

2024 NEPP Electronics Technology Workshop

Systematic Assurance Analysis of Components Radiation Effects on System Performance

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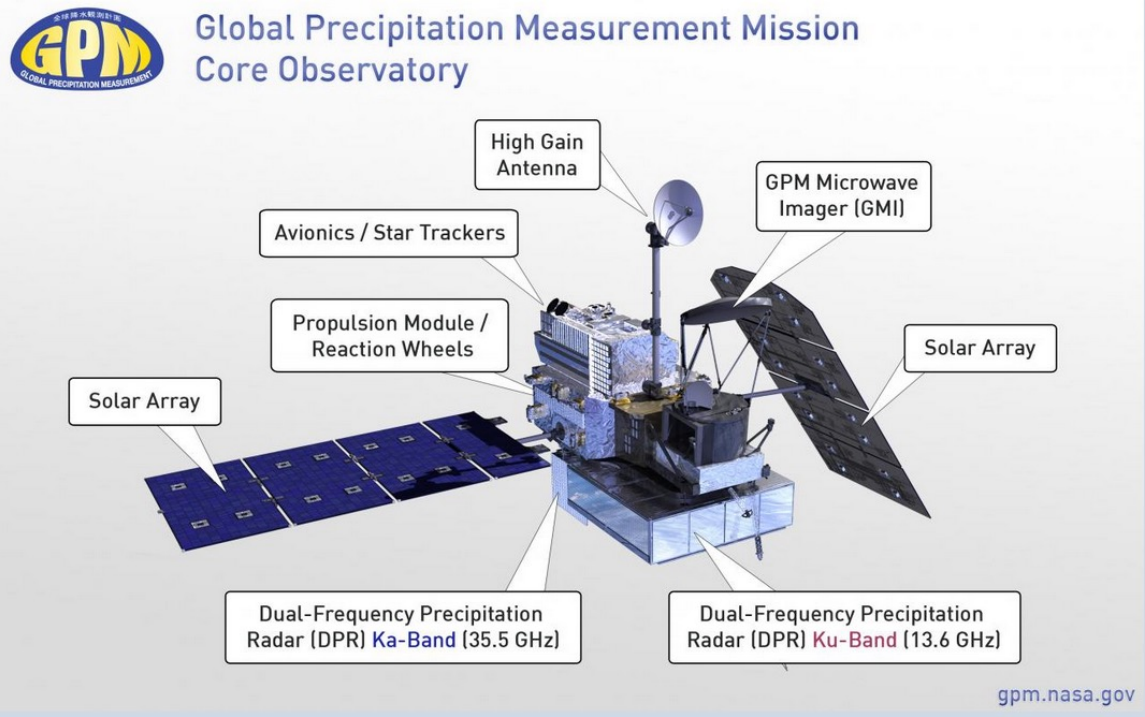
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What is a System? What is a Component?

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https://gpm.nasa.gov/missions/GPM/core-observatory

Working definition of a system: a system has one or more functions with sub-functions, one or more performance parameters, and multiple connected components

Integrated Circuit
IC: System on a Chip
Circuit Boards
Sensor Assembly
Reaction Wheels
Flight Computer
Payload/Experiment
Navigation/Star Tracker

Goal: Find radiation impacts on system performance

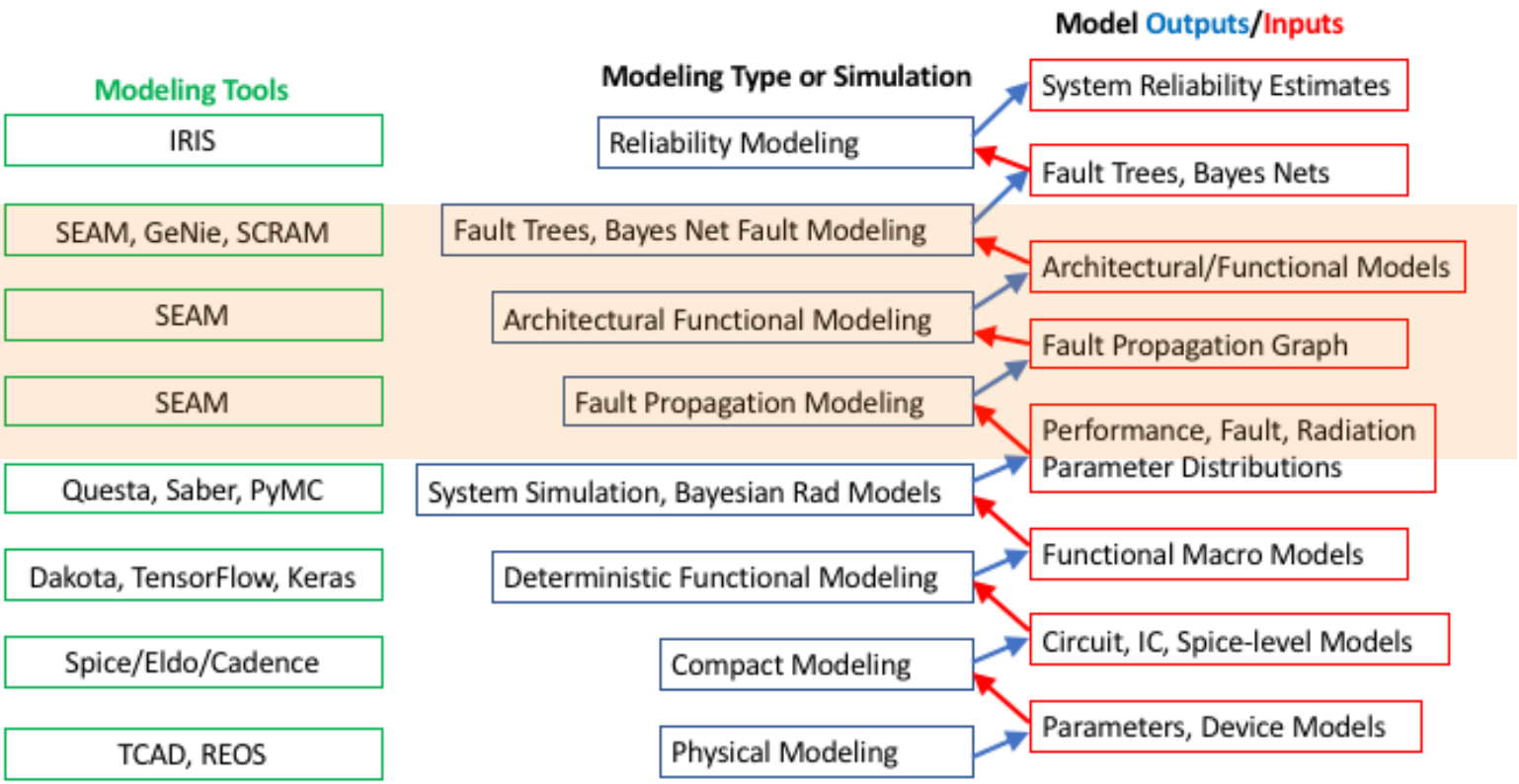
Ladder of Abstraction in Radiation Effects Modeling

