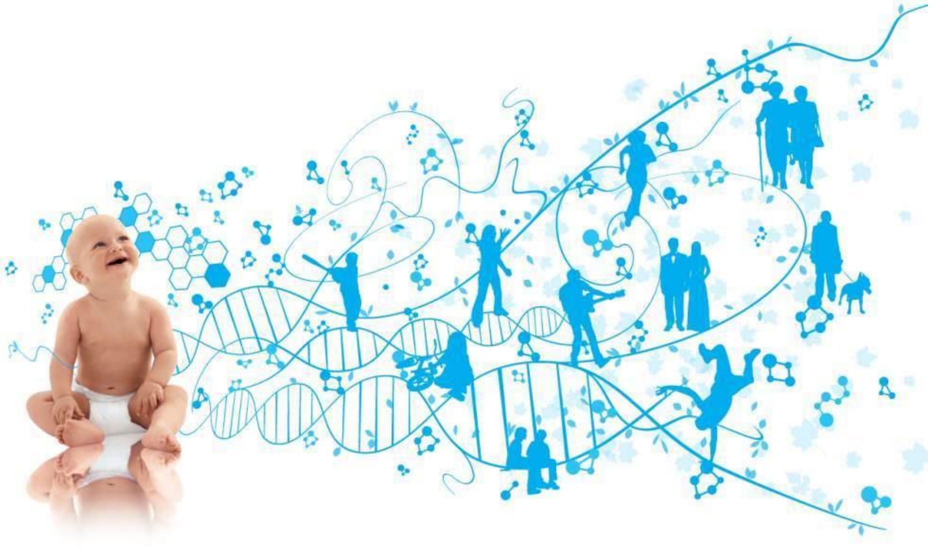
INCOSE Healthcare Working Group

4th Annual Systems Engineering in Healthcare Conference

Modeling and Simulation at GE Healthcare



Chris Unger

Chief Systems Engineer, GE Healthcare

Co-lead, INCOSE Healthcare WG

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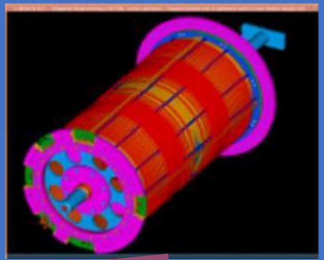
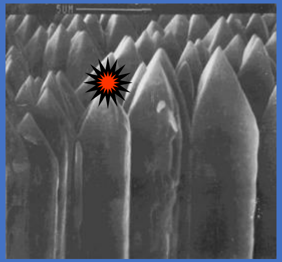
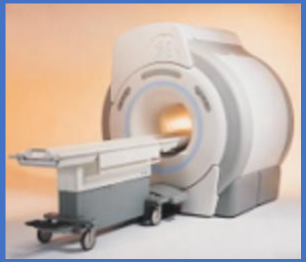
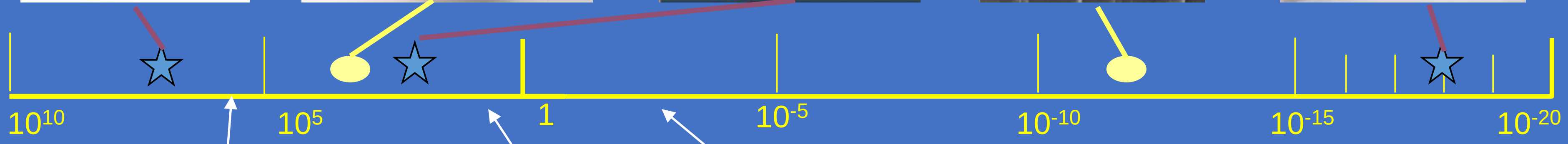
The Challenge… Energy Conversion & Detection

MR 3T	**Performix Pro**	**Gradient Coil**	**e^- Noise**	**MR Min Signal**
30 MJ	40 kJ	1 kJ	8 fJ	10^{-18} J





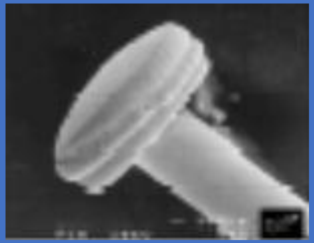
1MJ

Hummer @ 50 mph

400 J

Climbing 1 Step

2 mJ



Pin Dropping

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Vision

Design is a human activity

Fail early, fail often…in virtual space

Enable greater creativity…

"Predictive Directed Exploration"

Business Outcomes

Reduced Cycle time

Optimal designs (explore design space)

Predictability (better decisions earlier)

Behavior

Systems – SysML/UML
Control loops

Physics/Performance

Image/Signal Quality
Acoustics
Reliability

Business Integration

Parts stock/warranty reserve
Workflow
MFG capacity

Predictive, **multi-variable design models** enabling characterization, understanding of interactions and margin

Electrical performance
Thermal

Vibration
Structure/Stress/Stiffness

Safety
Lifing

Examples of Modelling

Control Algorithms

Joey Incubator

An incubator maintains a safe environment (heat, humidity, O2…) for a Infant.

