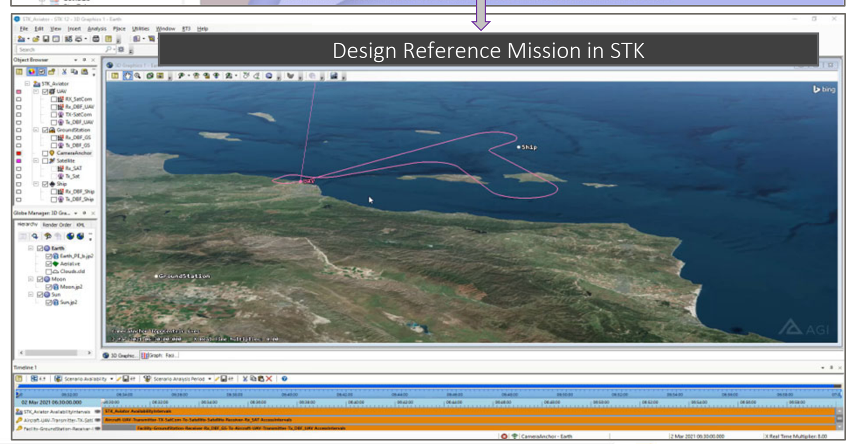
ModelCenter Multi-fidelity Analysis workflow

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 ($)
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

Antenna Configuration Database in Excel

Parameters





Design Reference Mission in STK

Ansys

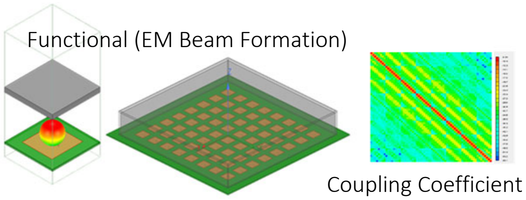
Preliminary Design: Antenna Trades Workflow

Design Space Exploration

Antenna Designer

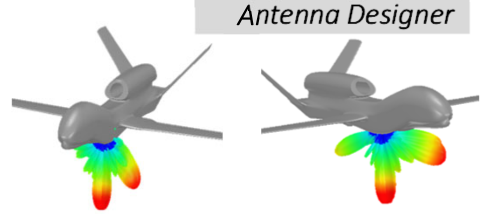
Objective: Maximize Rx SNR and Rx Signal Strength

Functional (EM Beam Formation)



Coupling Coefficient

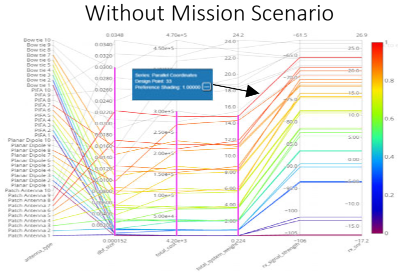
Unit Cell → Array Size and Element Spacing