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Most Abstract
Least Detailed
Most Scalable
Whole Spacecraft

System or Component

Most Physical
Most Detailed
Least Scalable
One Diode

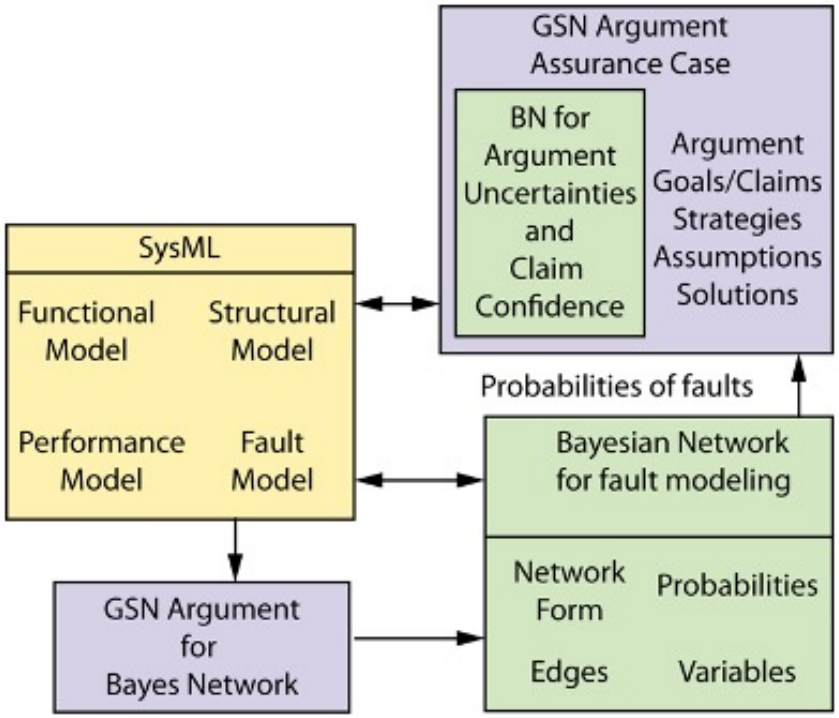


"All models are wrong, some are useful." –Statistician George Box
Some modeling is better than no modeling

Timeline of SEAM Development 2015-2018

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2015: Initial Goal: Look into Goal Structuring Notation (GSN) for radiation
2016 Integration of GSN with WebGME for "FML," NASA Reliability & Maintainability Template. CubeSat board, SEU in SRAM. Coupled with Bayesian nets
2017 Integrate SysML-like system description into WebGME structure. Add functional requirements diagram. Build system fault diagram for SRAM board
2018: Developed automatic construction of Bayesian Net graph from SysML. Systems Engineering Assurance Model=SEAM