Goal - To develop multi-physics, control & system model that will reduce design iterations

Detailed Goals:

Thermal: Build system CFD model and downselect 2 options for further physical prototyping and CFD; develop ROM for further control loop development

Electrical: Reduced board spins

EMI/EMC: Eliminate the need for screen room testing

Benefits

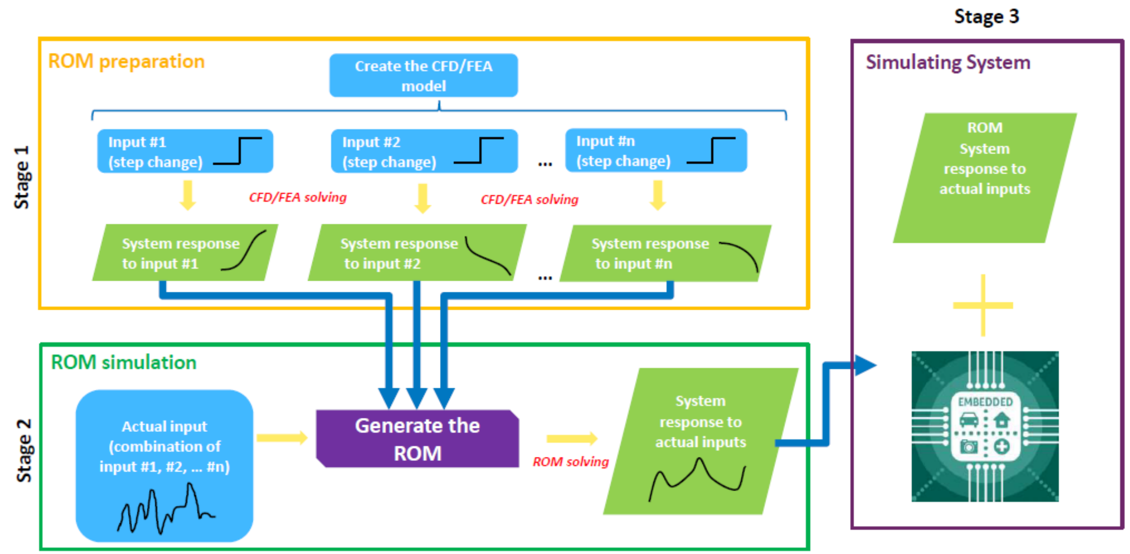
Design cycle acceleration

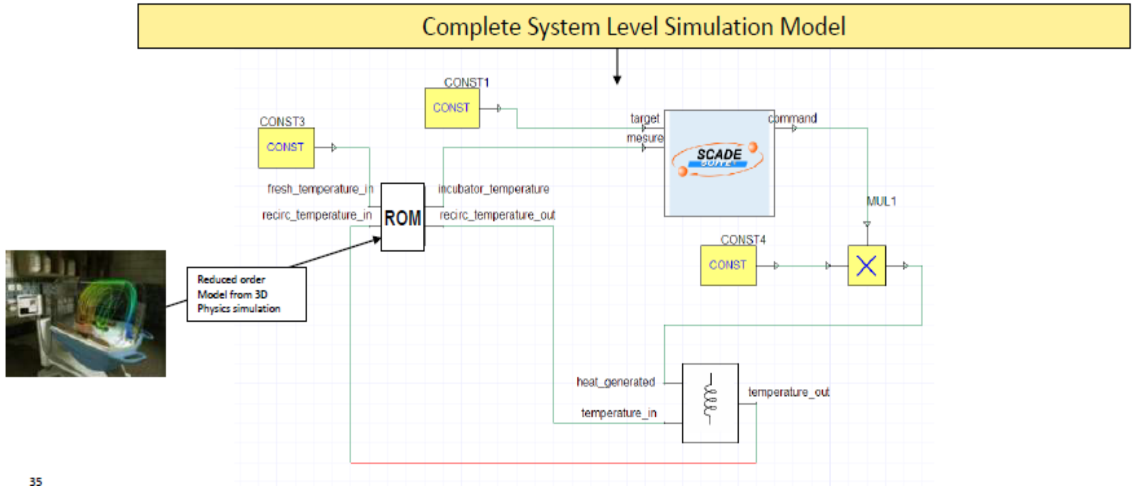
- Electrical: 0 board re-spin
- Control algorithms: Development, virtual testing and Automated design document generation
- Testing and Verification acceleration

Joey Incubator

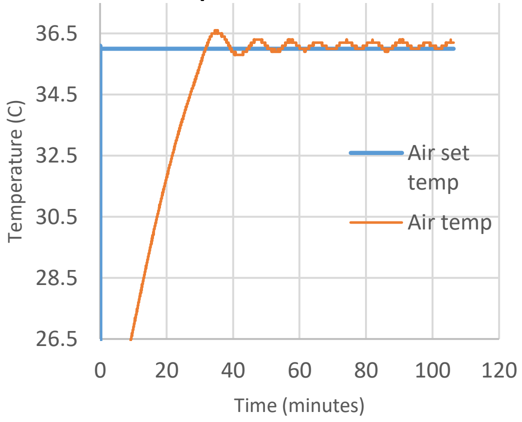
Thermal Control Modeling Goals

- Optimizing the thermal/humidity control loops in weeks (typically takes months)
- Balancing constraints
  - Thermal : Control accuracy, Stabilization time vs overshoot
  - Balancing performance vs. Acoustic noise