Platform Interaction, Element Gain, DBF weights

Platform Integration: Beam Steering using SystemVue

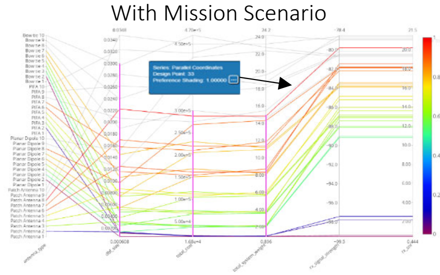
Without Mission Scenario

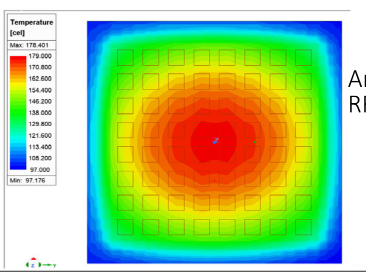


Over 40 different potential antenna designs were examined

System Power Dissipation: 992W
Single Channel: 15.5 W
Tx: 8.05W
Rx: 7.45W

With Mission Scenario



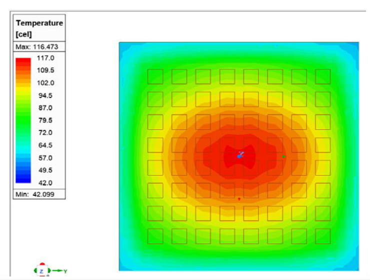