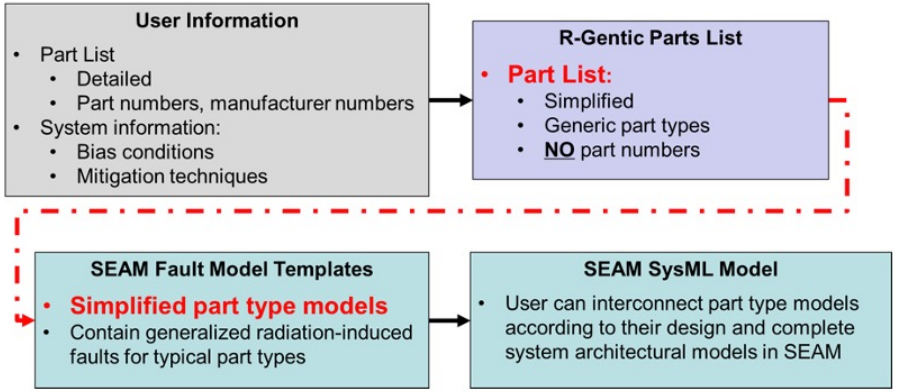


SEAM structure circa 2018

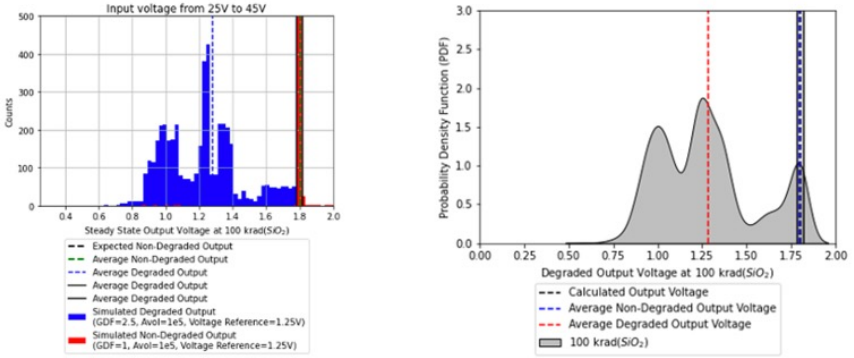
Timeline of SEAM Development 2019-2024

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2019 Reuse of Modeling: Importation of some models from Magic Draw (SysML). Requirements Diagram in SEAM
2020 Scalability: Automatic coverage checks between Functional, Structural, and GSN parts of model. Usability: R-GENTIC integration for initial SEAM model
2021 User Manual. Electronic part fault model template library. Switch to Fault Trees instead of Bayesian nets
2022: Public web page on Amazon Web Services. Start relating Fault Tree probabilities to radiation experiments
2023: Using Monte Carlo Simulations to evaluate sub-system fault probabilities
2024: Next level of complication/abstraction: SEAM modeling of PyCubed CubeSat board



SEAM circa 2021

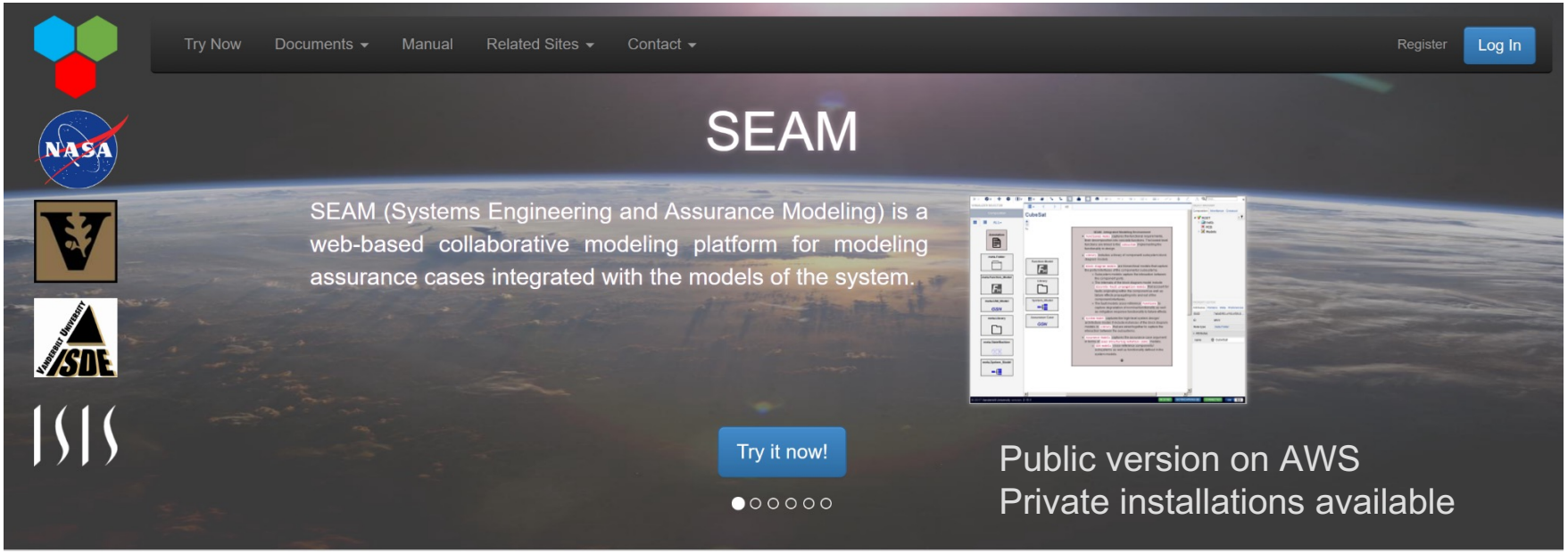


2023: Monte Carlo calculation of Sub-System PDF

SEAM (a web-based modeling platform)

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https://modelbasedassurance.org



GSN Assurance Models

SEAM supports the Goal Structuring Notations (GSN) standard to build assurance case models. SEAM uses hierarchical models, as well as cross-referencing to manage complexity in GSN models. Additionally, SEAM allows linking assurance cases to system models to provide context to the assurance case argument.

System Models

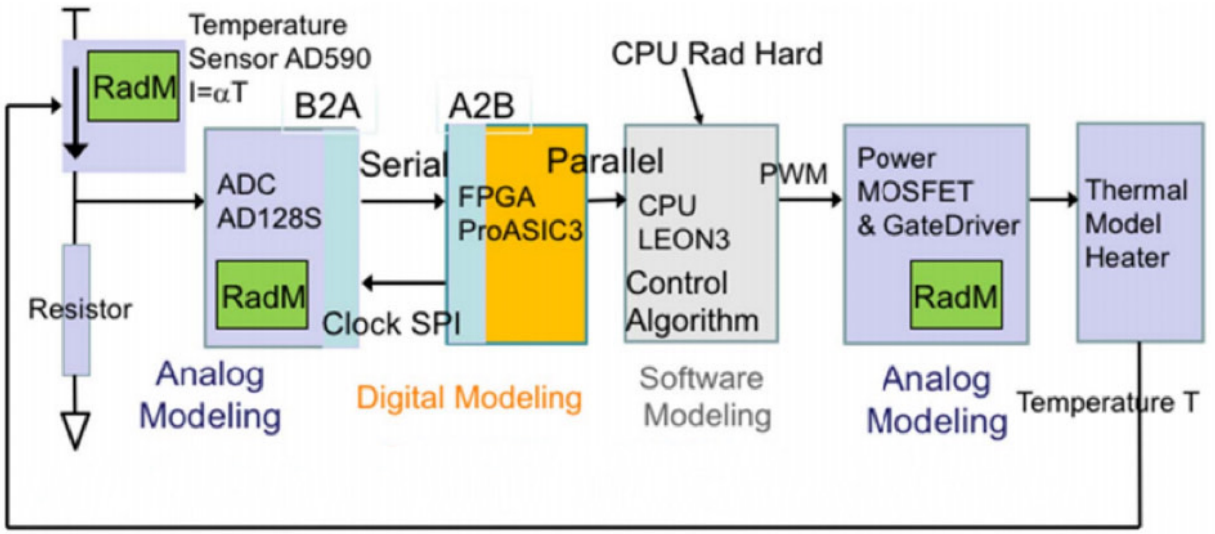
SEAM supports a subset of block diagram models in the SysML modeling standard. These include functional (hierarchical requirement) models and architecture design with block diagram models.