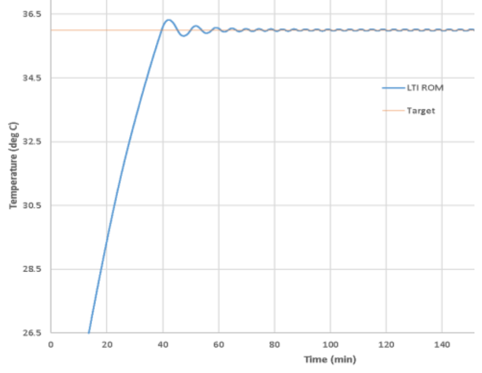




Experimental data



Prediction from ROM



Control Algorithm Conclusions

Achieved cycle time reductions

- Generated initial reduced order control model for ‘optimization’
- Chose optimal heater configuration (fans, heater coil configuration)
- Eliminated control board spins

Able to accelerate experiment cycle (thermal/humidity balancing)

Enabling actions

- Do the proper model validation
- Tight collaboration between modeling and systems teams

Examples of Modelling

Behavioral Modeling

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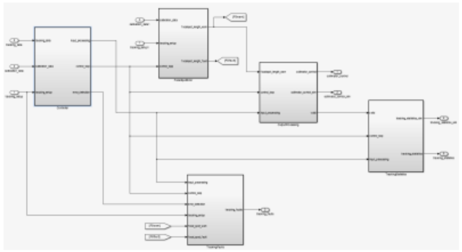
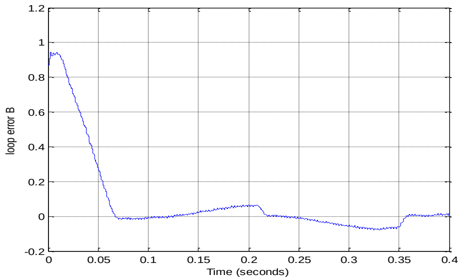
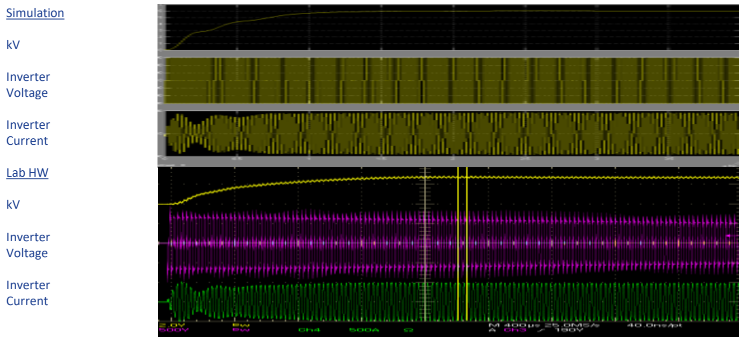
Behavioral Modeling in Computed Tomography

Moderately complex system with complex behavior

- ~5,000 parts
- ~5M lines of code
- Triple nested control loops
  - Axial, Cradle, mA/kV





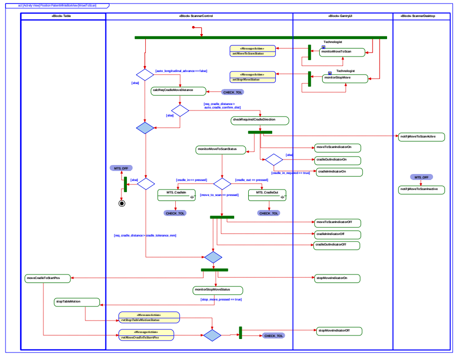


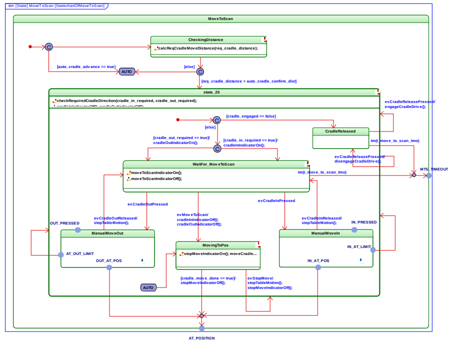
- Feature analysis and simulation in SIMULINK
- Auto-generation of code

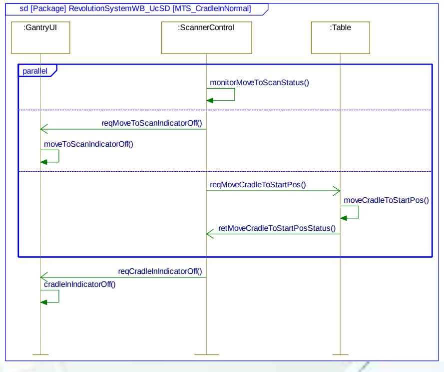
Computed Tomography

MBSE techniques are used to perform behavioral analysis of key system features and functions.