Antenna : 178.00 C
RF Board: 335.76 C

With Heatsink

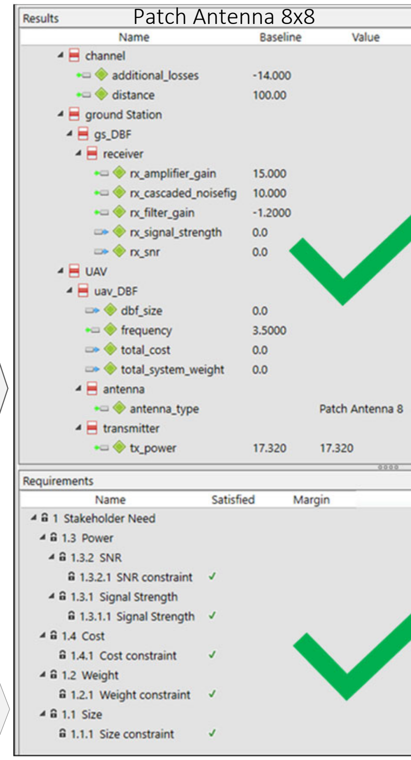
Antenna: 116.43 C
RF Board: 235.27 C

Thermal Management

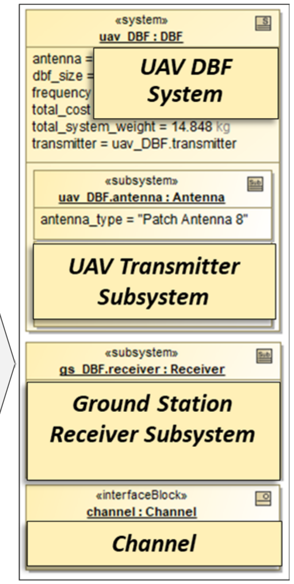


Thermal

Requirements Verification



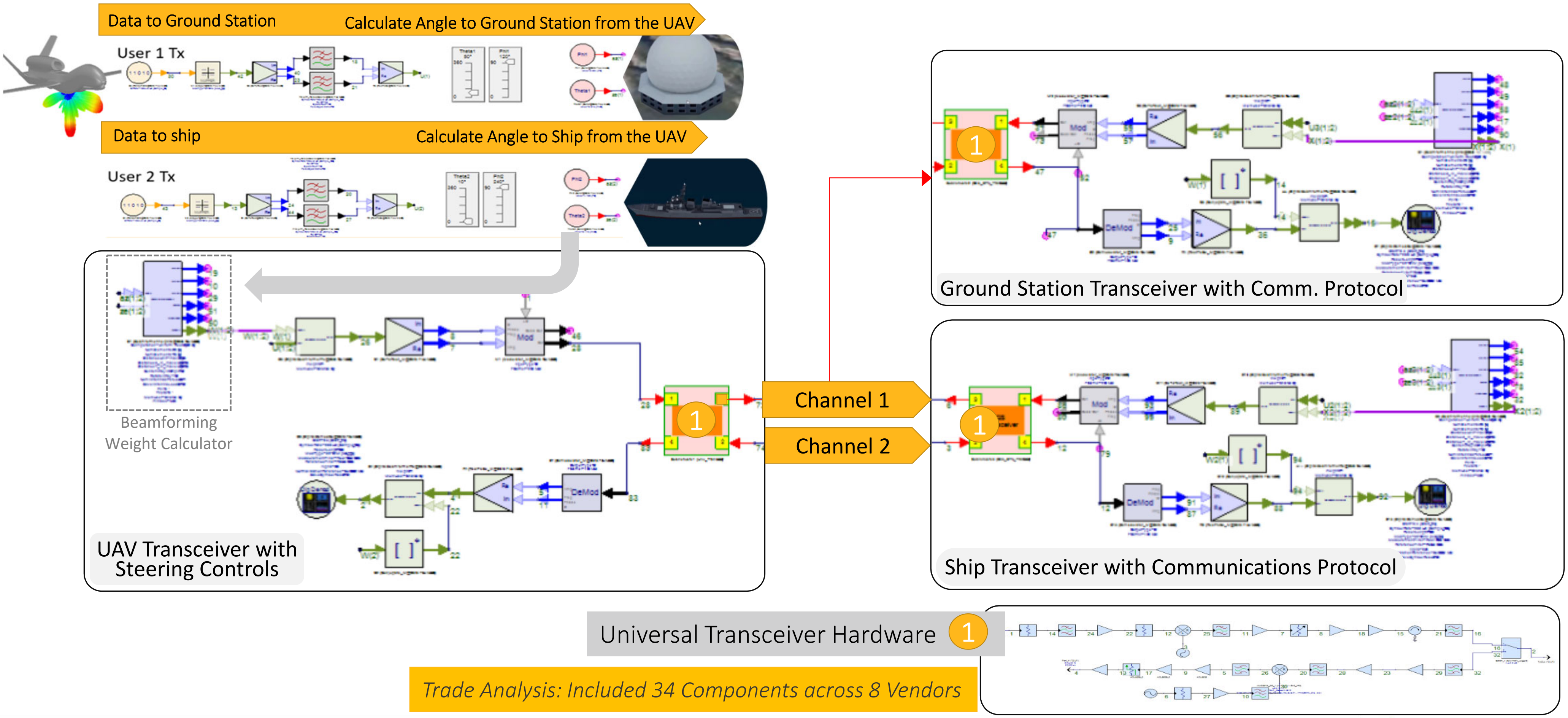
System Architecture Model



System Architects

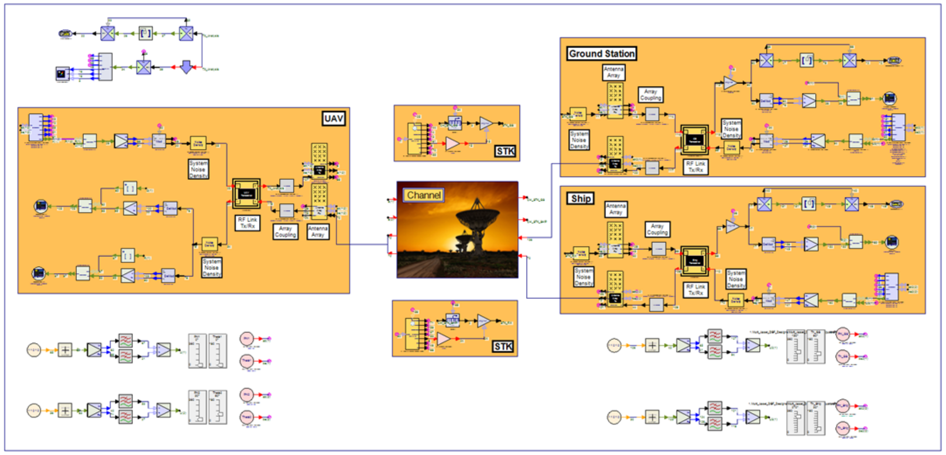
Approved for Public Release UNCLASSIFIED