Fault Models

SEAM extends the internal block diagram models to allow specification of discrete fault propagation to capture the faults and their anomalous effects within a block (subsystem) and their propagation across the system through subsystem interfaces.

Example: Temperature Control System

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Typical temperature range of commercial parts: 0 °C -120 °C

***One sub-system* on the flight computer board-several functions**

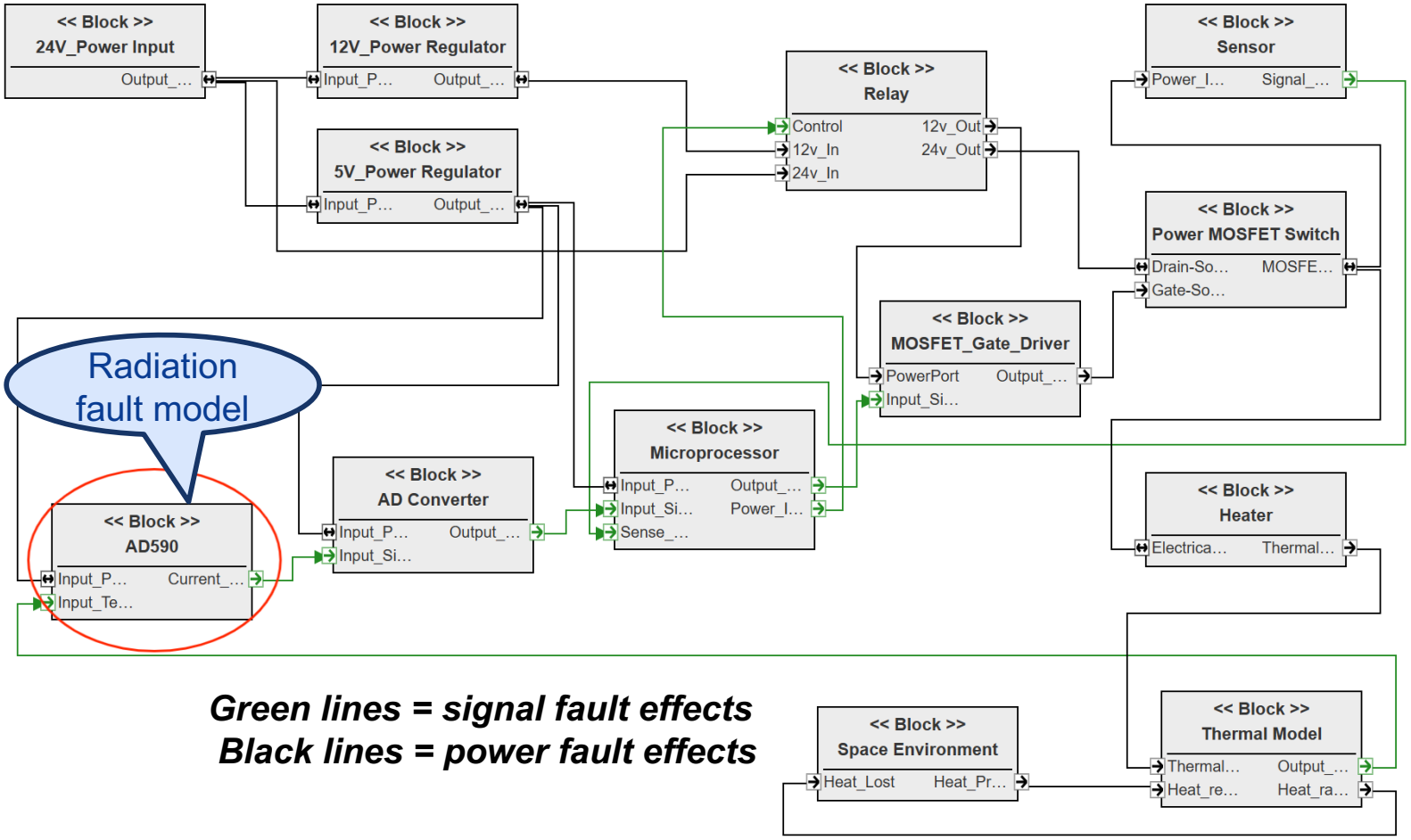
A. F. Witulski et al., "Simulation of Transistor-Level Radiation Effects on System-Level Performance Parameters," in IEEE Transactions on Nuclear Science, vol. 66, no. 7, pp. 1634-1641, July 2019.



When in the daytime, temperatures can soar up to approximately 120°C (248°F); when in the nighttime, temperatures can plummet to about -100°C (-148°F).