- discover and verify system requirements
- identify and detail subsystem functions and interfaces
- seed FMEA analysis
- develop system test scenarios

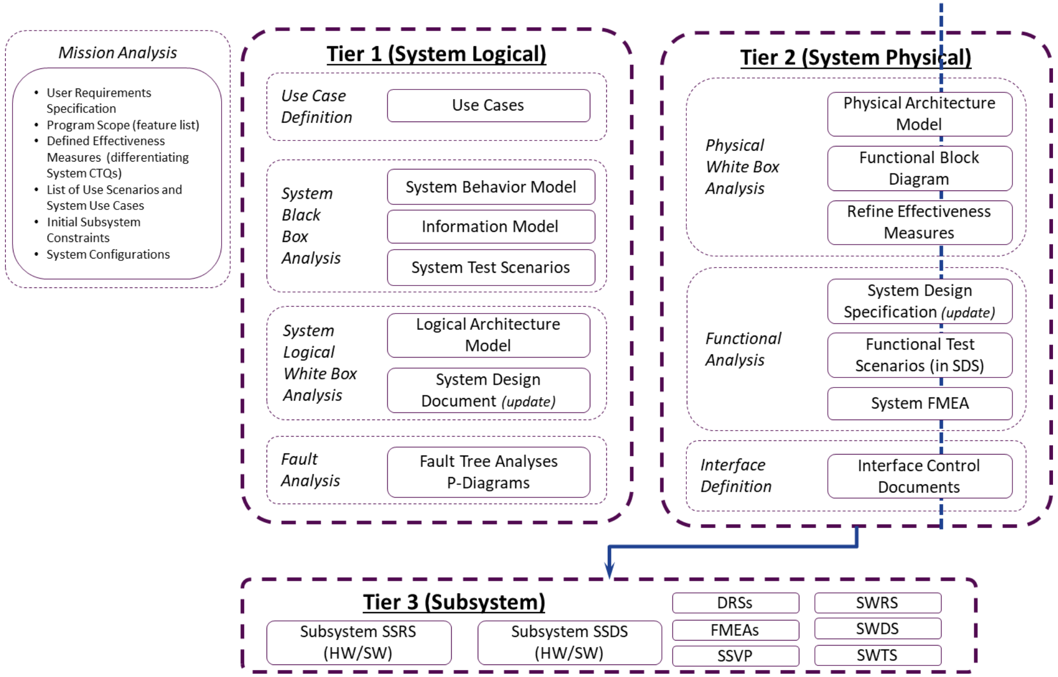






Behavioral Modeling Conclusions

- SysML is a "barrier to adoption"
  - Define clear roles and scaled training
  - Plan for how to communicate to non-experts
- Start with a pilot project to "work out the kinks" and tailor the process
  - Clearly define goals/step completion criteria
- Define a subset of views/diagrams to start with



Examples of Modelling

Reliability Modeling

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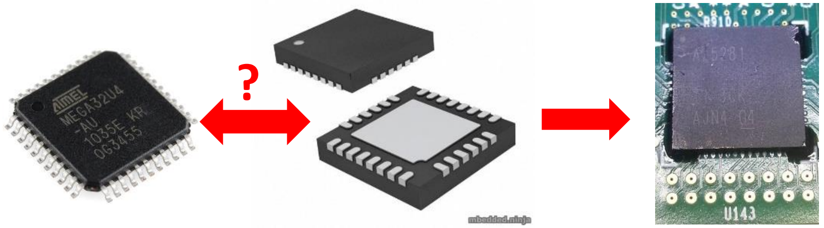
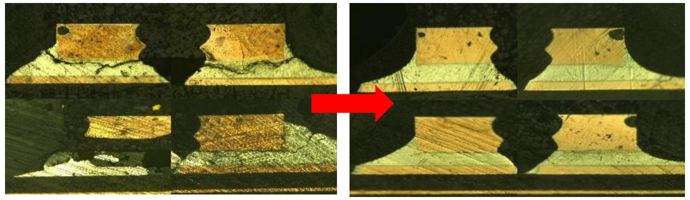
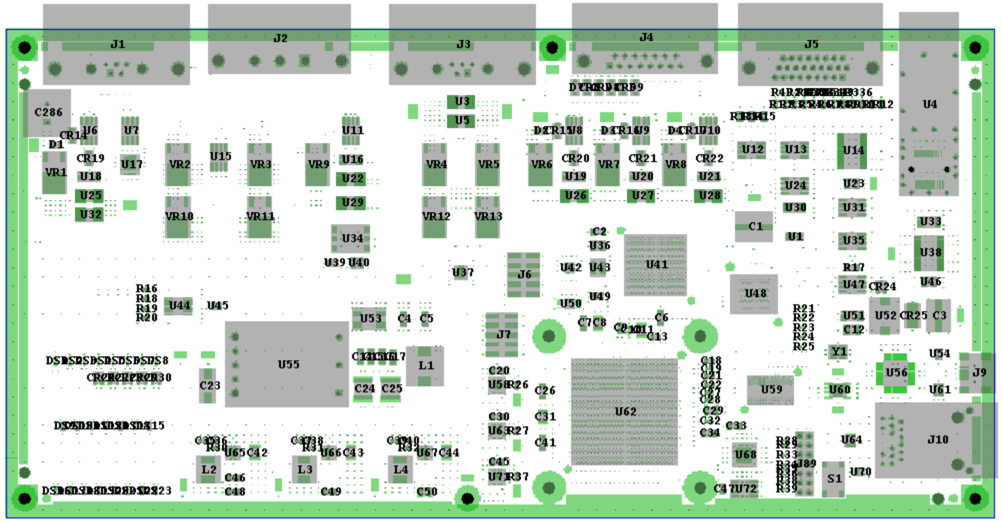
Solder joint reliability