Refine/Integration Phase: Digital Beam Former System Analysis



Trade Analysis: Included 34 Components across 8 Vendors

Validation Phase



Models Integrated

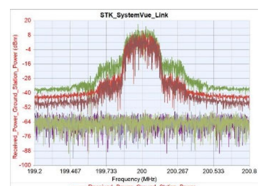
- COTS models
- Noise

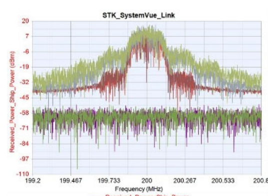
Verifications

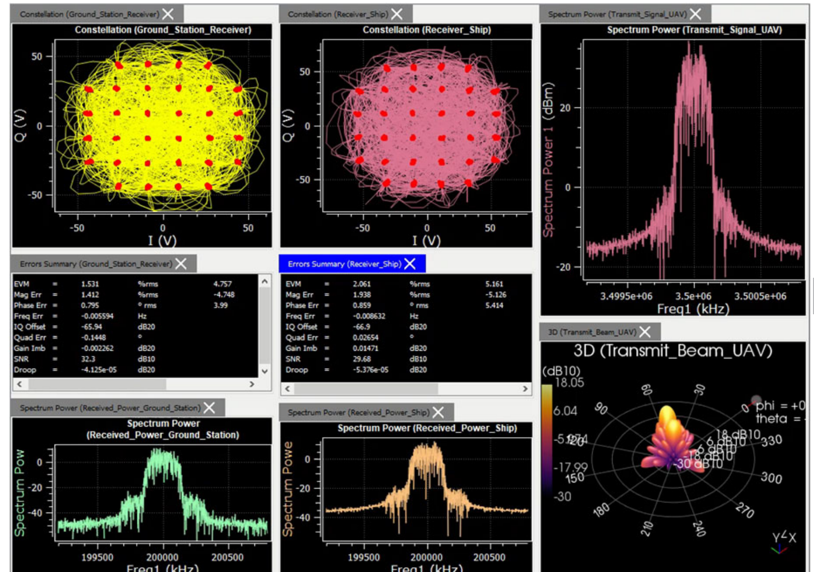
- Tx Power from single channel > 30dBm
- Rx Power at IF > ~10dBm
- Modulation: QAM 32
- Power Spectrum: Tx & Rx Beamforming

Dynamic Link between STK & SystemVue - HFSS

- Pathloss from STK
- Additional Loss: Atmospheric, Rain, Cloud







RF Power at Tx

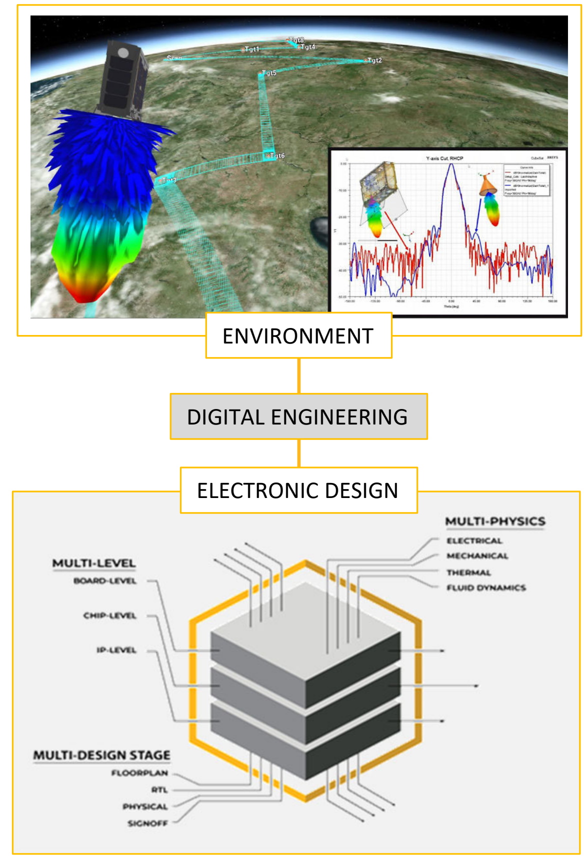
IF Power at Rx

Beamforming towards each user

Ansys

Conclusion

- Framework allows for:
  - Evaluation off new trades and discoveries
  - Different architectures
  - Alternate sources
- Embeds system engineering knowledge within and serve as an authoritative source
- Demonstrates the potential of a Digital Engineering Ecosystem
  - Couple microelectronics trades within the mission scenario
  - Integrate sensors to the environment through Digital Engineering
  - Full Hardware Stack integration of MBSE, MBE, and MS&A



Scenario driven Digital Engineering Enables informed decisions to occur across the total lifecycle of a system.

Thank you!

Ansys

Anirudh Mukhopadhyay, PhD
Fellow, Chief Technologist, Digital Engineering.
am@ansys.com +1 603 252 9360