Temperature Control System (Architectural) Model

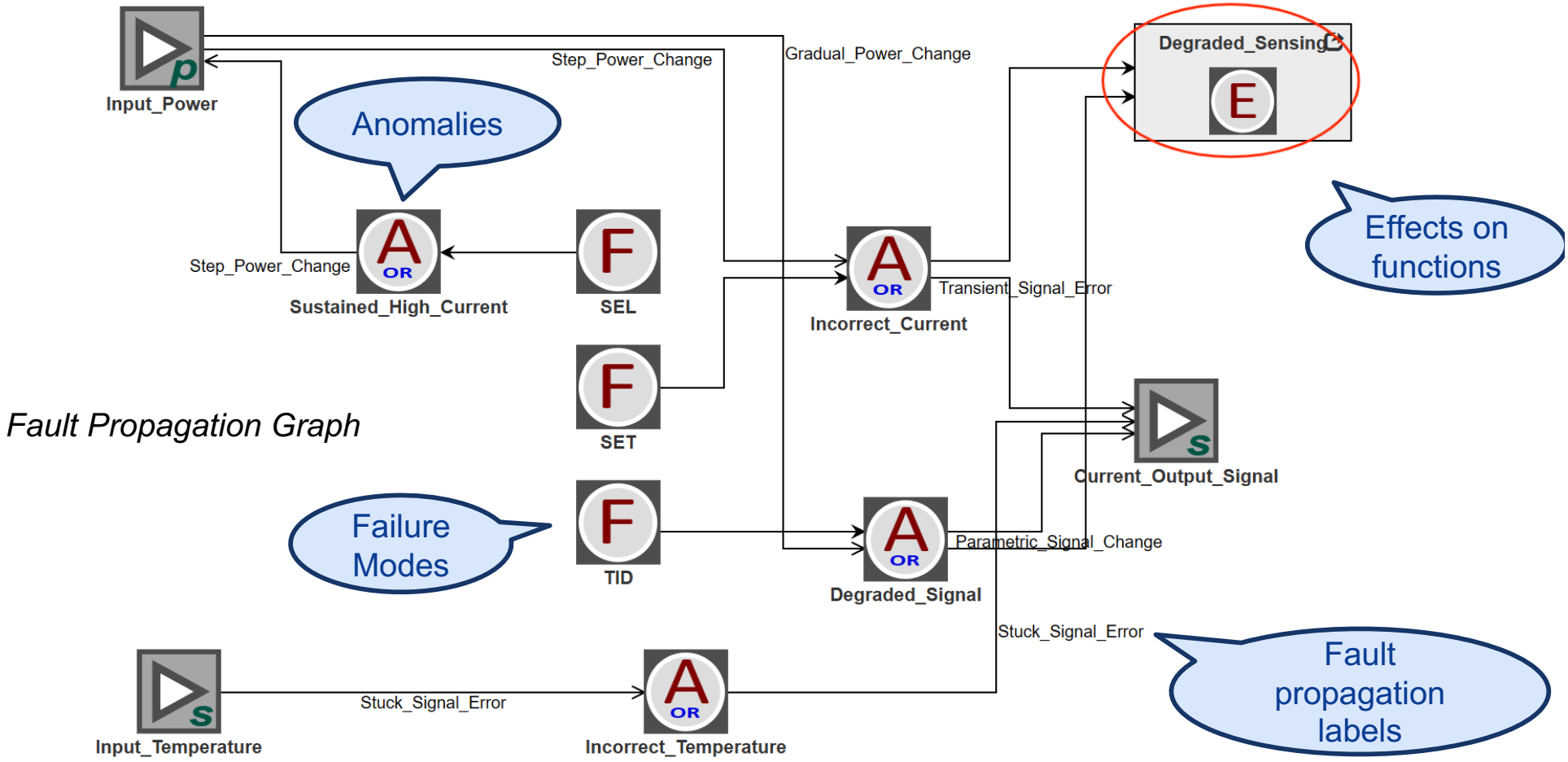
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Green lines = signal fault effects
Black lines = power fault effects

AD590 Temperature Sensor Fault Propagation Model

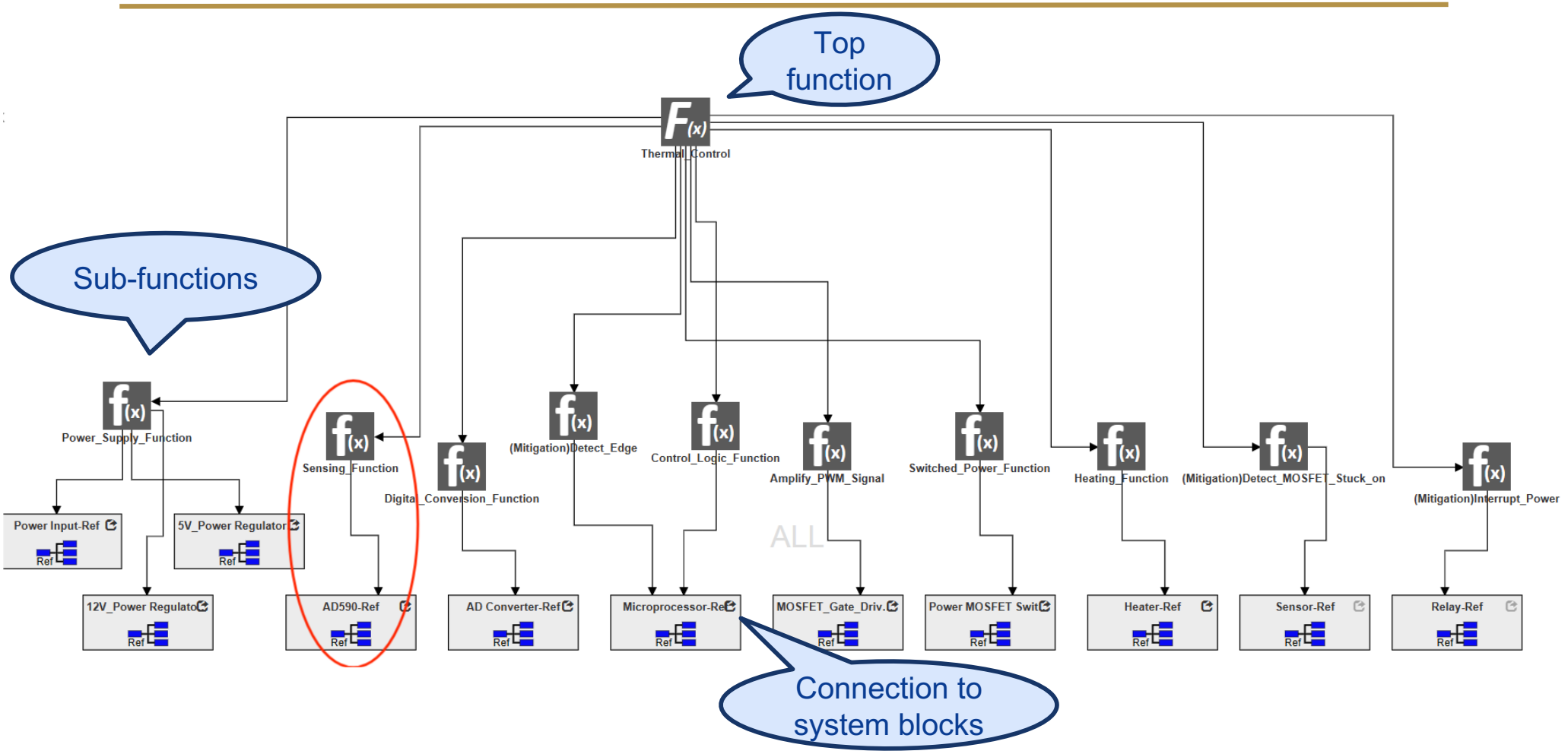
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Fault Propagation Graph