Once a board is designed, what is its reliability?

- Solution 1: accelerated reliability testing (~3 months)
- Solution 2: perform computer modeling (<1wk)
  - Provides quick response to make board changes
  - Choose different IC packages
  - Change component locations







Stackup Properties

The following board properties are based on the currently defined board outline and the individual layer properties shown below:

Board Dimension: 240 x 105 mm [9.4 x 4.1 in]
Board Thickness: 2.301 mm [90.6 mil]
Board Density: 2.7332 g/cc
Conductor Layers: 16

CTExy: 18.189 ppm/C
CTEz: 62.405 ppm/C
Exy: 33,989 MPa
Ez: 4,167 MPa

Board Weight: 155.2 grams
Total Part Weight: 607.6 grams
Mount Point Weight: 0 grams
Fixture Weight: 0 grams

Stackup Layers

Double click any row to edit the properties for that layer **or** select one or more rows and press the **Edit Selected** button below to edit properties for a batch of layers. Press the **Generate Stackup Layers** button to replace all layers using a given PCB thickness and default layer properties.

Layer	Type	Material	Thickness	Density	CTExy	CTEz	Exy	Ez
1	SIGNAL	COPPER (29.6%) / COPPER-RESIN	0.5 oz	3.9016	40.410	40.410	35,912	35,912
2	Laminate	Generic FR-4	4.92 mil	1.9000	17.000	70.000	24,804	3,450
3	POWER	COPPER (86.9%) / COPPER-RESIN	1.0 oz	7.9699	21.844	21.844	98,656	98,656
4	Laminate	Generic FR-4	4.92 mil	1.9000	17.000	70.000	24,804	3,450
5	SIGNAL	COPPER (31.7%) / COPPER-RESIN	0.5 oz	4.0507	39.729	39.729	38,212	38,212
6	Laminate	Generic FR-4	4.92 mil	1.9000	17.000	70.000	24,804	3,450
7	SIGNAL	COPPER (29.4%) / COPPER-RESIN	0.5 oz	3.8874	40.474	40.474	35,693	35,693
8	Laminate	Generic FR-4	4.92 mil	1.9000	17.000	70.000	24,804	3,450
9	POWER	COPPER (87.1%) / COPPER-RESIN	1.0 oz	7.9841	21.780	21.780	98,874	98,874
10	Laminate	Generic FR-4	4.92 mil	1.9000	17.000	70.000	24,804	3,450
11	SIGNAL	COPPER (11.7%) / COPPER-RESIN	0.5 oz	2.6307	46.209	46.209	16,312	16,312
12	Laminate	Generic FR-4	4.92 mil	1.9000	17.000	70.000	24,804	3,450

Solder joint reliability simulations

Thermal Cycling Solder Fatigue Model

(Modified Engelmaier – Leadless Device)

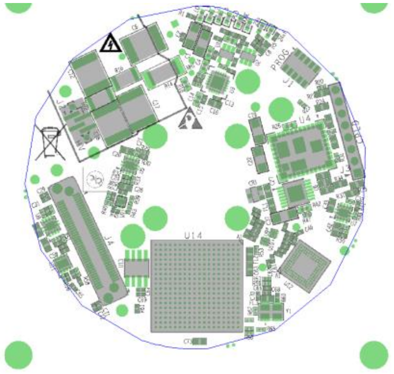
- Modified Engelmaier
  - Semi-empirical analytical approach
  - Energy based fatigue
- Determine the strain range ($\Delta\gamma$)

$$\Delta\gamma = C\frac{L_D}{h_s}\Delta\alpha\Delta T$$

- Where: C is a function of activation energy, temperature and dwell time, L_D is diagonal distance, α is CTE, ΔT of temperature cycle & h is solder joint height
- Determine the shear force applied at the solder joint

$$(\alpha_2-\alpha_1)\cdot\Delta T\cdot L_D = F\cdot\left(\frac{L_D}{E_1A_1}+\frac{L_D}{E_2A_2}+\frac{h_s}{A_sG_s}+\frac{h_c}{A_cG_c}+\left(\frac{2-\nu}{9\cdot G_b a}\right)\right)$$

  - Where: F is shear force, LD is length, E is elastic modulus, A is the area, h is thickness, G is shear modulus, and a is edge length of bond pad.
  - Subscripts: 1 is component, 2 is board, s is solder joint, c is bond pad, and b is board
  - Takes into consideration foundation stiffness and both shear and axial loads (Models of Leaded Components factor in lead stiffness / compliancy)



CCA Stackup Information

The following stackup information was used during the circuit card analysis.