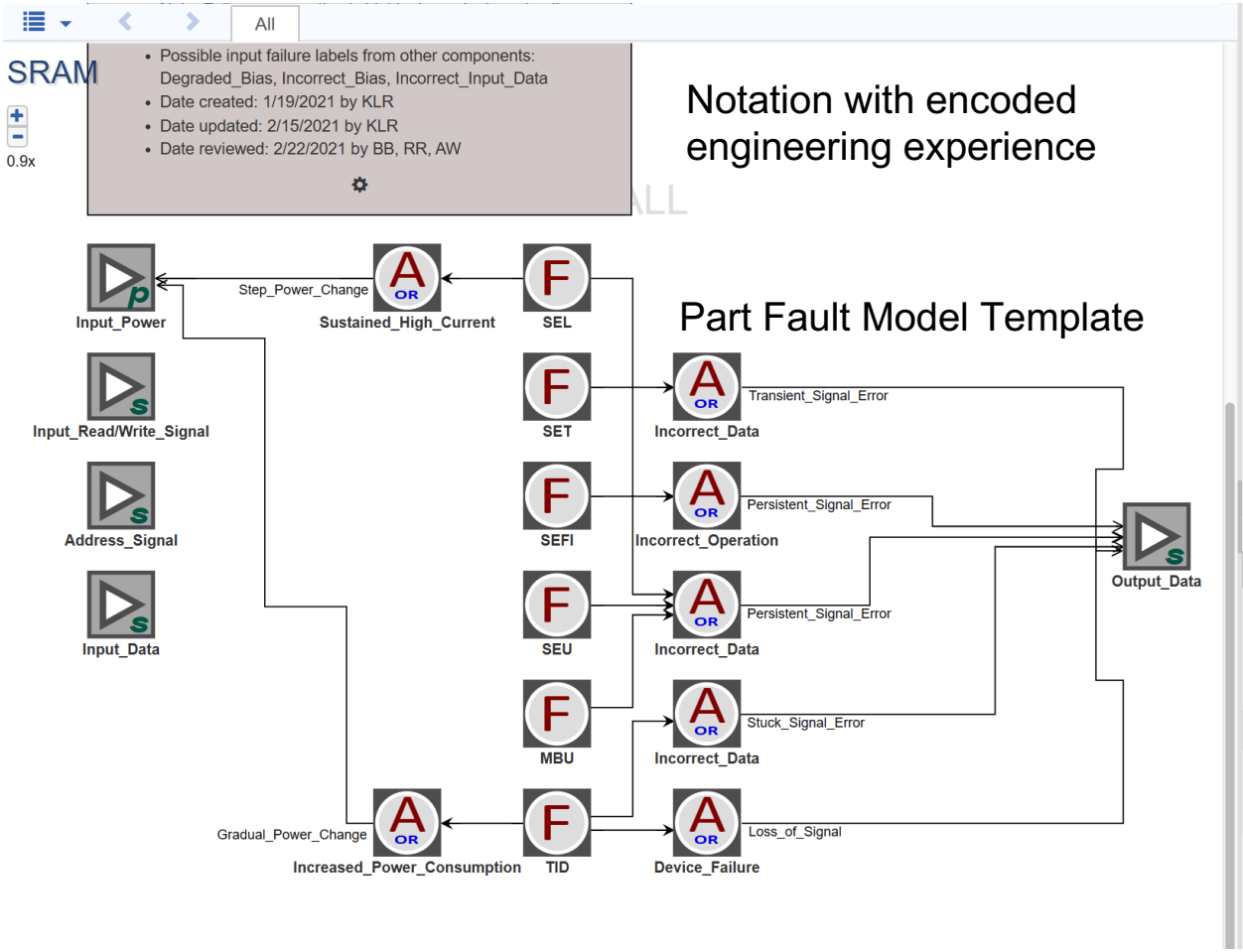
Temperature Control System Functional Model in SEAM