Board Size:	71 x 71 mm	**PCB CTExy:**	14.013 ppm/C
PCB Thickness:	91.1 mil	**PCB CTEz:**	43.699 ppm/C
PCB Density:	2.3076 g/cc	**PCB Exy:**	29,869 MPa
Copper Layers:	14	**PCB Ez:**	3,885 MPa

Layer	Type	Thickness	Material
1	SIGNAL	1.0 oz	COPPER (29.8%)
2	Laminate	.147 mm	370HR
3	POWER	0.5 oz	COPPER (74.2%)
4	Laminate	0.15 mm	370HR
5	SIGNAL	0.5 oz	COPPER (44.3%)

Physics of failure solder joint model → **Electronic circuit design** ← **Material properties**

Life estimation (cycles to failure) based on computer modeling

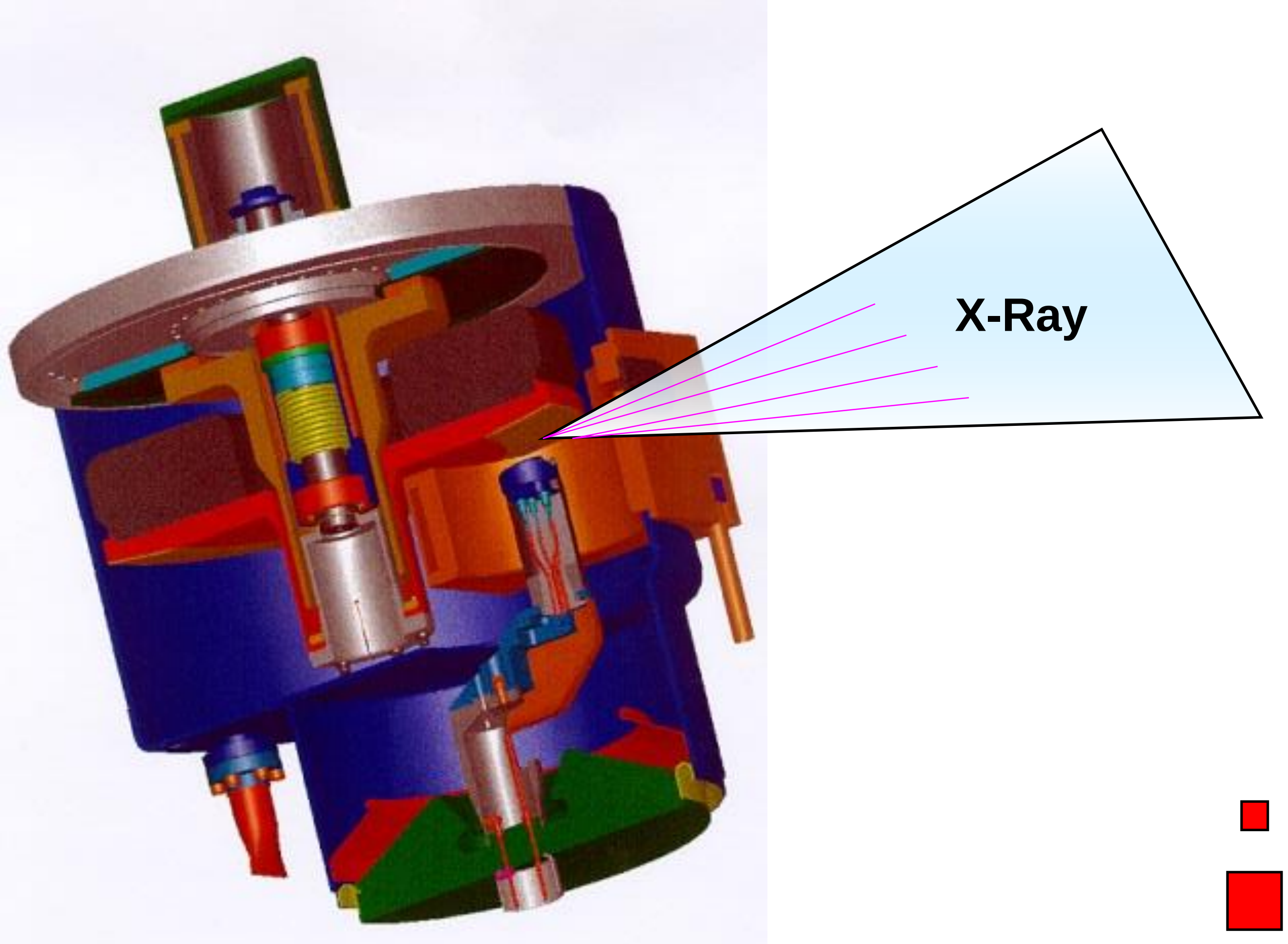
						ACCELERATED TESTING			USE CONDITIONS		
ID	**PACKAGE**	**MODEL**		**MATERIAL**	**PN**	**CY 0 100C**	**CY -40 125C**	**AF1**	**YRS 20 45C**	**CY 20 45**	**AF2**
U12	BGA-128	BGA	TOP	LAMINATE-BGA	5505464	1259	329	3.8	88	32061	97.5
U14	BGA-144	BGA	TOP	LAMINATE-BGA	5499296	4106	1071	3.8	286	104244	97.3
U4	QFN-40 (MO-251AFFB-1)	QFN	TOP	OVERMOLD-QFN	5504797	9272	2415	3.8	643	234822	97.2
Y1	QFN-4 (MO-220WEEB)	QFN	TOP	ALUMINA	5437405	21863	5684	3.8	1509	550823	96.9
U3	QFN-20 (MO-220VGGD-1)	QFN	TOP	OVERMOLD-QFN	5455903	95311	24782	3.8	6581	2402109	96.9
U11	QFN-12 (MO-208BBEA)	QFN	TOP	OVERMOLD-QFN	5498573	200956	52239	3.8	13868	5061976	96.9

Able to include Reliability in Up-Front Systems Trade Studies

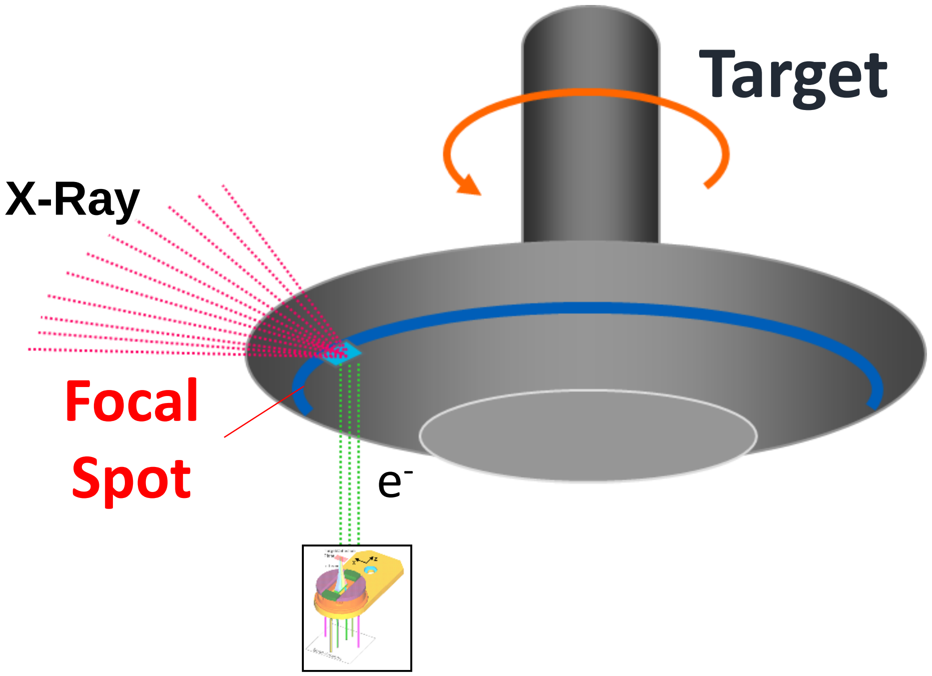
Examples of Modelling

Physics (Electro-Optics)

Cathode Design for X-Ray Tubes



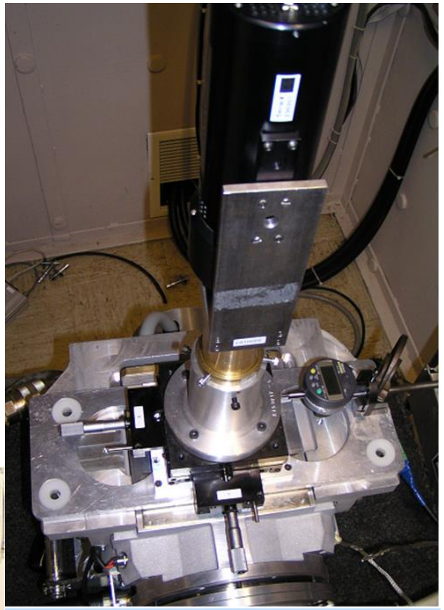
X-Ray Tube



Goals

- **Small focus -** High resolution
- **Large focus -** High contrast
- ⇔ **Position Control**