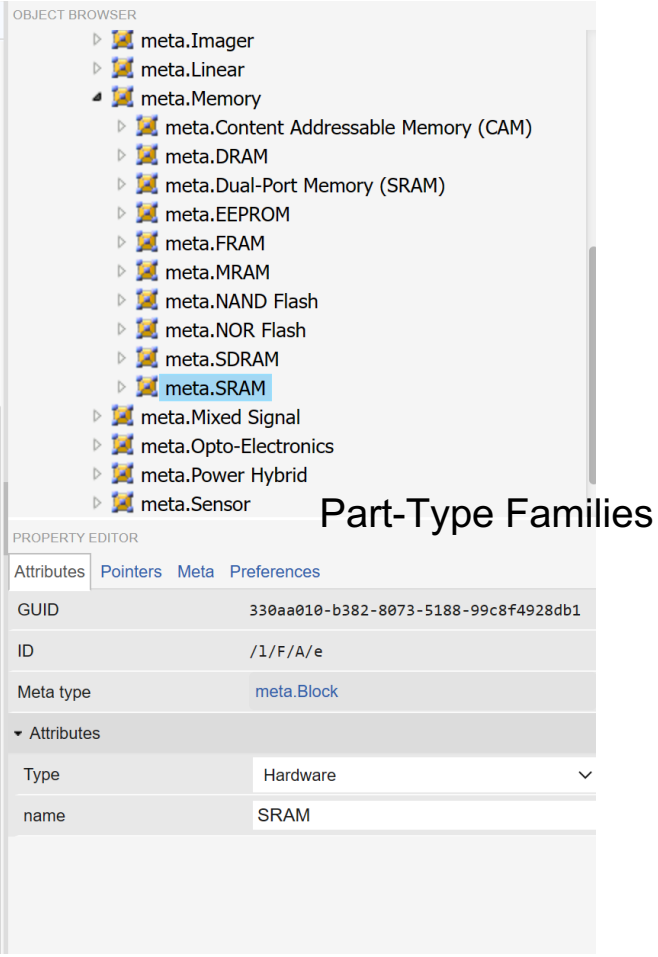
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SEAM Fault Model Template Library

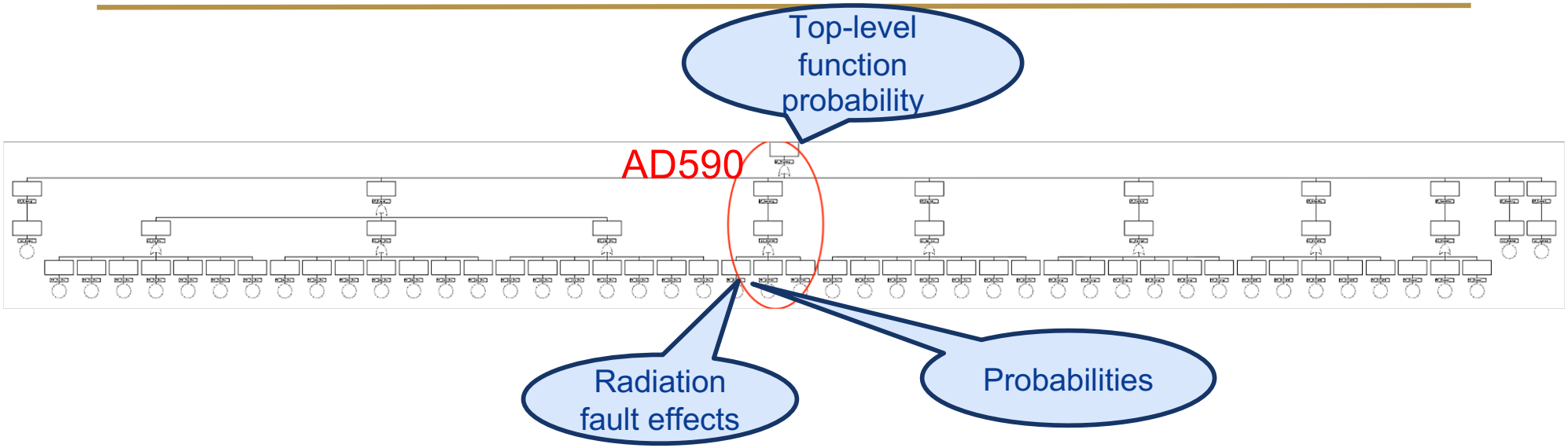
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Fault Tree Results

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- Fault tree can be automatically generated from system model, fault propagation model, and functional model.
- The fault tree clearly illustrates how combinations of radiation effects affect components, sub-functions, and the overall system.

Modeling a More Complex Subsystem: Packet Radio

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Hope RF LoRa Packet Radio:
- Multiple integrated circuits
- Multiple operating modes
- Many performance parameters

Does our approach scale to more complex subsystems?

Challenges:
- Many components
- Lack of physical knowledge of components
- Lack of observability of internal quantities

Complex Subsystem has the same basic system properties:
- Functions
- Operating modes
- Specifications quantified by Key Performance Indicators (KPIs)

Fault Propagation Graph approach still applies



Key Functions and Performance Parameters of Modular Radio

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KEY PRODUCT FEATURES

- LoRa™ Modem.
- 164 dB maximum link budget.
- +20 dBm - 100 mW constant RF output vs. 3.3V supply.
- +14 dBm high efficiency PA.
- Programmable bit rate up to 300 kbps.
- High sensitivity: down to -144 dBm.
- Bullet-proof front end: IIP3 = -12.5 dBm.
- Excellent blocking immunity.
- Low RX current of 10.3 mA, 200 nA register retention.
- Fully integrated synthesizer with a resolution of 61 Hz.
- FSK, GFSK, MSK, GMSK, LoRa™ and OOK modulation.
- Built-in bit synchronizer for clock recovery.
- Preamble detection.
- 127 dB Dynamic Range RSSI.
- Automatic RF Sense and CAD with ultra-fast AFC.
- Packet engine up to 256 bytes with CRC.
- Built-in temperature sensor and low battery indicator.
- Modue Size：16*16mm