Cathode Optimization

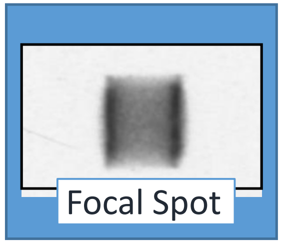


Focal spot camera mounted on x-ray tube

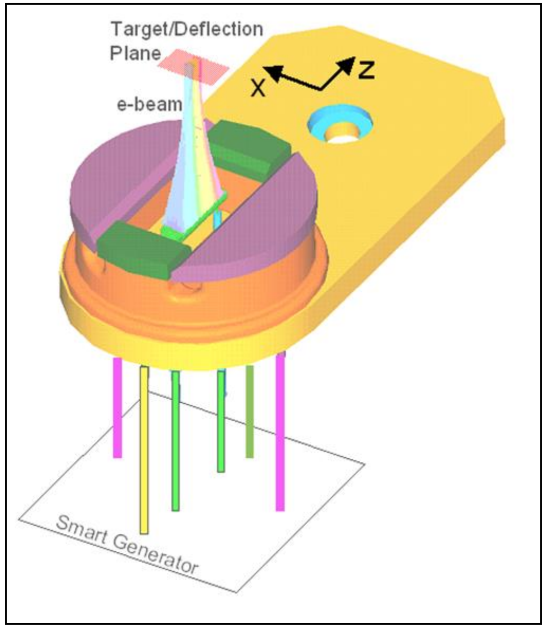
Bias Tank

Validation

Simulation

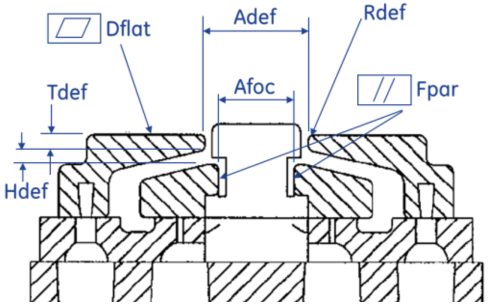


Focal Spot



Electron optics simulation SW

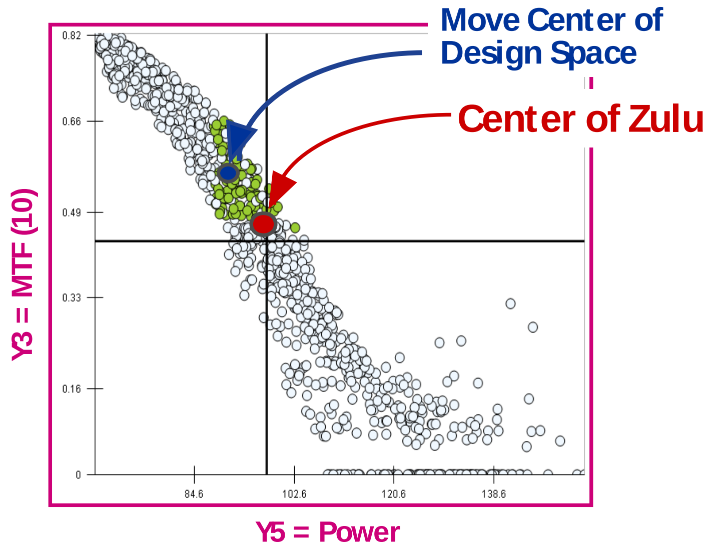
Optimization

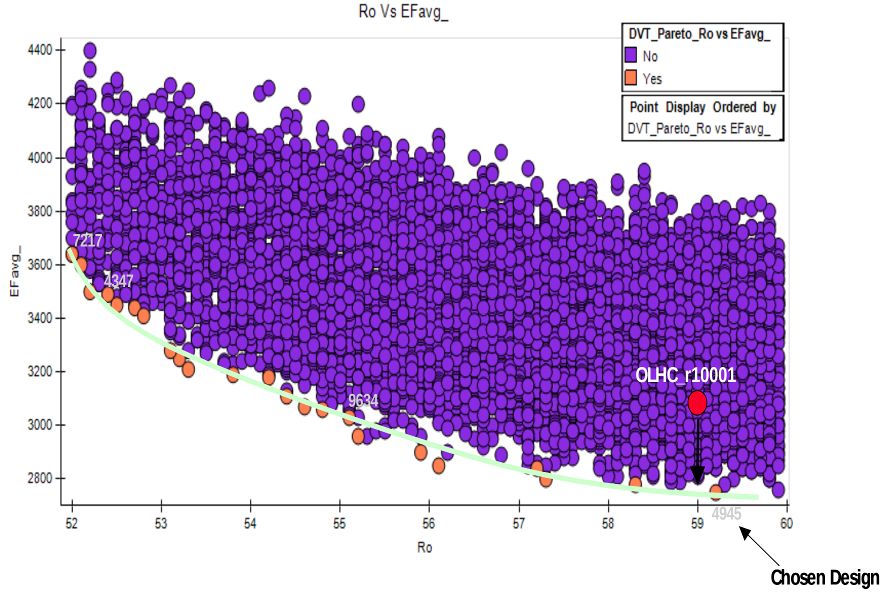


Optimization strategies

- Parameterized model
- DOE
- Latin Hypercube
- Genetic Algorithm
- Intuition

Performing Systems Optimization Tradeoffs Visually





- Extensively explored design space
- Identified opportunities for increased production margin (design robustness)
- Helped save iterations…several further iterations were planned…full design verification

Summary – Benefits to Industry of MBSE

- Improved Communication: *Pictures, Models vs. Text*
- Improved Quality: *Model Analysis, Simulation vs. Reviews*
- Improved Quality: *Identify Root Cause of Integration Issues*
- Improved Predictability and Efficiency (Time to Market)

Questions?

Chris Unger
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INCOSE ESEP
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Thank you for attending!
Share your experiences at #HWGSEC

Questions?

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