1.1. Simplified Block Diagram

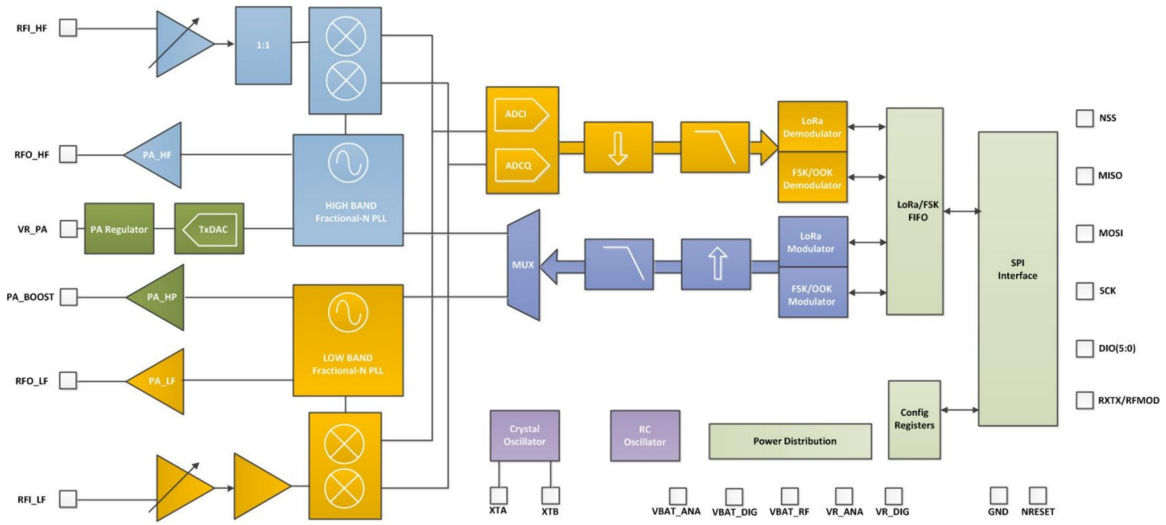
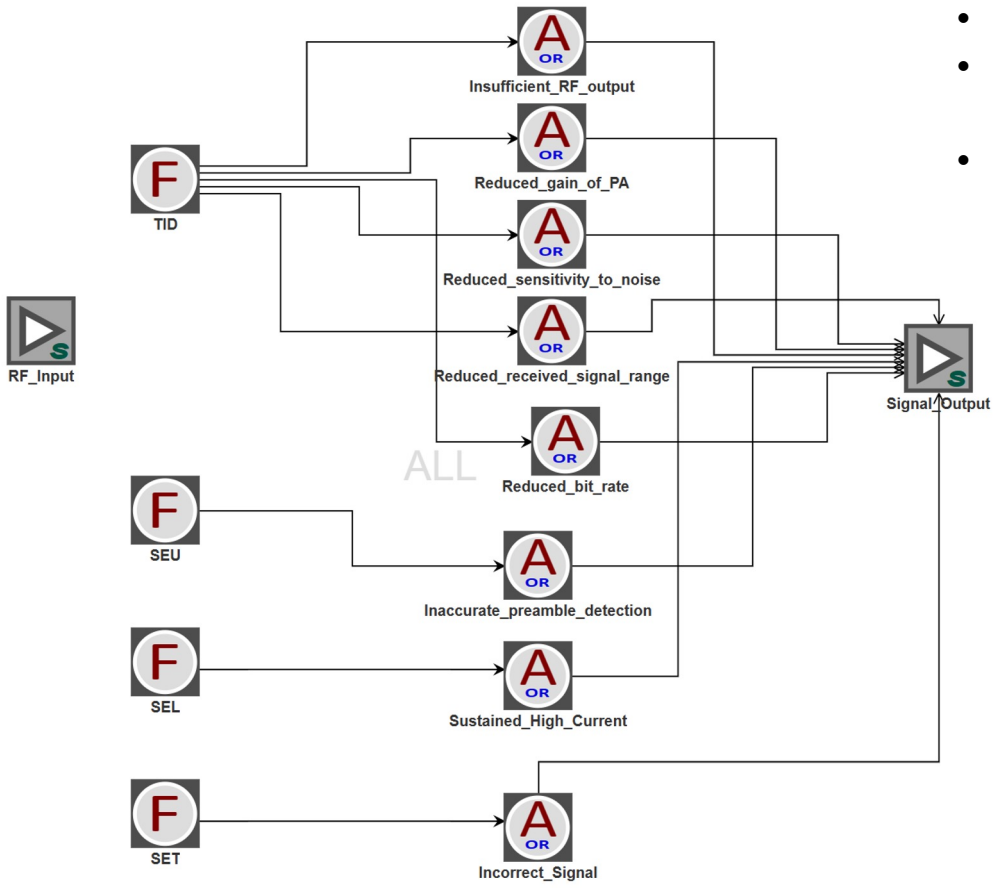


Figure 1. Block Diagram

Proposed Fault Propagation Model of Modular Radio

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- Fault Propagation Graph
- Informed selection of radiation effects on KPIs
- Automatically selects right abstraction level for model

Conclusions

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- Fault propagation graph model captures the faults and their effects in the components
  - Relate fault cause, fault effect, propagation path of fault effect
  - Template library available to speed assembly of radiation system fault models
- System models have to “climb the ladder of abstraction”
  - Trade-off resolution for scalability
- Systems characterized by functions, operating modes, KPIs
- System functions and subfunctions can be related to radiation fault effects through the functional model.
- Fault propagation graph model works at various levels of complexity
- Complete model links effects from different levels of abstraction and complexity